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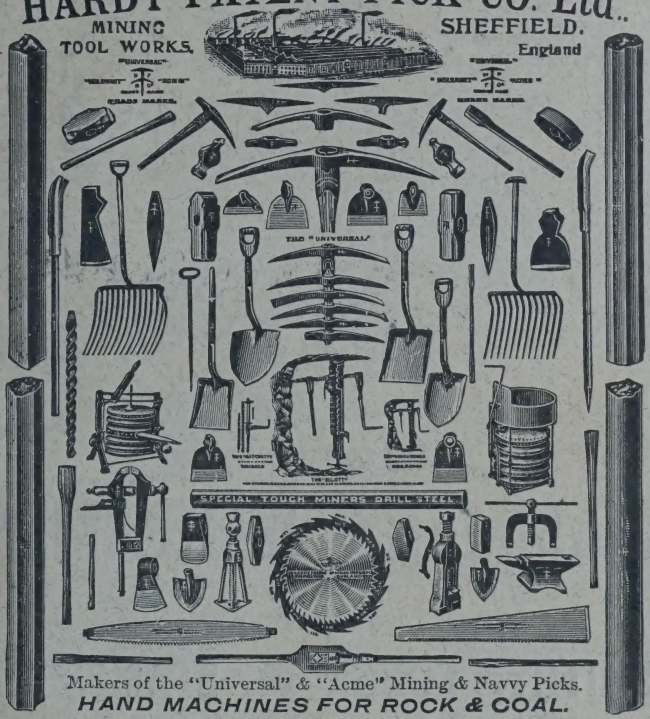

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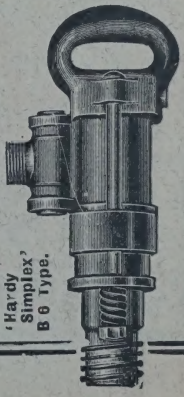
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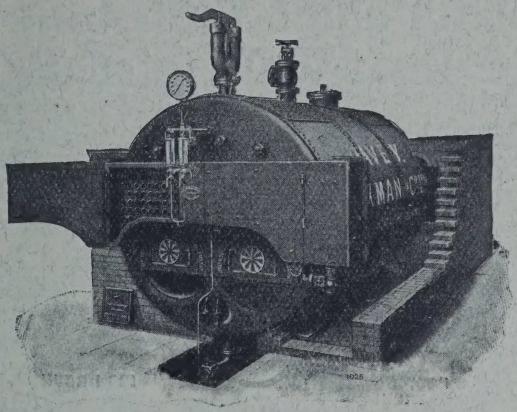

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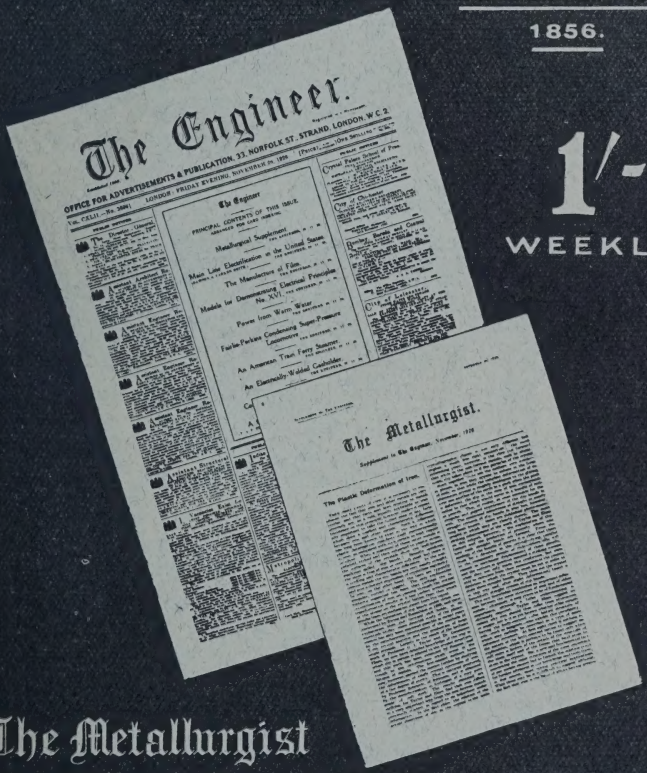

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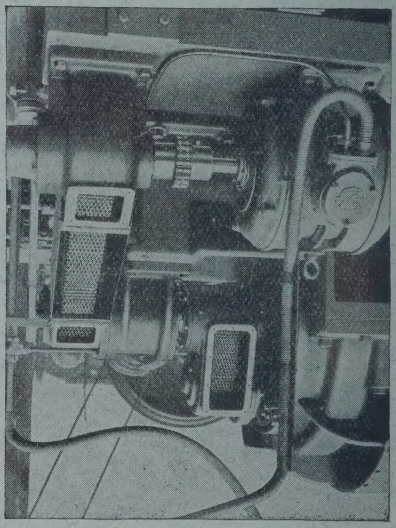

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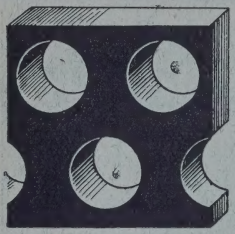

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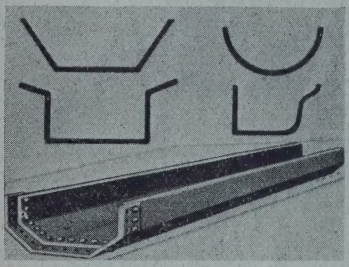

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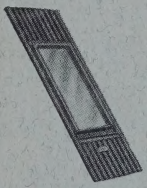

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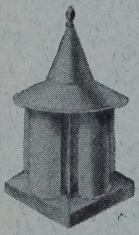

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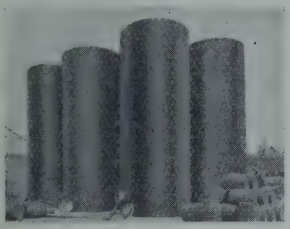

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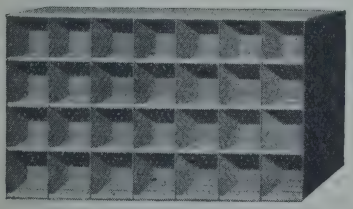

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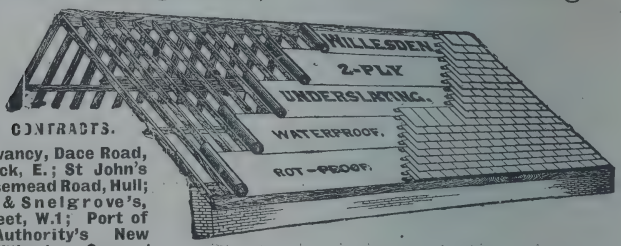

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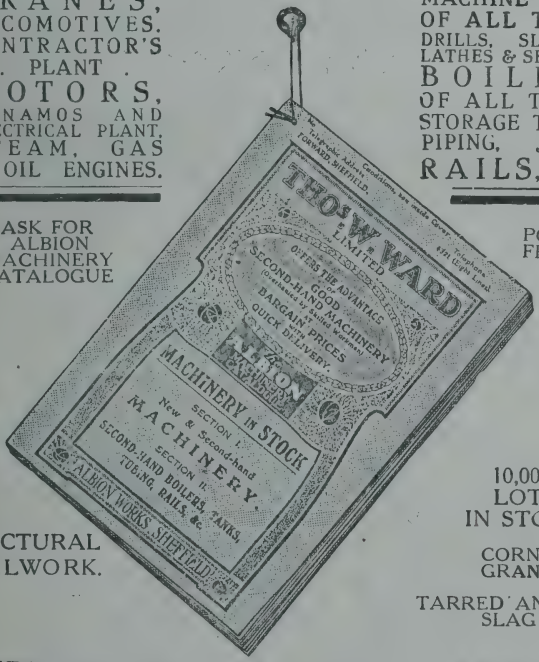

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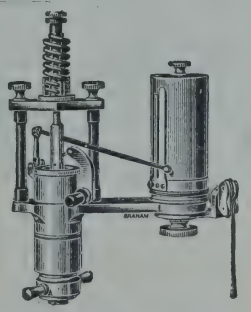

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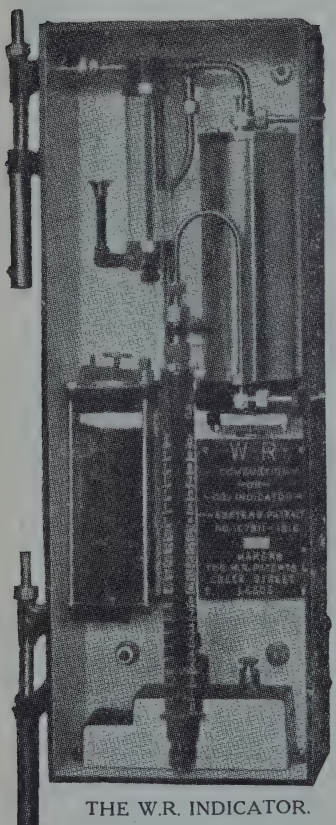

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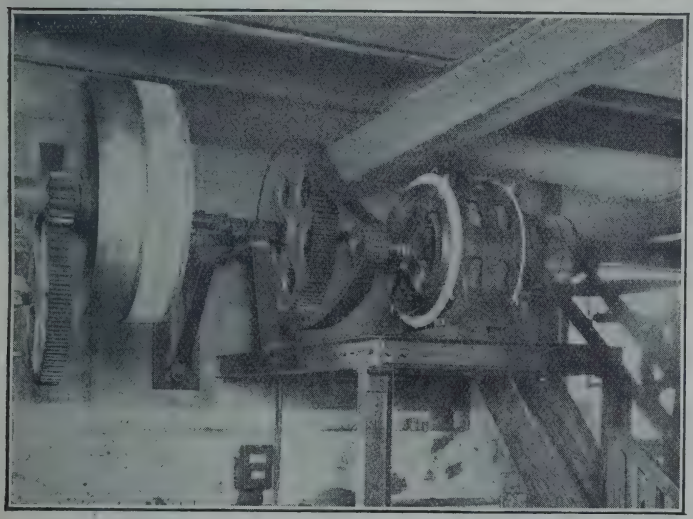

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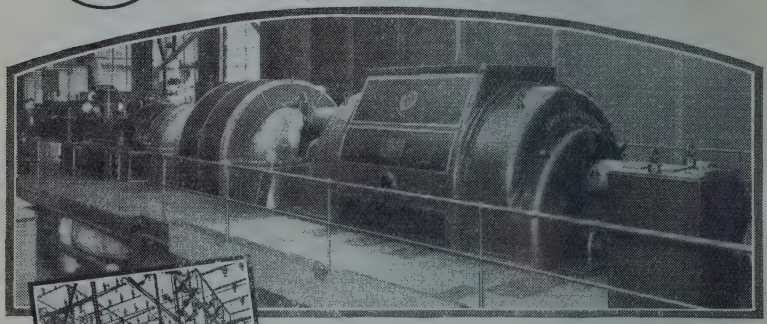

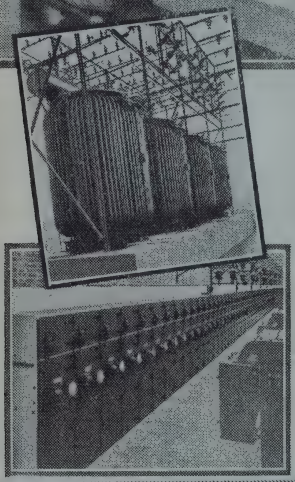

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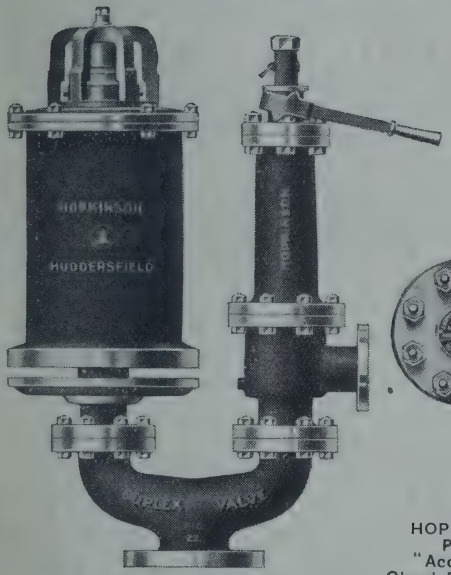

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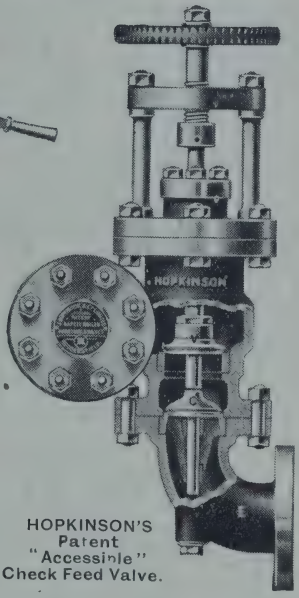

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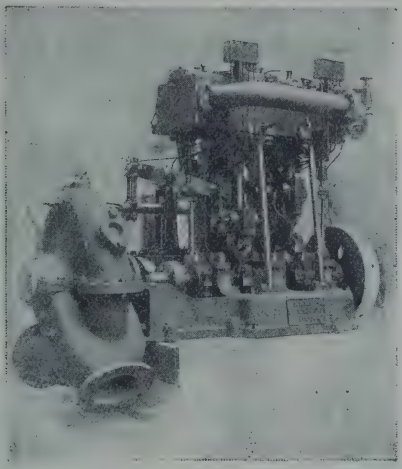

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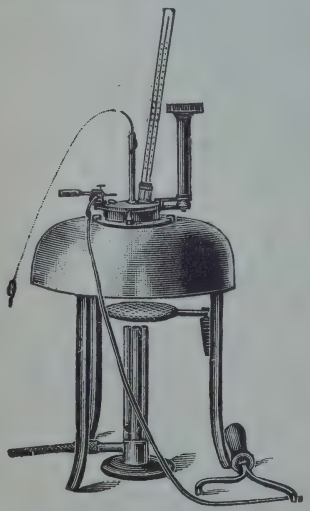

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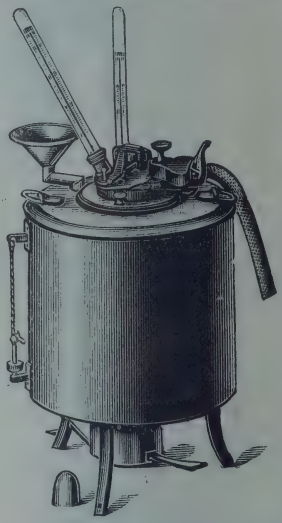

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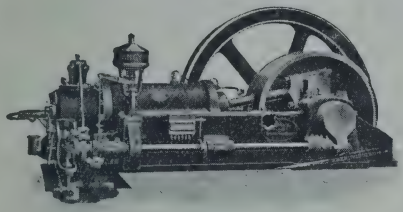

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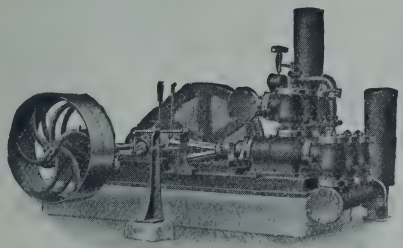

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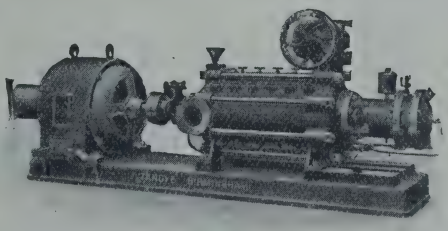

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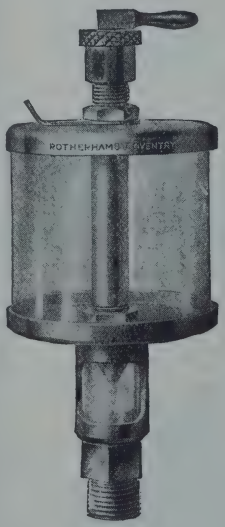

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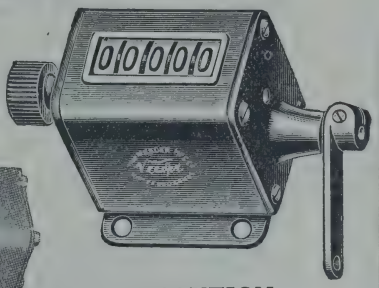

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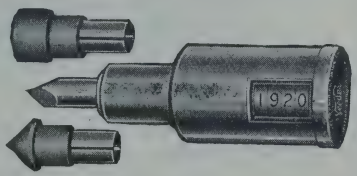

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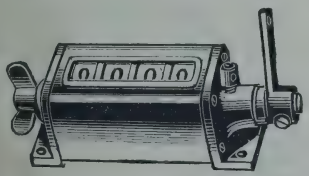

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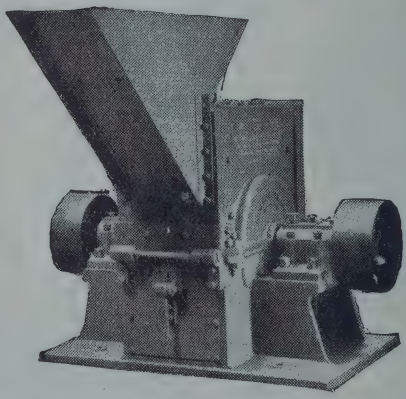

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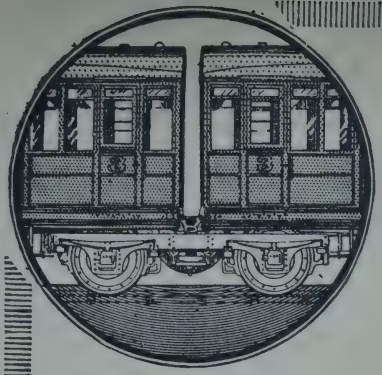

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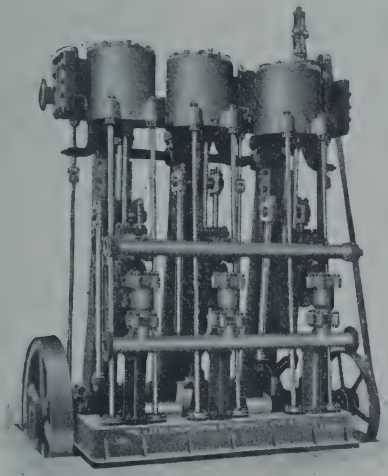

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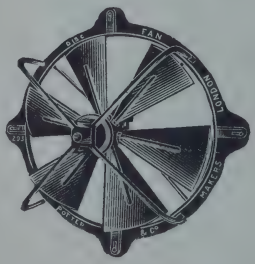

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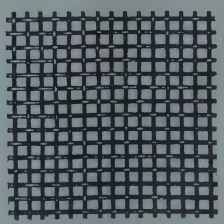

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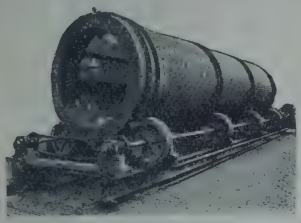

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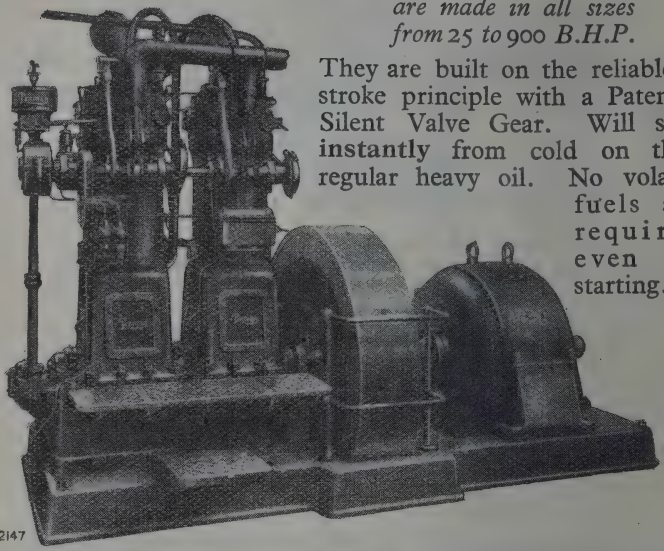

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In the work of compilation, most valuable assistance has been rendered by numerous practising Engineers, including those of the principal English Railway Companies, and of the Queensland Government, as well as by

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Girder Manufacturers, Boiler and Engine Makers, and many other persons of experience. Every available work has been searched through and consulted for information, but in making use of particulars so obtained the compiler has been at pains to trace the matter to its original source, so as to determine its authoritative value, and in every case where it appeared necessary he has redrawn existing figures and verified current formulæ, so that clearness and accuracy might be ensured.

Obviously a work of this nature, to fulfil its purpose of being kept up to date, will require periodical revision, and it is accordingly intended to REISSUE IT FROM YEAR TO YEAR. The facilities thus afforded for thorough revision throughout the volume will make it practicable to *insert every year new matter of importance in any Section*, and render the book at all times a safe and reliable DAILY REFERENCE BOOK for the PRACTICAL ENGINEER.

Kindly criticism and help towards making the work as complete and as useful as possible are earnestly invited, and any suggestions, addressed to the care of the Publishers, with this object, will be gladly received, and, as far as possible, acted upon.

I have to thank Mr. H. HARTNELL, Technical Officer of the Engineer-in-Chief's Office, for great assistance rendered in the work of compilation.

Finally, I think more than a word of thanks is due to the printers, Messrs. SPOTTISWOODE & Co., for the able manner in which they have executed the difficult task of concisely and clearly arranging the letter-press.

H. R. KEMPE.

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PREFACE TO 1928 EDITION.

As in previous issues, in addition to the usual general revision of the work by the Editors-in-Chief, the numerous Associate-Editors and Contributors (who have been selected for their expert knowledge of the particular branches with which they deal) have subjected the sections to a complete revision, making important alterations and additions, in order that Modern Engineering Practice may be the standard throughout the work.

In carrying out the revision not only have fresh data and tables been incorporated and existing matter rearranged where considered advisable, but much information which advances in practice have rendered obsolete has been excised. It will be obvious therefore that the nature and extent of the alterations made cannot be measured in terms of the numerical pagination total, although the latter has now reached nearly 3000, as compared with 570 of the first issue.

The consistent and thorough annual revision of the book, with the co-operation of so many distinguished specialists, has resulted in the production of a uniquely authoritative work of reference, the value of which is now universally recognised.

In the preparation of the work full advantage has been taken of the official permission given by the several Institutions of Civil, Mechanical, and Electrical Engineers, and of Naval Architects, to publish extracts from their proceedings, a privilege which, it is needless to say, has proved of exceptional value.

The British Engineering Standards Association, also, has authorised the inclusion in the volume, of abridgements of their Specifications, the range and importance of which increase year by year, and accordingly full abstracts of a large number of their Reports have been incorporated.

Invaluable assistance in the preparation of the present issue has been rendered by Mr. W. Hanneford Smith, F.R.S.E., who for the past twenty years has most ably discharged the duties of Associate Editor-in-Chief, and it should be added that the excellent general appearance of the book is due to his care in supervising, at every stage, the production of the work. To Mr. Francis C. Smith, also, thanks are due for great assistance rendered.

The Editors have to thank numerous contributors for useful matter supplied, and for practical suggestions, and will be glad to receive at all times friendly criticism calculated to increase the utility of the work.

As the object of the work is to combine technical with commercial information, the introduction of matter of an advertising character (but which has been inserted in harmony with the general scheme of the book) has been inevitable; great care, however, has been exercised to ensure that such information shall be authoritative, and the sole responsibility for its insertion rests on the Editor-in-Chief.

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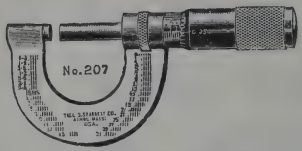

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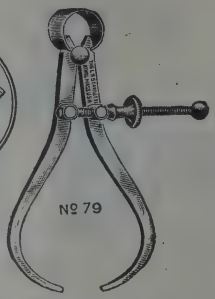

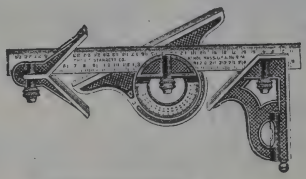

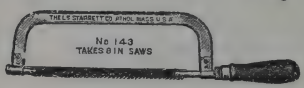

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THE PAST YEAR'S PROGRESS.

(Abstracted from the Annual Engineering Review of 'The Times' Trade and Engineering Supplement, January 21, 1928.)

SHIPBUILDING.

According to the statistics compiled by *The Glasgow Herald*, the total output for the world was 2,750 vessels measuring 2,897,114 tons, and propelling machinery of 3,880,967 h.p., compared with 2,371 vessels, 2,151,996 tons, and 3,236,203 h.p. in 1926.

The gain is mainly that of Great Britain and Ireland, combined with that of Germany. In the United Kingdom there was an advance of 299 vessels, 617,782 tons, and 308,447 h.p., while the German production increased by 73 vessels, 142,945 tons, and 177,420 h.p. British shipyards accounted for by far the greater part of the gain in tonnage.

On the Clyde the advance was from 173 vessels, 286,350 tons and 433,465 h.p., to 274 vessels, 463,528 tons and 647,824 h.p.; on the Tyne it was from 26 vessels, 131,001 tons and 275,315 h.p., to 65 vessels and 320,947 tons, but, owing to the lack of naval work, the horse power decreased from 275,315 to 203,220. On the Wear the increase was very pronounced—from 8 vessels, 35,123 tons and 22,640 h.p., to 38 vessels, 165,645 tons and 112,690 h.p.—while on the Tees it was only slightly less so—from 24 vessels, 37,193 tons and 23,687 h.p., to 32 vessels, 130,638 tons and 113,710 h.p. In Ireland the output increased from 12 vessels, 93,257 tons and 63,000 h.p., to 39 vessels and 113,554 tons, but the horse power fell from 63,000 to 60,825, mainly because the machinery of one of the largest vessels was made at Sunderland.

The largest production was that of Messrs. Swan, Hunter and Wigham Richardson, of Wallsend-on-Tyne and Sunderland, whose output is given as 22 vessels of 137,397 tons. One vessel of 2,400 tons had not, however, been actually put into the water by the end of the year, and there is included in the total the Admiralty floating dock for Singapore, which accounts for 51,000 tons—not Board of Trade tons gross. But for the inclusion of this structure in the North-East Coast firm's return Messrs. Harland and Wolff would have been first, with an aggregate of 49 vessels of 94,700 tons from their Belfast, Glasgow, and Greenock yards. As it is, the two firms lead the world in tonnage launched. The highest horse power was produced by a French company—the Ateliers et Chantiers de Bretagne of Nantes, who made engines of 242,150 h.p. for two French cruisers. Messrs. John Brown and Co., Clydebank, were second with 165,350 h.p., including the machinery of their two Australian cruisers. Messrs. Orlando Brothers, of Leghorn, were third with 150,000 h.p. for

one Italian cruiser; the Fairfield Shipbuilding and Engineering Company, Glasgow, were fourth with 132,300 h.p.; and Messrs. Vickers, Barrow-in-Furness, fifth with 105,300 h.p.

The largest vessels launched were the twin-screw turbine liners *Conte Grande*, of 25,000 tons and 25,000 h.p., built by the Stabilimento Tecnico Triestino for the Lloyd Sabaudo Company of Genoa, and the *Cap Arcona*, of 25,000 tons and 24,000 h.p., by Messrs. Blohm and Voss, of Hamburg, for the Hamburg-South America Line; the Canadian Pacific Railway Company's twin-screw turbine liner *Duchess of Atholl*, of 21,500 tons and 18,500 h.p., built by Messrs. William Beardmore and Co., Dalmuir; the Orient Line's twin-screw turbine liner *Orford*, of 20,000 tons and 19,500 h.p., built at Barrow-in-Furness; the quadruple-screw motor liner *Bermuda*, of 19,086 tons and 15,000 h.p., built by Messrs. Workman, Clark and Co., Belfast, for one of the Furness Withy associated lines; and the triple-screw turbine and reciprocating engined vessel *Laurentic*, of 18,724 tons and 13,000 h.p., built by Messrs. Harland and Wolff, Belfast, for the White Star Line.

A large number of ocean-going motor-ships, with various types of propelling machinery, were launched. The great majority of the motor vessels built were oil tankers, and the types of engines favoured were mostly the Burmeister and Wain, the Sulzer and the Doxford in the United Kingdom, and the first named, several German types and the Dutch Werkspoor, on the Continent.

MARINE ENGINEERING.

In Holland there was completed a 500-lb. pressure reciprocating engine of the Lentz type, fitted with hydraulically operated valve gear, for the *Borneo*, which has run trials with successful results and is now in service.

The vessels of the Blue Star fleet built by Messrs. Cammell, Laird and Co., and Messrs. John Brown and Co., fitted with single-reduction geared turbines, have proved very successful in spite of the strenuous conditions under which they work, it being understood that they are operating under maximum power during their whole run from London to South America.

It is understood that a well-known company is arranging for the substitution of single for double reduction gears in certain of its large vessels, and practice on the Continent is in agreement with that in this country, as the latest German craft all have single-reduction gearing, mostly with a three-turbine arrangement with separate pinions for each turbine, such as is being fitted in the Duchess Class of the C.P.R. The *Ausonia*, however, has 18,000 s.h.p. machinery with double-reduction gears. The *Laurentic*, which has the usual Harland and Wolff combination of reciprocating engines and exhaust turbine, was completed, as were the first units of the Beaver Class for the C.P.R., which are fitted with Parsons single-reduction gears.

The conversion of the *Empress of Australia*, by the Fairfield Company, from direct-coupled impulse turbines to a single-reduction geared Parsons equipment, proved a conspicuous success. A new low record of fuel consumption for this class of vessel, 0·69 lb. of oil fuel for all

propelling purposes per s.h.p. per hour, was reported. This figure was attained very largely through the use of electrically driven auxiliaries, the current being furnished by Diesel-driven generators.

There has been a general adoption of monel metal and stainless steel for turbine blading subject to high superheat, to minimise the erosion troubles that manifested themselves in certain of the earlier vessels, particularly in the nozzle plates of impulse turbines.

The Caprotti valve gear, successfully fitted to a number of locomotives, has been applied to a paddle steamer in Italy and to a small coaster built by the Burntisland Shipbuilding Company, the engine being supplied by Messrs. Beardmore, who own the British rights for this gear. The reduction in size of the engine and the improved economy which can be obtained are said to be of the order of 10 per cent.

A further notable development has been the application of the Bauer-Wach system of combining an exhaust steam turbine with a reciprocating engine. The fuel saving may be as much as 25 per cent., as has been proved by the trials of several of the ships to which an exhaust turbine has been fitted. Particularly successful have been the Hamburg-South America vessels *Cap Norte* and *Antonio Delfino*, in which the speed has been increased one knot without increase of fuel consumption.

Several outstanding vessels were put into service with internal combustion prime movers. The double-acting four-stroke engine appears to be the favourite design so far for large craft, the engines ranging up to 10,000 i.h.p. per shaft. The *de luxe* ship *Bermuda*, launched in June by Messrs. Workman, Clark and Co., was completed at the end of the year. Her machinery, consisting of four Doxford engines, one on each shaft, is the largest equipment of the type so far built. Of smaller craft, a notable ship was the *Itapé*, one of three building for South American interests, in which supercharging was employed for the first time in a British-built engine. The published trial results indicated that at least 10 per cent. additional power can be obtained from the same engines by this system of forced induction, without any distress or increase of heat stresses or exhaust temperatures.

The P. and O. Company, departing from their usual practice of employing reciprocating engines, ordered a large steamer from Messrs. Stephen, in which two large turbo-alternators will supply current to the driving motors on two propelling shafts. One generator is to be capable of driving both shafts at the normal sea speed, and the other set will be in reserve, or can be brought in to assist the first set when it is necessary to speed up the ship substantially to make up lost time due to mail and passenger trains being delayed or other exceptional circumstances; the electrical equipment will be supplied by the British Thomson-Houston Company.

The application of Contra-propellers for improving the overall efficiency of propulsion is being applied to the Italian Conte boats, *Saturnia*, *Vulcania*, and *Augustus*, and to a large number of smaller craft. The Oertz and Flettner designs of rudders have contributed to a reduction in the total fuel necessary to be expended per nautical mile run, and bilge water

purifiers and oil separators have further assisted in reduction of maintenance charges and have salved a considerable quantity of oil which would otherwise have been wasted.

Besides the investigation into the question of powdered fuel, further important work was carried out during the year, particularly on propellers and ship form. A detailed account of a full scale research into the variations of power required by ships under different weather conditions was given by Mr. Kent at the spring meeting of the Institution of Naval Architects, and the subject of resistance was also dealt with before the same institution and several of the provincial societies. The failure of metals due to 'creep' at high temperatures also received a great amount of attention, and the physical characteristics of the materials employed by engineers in modern plant are becoming more definitely known.

STEAM GENERATION.

The outstanding features of steam generation practice in 1927, particularly as regards large water-tube boilers, were the increased use of very high steam pressures, from 500 lbs. to 1,500 lbs. per sq. in.; continued progress with pulverised-fuel firing; still further improvements in mechanical stoking; rapid spread of the water-cooled combustion chamber wall, composed of steel tubes in series with the boiler; and the development of completely automatic boiler-plant control, these last two items being equally applicable to mechanical stoking and to pulverised-fuel firing.

In the field of superpressure boilers, up to 1,500 lbs. pressure, with forged steel drums, new designs have been brought out by Messrs. Sulzer Bros., in Switzerland, and the Heine Boiler Company, in the United States. During the year, the Bradford Corporation placed an order for a Babcock and Wilcox forged drum water-tube boiler to work at 1,100 lbs. per sq. in., with a turbine discharging at 210 lbs.

Detailed information was published about the boiler now operating at the Lakeside Station of the Milwaukee Electric Light and Power Company, which has an evaporative capacity of 240,000 lbs. of water an hour, with a maximum pressure of 1,390 lbs. per sq. in., and a normal working pressure of 1,200 lbs. This installation, which is fired with pulverised fuel, is regarded as the outstanding achievement of American boiler plant practice in 1927. Details were also published concerning the performance over two years of the 1,200 lbs. boiler and 3,000 kw. turbine plant at the Edgar Station, Boston, the turbine exhausting at 360 lbs. Successful results have been obtained, apart from minor troubles (as with feed water regulators), and the installation is being extended. Several Loeffler plants are at work with steam at 1,500 to 1,800 lbs. pressure, which is generated by blowing into the water very highly superheated steam from a coil constituting the only part of the system to which heat is applied. Increased attention has been given to the Atmos revolving tube boiler operating at 1,500 lbs. pressure, and a new plant has been installed with a turbine exhaust at only 90 lbs. per sq. in.

In Great Britain the use of pulverised fuel is advancing. International Combustion, Limited, have started up a number of plants, including

installations at the Derby and Poplar electricity stations, while the same principle is being adopted for the second section (100,000 kw.) of the Barking station, although the first section, now in operation, is fired by mechanical stokers. The contract for the first section of the new Hams Hall station, at Birmingham, of 60,000 kw., includes two 30,000 kw. turbines and boilers with an evaporative capacity of 200,000 lbs. per hour at 375 lbs. per sq. in., with pulverised fuel. The new Kirkstall station for Leeds is to have forged drum boilers working at 490 lbs. and 750° F. steam temperature. Further at the Hams Hall station unit pulverisers on the Atritor system by Alfred Herbert, Limited, are being applied to five very large boilers of 200,000 lbs. evaporation per hour each. The pulverisers are of the duplex type, electrically driven, without coal dryers.

During the year a new type of "underfeed" travelling grate stoker was developed in Great Britain, whereby equal air supply is given at every point of the grate, even when it is, say, 20 ft.–25 ft. wide, or more. The suspended arch has rendered this achievement possible, while mechanically operated riddlings discharge gear becomes unnecessary. Multiple retort designs of great size are in operation, up to 300,000 lbs. evaporation of water per hour. An 18-retort Erith-Roe stoker for a boiler with an evaporation of 150,000 lbs. per hour has been sent to Brisbane, and new developments in this connexion are the long 'Class B' stoker and the addition of a clinker grinder for the largest units. A new principle is the addition of air blasts at the back of the combustion chamber to give a better mixing of air and gases.

A new apparatus, known as the 'Supermiser,' is essentially a combined economiser and air heating unit in one casing, and is particularly intended for application to cylindrical boilers.

INTERNAL COMBUSTION ENGINES.

Although not a new type, one of the most noteworthy oil engines built in this country during the past year for stationary purposes was a 1,750 b.h.p. six-cylinder Fraser and Chalmers unit, the largest stationary oil engine constructed by a British firm. In this engine the pistons are of aluminium alloy, while the liners and cylinder covers are of steel. The speed is unusual for such a large unit, being 300 r.p.m., and, as a result, size and weight are considerably reduced compared with normal slow-running oil engines. At full load the fuel used is 0·39 lb. per b.h.p. hour, and the thermal efficiency on an i.h.p. basis is 46 per cent.

A special design of horizontal oil engine has been constructed by the Premier Gas Engine Company for driving horizontal refrigerating plant in passenger liners. This is the first time that such an arrangement has been devised for this work, although smaller refrigerating plants, driven by oil engines, have been in service on land for some time past.

The Sulzer experimental two-stroke double-acting engine has an output larger than any other that has yet been built, for it develops 2,100 b.h.p. at the moderate speed of 100 r.p.m. So far as the upper cylinder is concerned it resembles the Sulzer two-stroke single-acting design, and a similar system of scavenging is utilised—namely, by the

provision of two sets of ports, one for a supercharge of air after the main scavenging ports have been closed.

In this country Messrs. Beardmore have taken the lead in high-speed oil-engine manufacture with the production of units up to over 1,000 b.h.p. running at speeds of from 700 r.p.m. to 1,000 r.p.m. Such engines have been fitted for locomotive drive, with electric transmission, apparently with very satisfactory results, and they are now being developed for other commercial purposes. They are units with monobloc cylinders and separate liners, steel and aluminium alloy being largely used to reduce weight. Airless injection of fuel is adopted, and the fuel consumption appears to be remarkably good.

The production of oil in 1927 was far greater than ever previously recorded, and was probably quite 15 to 20 per cent. more than in 1926. Prices were, on the whole, somewhat lower, and all authorities are now agreed that there is no prospect of immediate shortage. There is little doubt that the average prices paid for liquid fuel throughout all parts of the world during 1928 will be lower than in 1927.

COAL MINING.

A number of new pits have reached the productive stage. The shafts of the new Betteshanger Colliery, in Kent, were sunk to a depth of 2,400 ft., and work was started on a 4-ft. 6-in. seam at 2,150 ft. There are in reserve five other seams over 3 ft. in thickness. During the year the owners of the Tilmanstone Colliery obtained powers for the construction of a rope-way from that colliery to Dover Harbour, and Betteshanger may shortly apply for similar facilities.

At Upton Colliery, in South Yorkshire, the Barnsley Bed was reached in March at a depth of 711 yards. The Top Hard seam was also reached at the Bilsthorpe Colliery, in Notts, of the Stanton Iron Company in August. It is anticipated that the sinking of the new Londonderry pits at Seaham Harbour, where the freezing process has been employed, will be finished this year; the Hutton seam was reached in one of the shafts at a depth of 1,840 ft. in March last.

An exceptionally well equipped anthracite colliery was opened in October at Gwaun-cae-Gurwen by Messrs. Guest, Keen, and Nettlefolds, and another sinking has been started at Cwmgorse.

An important borehole put down near Clackmannan to a depth of 563 fathoms proved the full range of coals.

The Bolsover Company have linked up five large collieries in a ring-feeder system, in this respect resembling the Powell-Duffryn system, which is probably the most extensive colliery power scheme in the world. The electrification scheme in the North of France, which is now complete, follows the same model.

In the North of England, Scotland, and Staffordshire the 'arcwall' and 'short-wall' machines have been introduced from America. With these, in Scotland, a 2-ft. 7-in. seam has been cut at an overall cost of 3·69*d.* per ton. At the Cannock Chase Colliery an output of 15 tons per man-shift has been secured.

In South Wales the use of conveyors has developed most rapidly; 30-cwt. trams and 40-lbs. to 45-lbs. rails on a 3-ft. 2-in. gauge are being employed. In America 12-yard rails weighing 100 lbs. to the yard on a 3-ft. to 4-ft. gauge are not uncommon in conjunction with locomotive haulage, which for various reasons makes slow progress in British mines.

At the Taff Merthyr Colliery coal is delivered from face conveyors 90 ft. long upon shaker conveyors, which conduct it to the loading points. At the Newbattle Colliery in the Lothians, there are in use quick adjustable connexions on trunk conveyors, and means to protect belting and prevent the spillage of coal. At several collieries ball bearings are being adopted for both conveyors and screens. Flexible suction conveyors are in use at Tursdale and Bowburn Collieries in Durham, and somewhat similar plant at the Bestwood Collieries in Notts.

An event of the year was the official opening in June of the new experimental station of the Safety in Mines Research Board at Harpur Hill, near Buxton, to replace the Eskmeals establishment. There are three explosion galleries, one 4 ft. in diameter and 1,000 ft. long being intended for experiments on coal-dust explosions. Already a good deal of large-scale work has been carried out, but it is becoming evident that each seam presents certain physical characteristics which can be determined only by prolonged experiment, accompanied by extended research into the constitution of the coal substance. Close co-operation has been maintained between the United States Bureau of Mines and the Safety in Mines Research Board, one important result of which has been that the British view has gradually tended towards that held by the American investigators, that the presence of firedamp modifies the proportions of combustible and inert matter statutorily required. The experiments so far carried out indicate that for every 1 per cent. of firedamp in the air about 5 per cent. more incombustible dust should be added to render the mixture incapable of propagating flame than when the air is gas-free. The minimum of non-combustible matter now laid down by the Bureau of Mines is 65 per cent.

The most notable development in regard to blasting explosives has been the addition to the 'permitted' list of a number of 'low-freeze' explosives.

An investigation at Sheffield on the effect of changes in the construction of approved flame lamps has resulted in the discovery that by a variation in the height of the gauzes it is possible to obtain an increased candle power varying from 50 per cent. in the case of Marsaut lamps to 180 per cent. in lamps of the 'combustion tube' type. Satisfactory tests have also been made with a flame lamp fitted with an incandescent mantle, differing somewhat from the Molnia lamp used in France.

FUEL UTILISATION.

An announcement was made during the year to the effect that an agreement had been signed between the Public Service Electric and Gas Company, of New Jersey, and the International Combustion Engineering Corporation of New York, for erecting in Rariton, New Jersey, a low

temperature carbonisation plant for use in connexion with the supply of towns' gas. Work is to be completed by March, 1929, and the plant is to consist of eight 'K.S.G.' process retorts, each with a throughput of 80 tons of coal per day, or 640 tons for the complete installation. This will give a daily yield of 2,500,000 to 3,000,000 cu. ft. of gas, of 800 B.Th.U. per cu. ft., which is to be mixed with carburetted water gas. The plant will have a daily output of 450 tons of smokeless fuel and 16,000 gallons of low temperature tar. In the 'K.S.G.' process the retort is a horizontal rotary steel cylinder, 76 ft. long and 10 ft. in diameter, having an inner cylinder 5 ft. 8 in. in diameter. The heating is on the external principle. The small coal travels first through the inner cylinder and then back along the outer cylinder, giving about 2½ hours' carbonisation, at a temperature of from 950 to 1,000° F., and 10 to 12 per cent. of volatile matter in the residual fuel. It is claimed that in this way, as a result of the large-scale commercial experience with the plant at Essen, hard smokeless fuel in lumps can be obtained from bituminous coal smalls with a throughput averaging 80 tons per retort per day.

A Turner plant is now in commercial operation at Coalburn, Lanarkshire, and it is claimed that the recovery of oil per ton is higher than with any other method, owing to the fact that no permanent gases are produced, the whole of the hydrocarbons evolved being thus recovered in liquid form. The Turner retort is internally heated by low-pressure superheated steam, and, by a device designed for varying the pressure within the retort, the volatile gases are swept by steam into cooler zones and thus removed from those influences which normally give rise to 'cracking.'

The fourth memorandum of the Fuel Research Board on 'Fuel for Motor Transport,' published in November, recorded a distinct advance in chemical research on the production of power alcohol from grasses, straws, and waste vegetable materials. The statement was made that a satisfactory method presenting no real technical difficulties, once the raw material is available cheaply, has been worked out. The method consists of soaking material such as wheat straw, rice straw, maize-cobs, etc., in 2 per cent. sulphuric acid (in the proportions of one part of straw to three parts of acid solution) for four hours, and following this treatment with steaming the drained straw for six hours at atmospheric pressure. The result is the production from the hemi-cellulose of from 5·5 to 23·3 per cent. of copper-reducing substances (calculated as pentoses), according to the material used. As the difficulty of transporting sulphuric acid in countries with undeveloped road systems was considered likely to limit the use of this acid, a search for an alternative resulted in the discovery that oxalic acid was the only suitable substitute. A complete system of fermentation of the hydrolysed liquor to alcohol and acetone was also satisfactorily worked out.

In this country the Imperial Chemical Industries are erecting plant for the manufacture of methanol from water gas, and, therefore, indirectly from coal and coke, and there is some indication that it may also be possible to carry this process as far as the production of higher alcohols. In addition, there is the possibility of creating an industry based upon the

conversion of methane (obtained by the distillation of coal) into acetylene, from which substance a large number of organic products which may be said to belong to the heavy organic chemical industry, *e.g.* acetic acid, can be produced.

Particular interest attaches to the intermediate scale tests now being conducted at the Fuel Research Station into the Bergius system of hydrogenation, under which, in addition to other products, 50 to 60 per cent. of crude oil and spirit are obtained from coal. The process consists essentially in submitting powdered coal to the action of hydrogen at about 450° C. under a pressure of about 200 atmospheres, some iron oxide being added (partly to remove sulphur), and the whole being usually mixed before treatment into a stiff paste with heavy oil or tar from a previous treatment. The present plant deals continuously with about one ton a day. The yields so far obtained from typical bituminous coals are approximately as follows :—Crude oil and spirit 50 to 60 per cent., gas 20 per cent., and partially converted organic matter 15 per cent., the remainder being water and inorganic matter. This compares with, say, 10 per cent. or less of oil-producing tar, which is the maximum obtainable from similar coals by low-temperature carbonisation. The oil produced contains cyclic, aliphatic, and aromatic hydrocarbons, phenols, and a small proportion of acids and bases. On distillation some 20 to 25 per cent. of the oil remains as pitch. The new plant will be used for investigating outstanding problems and methods of improving the process generally as applied to British bituminous coals.

A new burner of novel design has been invented in America. This burner can be used for powdered coal, oil fuel, or gas, and it is claimed that it eliminates all stand-by losses, because oil can be used for starting or manœuvring ships while in port and the pulverised coal can then be turned on merely by shutting one valve and opening another, or both fuels may be used at the same time. Gas also may be used in land installations if it should be deemed desirable. The same air control is used for all three fuels.

GAS ENGINEERING.

The price conditions which prevailed during the year as regards the Gas Light and Coke Company of London were that for the June quarter this undertaking reduced the price of gas by 1·4*d.* per therm ; for the September quarter a reduction of 0·8*d.* per therm was made, followed by a further reduction of 0·4*d.* for the final quarter of the year ; while at the end of the year it was announced that a still further reduction of 0·4*d.* per therm would be made for the first quarter of the present year, thus bringing the cost of gas to no less than 25 per cent. below the price prevailing a year ago.

In the report which was published during the year by the Fuel Research Board relating to the temperature of initial decomposition of coal, it is stated that when coal is heated in a retort the products of decomposition remain in it for a time, which varies with the means by which they are removed. If, as is usual, the products get hotter during that time, the

result is likely to make the temperature of initial decomposition appear higher than it really is. The net result of the experiments described in the report is to suggest that the temperature at which decomposition first appears in the types of coal examined is, in fact, substantially lower than had previously been believed. In this conclusion the experiments thus have a direct bearing on practice. The results, moreover, may also have to be taken into account in considering problems of the spontaneous combustion of coal in bulk and of coal-dust explosions in mines and elsewhere, when an accurate knowledge of the temperature at which decomposition begins must evidently be of capital importance. They will also affect investigations into the constitution of coal, as determining a critical point beyond which the coal cannot be heated without risk of change. The Fuel Research Board pointed out that when particles of a caking coal are exposed to a temperature of 600° C. carbonisation is accompanied by the formation of minute hollow spheres known as 'cenospheres,' while if the temperature be 800° C. the original diameter is approximately doubled, the volume of the cenospheres being about eight times that of the original coal particles. Cenospheres are found under the microscope to consist of two main structures—a practically opaque skeleton or framework, to which the name 'lattice' has been given, and thin, transparent, brownish films (filling the interspaces in the lattice) which have been termed 'windows.' The coke produced appears to be eminently suitable for use in powdered fuel plants, since it presents an enormous surface upon which combustion can take place. The cenospheres are extremely delicate and are easily crushed to a much greater degree of fineness should this prove necessary.

The Gas Investigation Committee referred to the effect of adding to coal about 2 per cent. of lime, iron, and sodium carbonate, and showed that extra gas, although of poorer quality, was obtained in each instance, and that the therm yield was increased in some cases by as much as 12 per cent. In each case the yield of sulphuretted hydrogen was approximately halved, but the ammonia yield was not greatly affected except with the calcium carbonate, which gave a 35 per cent. increase. The cokes remaining showed no great structural changes, but displayed an increased reactivity towards steam.

So far as the development of gasworks plant in the past year was concerned mention must be made of the growth in popularity of the waterless gasholder. Up to the present more than 120 of these holders have been erected throughout the world, the largest (in America) having a capacity of 15,000,000 cu. ft. During the year the first installation of the kind in this country was brought into satisfactory operation at Ipswich, while other installations are now in the course of completion.

A report of some importance was published in March by the Joint Benzole Research Committee, dealing with the tendency to resinification, in which lies the most important difference between a crude and a refined benzole motor spirit. This resinification may occur only to a slight extent in a comparatively crude benzole if used at once, but manifests

itself unmistakably after storage; and it is essential to know, before a benzole can be regarded as satisfactory, not only whether it contains objectionable resinous constituents, but also whether it will resinify under normal conditions or during storage. As a result of recent work, the committee reported that it was probable that an ultra-violet light test could be made satisfactorily in this connexion. There is also reason to suppose that the presence of certain minor constituents (*e.g.* phenols, even in minute quantities) now classed as impurities is beneficial in inhibiting resinification.

OIL AND ITS USE.

Early in August the purveyors of the leading brands of motor spirit announced a reduction—the third in five months—in the price of petrol to 1*s.* 1½*d.* per gallon in London. This was the lowest level touched for a quarter of a century, being no less than 3*s.* 6*d.* per gallon below the highest price ever recorded, which ruled in August 1920.

One of the few mineral oil products the value of which increased during the year was the fraction known as 'gas oil,' which is utilised by gas undertakings for the enrichment of water-gas. The increase is primarily explained by the fact that the gas-oil fraction is undoubtedly that which lends itself best to the cracking process. That lighter spirits can be obtained in considerable quantities by cracking the heavier fuel oils has frequently been demonstrated, but for most of the cracking processes it is more economical to use gas oil than the heavier fuel oils, although the latter are cheaper. The tendency is, therefore, for the output of petrol to be increased at the expense of gas oil.

During the year a report was published of investigations made at the Air Ministry Laboratory at the Imperial College of Science, with a full account of the experiments, which were based on a nuclear theory of detonation founded on the thermo-dynamic and physical properties of paraffin fuels under the conditions prevailing in the cylinder of a high-compression engine. It was shown that residual drops, consisting chiefly of the higher paraffins, would tend to persist in the charge during compression, and in the portion of the charge remaining unburnt at any moment after ignition. These nuclear drops, on account of their low ignition temperature, act as foci of simultaneous inflammation giving rise to detonation, although they form a very small percentage of the whole mixture. The effectiveness of the metallic dopes, tetraethyl lead and iron or nickel carbonyl, was explained by the fact that they naturally become concentrated in the nuclear drops, where they decompose, depositing metal which tends to delay the oxidation of the drops. The low ignition temperature of liquid drops of the higher paraffins was accepted as an experimental fact, but it was anticipated that further light might be obtained when the chemical side of the problem had been adequately explored. The conclusion drawn from the experiments was that detonation in paraffin fuels is due to the accumulation of peroxides in the nuclear drops during rapid compression. These drops ignite simultaneously when the detonation temperature of the peroxide is reached.

NITROGEN PRODUCTS.

There would appear to be no end to the possibilities of developing the synthetic nitrogen industry. A decade ago the fixation of atmospheric nitrogen, apart from the comparatively small scale production in Germany, had progressed little farther than the theoretical stage, but in the intervening years so rapidly have large capacity plants sprung up in almost all the more important countries throughout the world that the problem of the near future must undoubtedly lie in extending consumption to such an extent that it will keep pace with production.

In the report of the British Sulphate of Ammonia Federation, published in November, it was estimated that if the synthetic plants now in course of construction or announced by responsible undertakings are completed according to plan, the annual production of fixed nitrogen in the world will have increased by 1930–31 to about 2,000,000 tons. This figure makes no allowance for any production in Chile, which, if only continued on the present low scale, would bring the total quantity of nitrogen then available up to 2,200,000 tons. This amount exceeds the present consumption by 900,000 tons, so that an increase in use at the rate of 225,000 tons per annum for the next four years must be assumed if production is not to outdistance consumption. The actual increase in consumption during the four years 1923–27 was 261,000 tons, or an average rate of only 65,000 tons per annum.

The synthetic production of combined nitrogen products in this country is still confined to the Billingham works of Imperial Chemical Industries. It was pointed out that the plant was producing 65 tons of ammonia a day, but that a further unit was undergoing construction the daily capacity of which would be 165 tons of ammonia. At the same time the erection was proceeding of other plant for the manufacture of nitric acid, ammonium nitrate, ammonium carbonate, anhydrous ammonia, and nitro-chalk.

In France the yearly production of sulphate of ammonia is only some 150,000 tons, whereas the consumption is double that amount. The situation, however, seems likely to be remedied in the near future, for the State synthetic ammonia plant which was constructed at the former powder works at Toulouse began production during the year after many unforeseen delays, and while the present output is only about 40 tons of sulphate of ammonia per day it was estimated that by the end of 1928 production would approach 150,000 tons of sulphate per annum. It seems probable, however, that the French output of sulphate will within a year reach the figure of 500,000 tons per annum, thus rendering the country independent of foreign imports.

In other parts of the world, Korea is to have a Casale plant with an annual output of 20,000 tons of pure nitrogen, while in Japan the well-known Nippon Chisso undertaking is developing a large water-power plant at Chosen, with the object of erecting a synthetic ammonia installation having an annual capacity of some 50,000 tons of pure nitrogen. In Brazil the prospective programme provides for synthetic ammonia plants at Sao Paulo and Rio de Janeiro, while in the United States a plant which,

it is said, is to be the largest of its character in the world, is to be constructed by the Allied Chemical and Dye Corporation of America. It has been estimated that the plant will cost £2,500,000, in addition to £1,000,000 already paid for the site. At the present time the United States imports over 1,200,000 tons of nitrate, or more than half of Chile's export. It is anticipated that the new plant will render the country to a large extent independent of supplies from abroad.

IRON AND STEEL.

The influence of ash in coke on blast-furnace working was exhibited during the year very strikingly by Mr. C. S. Gill from the experience of the Consett Company. He was able to show that fluctuations in the quality of the iron from cast to cast, even though the average ash contents of the coke did not fluctuate abnormally from day to day, were due to hourly variations in the ash figure. On one occasion the coke supply of the whole blast-furnace plant was completely changed; both cokes were of similar character, made in the same ovens under identical conditions, and differed only in that the second coke had about 2½ per cent. less ash than the first. The averages of the figures for the whole of the furnaces for the five weeks before and after the week in which the change was made worked out, on the average weekly make of 3,000 to 4,000 tons, at an increase for the later period of over 15 per cent. in make, with a reduction in coke consumption of over 1 cwt. per ton of pig, in addition to a number of incidental advantages. As the result of these and other confirmatory observations it appeared that every 1 per cent. reduction of ash showed a direct saving of about ½ cwt. of coke and an increase of 6 to 7 per cent. in the make, with the considerable incidental advantages arising from more regular quality and larger turnover.

On another matter of fundamental importance observations made by Mr. Edwin H. Lewis, of Wishaw, indicated that a substantial advance had been made in the practice of dry-blast working. In Scottish practice the blast air weighs per ton of pig iron about ½ ton more than the total burden. Experience at Wishaw shows it may carry anything from just over 1 to about 6½ grains of water per cu. ft., each ½ grain of which per cu. ft. represents about 10 lbs. of water per ton of pig iron made. Following a suggestion made a few years ago, the Wishaw Company put into operation last year a plant for drying the blast with silica gel, which can absorb at least 20 per cent. of its own weight of water from the air, and be regenerated by merely raising its temperature. Three months' experience of the working of the plant showed not only a more regular quality of iron but a substantial return on the first cost. As yet, too, the optimum dryness, which probably lies between 0·1 and 1·0 grain per cu. ft., remains to be determined.

Probably, however, the most important outcome of last year's work is to be found among the researches initiated by the Cast Iron Research Association at the National Physical Laboratory, under the general supervision of Dr. Rosenhain, into the separate effects of silicon, phosphorus, sulphur, and manganese in ternary alloys with iron and carbon.

The first of these investigations, undertaken by Professor Hanson, includes the iron-carbon-silicon alloys. Though not complete, it has already led to observations on the strength of which Professor Hanson has been able to suggest a new theory of the equilibrium of the cast irons, which appears to explain many hitherto obscure points in their behaviour.

Another investigation, undertaken jointly by Dr. A. B. Everest, Mr. T. Henry Turner, and Professor Hanson, for the same Association, relates to the influence of nickel and silicon on iron-carbon alloys and the effect of varying conditions of manufacture. It has already led to results which seem likely to have practical importance, defining much more closely than before the behaviour of these alloys with both high and low nickel, and preparing the way for experiments with more complex alloys and on commercial cast irons, which are being carried out.

The need for improvements in steel has been urged for some time. Even with ordinary structural steel endeavours are being made to obtain improved physical qualities without substantial advance in cost, and in alloy steels the needs for greater physical and chemical resistance at high temperatures continue to increase, particularly for engineering purposes.

Opinion seems to be coming to agreement as to the purposes for which iron-chromium alloys are sufficient, and those for which the addition of nickel is desirable. The use of iron-chromium alloys in the form of stainless materials continues to spread, notably in the chemical, food, and brewing industries. It is also satisfactory to observe that the price of ferro-chromium seems to be coming down continuously.

A notable addition to the plant of the industry was made during the year by the introduction of the high-frequency induction furnace, already used in this country for some years past in melting non-ferrous metals. In its application to steel-making it seems likely to be a convenient alternative to crucible melting and arc furnaces, and to present considerable advantages for some purposes.

NON-FERROUS METALS.

Research has been made by Dr. W. H. J. Vernon for the British Non-Ferrous Metals Research Association on the atmospheric corrosion of non-ferrous metals and to some extent of iron. This work has been going on since 1921, and the importance of the first report, published in 1923, was generally recognised. A second report of no less consequence appeared last year. The research is perhaps best characterised by the fact that throughout its many branches it distinguishes the type of corrosion which removes material from the surface attacked, described in the investigation as erosion, from those which add weight and are described as surrosion, the two together representing the total corrosion. These have been traced out in a large variety of circumstances for a number of different metals, and in particular it has been found that against indoor tarnishing sufficient protection may in many cases be obtained by forming protective surface films, instead of by modifying chemical composition.

Among other uniformities and diversities that have been discovered is the fact that corrosion effects on prolonged exposure differ for different

types of metal and circumstances. In some, for example, such as zinc in an unsaturated atmosphere, corrosion increases in direct proportion to the time of exposure, and therefore at a constant rate. In others, such as iron in an atmosphere varying from high humidity to saturation, the attack is accelerated in proportion to what has already occurred. In others, again, such as copper in a wide range of humidity conditions, the attack is proportional to the square root of the time of exposure, and thus is retarded when the period increases. In others, as with aluminium and lead, the retardation is very much more rapid, and after a short time the attack ceases altogether for the time being. Among results with immediate practical importance it has been found that against open-air exposure to a corrosive atmosphere a fractional percentage of arsenic, or a small percentage of nickel or tin, reduces the corrosion of copper to extents varying from more than half to one-quarter of the attack undergone by high-conductivity copper in like conditions.

During last year a third report of the British Non-Ferrous Metals Research Association by Dr. H. Moore, of the Woolwich Research Department, described results in regard to the deterioration of lead-sheathed cables by cracking obtained by Mr. S. Beckinsale and Mr. H. Waterhouse. The failure appears to be due mainly to inter-crystalline cracks, which start at the inner surface of the sheath in situations in which the cable is subjected to vibration. Initially they are in no way associated with any kind of corrosion or chemical attack, and can be produced experimentally only by the effect of alternating stresses, such as may be applied in the Haigh fatigue-stress machine. It was found that by suitable additions of one or more alloying elements, such as tin, antimony, and cadmium, the fatigue limit of lead can be raised so considerably as to make liability to this kind of failure likely to be negligible.

The year was notable as regards nickel for a growing conviction that the long-standing trouble in respect to the corrosion and pitting of condenser tubes is likely to be solved by the use of 20 to 45 per cent. nickel-copper alloys, which have been adopted by some steamship owners both for new tonnage and for renewals. The resistance of the 45 per cent. alloy to tarnish and corrosion seems, moreover, to be creating for it an extended demand in many fresh directions. The practice of nickel plating also has undergone considerable improvement as the result of fundamental research. It appears now to be possible to produce thick deposits without fear of scaling, while avoiding the porosity from which the thin deposits of earlier days were seldom or never free. Important advances have also been made in the technique of chromium plating.

The use of aluminium alloys in the construction of textile machinery has been going on for some years, but the experience obtained by their use led to a considerable increase last year.

ELECTRICITY SUPPLY.

The Central Electricity Board, established under the Electricity (Supply) Act of 1926, came into existence in the earlier part of the year, with Sir Andrew Duncan as chairman and Mr. Archibald Page as chief

engineer, and in May issued its first scheme, that for the Central Scottish area, transmitted to it by the Electricity Commissioners. This area extends to 4,980 square miles, and the scheme contemplates that in about ten years it shall be supplied from 8 capital stations, 2 being new ones, instead of from the 36 now in existence. The main 132,000-volt transmission lines to be erected by the Board are to extend from Dundee to Dunfermline and then on to Glasgow by way both of Bonnybridge and of Edinburgh and Motherwell, while on the west there will be a ring main linking Glasgow with Greenock, Saltcoats, Kilmarnock, and Paisley. The estimated cost of the transmission lines and transforming stations is £2,204,034, and of standardising the frequency at 50 cycles £2,921,250. A contract for the erection of about 29 route miles of double-circuit and 199 miles of single-circuit three-phase mains was placed with British Insulated Cables, Limited, Prescot, in December. It involves 999 miles of steel-cored aluminium conductors, with 1,500 steel lattice towers each between 70 ft. and 80 ft. high and weighing in all 6,000 tons.

In the autumn the Board issued a second scheme, for South-East England, an area of about 8,828 square miles, extending from Wisbech and Peterborough in the North to the South Coast, and including London and Middlesex. Under it the current required will, by 1940, be supplied from 27 stations instead of from the 135 now in use. The cost of the primary transmission system is put at about £6,500,000.

Among new stations opened during the year was that of the Shropshire, Worcestershire, and Staffordshire Electric Power Company at Stourport, with an initial installation of two 22,500 kv.a. sets made by the British Thomson-Houston Company and working at a frequency of 25 cycles. A new municipal station was opened at Poplar, with a G.E.C. 12,500 kv.a. set. In November the Charing Cross Electricity Supply Company inaugurated at its Shorts Gardens station a 1,200 kw. direct-current generator driven by a six-cylinder Diesel engine of 1,750 b.h.p., which is claimed to be the largest of its kind yet installed in a power station in this country. Both generator and engine were made by the General Electric Company, the former at Witton and the latter at the Fraser and Chalmers Engineering Works, Erith.

The programme of extensions which the London Power Company has in hand includes the addition of some 220,000 kw. of plant to the existing stations at Bow, Grove Road, Willesden, and Deptford; and in October it received the consent of the Electricity Commissioners, subject to certain conditions, to the construction of a huge station at Battersea, which it is proposed shall contain initially two 75,000 kv.a. units and ultimately six such units, or a total of 450,000 kv.a. The Metropolitan-Vickers Company is supplying a 25,000 kw. set for the Neasden power station of the Metropolitan Railway, and is engaged in making what will be the largest turbo-alternator yet installed in this country, in the shape of a 41,000 kw. unit for the Barton station of Manchester Corporation.

The Stonebyres and Bonnington stations on the Clyde, belonging to the Lanarkshire Hydro-Electric Power Company, were brought into operation during the year. Both were equipped by the English Electric

Company with vertical reaction turbines and alternators, the two sets at the former station being each of 4,000 h.p. and the two at the latter of 6,750 h.p. The same firm received an order for five 9,000 h.p. impulse water turbines and five 6,000 kw. direct-current generators, with control gear, for the Lochaber scheme of the North British Aluminium Company. The normal speed of the turbines is to be 250 r.p.m. under a head of 720 ft., and each will drive two 3,000 kw. generators in tandem, an exciter capable of supplying excitation current to the fields of two complete units being mounted on the same shaft.

Three 13,330 kv.a. waterwheel alternators of the vertical type, larger than any other machines of the kind yet built in this country, were completed last year by the Metropolitan-Vickers Company and are now being erected in the Maipo River station of the Compañia Hidro-Electrica Volcan of Chile. A feature of this installation is the use of a vertical shaft arrangement in conjunction with Pelton wheel drive, the principal reason for its adoption being the possibility of designing the turbines for the relatively high speed of 250 r.p.m. by providing four water inlets. On test these alternators realised a full-load efficiency of over 96 per cent. at 0·9 power factor. An installation of motor-generating plant made for the works of the International Aluminium Company, at Glom Fjord, Norway, consists of three 8,000 h.p. 6,600-volt induction motors each driving in tandem two 2,760 kw. d.c. generators at 400/325 volts, the current from each machine at the latter voltage being 8,500 amperes. These sets supply power for aluminium furnaces, two sets operating one furnace and one set being used as a stand-by.

The largest single-phase and three-phase transformers yet built in this country were under construction by the Metropolitan-Vickers Company, in the shape of four 54,000 kv.a. three-phase banks for Buenos Aires, each consisting of three 18,000 kv.a. single-phase units and one spare, of which one bank has been completed. Two 25,000 kv.a. three-phase transformers for the extensions at the Barton Station of Manchester Corporation were also in hand. These transformers are all for indoor service, and are fitted with oil conservators. The method of cooling is by forced oil circulation with external oil coolers arranged for water cooling.

The Southern Railway was engaged in equipping a further section of its suburban lines for electric working, and made a start, on the South London line, with the substitution of the third-rail direct-current for the alternating-current overhead system. Towards the end of the year the London Underground Railways announced a programme for modernising the rolling-stock and equipment of their system at an estimated cost of £2,500,000, the object of the overhaul, which will occupy two years, being to level up the efficiency to the standard represented by the new material put into the latest extensions, and thus permit greater loads and higher speeds. An order was placed with the General Electric Company for nearly 400 railway motors of 240 h.p. to replace existing motors on the tube lines, together with multiple-unit control equipments for 63 motor-coaches and 107 trailer cars.

In India the electrification by the Bombay, Baroda and Central India

Railway Company of 23 miles of its Bombay suburban lines was completed during the year.

Extensive installations of light signals have been carried out by the Westinghouse Brake and Saxby Signal Company at the London terminals of the Southern Railway. Towards the end of the year this firm received from the L.M.S. Railway an order for an installation of power signalling in connexion with the remodelling of the Victoria and Exchange stations at Manchester. Here the installation will include 3 new signal boxes with a total of 209 levers, 128 electrically-driven point machines, over 200 colour light signals of 4, 3, and 2 aspects, 26 optical route indicators, and 176 alternating-current condenser-fed track circuits. The point machines will be worked by direct current derived from the alternating-current mains by means of Westinghouse metal rectifiers.

The Metropolitan-Vickers Company supplied, for the Grimethorpe pit of the Carlton Main Colliery, near Doncaster, the largest electric winder yet installed in this country. Of 3,000/7,500 h.p., the equipment consists of a double-unit d.c. motor, direct coupled to the winding drum and controlled on the Ward-Leonard principle, and a flywheel motor-generator set, by means of which power received at 3,000 volts 50 cycles is supplied as direct current at 1,000 volts to the winder motor.

TELEPHONES.

A good deal of work was done last year by the engineers of the Post Office and their specialised contractors for the improvement of telegraph and telephone facilities. About 300 miles of duct were laid in roads which were excavated for the purpose to the extent of about 100 miles, and 430 miles of main underground cables were laid, containing 33,000 miles of pairs of conductors for trunk and toll use. For local underground lines about 2,000 miles of duct were laid and cables with a wire mileage of 610,000 drawn in. The value of the contracts placed by the Post Office for the installation of engineering plant was £4,315,000, compared with £3,210,000 in the previous year, and all the contracts were given to British firms, the value of material not of British manufacture used on them being only £1,700.

In Great Britain 90 new urban exchanges, 36 of them automatic, were opened, extensions were made to 22 existing exchanges, and 247,000 new subscribers' stations were added to the exchange system.

The opening of telephone repeater stations at Leeds, Catterick, Newcastle, Jedburgh, and Edinburgh completed the chain between London and Edinburgh, and with the associated underground cables provided a link between London and the North independent of weather conditions. A repeater station was also opened at Canterbury to serve the South-Eastern district of England and the Continental routes *via* Belgium and France, and others are approaching completion at Taunton, for the West of England route, and at Halesworth on the route to Norwich.

During the year direct telephonic communication was established with Sweden and Switzerland and, by means of switched circuits, with Denmark and Austria. Commercial speech is now possible between

Glasgow and Stockholm, over a telephonic circuit about 2,000 miles long, thanks to the development of the telephone repeater and modern submarine cables.

WIRELESS.

The first 'beam' station, for communication by means of short waves with Canada, was opened in the autumn of 1926, and was followed last year by stations successively for Australia, South Africa, and India. All these stations were built by the Marconi Company for the Post Office, and that company also erected for itself, at Dorchester and Somerton, stations through which it is conducting short-wave telegraphic services with North and South America.

The transmitting stations for the Canadian and South African services are situated near Bodmin and the receiving stations near Bridgwater, Somerset. The Australian and Indian transmitting stations are near Grimsby and the receiving stations at Skegness. All these stations employ the flat grid reflector system developed by Mr. Franklin, of the Marconi Company. The normal speed of working is 100 words a minute, but on one occasion messages sent from Australia at a speed of 325 words a minute were successfully recorded at Skegness. The wave-lengths employed are between 16 and 34 metres, and they are changed according to the 'daylight' and 'night' periods. In the case of the Australian services, however, transmission takes place in either an easterly or a westerly direction on a single wave-length—an arrangement which has been made possible by providing two sets of active aerials back to back, with a common reflector system between them, one or other of the aerials being energised according to the time of day.

A new transmitting station for long-distance communication with ships has nearly been completed by the Post Office, and will replace the present station at Devizes. It has one 25 kw. and two 6 kw. transmitters, instead of the two 6 kw. transmitters at Devizes, and all of them are equipped with tuning-fork control to ensure constancy of frequency.

LOCOMOTIVES.

Locomotive builders, other than the railway companies, were fairly busy last year, except possibly in the earlier part, and in the majority of cases the orders obtained were for engines to be supplied to foreign railways. In this connexion it is to be noted that locomotives of the Garratt type increased in popularity. One firm, Messrs. Kitson and Co., of Leeds, designed and built, for experimental purposes, a Kitson-Still combined internal combustion and steam locomotive, with eight cylinders and geared drive.

The past year witnessed some distinctly important developments in locomotive practice, not the least significant of which was the adoption, by both the Great Western and the London Midland and Scottish Railways, of the comparatively high steam pressure of 250 lbs. per sq. in., in

each case in new non-compounds of the 4–6–0 express type. The Great Western had previously employed 225 lbs. for corresponding simple engines, and the L.M. and S. (with a few exceptions) from 175 lbs. to 180 lbs.

Another line, the London and North-Eastern, also decided to try an increase in pressure, in this instance in engines of the Pacific class. Recently, one of the 1923 4–6–2's was re-boilered and given a working pressure of 220 lbs., representing for this type an addition of 40 lbs. per sq. in., and this higher pressure will be used in ten new Pacifics under construction at Doncaster. The long valve travel principle, applied to the rebuilt 4–6–2, is being adopted in the new engines. The L. and N.E. was the only one of the grouped railways which brought out what was in one respect a novelty—a 4–4–0 express locomotive of the three-cylinder simple type.

A four-cylinder Claughton 4–6–0, No. 5908, fitted with the Beardmore-Caprotti gear, was tested against No. 5917, an ordinary engine of the same series, on certain dates in January and February, a dynamometer car being used for the trials. The results showed that No. 5908, as compared with No. 5917, working under similar conditions, could maintain a higher average speed on a smaller consumption of fuel. The London Midland and Scottish Railway are having the new gear fitted to nine more engines of the Claughton type.

Ten new Pacifics are under construction at Doncaster. These will have 220 lbs. pressure, compared with the former figure of 180 lbs., and they will, it is understood, be generally similar to No. 4480, Enterprise, a 4–6–2 turned out in 1924, and rebuilt during the summer of 1927 with a new boiler carrying the higher pressure mentioned.

The North British Locomotive Company supplied a number of tank engines of the 2–6–2 type to the Egyptian Government, and others of the 2–6–4 notation to the Madras and Southern Mahratta Railway, the Indian State Railways, and the Eastern Bengal line. Other construction included 4–6–2 and 4–8–2 tender engines for the Sudan Government and the Mashonaland Railways respectively, and also some 4–6–4 tank engines for the Cordoba Railway (Argentina), and 2–8–4 T's for the Antofagasta and Bolivia Railway (Chile).

Messrs. Beyer, Peacock and Co. turned out thirty-eight Garratt locomotives for various foreign railways, six of which, of the 4–8–2–2–8–4 wheel arrangement, had a tractive force (at 75 per cent. of the boiler pressure) of 46,200 lbs., and a total weight of 158 tons. A like number of 2–6–2–2–6–2 Garratts for the Sao Paulo Railway also weigh 158 tons, and with 20 in. by 26 in. cylinders, 5 ft. 6 in. coupled wheels, and 200 lbs. pressure, have a tractive effort of 47,270 lbs. This firm also built nine 4–6–0 tender engines for the Ceylon Government Railways, and seven and ten 4–6–2's for the Federated Malay and the Leopoldina Railways respectively. Twenty three-cylinder 4–8–0's are being built for the Buenos Ayres Great Southern Railway.

Sir W. G. Armstrong, Whitworth and Co., among other items, furnished twenty-five 4–8–0's (3 ft. 6 in. gauge) to the Queensland Government Railways.

Eight engines of the 2–8–2 tender type were built by Messrs. Robert Stephenson and Co., six (with cylinders 21¼ in. by 28 in. and 4 ft. 3 in. wheels) for the Kenya-Uganda Railway.

For the Giradot Railway Messrs. Kitson and Co. supplied four Kitson-Meyer 2–6–6–2 engines; for the Cordoba Central Railway five 4–6–2's; and for the Midland Railway of Western Australia three 2–8–2 tender engines.

In the carriage and wagon department there is little to record. The more noteworthy items are the introduction of twin-coaches for branch-line working on the L. and N.E. Railway; the construction of new first-class corridor carriages (57 ft. 1 in. long, and without side doors) for the Royal Scot trains of the L.M.S. Railway; and the putting into service by the Great Western Railway of twelve glass-lined tank wagons, of 3,000 gallons capacity, for the conveyance of milk in bulk. The United Dairies, Limited, supplied the tanks, which are mounted upon steel-framed wagons specially designed for the purpose by the Great Western at Swindon.

AERONAUTICS.

Of the flights across the North Atlantic from West to East the following succeeded:—Lindbergh, New York to Paris (3,600 miles in 33½ hours); Chamberlin and Levine, New York to Helfde (Germany) (3,900 miles in 43 hours); Byrd and his three companions, New York to Ver-sur-Mer (between Cherbourg and Havre) (40 hours in the air, distance covered uncertain, as machine flew around over France for hours); and finally, the flight of Brock and Schlee, from Harbour Grace, Newfoundland, to London (2,350 miles in 23 hours 20 minutes), as a stage in their attempt to fly round the world in a fortnight.

Among types of flying-boats produced during the year may be mentioned the Saunders Valkyrie, the Supermarine metal hull Southampton, the Short Singapore, and the Blackburn Iris II. Four of these boats made a highly successful cruise to the Baltic and Scandinavia last summer, and four Southamptons started on a tour to Australia and the East.

For commercial work two Short flying-boats of the Calcutta type are nearing completion at Rochester and will be put into service this year.

During 1927 only a single new British commercial aeroplane was produced. This was the de Havilland Canberra, with Bristol Jupiter engine, a biplane designed for a firm in Australia.

The world's distance 'record' in a straight line was raised to 3,911·1 miles by Clarence Chamberlin with his flight from New York to Helfde, Germany, while the duration 'record' (closed circuit) now belongs to Germany, with 52 hrs. 22 mins. 31 secs.

In the light aeroplane class Great Britain holds two world's 'records'—for speed and altitude. The former was established by Captain Broad, who, on a de Havilland Tiger Moth monoplane with 130 h.p. de Havilland engine, reached a speed over a triangular course of 186·47 miles an hour; and the latter by Lady Bailey, who, flying a de Havilland Moth biplane and carrying Mrs. de Havilland as a passenger, reached a corrected height of 17,284 ft.

1927 was characterised by an increased use of the radial air-cooled type of engine. Technical development in aero engines was mainly in the direction of, apart from the usual search for greater power and smaller weight, supercharging by blower, and gearing of the propeller.

In the water-cooled class there are three new types to be recorded—the Rolls-Royce F.10, the Napier racing engine fitted in the Schneider Trophy machines, and the Bristol Mercury, also fitted in a Schneider machine, the Crusader. The F.10 is of the twelve-cylinder Vee type, rated at a normal power of 485 b.h.p. at 2,100 r.p.m., and is produced both with direct drive and with spur-type reduction gear. The Napier racing engine is of the 'broad arrow' type, with twelve cylinders arranged in three banks of four each. Like the F.10, it is produced both as a direct-drive and as a geared engine.

MOTOR CARS.

The general tendency in car design is towards the low-built chassis carrying a lightly but strongly built body and driven by a relatively small engine of high efficiency. The present demand appears to be for an engine of 1½ to 2 litres. In order to augment the power output of such small engines superchargers of the rotary-blower type are fitted on several commercial models.

The outstanding innovations of the past year include the introduction of more British light six-cylinder engines, better mixture distribution, the application of free-wheel clutches in or adjoining the gearboxes (to facilitate gear changing and to economise petrol), improved steering and new steering layouts, the separate springing of each wheel, instead of the 'solid' axle method, the more general adoption of the fabric or light saloon, the cheapening of production by producing greater numbers, and, finally, a general advance in maximum speed and hill climbing ability. It is now quite common to find small cars of 1,100 c.c. engine capacity, fitted with a light saloon body carrying four people, which will maintain a speed of 35 to 40 miles an hour on the level and touch 55 to 60 miles when on full throttle.

During the past year there was an increase of nearly 10 per cent. in the number of new six-cylinder engines; about 45 per cent. of the Olympia show models had this type, about 45 per cent. four cylinders, 8 per cent. eight cylinders, and less than 1 per cent. each two, three, and twelve cylinders.

The general tendency is towards greater rigidity of crankshaft and crankcase; more bearings are now fitted to the crankshaft. In regard to valves the overhead arrangement is in the majority; it is to be found in about 47 per cent. of modern cars, while 42 per cent. are fitted with the side-by-side type. The single and double sleeve valve engines still maintain their hold, with 10 per cent. of the total. There appears to be a slight tendency to raise compression ratios in the case of high speed small engines; the usual ratio is 5 to 1, but 5½ to 1 is not unusual in fast touring engines, and sports models using 'doped' petrol often reach

6 to 1. Engine speeds show a slight improvement in maximum values; many 1,500 c.c. engines now attain speeds of 4,000 r.p.m.

The single-plate type clutch continues to find fresh adherents, and it is fitted in no fewer than 65 per cent. of modern cars. About 20 per cent. of cars are now fitted with multiple-plate clutches, and only 10 per cent. with cone clutches.

In gearboxes there is little change. There are now more British cars with central gear control than hitherto, about 65 per cent. of cars being thus fitted. That the method of arranging the gearbox, clutch-pit, and engine as an integral unit is popular is shown by the fact that three out of every four cars now employ this system. There are more four-speed than three-speed gearboxes in use by about 15 per cent.; this is due in part to the smaller engines now used, and in part to their higher speed range. In general, gear-changing is rather more easy than it was twelve months ago, and it is a much lighter operation.

In most popular makes of car the suspension has almost become standardised, half-elliptic springs for the fore end being found in at least 90 per cent. of all makes. The other 10 per cent. employ quarter-elliptics, transverse and cantilever. Of the methods of rear suspension in vogue, nearly 70 per cent. are half-elliptic, 16 per cent. cantilever, and 10 per cent. quarter-elliptic, the rest being transverse and independent wheel springing systems.

For ignition devices the magneto system still holds the premier position in this country, no fewer than 60 per cent. of cars being fitted with magnetos. On the other hand, there has been a notable increase in battery ignition, which is used in 30 per cent. of British cars, while about 7 per cent. employ both systems. Magnetos are still more reliable, and are invariably placed in accessible positions. Another point of interest is the tendency to relieve the driver of responsibility in regard to ignition advance by fitting an automatic centrifugally operated advance and retard device.

The range of commercial vehicles now available includes, apart from small tradesmen's vans, the 20 cwt. to 30 cwt. chassis type, with solid, cushion, or pneumatic tyres, at one end, and at the other the 12 ton to 17 ton six or eight wheeler for really heavy duty. The type of chassis most favoured for high-speed passenger work appears to be the 20- to 32-seater of low build, fitted with a six-cylinder engine of 25 h.p. to 36 h.p. on the R.A.C. rating, weighing from 1½ ton to 4 tons, fitted with pneumatic tyres, and capable of cruising speeds of 30 to 40 miles an hour. One recent 20-seater motor-coach has a maximum speed of 60 miles, a cruising speed of 40 to 45 miles, and, at half-throttle, a speed of 30 miles, when loaded with its full complement of passengers. It will climb hills of 1 in 4½ on first speed at 10 miles an hour with power in reserve.

A considerable improvement is evident in engine design, the more recent models tending to follow orthodox motor-car engine practice. Not only are the engines lighter and more efficient in power output, but they are more flexible. The speeds of revolution are higher than hitherto, the maximum having risen from 1,000–1,500 r.p.m. up to 2,000–3,000 r.p.m.

during the last two years. Further, whereas there were practically no six-cylinder engine vehicles two years ago, to-day at least 15 per cent. of commercial engines belong to this type, and the proportion is growing.

PORTLAND CEMENT.

The value of the cement industry to the community at large cannot be over-estimated. All the raw materials needed are furnished, in one form or another, by our own native soil, the coal used in the conversion of the materials into cement is a British product, and British labour is an all-important factor. A conservative estimate shows that over 2,500,000 tons of coal are consumed by the cement industry every year, a quantity involving a distinctly useful contribution to the wages bill of the coal-miners. General labour, again, shares on a liberal scale in the prosperity of cement manufacturers, the participation of the workers directly and indirectly amounting to about £1 per ton of cement and representing in the aggregate over £5,000,000 annually. Statistics so far available show that the consumption of all varieties and brands of Portland cement in the United Kingdom was some 5,300,000 tons in 1927, an increase of about 300,000 tons compared with the figures for the preceding year.

The reconstruction of a considerable length of Broadway in New York was carried out in the 'Ferrocrete' cement of the British Associated Portland Cement Manufacturers, and an American firm under the style of the Ferroconcrete Import Company, Inc., has started business in New York for the sale of the same cement.

Originally introduced by the Associated Portland Cement Manufacturers, rapid-hardening cements are now being made under different trade names by most of the leading manufacturers. In the home market, rapid-hardening cements have made great headway, sales during 1927 having been fully double those for the preceding twelve months.

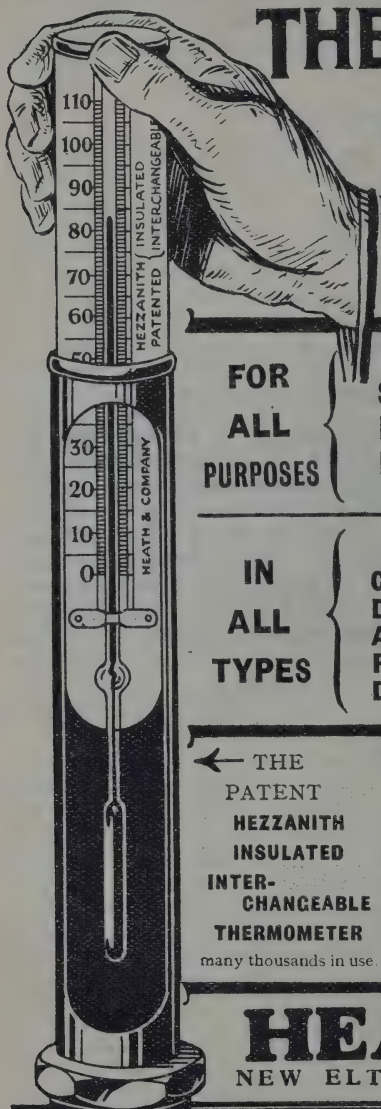
In Scotland extensive use is made of 'Giscol,' consisting of Portland cement clinker carrying a proportion of granulated blast-furnace slag added in the final grinding. This cement, which is made by the Glasgow Iron and Steel Company, of Wishaw, is manufactured under somewhat unusual conditions, being the only cement made with the incorporation of blast-furnace slag in which all the raw materials are produced by the same firm and controlled by them from their various sources of supply.

The confidence of manufacturers in the continued increase of the demand for cement has been evidenced by considerable extensions of existing works and the building and equipment of new works by recently formed companies as well as by old-established firms.

SECTION I

MATHEMATICS

ALGEBRA — PROGRESSION — INTEREST — ANNUITIES — SINKING FUND —PRESENT VALUE — AMORTIZATION — SERIES — PERMUTATIONS AND COMBINATIONS — THE CALCULUS–GEOMETRY—CONIC SECTIONS—CURVES—THE CIRCLE—CIRCLE AREAS AND CIRCUMFERENCES—CIRCLE SEGMENTS — TRIGONOMETRY — TRIGONOMETRICAL TABLES — SQUARES — CUBES — ROOTS — RECIPROCALS — LOGARITHMS — HYPERBOLIC FUNCTIONS — THE SLIDE RULE–NOMOGRAPHIC OR ALIGNMENT CHARTS.



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MATHEMATICS

ALGEBRA — PROGRESSION — INTEREST — ANNUITIES — SINKING FUND — PRESENT VALUE — AMORTIZATION — SERIES — PERMUTATIONS AND COMBINATIONS — THE CALCULUS — GEOMETRY — CONIC SECTIONS — CURVES — THE CIRCLE — CIRCLE AREAS AND CIRCUMFERENCES — CIRCLE SEGMENTS — TRIGONOMETRY — TRIGONOMETRICAL TABLES—SQUARES—CUBES—ROOTS—RECIPROCALS—LOGARITHMS — HYPERBOLIC FUNCTIONS — THE SLIDE RULE—ALIGNMENT CHARTS.

ALGEBRA.

Ratio.

Ratio is the relation of one quantity to another in respect of magnitude.

The magnitudes of two quantities of the *same kind* may be compared in two ways :—

(1.) By finding their difference, or how much one is greater than the other. This gives the *Arithmetical Ratio* of the quantities.

(2.) By finding how many times the one contains the other. This determines their *Geometrical Ratio*, or, simply, their *Ratio*.

For example, if a and b be the measures of two quantities, their *Arithmetical Ratio* is $a-b$, and their (*Geometrical*) *Ratio* is $a : b$ or $\frac{a}{b}$; a and b are called the *Terms* of the ratio ; a is called the *Antecedent*, and b the *Consequent*. The ratios $a^2 : b^2$, $a^3 : b^3$, $\sqrt{a} : \sqrt{b}$, and $\sqrt[3]{a} : \sqrt[3]{b}$ are called respectively the *duplicate*, the *triplicate*, the *subduplicate*, and the *subtriplicate* ratio of $a : b$.

If $\frac{a}{b} = \frac{c}{d} = \frac{e}{f} = \cdot\cdot\cdot\cdot$ each of these ratios is equal to $\frac{a+c+e+\cdot\cdot\cdot\cdot}{b+d+f+\cdot\cdot\cdot\cdot}$. The application of this principle greatly simplifies many problems.

Proportion.

Proportion is the equality of two ratios. The ratio of $a : b$ will be equal to $c : d$ if $\frac{a}{b} = \frac{c}{d}$, and the four numbers represented by a, b, c, d are then said to be *proportionals*.

The proportion is usually stated thus :—$a : b = c : d$, or $a : b :: c : d$ (read a is to b as c is to d). The two terms a and d are called the *extremes*, and b and c the *means*.

If a, b, c, d be proportionals, the product of the *extremes* is equal to the product of the *means*. or,

$$ad = bc.$$

Conversely, if $ad = bc$,

$a : b = c : d.$ $\quad a : c = b : d.$ $\quad d : b = c : a.$ $\quad d : c = b : a.$

Also, if $a : b :: c : d$,

$a+b : b = c+d : d.$ $\quad a-b : b = c-d : d.$ $\quad a+b : a-b = c+d : c-d.$

Arithmetical Progression.

An *Arithmetical Progression* is a series of numbers which increase or decrease by a *constant difference*. Thus 1, 3, 5, 7, 9 ; 10, 8, 6, 4, 2 are *arithmetical progressions*, the constant difference being 2 in the first series and -2 in the second.

Let a = the first term of the series. z = the last term. n = the number of terms.
d = the constant difference. S = the sum of all the terms.

$$a = z - d\,(n-1). \qquad a = \frac{2S}{n} - z. \qquad a = \frac{S}{n} - \frac{d}{2}(n-1). \qquad z = a + d\,(n-1).$$

$$z = \frac{2S}{n} - a. \qquad z = \frac{S}{n} + \frac{d}{2}(n-1). \qquad n = \frac{z-a}{d} + 1. \qquad n = \frac{2S}{a+z}.$$

$$d = \frac{z-a}{n-1}. \qquad d = \frac{(z+a)(z-a)}{2S - a - z}. \qquad d = \frac{2\,(S - an)}{n\,(n-1)}. \qquad d = \frac{2\,(zn - S)}{n\,(n-1)}.$$

$$S = \frac{n\,(a+z)}{2}. \qquad S = \frac{(a+z)(z+d-a)}{2\,d}. \qquad S = n\left[a + \frac{d}{2}(n-1)\right].$$

$$S = n\left[z - \frac{d}{2}(n-1)\right]. \qquad a = \frac{d}{2} \pm \sqrt{\left(z + \frac{d}{2}\right)^2 - 2dS}.$$

$$z = \frac{d}{2} \pm \sqrt{\left(a - \frac{d}{2}\right)^2 + 2dS}. \qquad n = \frac{1}{2} - \frac{a}{d} \pm \sqrt{\left(\frac{1}{2} - \frac{a}{d}\right)^2 + \frac{2S}{d}}.$$

$$n = \frac{1}{2} + \frac{z}{d} \pm \sqrt{\left(\frac{1}{2} + \frac{z}{d}\right)^2 - \frac{2S}{d}}.$$

When the series is a decreasing one make the first term $= z$, and the last term $= a$.

The *Arithmetical Mean* of two quantities, A and B, $= \frac{A + B}{2}$.

Geometrical Progression.

A *Geometrical Progression* is a series of numbers which increase or decrease by a *constant factor*, or *common ratio*. For example, 2, 4, 8, 16, 32 ; 4, $-\frac{1}{2}$, $\frac{1}{16}$, $-\frac{1}{128}$, $\frac{1}{1024}$, are Geometrical Progressions, the constant factor being 2 in the first series and $-\frac{1}{8}$ in the second.

Let a = the first term. z = the last term. n = the number of terms.
r = the constant factor. S = the sum of the terms.

$$a = \frac{z}{r^{n-1}}. \qquad a = S - r(S - z). \qquad a = S\,\frac{r-1}{r^n - 1}. \qquad z = ar^{n-1}.$$

$$z = S - \frac{S-a}{r}. \qquad z = S\left(\frac{r-1}{r^n - 1}\right)r^{n-1}. \qquad r = \sqrt[n-1]{\frac{z}{a}}. \qquad r = \frac{S-a}{S-z}.$$

$$ar^n + S - rS - a = 0. \qquad S = \frac{a(r^n - 1)}{r - 1}. \qquad S = \frac{a(1 - r^n)}{1 - r}. \qquad S = \frac{rz - a}{r - 1}.$$

$$S = \frac{z(r^n - 1)}{(r-1)r^{n-1}}. \qquad n = 1 + \frac{\log z - \log a}{\log r}. \qquad n = 1 + \frac{\log z - \log a}{\log (S + a) - \log (S - z)}.$$

$$n = \frac{\log [a + S(r-1)] - \log a}{\log r}. \qquad n = 1 + \frac{\log z - \log [zr - S(r-1)]}{\log r}. \qquad S = \frac{z\sqrt[n-1]{z} - a\sqrt[n-1]{a}}{\sqrt[n-1]{z} - \sqrt[n-1]{a}}.$$

The *Geometric Mean* of two quantities, A and B, $= \sqrt{AB}$.

Harmonical Progression.

Quantities are said to be in *Harmonical Progression* when any three consecutive terms being taken, the first is to the third as the difference between the first and second is to the difference between the second and third. Thus, if a, b, c be the consecutive terms in a series, then, if $a : c :: a - b ; b - c$, a, b, c are in harmonical progression. If quantities are in harmonical progression, their reciprocals are in arithmetical progression.

There is no method by which the sum of an harmonic series can be found.

The *Harmonic Mean* of two quantities, A and B, $= \frac{2AB}{A + B}$.

Simple Interest.

Interest is money paid for the use of other money lent for a certain time at a fixed rate per cent.

Let P = the *Principal*, or money lent, in pounds. R = the *Rate per Cent.*, or interest of £100 for one year. I = the *Interest*. A = the *Amount*, or principal + interest. T = the *Time* in years.

Then

$$I = \frac{P \times T \times R}{100}. \qquad R = \frac{100 \times I}{PT}. \qquad P = \frac{100 \times I}{RT}. \qquad T = \frac{100 \times I}{PR}.$$

$$A = P + I = \frac{P(100+RT)}{100}. \qquad P = \frac{100 \times A}{100+RT}.$$

If the *Time* (T) be given in *months*, *weeks*, or *days*, multiply the 100 in the above equations by **12, 52,** or **365** as the case requires.

Compound Interest.

In *Compound Interest*, the interest due at the end of the first period is added to the principal, and the *amount* thus obtained is taken as the principal in calculating the interest for the next period, and so on.

Let P = Principal. A = Amount. r = Interest on £1 for a year or given period. n = Number of years, or periods.

Then

$$A = P(1+r)^n. \qquad P = \frac{A}{(1+r)^n}. \qquad r = \sqrt[n]{\frac{A}{P}} - 1. \qquad n = \frac{\log A - \log P}{\log (1+r)}.$$

Compound Interest Table.

Showing the sum to which £1 will increase at *Compound Interest* during any number of years not exceeding 50; interest being calculated to and added on at the end of every year.

No. of Years	2½ per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.
1	1·02500	1·030000	1·040000	1·050000	1·060000
2	1·05063	1·060900	1·081600	1·102500	1·123600
3	1·07689	1·092727	1·124864	1·157625	1·191016
4	1·10381	1·125509	1·169859	1·215506	1·262477
5	1·13141	1·159274	1·216653	1·276282	1·338226
6	1·15969	1·194052	1·265319	1·340096	1·418519
7	1·18869	1·229874	1·315932	1·407100	1·503630
8	1·21840	1·266770	1·368569	1·477455	1·593848
9	1·24886	1·304773	1·423312	1·551328	1·689479
10	1·28008	1·343916	1·480244	1·628895	1·790848
11	1·31209	1·384234	1·539454	1·710339	1·898299
12	1·34489	1·425761	1·601032	1·795856	2·012196
13	1·37851	1·468534	1·665074	1·885649	2·132928
14	1·41297	1·512590	1·731676	1·979932	2·260904
15	1·44830	1·557967	1·800944	2·078928	2·396558
16	1·48451	1·604706	1·872981	2·182875	2·540352
17	1·52162	1·652848	1·947901	2·292018	2·692773
18	1·55966	1·702433	2·025817	2·406619	2·854339
19	1·59865	1·753506	2·106849	2·526950	3·025600
20	1·63862	1·806111	2·191123	2·653298	3·207135
21	1·67958	1·860295	2·278768	2·785963	3·399564
22	1·72157	1·916103	2·369919	2·925261	3·603537
23	1·76461	1·973587	2·464716	3·071524	3·819750
24	1·80873	2·032794	2·563304	3·225100	4·048935
25	1·85394	2·093778	2·665836	3·386355	4·291871
26	1·90029	2·156591	2·772470	3·555673	4·549383
27	1·94780	2·221289	2·883369	3·733456	4·822346
28	1·99650	2·287928	2·998703	3·920129	5·111687
29	2·04641	2·356566	3·118651	4·116136	5·418388
30	2·09757	2·427262	3·243398	4·321942	5·743491
31	2·15001	2·500080	3·373133	4·538039	6·088101
32	2·20376	2·575083	3·508059	4·764941	6·453387
33	2·25885	2·652335	3·648381	5·003189	6·840590
34	2·31532	2·731905	3·794316	5·253348	7·251025
35	2·37321	2·813862	3·946089	5·516015	7·686087
36	2·43254	2·898278	4·103933	5·791816	8·147252
37	2·49335	2·985227	4·268090	6·081407	8·636087
38	2·55568	3·074783	4·438813	6·385457	9·154252

COMPOUND INTEREST TABLE (*continued*).

No. of Years	$2\frac{1}{2}$ per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.
39	2·61957	3·167027	4·616366	6·704751	9·703507
40	2·68506	3·262038	4·801021	7·039989	10·285718
41	2·75219	3·359899	4·993061	7·391988	10·902861
42	2·82100	3·460696	5·192784	7·761588	11·557033
43	2·89152	3·564517	5·400495	8·149667	12·250455
44	2·96381	3·671452	5·616515	8·557150	12·985482
45	3·03790	3·781596	5·841176	8·985008	13·764611
46	3·11385	3·895044	6·074823	9·434258	14·590487
47	3·19170	4·011895	6·317816	9·905971	15·465917
48	3·27149	4·132252	6·570528	10·401270	16·393872
49	3·35328	4·256219	6·833349	10·921333	17·377504
50	3·43711	4·383906	7·106683	11·467400	18·420154

Present Value and Discount.

The *present value* or *present worth* of an amount due at some future time is the sum which, together with its interest from the present time to the time when payment is due, will be equal to the given amount. For example, the present value of £412 due 9 months hence at 4 per cent. simple interest is £100, since £400 + its interest for 9 months = £412. *True discount* is the difference between the amount and its present value; or, in other words, it is the *interest* on the *present value* for the given period. Ordinary commercial, or *banker's discount*, is *interest* on the *amount* of the debt, and is therefore always greater than the true discount. In the above example the true discount of £412 = £12; the banker's discount = £12 7*s.* $2\frac{2}{5}$*d.*

Let A = amount of debt. P = present value. D = true discount. D_b = banker's discount.
r = interest of £1 for one year. n = number of years.

Then

$$A = P(1 + nr). \qquad A = \frac{D(1 + nr)}{nr}. \qquad P = \frac{A}{1 + nr}.$$

$$D = A - P = A - \frac{A}{1 + nr} = \frac{Anr}{1 + nr}.$$

$$D_b = Anr. \qquad r = \frac{A - P}{Pn}. \qquad n = \frac{A - P}{Pr}.$$

Annuities.

An *annuity* is a fixed sum of money paid periodically. An annuity, N, is left unpaid for n years; to find the whole amount, A, allowing simple interest (interest on £1 for one year = r) :—

$$A = nN + \frac{n(n-1)}{2} rN.$$

If compound interest allowed :—

$$A = \frac{(1 + r)^n - 1}{r} N.$$

To find the present value, P, of an annuity, N, to continue for n years, allowing compound interest :—

$$P = \frac{1 - (1 + r)^{-n}}{r} N \quad (*)$$

[If simple interest be reckoned in calculating the present value of an annuity, the results obtained will be untrustworthy.]

The present value of a perpetual annuity is obtained by making n infinite in formula (*), which then becomes

$$P = \frac{N}{r}.$$

If mN is the present value of an annuity, N, the annuity is said to be worth *m years' purchase*. The number of years' purchase, m, of a perpetual annuity is :—

$$m = \frac{1}{r} = \frac{100}{\text{rate per cent.}}.$$

A debt, D, bearing compound interest is diminished by an annual payment, N; to find the debt, d, after n years, and the time, m, when it will be fully paid :—

$$d = \frac{(Dr - N)(1 + r)^n + N}{r}.$$

$$m = \frac{\log N - \log (N - Dr)}{\log (1 + r)}.$$

If $N = Dr$, then $m = \infty$, or the debt D will never be paid. If $N < Dr$ the debt will be increased. To find the yearly payment, N, which will pay a debt, D, in n years at r per cent. compound interest :—

$$N = \frac{Dr(1 + r)^n}{(1 + r)^n - 1}.$$

ANNUITY TABLE.

Showing the Amount of an Annuity of £1 for any number of Years not exceeding 50, and for various rates of Interest.

No. of Years	3 per cent.	3½ per cent.	4 per cent.	4½ per cent.	5 per cent.	6 per cent.
1	1·00000	1·00000	1·00000	1·00000	1·00000	1·00000
2	2·03000	2·03500	2·04000	2·04500	2·05000	2·06000
3	3·09090	3·10622	3·12160	3·13702	3·15250	3·18360
4	4·18362	4·21494	4·24646	4·27819	4·31012	4·37461
5	5·30913	5·36246	5·41632	5·47070	5·52563	5·63709
6	6·46840	6·55015	6·63297	6·71689	6·80191	6·97531
7	7·66246	7·77940	7·89829	8·01915	8·14200	8·39383
8	8·89233	9·05168	9·21422	9·38001	9·54910	9·89746
9	10·15910	10·36849	10·58279	10·80211	11·02656	11·49131
10	11·46387	11·73139	12·00610	12·28820	12·57789	13·18079
11	12·80779	13·14199	13·48635	13·84117	14·20678	14·97164
12	14·19202	14·60196	15·02580	15·46403	15·91712	16·86994
13	15·61779	16·11303	16·62683	17·15991	17·71298	18·88213
14	17·08632	17·67698	18·29191	18·93210	19·59863	21·01506
15	18·59891	19·29568	20·02358	20·78405	21·57856	23·27596
16	20·15688	20·97102	21·82453	22·71933	23·65749	25·67252
17	21·76158	22·70501	23·69751	24·74170	25·84036	28·21287
18	23·41443	24·49969	25·64541	26·85508	28·13238	30·90565
19	25·11686	26·35718	27·67122	29·06356	30·53900	33·75999
20	26·87037	28·27968	29·77807	31·37142	33·06595	36·78559
21	28·67648	30·26947	31·96920	33·78313	35·71925	39·99272
22	30·53678	32·32890	34·24796	36·30337	38·50521	43·39229
23	32·45288	34·46041	36·61788	38·93702	41·43047	46·99582
24	34·42647	36·66652	39·08260	41·68919	44·50199	50·81557
25	36·45926	38·94985	41·64590	44·56521	47·72709	54·86451
26	38·55304	41·31310	44·31174	47·57065	51·11345	59·15638
27	40·70963	43·75906	47·08421	50·71132	54·66912	63·70576
28	42·93092	46·29062	49·96758	53·99333	58·40258	68·52811
29	45·21885	48·91079	52·96628	57·42303	62·32271	73·63979
30	47·57541	51·62267	56·08493	61·00706	66·43884	79·05818
31	50·00267	54·42947	59·32833	64·75238	70·76078	84·80167
32	52·50275	57·33450	62·70146	68·66624	75·29882	90·88977
33	55·07784	60·34121	66·20952	72·75620	80·06377	97·34316
34	57·73017	63·45315	69·85790	77·03025	85·06695	104·18375
35	60·46201	66·67401	73·65222	81·49661	90·32030	111·43477
36	63·27594	70·00760	77·59831	86·16396	95·83632	119·12086
37	66·17422	73·45786	81·70224	91·04134	101·62813	127·26811
38	69·15944	77·02889	85·97033	96·13820	107·70954	135·90420
39	72·23423	80·72490	90·40914	101·46442	114·09502	145·05845
40	75·40125	84·55027	95·02551	107·03032	120·79977	154·76196
41	78·66329	88·50953	99·82663	112·84668	127·83976	165·04768
42	82·02319	92·60737	104·81959	118·92478	135·23175	175·95054
43	85·48389	96·84862	110·01238	125·27640	142·99333	187·50757
44	89·04840	101·23833	115·41287	131·91384	151·14300	199·75803
45	92·71986	105·78167	121·02939	138·84996	159·70015	212·74351
46	96·50145	110·48403	126·87056	146·09821	168·68516	226·50812
47	100·39650	115·35097	132·94539	153·67263	178·11942	241·09861
48	104·40839	120·38825	139·26320	161·58790	188·02539	256·56452
49	108·54064	125·60184	145·83373	169·85935	198·42666	272·95840
50	112·79686	130·99791	152·60708	178·50302	209·34799	290·33590

ANNUITY TABLE.

Showing the present value of annuities payable at the end of each year for the given number of years at various rates of interest per cent.

No. of Years.	¾ per cent.	⅞ per cent.	1 per cent.	1⅛ per cent.	1¼ per cent.	1⅜ per cent.	1½ per cent.	1⅝ per cent.	1¾ per cent.	1⅞ per cent.	2 per cent.	2½ per cent.
1	0·99256	0·99133	0·99010	0·98888	0·98765	0·98644	0·98522	0·98401	0·98280	0·98160	0·98039	0·97561
2	1·97772	1·97405	1·97040	1·96675	1·96312	1·95949	1·95588	1·95229	1·94870	1·94512	1·94156	1·92742
3	2·95556	2·94826	2·94099	2·93374	2·92653	2·91935	2·91220	2·90508	2·89798	2·89092	2·88388	2·85602
4	3·92611	3·91401	3·90197	3·88998	3·87806	3·86619	3·85438	3·84264	3·83094	3·81931	3·80773	3·76197
5	**4·88944**	**4·87138**	**4·85343**	**4·83558**	**4·81784**	**4·80019**	**4·78264**	**4·76520**	**4·74786**	**4·73061**	**4·71346**	**4·64583**
6	5·84560	5·82045	5·79548	5·77066	5·74601	5·72152	5·69719	5·67301	5·64900	5·62514	5·60143	5·50813
7	6·79464	6·76129	6·72819	6·69534	6·66273	6·63035	6·59821	6·56631	6·53464	6·50320	6·47199	6·34939
8	7·73661	7·69397	7·65168	7·60973	7·56812	7·52686	7·48593	7·44532	7·40505	7·36511	7·32548	7·17014
9	8·67158	8·61856	8·56602	8·51395	8·46235	8·41120	8·36052	8·31028	8·26049	8·21115	8·16224	7·97087
10	**9·59958**	**9·53513**	**9·47130**	**9·40811**	**9·34553**	**9·28355**	**9·22218**	**9·16141**	**9·10122**	**9·04162**	**8·98259**	**8·75206**
11	10·52067	10·44374	10·36763	10·29232	10·21780	10·14407	10·07112	9·99893	9·92749	9·85680	9·78685	9·51421
12	11·43491	11·34448	11·25508	11·16669	11·07931	10·99292	10·90751	10·82305	10·73955	10·65698	10·57534	10·25776
13	12·34235	12·23740	12·13374	12·03134	11·93018	11·83025	11·73153	11·63400	11·53764	11·44244	11·34837	10·98319
14	13·24302	13·12258	13·00370	12·88637	12·77055	12·65623	12·54338	12·43198	12·32201	12·21344	12·10625	11·69091
15	**14·13700**	**14·00008**	**13·86505**	**13·73189**	**13·60055**	**13·47101**	**13·34323**	**13·21720**	**13·09288**	**12·97024**	**12·84926**	**12·38138**
16	15·02431	14·86997	14·71787	14·56800	14·42029	14·27473	14·13126	13·98987	13·85050	13·71312	13·57771	13·05500
17	15·90502	15·73231	15·56225	15·39480	15·22992	15·06755	14·90765	14·75018	14·59508	14·44233	14·29187	13·71220
18	16·77918	16·58717	16·39827	16·21241	16·02955	15·84962	15·67256	15·49833	15·32686	15·15811	14·99203	14·35336
19	17·64683	17·43462	17·22601	17·02093	16·81931	16·62108	16·42617	16·23452	16·04606	15·86073	15·67846	14·97889
20	**18·50802**	**18·27471**	**18·04555**	**17·82045**	**17·59932**	**17·38207**	**17·16864**	**16·95893**	**16·75288**	**16·55041**	**16·35143**	**15·58916**
21	19·36280	19·10752	18·85698	18·61107	18·36970	18·13275	17·90014	17·67177	17·44755	17 22739	17·01121	16·18455
22	20·21121	19·93311	19·66038	19·39290	19·13056	18·87324	18·62082	18·37320	18·13027	17·89192	17·65805	16·76541
23	21·05331	20·75153	20·45582	20·16604	19·88204	19·60369	19·33086	19·06342	18·80125	18·54421	18·29220	17·33211
24	21·88915	21·56286	21·24339	20·93057	20·62423	20·32423	20·03041	19·74261	19·46069	19·18451	18·91393	17·88499
25	**22·71876**	**22·36715**	**22·02316**	**21·68659**	**21·35727**	**21·03500**	**20·71961**	**20·41093**	**20·10878**	**19·81301**	**19·52346**	**18·42438**
26	23·54219	23·16446	22·79520	22·43421	22·08125	21·73613	21·39863	21·06856	20·74573	20·42995	20·12104	18·95061
27	24·35949	23·95485	23·55961	23·17351	22·79630	22·42775	22·06762	21·71568	21·37173	21·03553	20·70690	19·46402
28	25·17071	24·73839	24·31644	23·90458	23·50252	23·10999	22·72672	22·35246	21·98695	21·62397	21·28127	19·96489
29	25·97589	25·51513	25·06579	24·62752	24·20002	23·78297	23·37608	22·97905	22·59160	22·21347	21·84438	20·45355
30	**26·77508**	**26·28514**	**25·80771**	**25·34242**	**24·88891**	**24·44683**	**24·01584**	**23·59562**	**23·18585**	**22·78623**	**22·39646**	**20·93029**
31	27·56832	27·04846	26·54229	26·04936	25·56929	25·10168	24·64615	24·20233	23·76988	23·34844	22·93770	21·39541
32	28·35565	27·80517	27·26959	26·74844	26·24127	25·74765	25·26714	24·79934	24·34386	23·90031	23·46833	21·84918
33	29·13712	28·55531	27·98969	27·43975	26·90496	26·38486	25·87895	25·38681	24·90797	24·44203	23·98856	22·29188
34	29·91278	29·29894	28·70267	28·12336	27·56046	27·01342	26·48173	25·96488	25·46238	24·97377	24·49859	22·72379

No. of Years.	⅜ per cent.	⅝ per cent.	1 per cent.	1¼ per cent.	1½ per cent.	1⅝ per cent.	1¾ per cent.	1⅞ per cent.	1⅞ per cent.	2 per cent.	2½ per cent.
35	30·68266	30·03613	29·40858	28·79936	28·20786	27·63346	27·07559	26·53370	26·00725	25·49572	24·99862	23·14516
36	31·44681	30·76692	30·10751	29·46785	28·84727	28·24509	27·66068	27·09343	26·54275	26·00807	25·48884	23·55625
37	32·20527	31·49137	30·79951	30·12890	29·47878	28·84843	28·23713	27·64422	27·06904	26·51099	25·96945	23·95732
38	32·95808	32·20954	31·48466	30·78260	30·10250	29·44358	28·80505	28·18619	27·58628	27·00465	26·44064	24·34860
39	33·70529	32·92147	32·16303	31·42902	30·71852	30·03065	29·36458	28·71950	28·09463	27·48923	26·90259	24·73034
40	34·44694	33·62723	32·83469	32·06825	31·32693	30·60977	29·91585	29·24428	28·59423	27·96489	27·35548	25·10278
41	35·18307	34·32687	33·49969	32·70037	31·92784	31·18103	30·45896	29·76067	29·08524	28·43179	27·79949	25·46612
42	35·91371	35·02045	34·15811	33·32546	32·52132	31·74544	30·99405	30·26880	29·56780	28·89010	28·23479	25·82061
43	36·63892	35·70800	34·81001	33·94600	33·10748	32·30041	31·52123	30·76881	30·04207	29·33998	28·66156	26·16645
44	37·35873	36·38959	35·45545	34·55485	33·68640	32·84874	32·04062	31·26082	30·50817	29·78157	29·07996	26·50385
45	38·07318	37·06527	36·09451	35·15931	34·25817	33·38964	32·55234	31·74496	30·96626	30·21504	29·49016	26·83302
46	38·78231	37·73509	36·72724	35·75705	34·82288	33·92319	33·05649	32·22137	31·41647	30·64053	29·89231	27·15417
47	39·48617	38·39910	37·35370	36·34813	35·38062	34·44951	33·55319	32·69015	31·85894	31·05819	30·28658	27·46748
48	40·18478	39·05734	37·97396	36·93264	35·93148	34·96869	34·04255	33·15144	32·29380	31·46816	30·67312	27·77315
49	40·87820	39·70988	38·58808	37·51064	36·47554	35·48083	34·52468	33·60535	32·72118	31·87059	31·05208	28·07137
50	41·56645	40·35676	39·19612	38·08222	37·01288	35·98602	34·99969	34·05201	33·14121	32·26561	31·42361	28·36231

No. of Years.	3 per cent.	3½ per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.	12 per cent.	15 per cent.
1	0·97087	0·96618	0·96154	0·95238	0·94340	0·93458	0·92593	0·91743	0·90909	0·89286	0·86957
2	1·91347	1·89969	1·88609	1·85941	1·83339	1·80802	1·78326	1·75911	1·73554	1·69005	1·62571
3	2·82861	2·80164	2·77509	2·72325	2·67301	2·62432	2·57710	2·53129	2·48685	2·40183	2·28323
4	3·71710	3·67308	3·62990	3·54595	3·46511	3·38721	3·31213	3·23972	3·16987	3·03735	2·85498
5	4·57971	4·51505	4·45182	4·32948	4·21236	4·10020	3·99271	3·88965	3·79079	3·60478	3·35216
6	5·41719	5·32855	5·24214	5·07569	4·91732	4·76654	4·62288	4·48592	4·35526	4·06131	3·78448
7	6·23028	6·11454	6·00205	5·78637	5·58238	5·38929	5·20637	5·03295	4·86842	4·56376	4·16042
8	7·01969	6·87396	6·73274	6·46321	6·20979	5·97130	5·74664	5·53482	5·33493	4·96764	4·48732
9	7·78611	7·60769	7·43533	7·10782	6·80169	6·51523	6·24689	5·99525	5·75902	5·32825	4·77158
10	8·53020	8·31661	8·11090	7·72173	7·36009	7·02358	6·71008	6·41766	6·14457	5·65022	5·01877
11	9·25262	9·00155	8·76048	8·30641	7·88687	7·49867	7·13896	6·80519	6·49506	5·93770	5·23371
12	9·95400	9·66333	9·38507	8·86325	8·38384	7·94269	7·53608	7·16073	6·81369	6·19437	5·42062
13	10·63496	10·30274	9·98565	9·39357	8·85268	8·35765	7·90378	7·48690	7·10336	6·42355	5·58315
14	11·29607	10·92052	10·56312	9·89864	9·29498	8·74547	8·24424	7·78615	7·36669	6·62817	5·72448

ANNUITY TABLE—*continued.*

No. of Years.	3 per cent.	3½ per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.	12 per cent.	15 per cent.
15	11·93794	11·51741	11·11839	10·37966	9·71225	9·10791	8·55948	8·06069	7·60608	6·81086	5·84737
16	12·56110	12·09412	11·65230	10·83777	10·10590	9·44665	8·85137	8·31256	7·82371	6·97399	5·95423
17	13·16612	12·65132	12·16567	11·27407	10·47726	9·76322	9·12164	8·54363	8·02155	7·11963	6·04716
18	13·75351	13·18968	12·65930	11·68959	10·82760	10·05909	9·37189	8·75563	8·20141	7·24967	6·12797
19	14·32380	13·70984	13·13394	12·08532	11·15812	10·33560	9·60360	8·95011	8·36492	7·36578	6·19823
20	14·87747	14·21240	13·59033	12·46221	11·46992	10·59401	9·81815	9·12855	8·51356	7·46944	6·25933
21	15·41502	14·69797	14·02916	12·82115	11·76408	10·83553	10·01680	9·29224	8·64869	7·56200	6·31246
22	15·93692	15·16712	14·45112	13·16300	12·04158	11·06124	10·20074	9·44243	8·77154	7·64465	6·35866
23	16·44361	15·62041	14·85684	13·48857	12·30338	11·27219	10·37106	9·58021	8·88322	7·71843	6·39884
24	16·93554	16·05837	15·24696	13·79864	12·55036	11·46933	10·52876	9·70661	8·98474	7·78432	6·43377
25	17·41315	16·48151	15·62208	14·09394	12·78336	11·65358	10·67478	9·82258	9·07704	7·84314	6·46415
26	17·87684	16·89035	15·98277	14·37519	13·00317	11·82578	10·80998	9·92897	9·16095	7·89566	6·49056
27	18·32703	17·28536	16·32959	14·64303	13·21053	11·98671	10·93516	10·02658	9·23722	7·94255	6·51353
28	18·76411	17·66702	16·66306	14·89813	13·40616	12·13711	11·05108	10·11613	9·30657	7·98422	6·53351
29	19·18845	18·03577	16·98371	15·14107	13·59072	12·27767	11·15841	10·19828	9·36961	8·02181	6·55088
30	19·60044	18·39205	17·29203	15·37245	13·76483	12·40904	11·25778	10·27365	9·42691	8·05518	6·56598
31	20·00043	18·73628	17·58849	15·59281	13·92909	12·53181	11·34980	10·34280	9·47901	8·08499	6·57911
32	20·38877	19·06887	17·87355	15·80268	14·08404	12·64656	11·43500	10·40624	9·52638	8·11159	6·59053
33	20·76579	19·39021	18·14765	16·00255	14·23023	12·75379	11·51389	10·46444	9·56943	8·13535	6·60046
34	21·13184	19·70068	18·41120	16·19290	14·36814	12·85401	11·58693	10·51784	9·60857	8·15656	6·60910
35	21·48722	20·00066	18·66461	16·37419	14·49825	12·94767	11·65457	10·56682	9·64416	8·17550	6·61661
36	21·83225	20·29049	18·90828	16·54685	14·62099	13·03521	11·71719	10·61176	9·67651	8·19241	6·62314
37	22·16724	20·57053	19·14258	16·71129	14·73678	13·11702	11·77518	10·65299	9·70592	8·20751	6·62881
38	22·49246	20·84109	19·36786	16·86789	14·84602	13·19347	11·82887	10·69082	9·73265	8·22099	6·63375
39	22·80822	21·10250	19·58448	17·01704	14·94907	13·26493	11·87858	10·72552	9·75696	8·23303	6·63805
40	23·11477	21·35507	19·79277	17·15909	15·04630	13·33171	11·92461	10·75736	9·77905	8·24378	6·64178
41	23·41240	21·59910	19·99305	17·29437	15·13802	13·39412	11·96723	10·78657	9·79914	8·25337	6·64502
42	23·70136	21·83488	20·18563	17·42321	15·22454	13·45245	12·00670	10·81337	9·81740	8·26194	6·64785
43	23·98190	22·06269	20·37079	17·54591	15·30617	13·50696	12·04324	10·83795	9·83400	8·26959	6·65030
44	24·25427	22·28279	20·54884	17·66277	15·38318	13·55791	12·07707	10·86051	9·84909	8·27642	6·65244
45	24·51871	22·49545	20·72004	17·77407	15·45583	13·60552	12·10840	10·88120	9·86281	8·28252	6·65429
46	24·77545	22·70092	20·88465	17·88007	15·52437	13·65002	12·13741	10·90018	9·87528	8·28796	6·65591
47	25·02471	22·89944	21·04294	17·98102	15·58903	13·69161	12·16427	10·91760	9·88662	8·29282	6·65731
48	25·26671	23·09124	21·19513	18·07716	15·65003	13·73047	12·18914	10·93358	9·89693	8·29716	6·65853
49	25·50166	23·27656	21·34147	18·16872	15·70757	13·76680	12·21216	10·94823	9·90630	8·30104	6·65959
50	25·72976	23·45562	21·48218	18·25593	15·76186	13·80075	12·23348	10·96168	9·91481	8·30450	6·66051

(Henry Louis.)

SINKING FUND TABLE.

Showing Annual Amount to be set aside at the *end* of each year and accumulated at Compound Interest, in order to provide 100*l.* at the end of a given number of Years.

Years. (*n*)	(R) 3½ per cent.	4 per cent.	4½ per cent.	5 per cent.	5½ per cent.	6 per cent.	Years. (*n*)
	(A)						
	£	£	£	£	£	£	
1	100·000	100·000	100·000	100·000	100·000	100·000	1
2	49·140	49·019	48·900	48·780	48·675	48·544	2
3	32·193	32·035	31·877	31·721	31·573	31·411	3
4	23·725	23·549	23·374	23·201	23·031	22·859	4
5	18·648	18·463	18·279	18·097	17·916	17·740	5
6	15·267	15·076	14·888	14·702	15·829	14·336	6
7	12·854	12·661	12·470	12·282	12·096	11·914	7
8	11·047	10·853	10·661	10·472	10·288	10·104	8
9	9·644	9·449	9·257	9·069	8·884	8·702	9
10	8·524	8·329	8·138	7·950	7·768	7·587	10
11	7·609	7·415	7·225	7·039	6·858	6·679	11
12	6·848	6·655	6·466	6·282	6·103	5·928	12
13	6·206	6·014	5·827	5·645	5·469	5·296	13
14	5·657	5·467	5·282	5·102	4·928	4·759	14
15	5·182	4·994	4·811	4·634	4·463	4·296	15
16	4·768	4·582	4·401	4·227	4·058	3·895	16
17	4·404	4·220	4·042	3·870	3·705	3·545	17
18	4·081	3·899	3·724	3·554	3·392	3·236	18
19	3·794	3·614	3·441	3·274	3·115	2·962	19
20	3·536	3·358	3·187	3·024	2·868	2·719	20
21	3·303	3·128	2·960	2·799	2·647	2·501	21
22	3·093	2·920	2·754	2·597	2·447	2·305	22
23	2·902	2·731	2·568	2·414	2·272	2·128	23
24	2·727	2·559	2·399	2·247	2·104	1·968	24
25	2·567	2·401	2·244	2·095	1·955	1·823	25
26	2·420	2·257	2·102	1·956	1·820	1·690	26
27	2·285	2·124	1·972	1·829	1·695	1·570	27
28	2·160	2·001	1·852	1·712	1·582	1·459	28
29	2·044	1·888	1·741	1·604	1·477	1·358	29
30	1·937	1·783	1·639	1·505	1·381	1·265	30
31	1·837	1·685	1·544	1·413	1·292	1·179	31
32	1·744	1·595	1·456	1·328	1·210	1·100	32
33	1·657	1·510	1·374	1·249	1·134	1·027	33
34	1·576	1·431	1·298	1·175	1·063	·960	34
35	1·500	1·358	1·227	1·107	·998	·897	35
36	1·428	1·289	1·160	1·043	·937	·840	36
37	1·361	1·224	1·098	0·984	·880	·786	37
38	1·298	1·163	1·040	·928	·827	·736	38
39	1·239	1·106	0·985	·876	·778	·689	39
40	1·183	1·052	·934	·828	·732	·646	40
41	1·130	1·002	·886	·782	·689	·606	41
42	1·080	0·954	·841	·739	·649	·568	42
43	1·032	·909	·798	·699	·611	·533	43
44	0·988	·866	·758	·661	·576	·501	44
45	·945	·826	·720	·626	·543	·470	45
46	·905	·788	·684	·593	·512	·442	46
47	·867	·752	·651	·561	·483	·415	47
48	·830	·718	·619	·532	·456	·390	48
49	·796	·686	·589	·504	·430	·366	49
50	·763	·655	·560	·477	·406	·344	50
51	·732	·626	·533	·453	·384	·324	51
52	·702	·598	·508	·429	·362	·305	52
53	·674	·572	·483	·407	·342	·287	53

SINKING FUND TABLE—*continued.*

Years. (*n*)	(R) 3½ per cent.	4 per cent.	4½ per cent.	5 per cent.	5½ per cent.	6 per cent.	Years. (*n*)
	(A)						
	£	£	£	£	£	£	
54	0·647	0·547	0·460	0·387	0·323	0·270	54
55	·621	·523	·439	·366	·305	·254	55
56	·597	·500	·418	·348	·289	·239	56
57	·573	·479	·398	·330	·273	·225	57
58	·551	·458	·380	·313	·258	·212	58
59	·529	·439	·362	·298	·244	·199	59
60	·509	·420	·345	·283	·231	·188	60
61	·489	·402	·329	·268	·218	·177	61
62	·470	·385	·314	·255	·206	·166	62
63	·452	·369	·300	·242	·195	·157	63
64	·435	·354	·286	·230	·185	·148	64
65	·419	·339	·273	·219	·175	·139	65
66	·403	·325	·260	·208	·165	·131	66
67	·388	·311	·249	·198	·157	·124	67
68	·373	·298	·237	·188	·148	·116	68
69	·359	·286	·227	·179	·140	·110	69
70	·346	·274	·216	·170	·133	·103	70
72	·321	·252	·197	·153	·119	·092	72
74	·298	·232	·180	·139	·107	·082	74
76	·276	·214	·164	·126	·096	·073	76
78	·257	·197	·150	·114	·087	·064	78
80	·238	·181	·137	·103	·077	·057	80
82	·221	·167	·125	·093	·069	·051	82
84	·206	·154	·114	·084	·062	·045	84
86	·191	·142	·104	·076	·056	·040	86
88	·178	·131	·095	·069	·050	·036	88
90	·166	·121	·087	·063	·045	·032	90
92	·154	·111	·080	·057	·040	·028	92
94	·143	·103	·073	·051	·036	·025	94
96	·134	·095	·067	·046	·032	·022	96
98	·124	·087	·061	·042	·029	·020	98
100	·116	·081	·056	·038	·026	·018	100

Example :—

Required the amount which should be set aside at the end of each year to form a Fund, at 4 per cent. interest, to replace, in 20 years, 5,000*l.* expended in the installation of electric light plant.

$$\text{Annual amount} = \frac{5{,}000l.}{100} \times 3{\cdot}358 = 167{\cdot}9l. = 167l.\ 18s.$$

Formula :—

$$A = \frac{R}{\left(1 + \frac{R}{100}\right)^n - 1},$$

where,

A = amount; R = rate per cent. per annum; n = number of years.

If the annual amount to be set aside at the *beginning* of each year is required, then the formula is :—

$$A = \frac{R}{\left(1 + \frac{R}{100}\right)^n - 1} \times \frac{100}{100 + R} = \frac{R}{\left(1 + \frac{R}{100}\right)^{n+1} - \left(1 + \frac{R}{100}\right)}$$

Present Value Table.

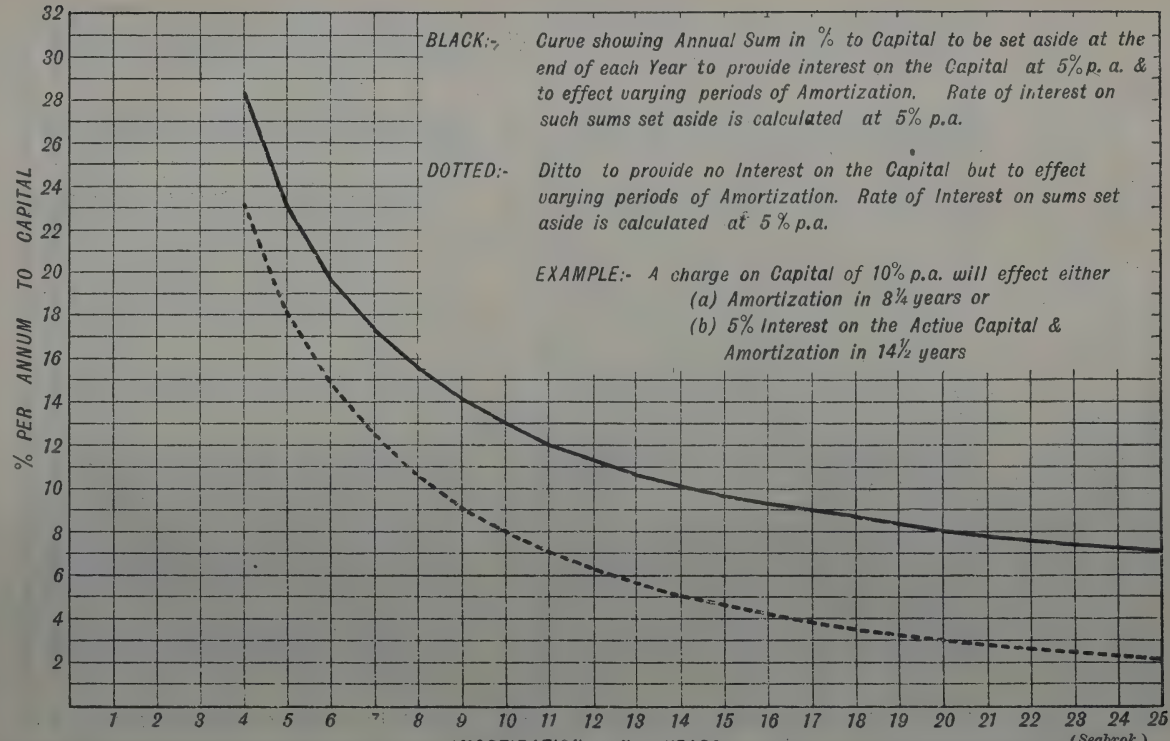
Present value of £1 due at the end of any one of a given number of years at various rates of interest per cent.

No. of Years.	1½ per cent.	1¾ per cent.	2 per cent.	2½ per cent.	3 per cent.	3½ per cent.	4 per cent.	4½ per cent.
1	0·98522	0·98280	0·98039	0·97561	0·97087	0·96618	0·96154	0·95694
2	0·97066	0·96590	0·96117	0·95181	0·94260	0·93351	0·92456	0·91573
3	0·95632	0·94929	0·94232	0·92860	0·91514	0·90194	0·88900	0·87630
4	0·94218	0·93296	0·92385	0·90595	0·88849	0·87144	0·85480	0·83856
5	0·92826	0·91691	0·90573	0·88385	0·86261	0·84197	0·82193	0·80245
6	0·91454	0·90114	0·88797	0·86230	0·83748	0·81350	0·79031	0·76790
7	0·90103	0·88564	0·87056	0·84127	0·81309	0·78599	0·75992	0·73483
8	0·88771	0·87041	0·85349	0·82075	0·78941	0·75941	0·73069	0·70319
9	0·87459	0·85544	0·83676	0·80073	0·76642	0·73373	0·70259	0·67290
10	0·86167	0·84073	0·82035	0·78120	0·74409	0·70892	0·67556	0·64393
11	0·84893	0·82627	0·80426	0·76214	0·72242	0·68495	0·64958	0·61620
12	0·83639	0·81206	0·78849	0·74356	0·70138	0·66178	0·62460	0·58966
13	0·82403	0·79809	0·77303	0·72542	0·68095	0·63940	0·60057	0·56427
14	0·81185	0·78436	0·75788	0·70773	0·66112	0·61778	0·57748	0·53997
15	0·79985	0·77087	0·74301	0·69047	0·64186	0·59689	0·55526	0·51672
16	0·78803	0·75762	0·72845	0·67362	0·62317	0·57671	0·53391	0·49447
17	0·77639	0·74459	0·71416	0·65720	0·60502	0·55720	0·51337	0·47318
18	0·76491	0·73178	0·70016	0·64117	0·58739	0·53836	0·49363	0·45280
19	0·75361	0·71919	0·68643	0·62553	0·57029	0·52016	0·47464	0·43330
20	0·74247	0·70682	0·67297	0·61028	0·55368	0·50257	0·45639	0·41464
21	0·73150	0·69467	0·65978	0·59539	0·53755	0·48557	0·43883	0·39679
22	0·72069	0·68272	0·64684	0·58086	0·52189	0·46915	0·42196	0·37970
23	0·71004	0·67098	0·63416	0·56670	0·50669	0·45329	0·40573	0·36335
24	0·69954	0·65944	0·62172	0·55288	0·49193	0·43796	0·39012	0·34770
25	0·68921	0·64810	0·60953	0·53939	0·47761	0·42315	0·37512	0·33273

No. of Years.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.	12 per cent.	15 per cent.
1	0·95238	0·94340	0·93458	0·92593	0·91743	0·90910	0·89286	0·86957
2	0·90703	0·89000	0·87344	0·85734	0·84168	0·82645	0·79719	0·75614
3	0·86384	0·83962	0·81630	0·79383	0·77218	0·75131	0·71178	0·65752
4	0·82270	0·79209	0·76290	0·73503	0·70843	0·68301	0·63552	0·57175
5	0·78353	0·74726	0·71299	0·68058	0·64998	0·62092	0·56743	0·49718
6	0·74622	0·70496	0·66634	0·63017	0·59627	0·56447	0·50663	0·43233
7	0·71068	0·66506	0·62275	0·58349	0·54703	0·51316	0·45235	0·37594
8	0·67684	0·62741	0·58201	0·54027	0·50187	0·46651	0·40388	0·32690
9	0·64461	0·59190	0·54393	0·50025	0·46043	0·42410	0·36061	0·28426
10	0·61391	0·55839	0·50835	0·46319	0·42241	0·38554	0·32197	0·24719
11	0·58468	0·52679	0·47509	0·42888	0·38753	0·35049	0·28748	0·21494
12	0·55684	0·49697	0·44401	0·39711	0·35553	0·31863	0·25668	0·18691
13	0·53032	0·46884	0·41496	0·36770	0·32618	0·28966	0·22917	0·16253
14	0·50507	0·44230	0·38782	0·34046	0·29925	0·26333	0·20462	0·14133
15	0·48102	0·41727	0·36245	0·31524	0·27454	0·23939	0·18270	0·12289
16	0·45811	0·39365	0·33873	0·29189	0·25187	0·21763	0·16312	0·10686
17	0·43630	0·37136	0·31657	0·27027	0·23107	0·19784	0·14564	0·09293
18	0·41552	0·35034	0·29586	0·25025	0·21199	0·17986	0·13004	0·08081
19	0·39573	0·33051	0·27651	0·23171	0·19449	0·16351	0·11611	0·07027
20	0·37689	0·31180	0·25842	0·21455	0·17843	0·14864	0·10367	0·06110
21	0·35894	0·29416	0·24151	0·19866	0·16370	0·13513	0·09256	0·05313
22	0·34185	0·27751	0·22571	0·18394	0·15018	0·12285	0·08264	0·04620
23	0·32557	0·26180	0·21095	0·17032	0·13778	0·11168	0·07379	0·04017
24	0·31007	0·24698	0·19715	0·15770	0·12640	0·10153	0·06588	0·03493
25	0·29530	0·23300	0·18425	0·14602	0·11597	0·09230	0·05882	0·03038

(Henry Louis.)

AMORTIZATION TABLE.



Binomial Theorem and Series.

This theorem is exceedingly useful in many algebraical operations, particularly in finding the terms of an infinite quotient; it enables the mechanical labour of multiplication in working out the expansion of an expression of the form $(a + b)^n$ to be greatly abridged.

$$(a+b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{1.2}a^{n-2}b^2 + \frac{n(n-1)(n-2)}{1.2.3}a^{n-3}b^3 + \&c.$$

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{1.2}x^2 + \frac{n(n-1)(n-2)}{1.2.3}x^3 + \&c.$$

$$\left(1+\frac{1}{n}\right)^n = e, \text{ if } n \text{ is very large.} \qquad e = 2{\cdot}71828.$$

$$\frac{1}{1+x} = 1 - x + x^2 - x^3 + x^4 - x^5 + \&c.$$

$$\log_e x = x - 1 - \tfrac{1}{2}(x-1)^2 + \tfrac{1}{3}(x-1)^3 - \tfrac{1}{4}(x-1)^4 + \&c.$$

$$\log(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \&c.$$

$$a^x = 1 + Ax + \frac{A^2x^2}{1.2} + \frac{A^3x^3}{1.2.3} + \frac{A^4x^4}{1.2.3.4} + \&c.,$$

where $A = \log_e a$.

Also,

$$a^x = 1 + x\left\{a - 1 - \tfrac{1}{2}(a-1)^2 + \tfrac{1}{3}(a-1)^3 - \tfrac{1}{4}(a-1)^4 + \&c.\right\}.$$

$$e^x = 1 + x + \frac{x^2}{1.2} + \frac{x^3}{1.2.3} + \frac{x^4}{1.2.3.4} + \&c.$$

$$\sin h = h - \frac{h^3}{1.2.3} + \frac{h^5}{1.2.3.4.5} - \frac{h^7}{1.2.3.4.5.6.7} + \&c.$$

$$\cos h = 1 - \frac{h^2}{1.2} + \frac{h^4}{1.2.3.4} - \frac{h^6}{1.2.3.4.5.6} + \&c.$$

Square Root.

To find $\sqrt{N}$ when N is very nearly a square :—

$$\text{If } N = a^2 + x, \quad \sqrt{N} = a + \frac{x}{2a}, \text{ if } x \text{ is small and } a \text{ great.}$$

From which we obtain this practical rule :—'Having found the square root of the integer part of a number, consisting partly of integers and partly of decimals, the remainder of the root may be found by dividing $N - a^2$, *i.e.* x, by $2a$.'

EXAMPLE.—Find the square root of 124·25.

$$\text{Here } N = 121 + 3{\cdot}25 = a^2 + 3{\cdot}25; \quad \therefore a = 11.$$

$$\frac{x}{2a} = \frac{3{\cdot}25}{22} = {\cdot}14. \quad \therefore \sqrt{N} = 11{\cdot}14.$$

Again, if $N = a^n + b$, and $\sqrt[n]{N}$ be required, then

$$\sqrt[n]{N} = a\left\{1 + \frac{b}{na^n} - \frac{n-1}{2n^2}\cdot\frac{b^2}{a^{2n}} + \frac{(n-1)(2n-1)}{1.2.3n^3}\cdot\frac{b^3}{a^{3n}} + \&c.\right\}.$$

EXAMPLE.—Find the 5th root of 35.

$$\text{Here } N = 35 = 32 + 3 = 2^5\left(1 + \frac{3}{2^5}\right);$$

$$\therefore a = 2,\ b = 3,\ n = 5.$$

$$\therefore \sqrt[5]{35} = 2\left\{1 + \frac{3}{5 \times 32} - \frac{4.3^2}{2 \times 5^2 \times (32)^2} + \frac{4.3.3^3}{2 \times 3 \times 5^3 \times (32)^3} - \&c.\right\}.$$

Permutations.

The different arrangements that can be made of any number of quantities are called *Permutations*.

If ${}^nV_r$ represent the variations of n things taken r together,

$${}^nV_r = n(n-1)(n-2)(n-3)\ \ldots\ (n-r+1).$$

The number of *permutations* of n things (all different), *i.e.*, of n things taken *all* together, is equal to the product of the first n digits.

Combinations.

The different collections that can be made of any number of things, without regard to their order, are called *Combinations*.

If ${}^nC_r$ be the number of combinations of n things taken r together, then

$$ {}^nC_r = \frac{n(n-1)(n-2)\ \ldots\ \{n-(r-1)\}}{1.2.3 \qquad\qquad r}. $$

The number of combinations of n things taken r together equals the number of combinations of n things taken $(n-r)$ together.

Prime Numbers.

A 'Prime Number' is a number which has no factors but itself and 1.

Every prime number greater than 3 is of the form $6n \pm 1$. Hence if to any prime number unity be added, or if from it unity be subtracted, then either the sum or the difference will be divisible by 6.

Example.—$17 + 1 = 18$, and $17 - 1 = 16$; of these two results, 18 is divisible by 6. $37 + 1 = 38$, and $37 - 1 = 36$; of these two results, 36 is divisible by 6.

Every number which is not divisible by a number equal to or less than its square root is a prime.

Miscellaneous.

$a^0 = 1$. $\quad \frac{a}{0} = \infty$. $\quad \log_a a = 1$. $\quad$ If $a^x = b$, $x = \log_a b$; also $x = \frac{\log b}{\log a}$,

the logs being to any base, *i.e.* common or otherwise. $\quad$ If $e^x = b$, $x = \log_e b$.

THE CALCULUS.

(G. A. Burls, M.Inst.C.E.)

THE DIFFERENTIAL CALCULUS.

Any expression containing x is termed a 'function' of x, and if the numerical value of x is changed, that of the function changes correspondingly.

The fundamental object of the differential calculus is to determine the ratio which the change in a function of x bears to the change in x when the change in x is very small. This ratio is termed the 'differential coefficient' of the function with respect to x.

Simple Example.—If the function under consideration be x^2 we have to ascertain the value of the ratio $\frac{\text{change in } x^2}{\text{change in } x}$ when the change in x is very small.

This is done thus: Let x increase to $x + \Delta x$, where Δx denotes a small change or 'increment' in x; then x^2 correspondingly changes to $(x + \Delta x)^2$; that is, to $x^2 + 2x \cdot \Delta x + (\Delta x)^2$. Accordingly the ratio $\frac{\text{change in } x^2}{\text{change in } x} = \frac{2x \cdot \Delta x + (\Delta x)^2}{\Delta x}$; that is, $= 2x + \Delta x$. Now suppose the increment Δx to become smaller and smaller without limit; then, ultimately, when Δx is on the

point of vanishing, we have $\frac{\text{change in } x^2}{\text{change in } x} = 2x$. Thus the differential coefficient of x^2 with respect to x is equal to $2x$; and this result is written $\frac{dx^2}{dx} = 2x$.

The geometrical interpretation of this process is enlightening and important. Fig. 1 represents the curve whose equation is $y = x^2$, which is, of course, a parabola. Let P be any point on the curve, whose co-ordinates are (x, y); and let Q be a second point on the curve near P, whose co-ordinates are $x + \Delta x$, $y + \Delta y$. Then obviously

$$\frac{\text{change in } x^2}{\text{change in } x} = \frac{\Delta y}{\Delta x} = \frac{\text{RQ}}{\text{MN}} = \frac{\text{RQ}}{\text{RP}} = \tan \text{XSQ}.$$

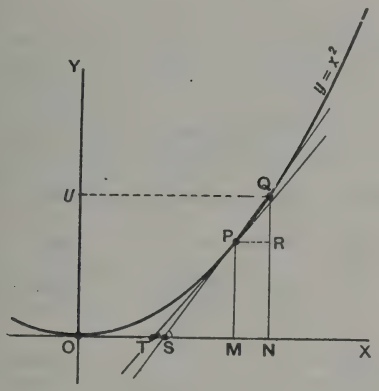


FIG. 1.

$\text{OM} = x$. $\text{MP} = y$. $\text{MN} = \Delta x$. $\text{RQ} = \Delta y$.

Let the point Q be moved along the curve until it is on the point of coinciding with P; that is, 'let Δx be diminished without limit'; then the secant QPS finally becomes PT, the tangent to the curve at P; and so, finally, $\frac{dy}{dx} = \tan \text{XTP}$.

Hence this fundamentally important result: If y be any function of x, then $\frac{dy}{dx}$ is the trigonometric tangent of the angle which the tangent to the corresponding curve makes with the axis of x.

When y is a function of x it is often convenient to indicate this by writing $y = \phi(x)$, or $\text{F}(x)$, etc.; also the differential coefficient of $\phi(x)$ is often written $\phi'(x)$, which is an abbreviation of $\frac{d \cdot \phi(x)}{dx}$.

By proceeding essentially in the manner exemplified above in the case when $y = x^2$, the differential coefficients of the standard elementary algebraic and trigonometric functions are found to be as given in the following table:—

TABLE OF DIFFERENTIAL COEFFICIENTS.

Type.	Function. $y =$	Diff. Coeff. $\frac{dy}{dx} =$	Remarks.
Algebraic functions	x^n	nx^{n-1}	For all values of n.
	a^x	$a^x \log_e a$	Hence if $y = e^x$, $\frac{dy}{dx} = e^x$.
	$\mathrm{Log}_a x$	$\frac{1}{x \mathrm{Log}_e a}$	Hence if $y = \log_e x$, $\frac{dy}{dx} = \frac{1}{x}$
Direct trigonometric functions	$\sin x$	$\cos x$	If ι denote $\sqrt{-1}$, then:
	$\cos x$	$-\sin x$	$\sin x = \frac{1}{2\iota}\left\{e^{\iota x} - e^{-\iota x}\right\}$.
	$\tan x$	$\frac{1}{\cos^2 x}$	$\cos x = \frac{1}{2}\left\{e^{\iota x} + e^{-\iota x}\right\}$.
Direct hyperbolic functions	$\sinh x$	$\cosh x$	$\sinh x = \frac{1}{2}\left\{e^x - e^{-x}\right\}$.
	$\cosh x$	$\sinh x$	$\cosh x = \frac{1}{2}\left\{e^x + e^{-x}\right\}$.
	$\tanh x$	$\frac{1}{\cosh^2 x}$	$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$.
Inverse trigonometric functions	$\sin^{-1} x$	$\frac{1}{\sqrt{1 - x^2}}$	$y = \sin^{-1} x$ means $x = \sin y$.
	$\cos^{-1} x$	$-\frac{1}{\sqrt{1 - x^2}}$	$y = \cos^{-1} x$ means $x = \cos y$.
	$\tan^{-1} x$	$\frac{1}{1 + x^2}$	$y = \tan^{-1} x$ means $x = \tan y$.
Inverse hyperbolic functions	$\sinh^{-1} x$	$\frac{1}{\sqrt{1 + x^2}}$	$y = \sinh^{-1} x$ means $x = \sinh y$.
	$\cosh^{-1} x$	$\frac{1}{\sqrt{x^2 - 1}}$	$y = \cosh^{-1} x$ means $x = \cosh y$.
	$\tanh^{-1} x$	$\frac{1}{1 - x^2}$	$y = \tanh^{-1} x$ means $x = \tanh y$.
Differentiation of a sum, difference, product, and quotient of functions.	$u + v$	$\frac{du}{dx} + \frac{dv}{dx}$	Here u and v are each functions of x. (See *infra.*)
	$u - v$	$\frac{du}{dx} - \frac{dv}{dx}$	
	uv	$u\frac{dv}{dx} + v\frac{du}{dx}$	
	$\frac{u}{v}$	$\frac{1}{v^2}\left\{v\frac{du}{dx} - u\frac{dv}{dx}\right\}$	

Two remarks may be made upon the preceding table:

(1) Throughout, the only quantity whose value is susceptible of change, *i.e.* the only 'variable,' is x; all other quantities are constants.

(2) The differential coefficient of any constant is zero; for to say that a quantity is constant is to say that it is incapable of any change in value.

Differential Coefficient of a Sum, Difference, Product, and Quotient, of Functions.

Mathematical expressions consist in general of a number of terms connected by + or − signs, each term consisting of a product or quotient of functions; for example, it may be desired to find $\frac{dy}{dx}$ from the equation—

$$y = x^2e^x + \frac{a^x}{\sin x} - bx^3. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Hence it is necessary to study how to determine the differential coefficient of a sum, difference, product, and quotient of functions. The results are given in the lower portion of the Table of Differential Coefficients above, and may be verbally enunciated thus:

(1) The differential coefficient of a sum or difference of functions is the sum or difference of the differential coefficients of the functions.

(2) The differential coefficient of a product of two functions is obtained by multiplying each function by the differential coefficient of the other, and adding the results.

(3) Quotient of functions: From the denominator multiplied by the differential coefficient of the numerator, subtract the numerator multiplied by the differential coefficient of the denominator and divide the result by the square of the denominator.

Thus, taking equation (1) as an illustration, we have—

$$\frac{dy}{dx} = \left\{\frac{dx^2}{dx}\cdot e^x + \frac{de^x}{dx}\cdot x^2\right\} + \left\{\frac{1}{\sin^2 x}\cdot\left(\sin x\,\frac{da^x}{dx} - a\,\frac{d\sin x}{dx}\right)\right\} - b\,\frac{dx^3}{dx}$$

—that is, from the Table of Differential Coefficients,

$$\frac{dy}{dx} = 2xe^x + x^2e^x + \frac{a^x\,\log_e a}{\sin x} - \frac{a^x\cos x}{\sin^2 x} - 3bx^2.$$

Differential Coefficient of a Function of a Function.

Expressions such as $\log(\sin x)$ may require to be differentiated with respect to x; it is thus necessary to determine how this may be done. If y is a function of u, and u is a function of x, the rule is:

$$\frac{dy}{dx} = \frac{dy}{du}\cdot\frac{du}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus if $y = \log(\sin x)$, we may denote $\sin x$ by u; then $y = \log u$; hence $\frac{dy}{du} = \frac{1}{u}$. Also $\frac{du}{dx} = \frac{d\sin x}{dx} = \cos x$; thus applying the rule: $\frac{dy}{dx} = \frac{dy}{du}\cdot\frac{du}{dx} = \frac{1}{\sin x}\cdot\frac{\cos x}{1}$; that is

$$\frac{d\log(\sin x)}{dx} = \cot x.$$

Similarly, if y be a function of u, u a function of v, and v a function of x, then

$$\frac{dy}{dx} = \frac{dy}{du}\cdot\frac{du}{dv}\cdot\frac{dv}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and so on.

It should be carefully noted that in mathematics $\log x$ means $\log_e x$, the natural logarithm of x; and also that in any trigonometric expression such as $\sin x$ etc., x is in the natural measure of angles, *i.e.* in *radians*. One radian = 57·29578° (approximately).

Differentiation of Implicit Functions.

The preceding rule enables any compound function of x alone to be differentiated. Suppose, however, that a relation $\phi(x, y,) = 0$ be found connecting y and x, and that $\frac{dy}{dx}$ is required. It

is frequently impossible to solve this equation so as to get y alone on the one side and an expression involving x alone on the other. We can, however, always obtain $\frac{dy}{dx}$ without the necessity of solving $\phi(x, y,) = 0$ as follows:—

First differentiate $\phi(x, y,)$ with respect to x, treating y as if it were a constant; call this $\left(\frac{d\phi}{dx}\right)$.

Next differentiate $\phi(x, y,)$ with respect to y, treating x as if it were a constant; call this $\left(\frac{d\phi}{dy}\right)$.

Then
$$\frac{dy}{dx} = -\frac{\left(\frac{d\phi}{dx}\right)}{\left(\frac{d\phi}{dy}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For example, if
$$x^2y^3 + 3y \sin x + x \log y = 0,$$

we have
$$\left(\frac{d\phi}{dx}\right) = 2xy^3 + 3y \cos x + \log y.$$
$$\left(\frac{d\phi}{dy}\right) = 3x^2y^2 + 3 \sin x + \frac{x}{y};$$

and accordingly
$$\frac{dy}{dx} = -\frac{2xy^3 + 3y \cos x + \log y}{3x^2y^3 + 3 \sin x + \frac{x}{y}}$$

Successive Differentiation.

If, for example, $y = \sin x$, we have seen that $\frac{dy}{dx} = \cos x$. Thus $\frac{dy}{dx}$ is also a function of x, and *its* differential coefficient with respect to x may be required. Evidently in this case $\frac{d\left(\frac{dy}{dx}\right)}{dx} = \frac{d \cos x}{dx} = -\sin x$. Similarly, we may proceed to a third, fourth . . . . . etc. differentiation.

The notation employed is as follows: $\frac{d\left(\frac{dy}{dx}\right)}{dx}$ is written $\frac{d^2y}{dx^2}$, and is called the second differential coefficient of y with respect to x. Similarly, $\frac{d\left(\frac{d^2y}{dx^2}\right)}{dx}$ is written $\frac{d^3y}{dx^3}$, and is called the third differential coefficient, and so on.

Expansions of Functions in Series.

Taylor's Theorem.—One of the most fundamentally important results in mathematics is that general formula of expansion termed Taylor's Theorem, which is as follows: Suppose $\phi(x + h)$ to be *any* function of $(x + h)$, and that it is desired to expand this in a series proceeding according to powers of h; then

$$\phi(x + h) = \phi(x) + h\,\phi^1(x) + \frac{h^2}{1.2} \cdot \phi^2(x) + \frac{h^3}{1.2.3} \cdot \phi^3(x), \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where $\phi^1(x) = \frac{d.\phi(x)}{dx}$; $\phi^2(x) = \frac{d^2\phi(x)}{dx^2}$; etc.

As an illustration, suppose $\phi(x + h) = (x + h)^n$; then $\phi(x) = x^n$, $\phi^1(x) = nx^{n-1}$, $\phi^2(x) = n(n - 1)x^{n-2}$, $\phi^3(x) = n(n - 1)(n - 2)\,x^{n-3}$; and so on. Hence by (5) we have—

$$(x + h)^n = x^n + nhx^{n-1} + \frac{n(n-1)}{1.2} h^2x^{n-2} + \frac{n(n-1)(n-2)}{1.2.3} h^3x^{n-3} + \ldots,$$

which is the Binomial Theorem. And similarly any other case may be treated.

Maclaurin's or Stirling's Theorem.—This is readily deduced from Taylor's Theorem, and is also a useful and important general theorem of expansion; it is as follows: Let $\phi(x)$ be any function of x; then

$$\phi(x) = \phi(o) + x\phi^1(o) + \frac{x^2}{1.2} \cdot \phi^2(o) + \frac{x^3}{1.2.3} \cdot \phi^3(o) + \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

To obtain $\phi(o)$, put $x = 0$ in $\phi(x)$; to obtain $\phi^1(o)$, form $\phi^1(x)$ $\left(i.e.\ \frac{d\phi(x)}{dx}\right)$, and in the result put $x = 0$. Similarly, $\phi^2(o)$ is obtained by putting $x = 0$ in $\frac{d^2(\phi(x))}{dx^2}$; and so on.

As an example, suppose $\phi(x) = \sin x$; then $\phi(x) = \sin x$, $\therefore\ \phi(o) = 0$. $\phi^1(x) = \cos x$, $\therefore\ \phi^1(o) = 1$. $\phi^2(x) = -\sin x$, $\therefore\ \phi^2(o) = 0$; $\phi^3(x) = -\cos x$, $\therefore\ \phi^3(o) = -1$ . . . and so on. Substituting these results in (6) gives:

$$\sin x = x - \frac{x^3}{1.2.3} + \frac{x^5}{1.2.3.4.5} - \frac{x^7}{1.2.3.4.5.6.7} + \ldots$$

And similarly any other case may be treated.

Maxima and Minima of a Function of one Variable.

If a curve corresponding to $y = \phi(x)$ be plotted there may be in it points, as shown in fig. 2,

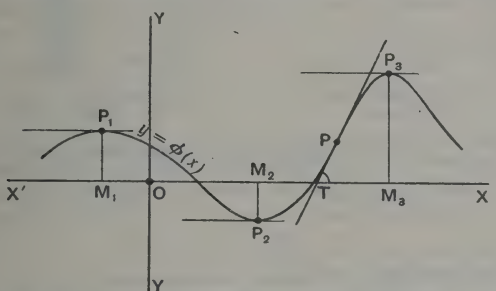


FIG. 2.

which are higher or lower than adjacent points on the curve on either side; such are termed 'maxima' and 'minima' values respectively. Thus in fig. 2 when $x = OM_1$ the value of the function y, or $\phi(x)$, is a maximum, and $= M_1P_1$; other maxima may occur as at P_3; similarly minima values occur at P_2, etc.

Differentiation provides a ready means of determining maxima and minima values of functions without recourse to plotting. For $\frac{dy}{dx}$ is always equal to tan XTP; and fig. 2 shows that at a point of maximum or minimum the tangent is parallel to the axis of x, and accordingly that at such points tan XTP, *i.e* $\frac{dy}{dx}$, is zero. Hence the values for which y is a maximum or minimum are obtained by solving the equation $\frac{dy}{dx} = 0$. Fig. 2 shows that maxima and minima values must occur alternately, and that they are *local* and not *absolute*.

Suppose, for example, $\phi(x)$, or $y, = x^3 + 6x^2 - 63x + 1$; then $\frac{dy}{dx} = 3x^2 + 12x - 63$. And $3x^2 + 12x - 63 = 0$ gives $x = -7$ or $+3$. Putting $x = -7$ makes $\phi(x) = +393$, a maximum. Putting $x = +3$ makes $\phi(x) = -107$, a minimum. Which is which is found by forming $\frac{d^2y}{dx^2}$; if this be *negative* the corresponding value of x gives a *maximum* value to y; and if *positive*, a *minimum* value. Thus here $\frac{d^2y}{dx^2} = 6x + 12 = 6(x + 2)$. $x = -7$ makes this $= -30$, and thus gives a maximum value; $x = +3$ makes it $= +30$, and thus gives a minimum.

Differential Coefficient of an Arc, an Area, and a Volume, and a Surface of Revolution.

Arc.—Referring to fig. 3, if PQ be a small piece $= \Delta s$, of the curve $y = \phi(x)$, then it is clear that PRQ is nearly a right-angled triangle, and $\therefore\ \overline{\Delta s}^2 = \overline{\Delta x}^2 + \overline{\Delta y}^2$, *i.e.* $\left(\frac{\Delta s}{\Delta x}\right)^2 = 1 + \left(\frac{\Delta y}{\Delta x}\right)^2$ very nearly; and this becomes more and more nearly true as Δ is taken smaller and smaller,

and, ultimately, when Δs is on the point of vanishing—at which instant it is written ds—we have *exactly*, $\left(\frac{ds}{dx}\right)^2 = 1 + \left(\frac{dy}{dx}\right)^2$; *i.e.* $\frac{ds}{dx} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2}$ . . . . . (6)

This is the differential coefficient of the arc of a curve with respect to x.

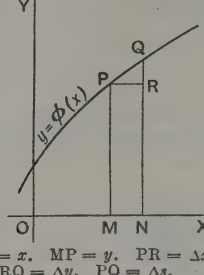


FIG. 3.

OM = x. MP = y. PR = Δx.
RQ = Δy. PQ = Δs.

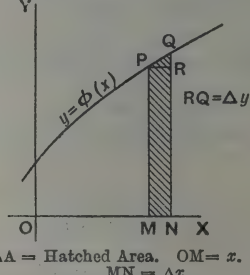


FIG. 4.

ΔA = Hatched Area. OM = x. MP = y.
MN = Δx.

Area.—Referring to fig. 4, it is evident that the little hatched strip of area, ΔA is greater than PM × MN and less than QN × MN; that is, ΔA lies between $y.\Delta x$ and $(y + \Delta y)\ \Delta x$; that is, $\frac{\Delta A}{\Delta x}$ lies between y and $(y + \Delta y)$. Now let Δx, and consequently Δy and ΔA, all diminish without limit; then ultimately we have—

$$\frac{dA}{dx} = y \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

as the differential coefficient of the area of a curve with respect to x.

Solid of Revolution.—Referring again to fig. 4, it is evident that if the curve $y = \phi(x)$ revolve around the axis of x it will generate a solid of revolution, and the volume described by the hatched area, ΔV, will be greater than $\pi y^2.\Delta x$ and less than $\pi(y + \Delta y)^2\Delta x$. That is, $\frac{\Delta V}{\Delta x} > \pi y^2$ and $< \pi(y + \Delta y).^2$ Now let Δx, and $\therefore\ \Delta y$ and ΔV, all diminish without limit; then ultimately we have—

$$\frac{dV}{dx} = \pi y^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

as the differential coefficient of the volume of a solid of revolution with respect to x.

Surface of Revolution.—Referring again to fig. 4, the element PQ (= ds, ultimately) of the curve $y = \phi(x)$ generates an extremely narrow ring of surface in revolving round the x-axis, which is ultimately a frustum of a cone, and the area of this surface is easily found to be, ultimately, $2\pi y.ds$. Hence if dC denote an element ring of the curved surface we have $dC = 2\pi y.ds$; and therefore,

$$\frac{dC}{dx} = 2\pi y.\frac{ds}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

expresses the differential coefficient of the surface of a solid of revolution with respect to x.

Substituting for $\frac{ds}{dx}$ from equation (6) this becomes:

$$\frac{dC}{dx} = 2\pi y.\sqrt{1 + \left(\frac{dy}{dx}\right)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

THE INTEGRAL CALCULUS.

The operation of differentiation is a direct operation, and by observing the rules above given any function whatever may be differentiated. Integration—so far as here regarded—is the inverse of differentiation; to 'integrate' a given function we have to find a function of which the given function is the differential coefficient. Integration is an inverse process, like division, and success depends accordingly on trial and systematised 'guessing,' though, of course, all ordinary functions are readily integrable as shown below.

The notation employed is as follows: If $\phi(x)$ be any function of x, the integral of $\phi(x)$ is written $\int.\phi(x).dx$; thus $\int \ldots dx$ denotes the operation of integration, just as $\frac{d}{dx}\ldots$ denotes

the operation of differentiation. Hence if $\int . \phi(x) . dx = \psi(x)$, the same relation between $\phi(x)$ and $\psi(x)$ is also expressed by writing :—$\phi(x) = \frac{d}{dx} . \psi(x)$.

The table following gives the integrals of the standard simple functions; they can all be immediately verified by differentiation with the aid of the table of § (5). For example, the table states that $\int . \cos x . dx = \sin x + c$; this assertion is merely that $\frac{d}{x}(\sin x + c) = \cos x$; and this is so, as already given in § (5). The quantity 'c' is termed the '**constant of integration**,' and is obviously admissible, since $\frac{dc}{dx} = 0$. 'c' may be any quantity constant relatively to x; in engineering and physical problems its value is always readily determined from the initial conditions of the problem.

TABLE OF INTEGRALS OF SOME SIMPLE FUNCTIONS.

Function y or $\phi(x) =$	Indefinite Integral. $\int . y . dx$ or $\int . \phi(x) . dx =$	Remarks.
x^n	$\frac{1}{n+1} . x^{n+1} + C$	Except when $n = -1$, and then :
x^{-1}	$\text{Log}\, x_e x + c$	
a^x	$\frac{1}{\text{Log}_e a} . a^x + c$	Whence, if $a = e$:
e^x	$e^x + c$	
$\text{Sin}\, x$	$-\text{Cos}\, x + c$	The direct trigonometric or '**circular**' functions.
$\text{Cos}\, x$	$\text{Sin}\, x + c$	
$\text{Tan}\, x$	$-\text{Log}_e(\cos x) + c$	
$\text{Sinh}\, x$	$\text{Cosh}\, x + c$	The direct hyperbolic functions.
$\text{Cosh}\, x$	$\text{Sinh}\, x + c$	
$\text{Tanh}\, x$	$\text{Log}_e(\cosh x) + c$	
$\text{Sin}^{-1} x$	$x \sin^{-1} x + \sqrt{1 - x^2} + c$	The inverse trigonometric or '**inverse circular**' functions
$\text{Cos}^{-1} x$	$x \cos^{-1} x - \sqrt{1 - x^2} + c$	
$\text{Tan}^{-1} x$	$x \tan^{-1} x - \frac{1}{2} \log_e(1 + x^2) + c$	
$\text{Sinh}^{-1} x$	$x \sinh^{-1} x - \sqrt{1 + x^2} + c$	The inverse hyperbolic functions.
$\text{Cosh}^{-1} x$	$x \cosh^{-1} x - \sqrt{x^2 - 1} + c$	
$\text{Tanh}^{-1} x$	$x \tanh^{-1} x + \frac{1}{2} \log_e(1 - x^2) + c$	
$\sqrt{a^2 - x^2}$	$\frac{x}{2}\sqrt{a^2 - x^2} + \frac{a^2}{2} \sin^{-1}\left(\frac{x}{a}\right) + c$	The '**circular integral.**'
$\sqrt{x^2 - a^2}$	$\frac{x}{2}\sqrt{x^2 - a^2} - \frac{a^2}{2} \log_e\left(\frac{x + \sqrt{x^2 - a^2}}{a}\right) + c$	The '**hyperbolic integral.**'
$\frac{1}{\sqrt{1 - x^2}}$	$\text{Sin}^{-1} x + c$	These are immediately obvious from the Table of Differential Coefficients of § (5) above.
$\frac{1}{\sqrt{1 + x^2}}$	$\text{Sinh}^{-1} x + c$	
$\frac{1}{1 + x^2}$	$\text{Tan}^{-1} x + c$	

Space does not permit of further integrals being tabulated, but reference to any work on the integral calculus will furnish numerous others.

The problem of finding the area of a curve, as, *e.g.*, between $x = \text{OM} =$ 'a' and $x = \text{ON} =$ 'b,' in fig. 5, was one from which the integral calculus took its rise. The second column of the preceding table is headed 'Indefinite' Integrals, which implies simply that the functions below this

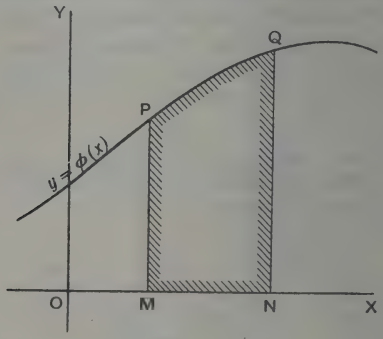


FIG. 5.

$$\text{OM} = a. \quad \text{ON} = b. \quad \text{Area MPQN} = \int_a^b \varphi(x) \, . \, dx.$$

heading on being differentiated with respect to x yield the functions tabulated in the first column. Suppose, however, it is desired to find the hatched area MQ in fig. 5. This is expressed thus:

Area MQ $= \int_a^b \phi(x) \, . \, dx$; and this is termed an integration between the limits a and b. If the indefinite integral of $\phi(x)$ be $\psi(x) + c$, that is, if $\frac{d \, . \, \psi(x) + c}{dx} = \phi(x)$, then it can be easily shown that

$$\int_a^b \phi(x) \, . \, dx = \psi(b) - \psi(a) \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Suppose the curve under consideration to be that of fig. 1, namely $y = \phi(x) = x^2$, and that it is required to find the area MPQN, given that $\text{OM} = a$, and $\text{ON} = b$. We have:—

$$\text{Area MPQN} = \int_a^b x^2 . dx.$$

Now the indefinite integral $\int x^2 . dx$ is $\frac{1}{3} x^3 + c$; hence $\psi(x) = \frac{1}{3} x^3 + c$; and accordingly $\psi(b) = \frac{1}{3} b^3 + c$ and $\psi(a) = \frac{1}{3} a^3 + c$; and therefore $\psi(b) - \psi(a) = \frac{1}{3}(b^3 - a^3)$. So that in this case, Area MPQN $= \frac{1}{3}(b^3 - a^3)$, and is accordingly known.

It may be noted that if $a = 0$, the area $\text{OQN} = \frac{1}{3} b^3 = \frac{1}{3} \, . \, b^2 \times b = \frac{1}{3} \, . \, \text{QN} \times \text{NO}$. Hence (fig. 1), $\text{OQU} = \frac{2}{3} \, . \, \text{QN} \, . \, \text{NO}$, which is the well-known property that the area of a parabola is equal to two-thirds that of the circumscribing rectangle.

Lengths and Areas of Curves, and Volumes and Surfaces of Solids of Revolution.

Equations 6, 7, 8, 9, and 10 above become in the notation of the integral calculus:

$$S = \int \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \, . \, dx \quad . \quad . \quad . \quad . \quad . \quad . \quad (6')$$

$$A = \int y \, . \, dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7')$$

$$V = \pi \int y^2 \, . \, dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8^1)$$

$$C = 2\pi \int y \frac{ds}{dx} dx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9^1)$$

or again:—

$$C = 2\pi \int y \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \, dx \quad . \quad . \quad . \quad . \quad . \quad (10^1)$$

From which S, A, V, and C may be obtained by proceeding as indicated above in any specific case by substituting for y (*i.e.* $\phi(x)$) the particular function of x corresponding to the case under investigation.

For example, let it be required to find the volume of a sphere of radius r. The procedure is as follows: The circle $y^2 = r^2 - x^2$ describes a sphere by revolving about the axis of x; the volume is

$$\therefore \text{by } (8^1): V = \pi \int_{-r}^{+r} (r^2 - x^2) \, dx = \pi r^2 \int_{-r}^{+r} dx - \pi \int_{-r}^{+r} x^2 \, . \, dx = \pi r^2 \Big[x \Big]_{-r}^{+r} - \pi \Big[\frac{1}{3} \, . \, x^3 \Big]_{-r}^{+r} =$$

$$\pi r^2 \Big[r - (-r) \Big] - \pi \Big[\frac{1}{3} r^3 - \frac{1}{3} (-r)^3 \Big] = 2\pi r^3 - \frac{2}{3} \, . \, \pi r^3 = \frac{4}{3} \pi r^3. \quad \text{And so in other cases.}$$

Note on Differential Equations.

Any equation involving differential coefficients is termed a differential equation. When from this an equation free from differential coefficients can be derived, which is the most general form possible, the differential equation is said to be completely solved.

Many engineering and most physical problems when expressed mathematically appear as differential equations, but the types met with by the engineer are usually of relatively simple character. It is easy to see how differential equations can arise; for example, referring to the Table of Differential Coefficients, § (5), *supra*, it is clear that as $y = e^x$ and $\frac{dy}{dx}$, also $= e^x$ then $y - \frac{dy}{dx} = 0$; if, then, an equation $y - \frac{dy}{dx} = 0$ presented itself it would at once be seen that $y = e^x$ is a solution. Again, if the equation $y + \frac{d^2y}{dx^2} = c$ appeared, it would soon be recognised that $y = \sin x + c$ is a solution; for by differentiating this twice the given equation arises. A few simple standard cases of 'linear' differential equations are given in the table below; these arise frequently in investigations and are of profound importance, particularly in vibrational problems.

Solutions of Three Typical Linear Differential Equations.

Differential Equation.	Solution.
$\frac{d^2y}{dx^2} - n^2y = 0$	$y = Me^{nx} + Ne^{-nx}$
$\frac{d^2y}{dx^2} + n^2y = 0$	$y = M.\sin nx + N \cos nx$
The above two are included in the more general form:— $\frac{d^2y}{dx^2} + A.\frac{dy}{dx} + By = 0$	(1)—If $4B = A^2$, the solution is: $y = e^{-\frac{1}{2}A.x} (M + Nx)$. (2)—If $4B$ be less than A^2, the solution is: $y = Me^{\frac{1}{2}(-A + \sqrt{A^2 - 4B})x} + Ne^{\frac{1}{2}(-A - \sqrt{A^2 - 4B})x}$. (3)—If $4B$ be greater than A^2 the solution is: $y = e^{-\frac{1}{2}A.x} \left(M.\sin \sqrt{B - \frac{A^2}{4}} \, x + N \cos \sqrt{B - \frac{A^2}{4}} \, x. \right)$

Throughout the above table, n, M, N, A, and B denote any constant quantities whatever. In any specific problem their values are always determinable from the data relating to the case.

Examples of simple differential equations arise in the ordinary theory of bending and torsion; strength of struts; of thick cylinders; of discharges of fluids through orifices; in theory of heat; naval architecture; electric phenomena; etc. They arise naturally, in fact, in almost every investigation of a general and fundamental character wherein quantities capable of *continuous* variation in value are involved.

GEOMETRY.

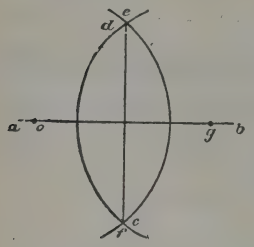


FIG. 5A.

To divide a given line, *ab*, into two equal parts.

From its ends *a* and *b* as centres, and with any radius greater than one-half of *ab*, describe the arcs *c* and *d*, and join *ef*. If the line *ab* is very long, first lay off equal distances, *ao* and *bg*, each way from the ends, so as to approach conveniently near to each other; and then proceed as if *og* were the line to be divided. Or measure *ab* by a scale, and thus ascertain its centre.

To divide a given line, *mn*, into any given number of equal parts.

From *m* and *n* draw any two parallel lines, *mo* and *na*, to an indefinite distance, and on them, from *m* and *n*, step off the required number of equal parts of any convenient length; finally, join the corresponding points thus stepped off. Or only one line, as *mo*, may be drawn and stepped off, as to *s*; then join *sn*; and draw the other short lines parallel to it.

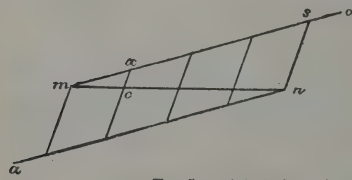


FIG. 5B.

To divide a given line, *mn*, into two parts which shall have a given proportion to each other.

This is done on the same principle as the last; thus, let the proportion be as 1 to 3. First draw any line, *mo*, and with any convenient opening of the dividers make *mx* equal to one step, and *xs* equal to three steps. Join *sn*; and parallel to it draw *xc*. Then *mc* is to *cn* as 1 is to 3.

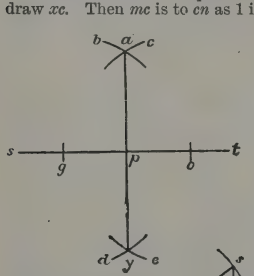


FIG. 5C.

From any given point, *p*, on a line, *st*, to draw a perpendicular, *pa*.

From *p*, with any convenient opening of the dividers, step off the equals *po*, *pg*. From *o* and *g* as centres, with any opening greater than half *og*, describe the two short arcs *b* and *c*, and join *ap*. Or, still better, describe four arcs, and join *ay*.

Or from *p* with any convenient scale describe two short arcs, *g* and *c*, one of them with a radius 3, and the other with a radius 4. Then from *g*, with a radius 5, describe the arc *b*. Join *pa*.

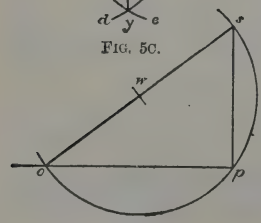


FIG. 5D.

If the point p is at one end of the line, or very near it, extend the line, if possible, and proceed as above. But if this cannot be done, then from any convenient point, *w*, open the dividers to *p*, and describe the semicircle *spo*; through *ow* draw *ows*; join *ps*.

Or use the foregoing process with radii 3, 4, and 5.

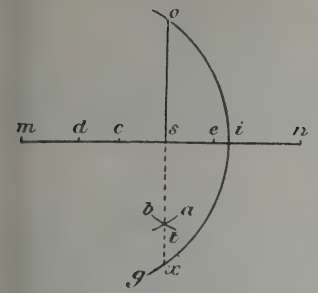


FIG. 6.

From a given point, *o*, to let fall a perpendicular, *os*, to a given line, *mn*.

From *o* measure to the line *mn* any two equal distances, *oc*, *oe*; and from *c* and *e* as centres, with any opening greater than half of *ce*, describe the two arcs *a* and *b*; join *ot*. Or from any point, as *d* on the line, open the dividers to *o*, and describe the arc *og*; make *ix* equal to *io*, and join *ox*.

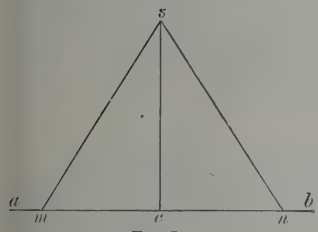


FIG. 7.

If the line ab *is on the ground*, and a perpendicular is required to be drawn from *c*, first measure off any two equal distances, *cm*, *cn*. At *m* and *n* hold the ends of a piece of string, tape-line, or chain, *msn*; then tighten out the string, &c., as shown by *msn*, *s* being its centre. Then will *sc* be the required perpendicular.

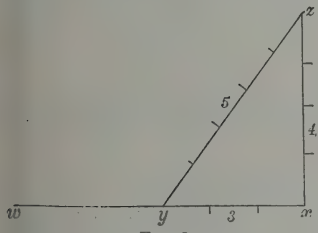


FIG. 8.

If the perpendicular, xz, *is to be drawn from the end of the line* wx, first measure *xy* upon the line, and equal to three feet; then, holding the end of a tape-line at *x*, and its nine-feet mark at *y*, hold the four-feet mark at *z*, keeping *zx* and *zy* equally stretched. Then *zx* will be the required perpendicular, because 3, 4, and 5 make the sides of a right-angled triangle. Instead of 3, 4, and 5, any multiples of those numbers may be used, such as 6, 8, and 10, or 9, 12, 15, &c.; also, instead of feet we may use yards, chains, &c.

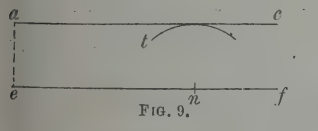


FIG. 9.

Through a given point, *a*, to draw a line, *ac*, parallel to another line, *ef*.

With the perpendicular distance *ae*, from any point, *n*, on *ef*, describe an arc, *t*; draw *ac* just touching the arc.

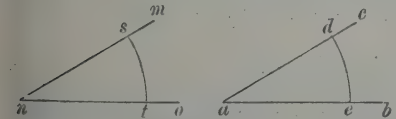


FIG 10.

At any point, *a*, in a line *ab*, to make an angle, *cab*, equal to a given angle, *mno*.

From *n* and *a*, with any convenient radius, describe the arcs *st*, *de*; measure *st*, and make *de* equal to it; through *ad* draw *ac*.

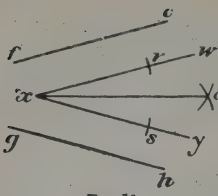


FIG. 11.

Bisection of an Angle.

Let *wxy* be the angle.

From *x* set off any two equal distances, *xr*, *xs*. From *r* and *s*, with any radius, describe two arcs intersecting, as at *o*, and join *ox*. If the two sides of the angle do not meet, as *cf* and *gh*, either first extend them until they do meet, or else draw lines, *xw* and *xy*, parallel to them, and at equal distances from them, so as to meet; then proceed as before.

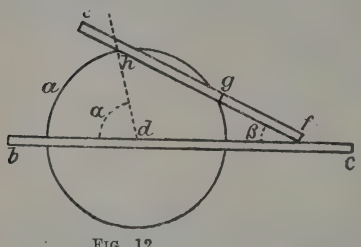


FIG. 12.

Trisection of an Angle.

a is a circle, of which *d* is the centre. *bc* is a ruler whose upper edge touches the centre *d*. *a* is the angle whose trisection is required. *ef* is a second ruler which has a mark at *g*, the distance *gf* being equal to the radius of the circle. At the point *h* a pin is inserted, on which the ruler *ef* can slide. To obtain a trisection of the angle *a*, slide the corner of the ruler *ef* along *bc* until the mark *g* comes on the circumference of the circle. Then the angle β will be equal to $a \div 3$.

See also p. 202. (*H. R. Kempe.*)

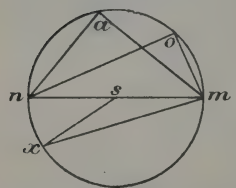


FIG. 13.

Angles at the circumference of a Semicircle.

All angles, as *nam*, *nom*, at the circumference of a semicircle, and standing on its diameter, *nm*, are right angles; or, as it is usually expressed, *all angles in a semicircle are right angles.* An angle, *nsx*, at the centre of a circle is twice as great as an angle, *nmx*, at the circumference, when both stand upon the same arc, *nx*.

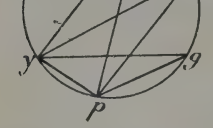


FIG. 14.

Angles at the circumference of a Circle.

All angles, as *ydp*, *yep*, *ygp*, at the circumference of a circle, and standing upon the same arc, as *yp*, are equal to each other; or, as usually expressed, *all angles in the same segment of a circle are equal.*

Angles of a Parallelogram.

A parallelogram is any four-sided straight-lined figure whose opposite sides are equal, as *abcd*, or a square, &c. Any line drawn across a parallelogram between two opposite angles is called a *diagonal*, as *ac* or *bd*. A diagonal divides a parallelogram into two equal parts, as does also any line, *mn*, drawn through the centre of either diagonal; and, moreover, the line *mn* itself is divided into two equal parts by the diagonal. Two diagonals bisect each other; they also divide the parallelogram into four triangles of equal area. The sum of the two angles at the ends of any one side is = 180°; thus $dab + abc = abc + bcd = 180°$; and the sum of the four angles, *dab*, *abc*, *bcd*, *cda* = 360°.

The sum of the squares of the four sides is equal to the sum of the squares of the two diagonals.

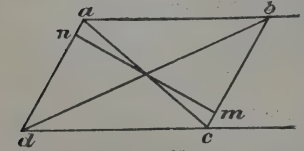


FIG. 15.

To Construct an Ellipse.

(1) Having given the two axes, fig. 16, set off from *c* half the great axis at *a* and *b*, which are the two foci in the ellipse. Take an endless string as long as the three sides in the triangle *abc*, fix two pins or nails in the foci, one in *a* and one in *b*, lay the string round *a* and *b*, stretch it with a pencil, *d*, which then will describe the desired ellipse.

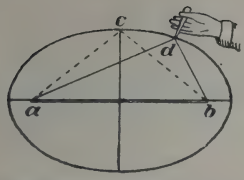


FIG. 16.

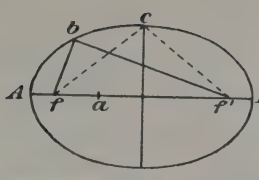


FIG. 17.

(2) Given the two axes, fig. 17, set off half the long axis from *c* to *f f'*, which will be the two foci in the ellipse. Divide the long axis into any number of parts, say *a* to be a division point. Take A*a* as radius and *f* as centre, and describe a circle arc about *b*; take *a*B as radius and *f* as centre, describe another circle arc about *b*; then the intersection *b* is a point in the ellipse, and so the whole ellipse can be constructed.

FIG. 18.

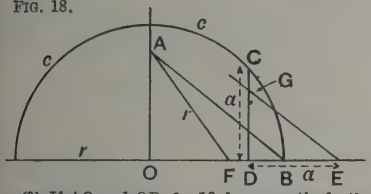
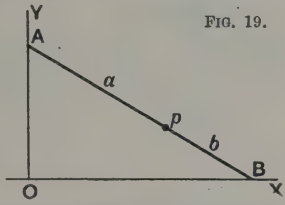


FIG. 19.



(3) If AO and OB, fig. 18, be respectively the semi-minor and semi-major axes of the ellipse, then from O as the centre and OB as radius, describe the semi-circle *c*. If any line CD (*a*) be drawn perpendicular to OB, and DE is made equal to CD, then if through E, EF be drawn parallel to AB, cutting CD at G, G will be a point on the circumference of the ellipse.

If AF be drawn equal to OB, then F will be a focus of the ellipse.

(4) If OX, OY, fig. 19, be at right angles to each other, then if a rod AB be moved so that A slides along OY, and B along OY, the point *p* will describe an ellipse of which *a* (when AB becomes coincident with OX) and *b* (when AB becomes coincident with OY) will be the semi-axes; if *a* is greater than *b*, then *a* will be the semi-major, and *b* the semi-minor axes.

If $a = b$ then *p* will describe a circle, of which O is the centre. (*H. R. Kempe.*)

To construct a Cycloid.

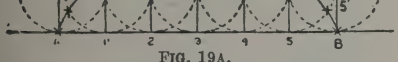


FIG. 19A.

On the line AB lay off any points, 1, 2, 3, 4, &c.; draw perpendicular lines at each point, and on each describe circles equal to the generating circle.

On the circum. of the circle at
1 lay off 1.1′ = A.1.
2 lay off 2.2′ = A.2.
3 lay off 3.3′ = A.3.

and so on; the points 1′, 2′, 3′, 4′, 5′, are points of the curve.

To construct a Screw Helix.

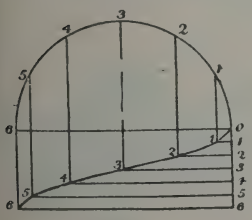


FIG. 20.

In a given Circle to inscribe any Regular Polygon.

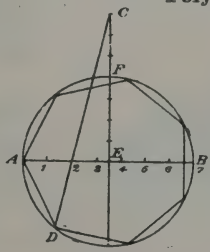


FIG. 21.

Draw the diameter, AB; from E, the centre, erect the perpendicular, EFC, cutting the circle at F. Divide EF into four equal parts, and set three parts from F to C. Divide the diameter, AB, into as many equal parts as the polygon is required to have sides. From C, through the second division in the diameter, draw CD. Join AD; it will be the side of the polygon required.

LONGIMETRY.

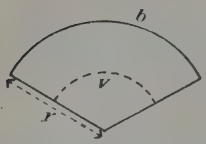


FIG. 22.

$b = \frac{\pi r v}{180} = 0{\cdot}0175rv,$

$= \frac{8e - c}{3},$ approximately, where e = chord of half the arc, and c = chord of whole arc.

$v = \frac{180b}{\pi r} = 57{\cdot}296\frac{b}{r}.$

$= \sqrt{2rh}$ (*see* fig. 24)

FIG. 23.

$w = 180 - \frac{v}{2},$

$v = 2(180° - w)$

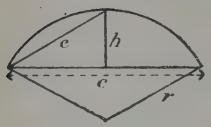


FIG. 24.

$r = \frac{c^2 + 4h^2}{8h} = \frac{e^2}{2h},$

$c = 2\sqrt{2hr - h^2}.$

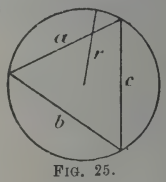


FIG. 25.

$r = \frac{ac}{2\sqrt{a^2 - \left(\frac{a^2+b^2-c^2}{2b}\right)^2}}.$

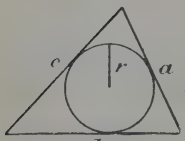


FIG. 26.

$r = \frac{b\sqrt{a^2 - \left(\frac{a^2+b^2-c^2}{2b}\right)^2}}{a+b+c}.$

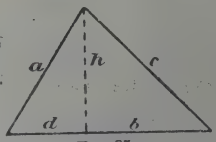


FIG. 27.

$c^2 = a^2 + b^2 - 2bd,$

$h = \sqrt{a^2 - d^2},$

$d = \frac{a^2+b^2-c^2}{2b}.$

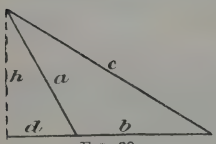


FIG. 28.

$c^2 = a^2 + b^2 + 2bd,$

$h^2 = \sqrt{a^2 - d^2},$

$d = \frac{c^2 - a^2 - b^2}{2b}.$

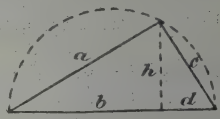


FIG. 29.

$a : b = h : c,$

$h = \frac{ac}{b} = \frac{ad}{c},$

$d = \frac{c^2}{b} = \frac{ch}{a}.$

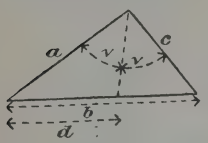


FIG. 30.

$a : c = d : (b - d),$

$d = \frac{ab}{c+a}.$

$v = v.$

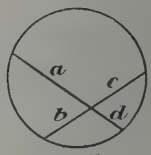


FIG. 31.

$a : c = b : d,$

$ad = bc.$

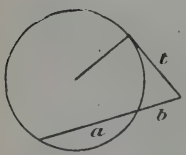


FIG. 32.

$a : t = t : b,$

$t^2 = ab.$

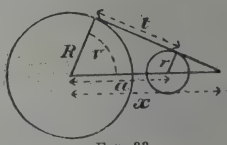


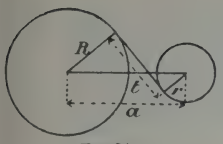
FIG. 33.

$x = \frac{aR}{R - r},$

$a = \sqrt{t^2 + (R-r)^2},$

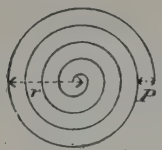
$t = \sqrt{a^2 - (R-r)^2},$

$\sin v = \frac{t}{a}.$



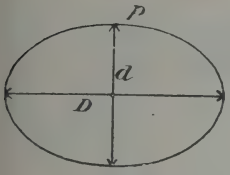
$t = \sqrt{a^2 - (R+r)^2}$,
$a = \sqrt{t^2 + (R+r)^2}$.

FIG. 34.



$l = \pi r n = \frac{\pi r^2}{P}$,
$n = \frac{l}{\pi r} = \frac{r}{P}$,
$P = \frac{\pi r^2}{l} = \frac{r}{n}$,
P = pitch.
l = length of spiral.
n = number of turns.

FIG. 35.

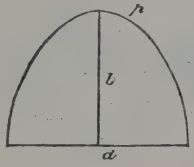


Ellipse.

$p = 2\sqrt{D^2 + 1{\cdot}4674d^2}$.

p = length of periphery.

FIG. 36.



Parabola.

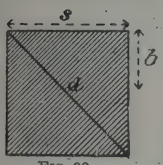
$p = \sqrt{a^2 + 1{\cdot}3333b^2}$.

p = length of periphery, not including base.

FIG. 37.

PLANIMETRY.

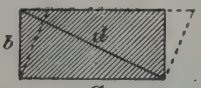
A = area.



Square.

$A = s^2 = 4b^2$
$= 0{\cdot}5d^2$.

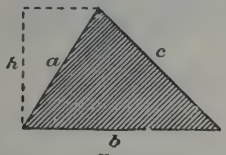
FIG. 38.



Rectangle.

$A = ab$
$= b\sqrt{d^2 - b^2}$.

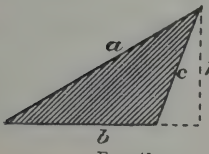
FIG. 39.



Triangle.

$A = \frac{bh}{2} = \frac{1}{2}bh$
$= \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$.

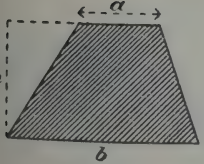
FIG. 40



Triangle.

$A = \frac{1}{2}bh$
$= \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 - a^2 - b^2}{2b}\right)^2}$.

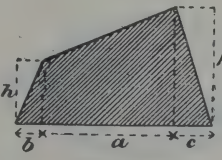
FIG. 41.



Quadrangle.

$A = \frac{1}{2}h(a+b)$.

FIG. 42.



Quadrangle.

$A = \frac{1}{2}(a[h+h'] + bh + ch')$.

FIG. 43.

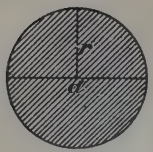


FIG. 44.

Circle Plane.

$A = \pi r^2 = 0{\cdot}785d^2$

$= \frac{pr}{2} = 0{\cdot}0796p^2.$

p = length of periphery.

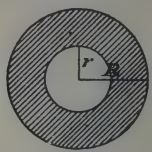


FIG. 45.

Circle Ring.

$A = \pi(R^2 - r^2)$

$= \pi(R+r)(R-r)$

$= 0{\cdot}785(D^2 - d^2).$

$D = 2R, \quad d = 2r.$

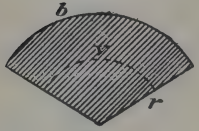


FIG. 46.

Sector.

$A = \frac{1}{2}br$

$= \frac{\pi r^2 v}{360} = \frac{r^2 v}{114{\cdot}5}.$

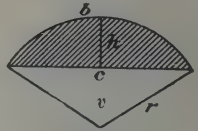


FIG. 47.

Segment.

$A = \frac{1}{2}[br - c(r-h)]$

$= \frac{\pi r^2 v}{360} \mp \frac{c}{2}(r-h)$

$= \frac{h^3}{2c} + \frac{2}{3}ch,$

approximately.

$(c = 2\sqrt{2rh - h^2}).$

FIG. 48.

Quadrant.

$A = 0{\cdot}785r^2 = 0{\cdot}3927c^2.$

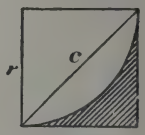


FIG. 49.

Corner Segment.

$A = 0{\cdot}215r^2 = 0{\cdot}1075c^2.$

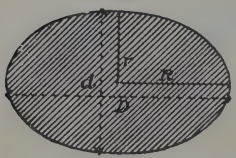


FIG. 50.

Ellipse.

$A = \pi Rr = 0{\cdot}785Dd.$

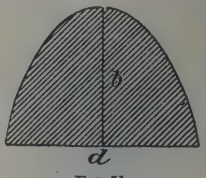


FIG 51

Parabola.

$A = \frac{2}{3}bd.$

Irregular Curvilinear Figure—Weddle's Rule.

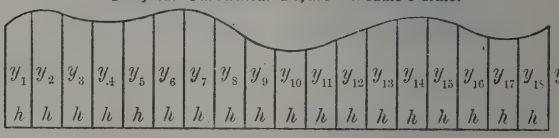


FIG. 52.

$$\text{Area} = \tfrac{3}{10}h\left\{y_1 + y_3 + y_5 + y_7 + y_9 + y_{11} + y_{13} + y_{15} + y_{17} + y_{19} + 5(y_2 + y_4 + y_6 + y_8 + y_{10} + y_{12} + y_{14} + y_{16} + y_{18}) + y_4 + y_7 + y_{10} + y_{13} + y_{16}\right\}$$

$= \frac{3}{10}h$ (sum of odd + 5 (sum of even) + sum of every third, excluding extremes

SURFACE OF SOLIDS.

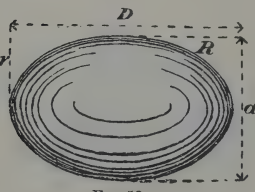


FIG. 53.

Prolate Spheroid.

$S = \frac{4\pi}{\sqrt{2}} \cdot r\sqrt{R^2 + r^2}$

$= 8{\cdot}88r\sqrt{R^2 + r^2} = 2{\cdot}22d\sqrt{D^2 + d^2}.$

Oblate Spheroid.

$S = \frac{4\pi}{\sqrt{2}} \cdot R\sqrt{R^2 + r^2}.$

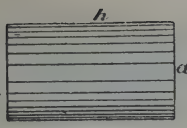


FIG. 54.

Cylinder.

$$S = 2\pi rh = \pi dh = 3{\cdot}1416dh,$$

$$h = \frac{S}{2\pi r} = \frac{S}{\pi d} = \frac{S}{3{\cdot}1416d}.$$

FIG. 55.

Sphere.

$$S = 4\pi r^2 = 12{\cdot}56r^2 = \pi d^2.$$

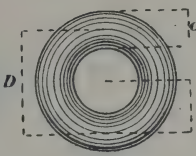


FIG. 56.

Forus.

$$S = 4\pi^2 Rr = 39{\cdot}44Rr$$

$$= 9{\cdot}86Dd.$$

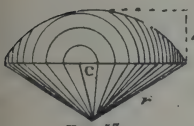


FIG. 57.

Sphere Sector.

$$S = \frac{\pi r}{2}(4h + c).$$

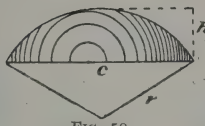


FIG. 58.

Circle Zone.

$$S = 2\pi rh = \frac{\pi}{4}(4h^2 + c^2).$$

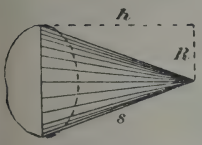


FIG. 59.

Cone.

$$S = \pi Rs$$

$$= \pi R\sqrt{R^2 + h^2}.$$

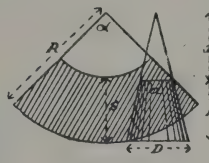


FIG. 60.

Cone.

$$x = \frac{dh}{D - d},$$

$$R = s + \frac{ds}{D - d}$$

$$= \frac{\pi s}{2}(D + d)$$

$$= \frac{180D}{R} = \frac{180(D - d)}{s}.$$

STEREOMETRY.

C = *Solid Content.*

FIG. 61.

Sphere.

$$C = \frac{4\pi r^3}{3} = 4{\cdot}189r^3$$

$$= \frac{\pi d^3}{6} = 0{\cdot}524d^3.$$

FIG. 62.

Forus.

$$C = 2\pi^2 Rr^2$$

$$= 19{\cdot}74Rr^2$$

$$= 2{\cdot}463Dd^2.$$

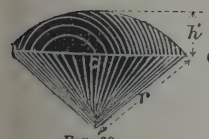


FIG. 63.

Sphere Sector.

$$C = \frac{2}{3}\pi r^2 h = 2{\cdot}0944r^2 h$$

$$= \frac{2}{3}\pi r^2(r \mp \sqrt{r^2 - \tfrac{1}{4}c^2}).$$

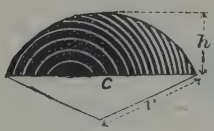


FIG. 64.

Circle Zone.

$$C = \pi h^2(r - \tfrac{1}{3}h)$$

$$= \pi h^2\left(\frac{c^2 + 4h^2}{8h} - \tfrac{1}{3}h\right)$$

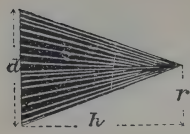


FIG. 65.

Cone.

$C = \frac{\pi r^2 h}{3} = 1{\cdot}047 r^2 h$

$= 0{\cdot}2618 d^2 h.$

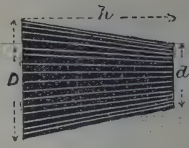


FIG. 66.

Conic Frustum.

$C = \frac{1}{12}\pi h(D^2 + Dd + d^2)$

$= \frac{1}{3}\pi h(R^2 + Rr + r^2),$

$R = \frac{D}{2}, \quad r = \frac{d}{2}.$

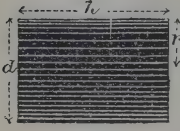


FIG. 67

Cylinder.

$C = \pi r^2 h = 0{\cdot}785 d^2 h$

$= \frac{p^2 h}{4\pi} = 0{\cdot}0796 p^2 h.$

p = length of periphery.

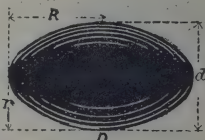


FIG. 68.

Prolate Spheroid.

$C = \frac{4}{3}\pi R r^2 = 4{\cdot}189 R r^2$

$= \frac{1}{6}\pi D d^2 = {\cdot}5236 D d^2.$

Oblate Spheroid.

$C = \frac{4}{3}\pi R^2 r = 4{\cdot}189 R^2 r$

$= \frac{1}{6}\pi D^2 d = {\cdot}5236 D^2 d.$

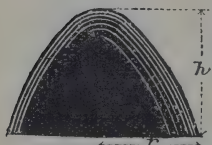


FIG. 69.

Paraboloid.

$C = \frac{1}{2}\pi r^2 h = 1{\cdot}5708 r^2 h.$

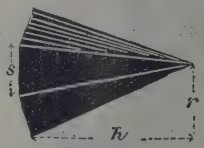


FIG. 70.

Pyramid.

$C = \frac{1}{3} ah$

$= \frac{nsh}{6}\sqrt{r^2 - \frac{s^2}{4}}.$

a = area of base.
n = number of sides.

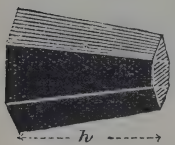


FIG. 71.

Pyramidic Frustum.

$C = \frac{h}{3}(A + a + \sqrt{Aa}).$

A and a = areas of the two ends.

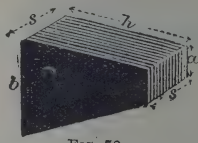


FIG. 72.

Wedge Frustum.

$C = \frac{hs}{2}(a + b).$

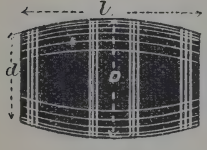


FIG. 73.

Cask

$C = {\cdot}0000321437$
$(39D^2 + 26Dd + 25d^2)$
gallons; l, D, and d being in inches.

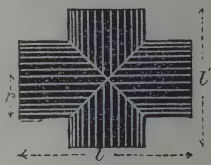


FIG. 74.

Cylinder Sections

$C = \pi r^2\left(l + l' - \frac{16}{3}r\right)$

$= \pi r^2(l + l') - 5{\cdot}333 r^3$

If l is inclined at an angle ϕ (less than 90°) to l', then
$C = \pi r^2(l + l') - 5{\cdot}333 r^3$ cosecant ϕ.

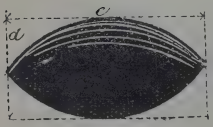


FIG. 75.

Parabolic Spindle.

$C = \frac{2}{15}\pi d^2 c = {\cdot}419 d^2 c.$

Circular Spindle.

$C = \frac{\pi}{32}\left(\frac{d^4}{l} + \frac{13}{3}d^2 l\right) = {\cdot}0982\left(\frac{d^4}{l} + 4{\cdot}333 d^2 l\right)$, approximately.

If $l = nd$,

$C = {\cdot}0982 d^3\left(\frac{1}{n} + 4{\cdot}333 n\right)$, approximately.

(*H. R. Kempe.*)

CONIC SECTIONS.

A *Cone* is a figure described by the revolution of a right-angled triangle about one of its legs, or it is a solid having a circle for its base, and terminated in a vertex.

Conic Sections are the figures made by a plane cutting a cone.

The *Axis* is the line about which the triangle revolves.

The *Base* is the circle which is described by the revolving base of the triangle.

If a cone is cut by a plane through the vertex and base, the section will be a triangle.

If a cone is cut by a plane parallel to its base, the section will be a circle.

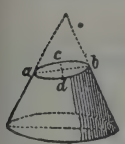


FIG. 76.

An *Ellipse* is a figure generated by an oblique plane cutting a cone above its base.

The *transverse axis* or diameter is the longest right line that can be drawn in it, as *ab*, fig. 76.

The *conjugate axis* or diameter is a line drawn through the centre of the ellipse perpendicular to the transverse axis, as *cd*.

A *Parabola* is a figure generated by a plane cutting a cone parallel to its side, as *abc*, fig. 77.

The *axis* is a right line drawn from the vertex to the middle of the base, as *bo*.

A parabola has no conjugate diameter.

FIG. 77.

An *Hyperbola* is a figure generated by a plane cutting a cone at any angle with the base greater than that of the side of the cone, as *abc*, fig. 78.

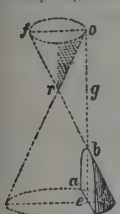


FIG. 78

The *transverse axis* or diameter, *ob*, is that part of the axis, *eb*, which, if continued, as at *o*, would join an opposite cone, *ofr*.

The *conjugate axis* or diameter is a right line drawn through the centre, *g*, of the transverse axis, and perpendicular to it.

The straight line through the *foci* is the indefinite transverse axis; that part of it between the vertices of the curves, as *ob*, is the definite transverse axis. Its middle point, *g*, is the centre of the curve.

The *eccentricity* of a hyperbola is the ratio obtained by dividing the distance from the centre to either *focus* by the semi-transverse axis.

The *asymptotes* of a hyberbola are two right lines to which the curve continually approaches, touches at an infinite distance, but does not pass; they are prolongations of the diagonals of the rectangle constructed on the extremes of the axes.

Two hyperbolas are *conjugate* when the transverse axis of the one is the conjugate of the other, and *vice versâ*.

General Definitions.

An *Ordinate* is a right line from any point of a curve to either of the diameters, *ae* and *do*, fig. 79; *ab* and *df* are double ordinates.

An *Abscissa* is that part of the diameter which is contained between the vertex and an ordinate, as *ce*, *go*.

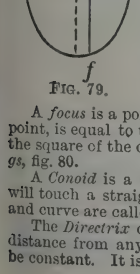


FIG. 79.

The *parameter of any diameter* is equal to four times the distance from the *focus* to the vertex of the curve; the parameter of the axis is the least possible, and is termed the parameter of the curve.

The *parameter of the curve of a conic section* is equal to the chord of the curve drawn through the *focus* perpendicular to the axis.

The *parameter of the transverse axis* is the least, and is termed the parameter of the curve.

The *parameter of a conic section* and the *foci* are sufficient elements for the construction of the curve.

In the *Parabola*, the parameter of any diameter is a third proportional to the abscissa and ordinate of any point of the curve, the abscissa and ordinate being referred to that diameter and the tangent at its vertex.

In the *Ellipse* and *Hyperbola* the parameter of any diameter is a third proportional to the diameter and its conjugate.

A *focus* is a point on the principal axis where the double ordinate to the axis, through the point, is equal to the parameter, as *ef*, fig. 80. It may be determined arithmetically thus: Divide the square of the ordinate by four times the abscissa, and the quotient will give the focal distance, *gs*, fig. 80.

A *Conoid* is a warped surface generated by a right line being moved in such a manner that it will touch a straight line and curve, and continue parallel to a given plane. The straight line and curve are called *directrices*, the plane a plane *directrix*, and the moving line the *generatrix*.

The *Directrix* of a conic section is a straight line such that the ratio obtained by dividing the distance from any point of the curve to it by the distance from the same point to the focus shall be constant. It is always perpendicular to the principal axis.

THE ELLIPSE.

To compute the Parameter of an Ellipse, the Transverse and Conjugate Diameters being given (fig. 80).

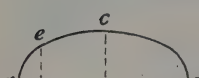


FIG. 80.

RULE.—Divide the square of the conjugate diameter by the transverse diameter, and the quotient is equal to the parameter.

EXAMPLE.—In the ellipse (fig. 80), the transverse and conjugate diameters, *gb*, *ck*, are 30 and 20.

Then $\frac{20 \times 20}{30} = 13{\cdot}333 = \textit{parameter}.$

The parameter of the curve = *ef*, a double ordinate passing through the focus, *s*.

To compute the Ordinate of an Ellipse, the Transverse and Conjugate Diameters and the Abscissa being given (fig. 81).

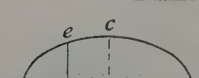


FIG. 81.

RULE.—As the transverse diameter is to the conjugate, so is the square root of the product of the abscissæ to the ordinate which divides them.

Or, $\frac{d}{D}\sqrt{a'(D-a')} = y$, D *representing the transverse diameter, d the conjugate, a' the lesser abscissa, and y the ordinate.*

EXAMPLE.—The transverse diameter, *gb*, of an ellipse (fig. 81) is 25 (D); the conjugate, *ck*, is 16 (*d*); and the abscissa, *gi*, 7 (*a'*); what is the length, *y*, of the ordinate, *ie*?

$25 - 7 = 18 = \textit{second abscissa}$; $\sqrt{7 \times 18} = 11{\cdot}225 = \textit{square root of the abscissæ}.$
Hence 25 : 16 :: 11·225 : 7·184 *inches = length of the ordinate.*

To compute the Abscissæ of an Ellipse, the Transverse and Conjugate Diameters and the Ordinate being given (fig. 81).

RULE.—As the conjugate diameter is to the transverse, so is the square root of the difference of the squares of the ordinate and semi-conjugate to the distance between the ordinate and centre; and this distance being added to, or subtracted from, the semi-transverse, will give the abscissæ required.

Or

$\frac{D}{d}\sqrt{\left(\frac{d}{2}\right)^2 - y^2} = x$, and $\left.\begin{array}{l} D \div 2 + x = a, \\ D \div 2 - x = a', \end{array}\right\}$ *x representing the distance obtained, and a, a', the greater and lesser abscissæ.*

EXAMPLE.—The transverse diameter, *gb*, of an ellipse (fig. 81) is 25 (D); the conjugate, *ck*, 16 (*d*); and the ordinate, *ie*, 7·184 (*y*); what are the abscissæ, *bi*, *gi*?

$\sqrt{8^2 - 7{\cdot}184^2} = 3{\cdot}519943 = \textit{square root of difference of squares of semi-conjugate and ordinate.}$

Hence, as 16 : 25 :: 3·52 : 5·5 = *distance between ordinate and centre.*

Then $\left.\begin{array}{l} 25 \div 2 = 12{\cdot}5, \text{ and } 12{\cdot}5 + 5{\cdot}5 = 18 = bi, \\ 25 \div 2 = 12{\cdot}5, \text{ and } 12{\cdot}5 - 5{\cdot}5 = \ 7 = gi, \end{array}\right\}$ *abscissæ.*

To compute the Transverse Diameter of an Ellipse, the Conjugate, Ordinate, and Abscissa being given (fig. 81).

RULE.—To or from the semi-conjugate, according as the greater or lesser abscissa is used, add or subtract the square root of the difference of the square of the ordinate and semi-conjugate. Then, as this sum or difference is to the abscissa, so is the conjugate to the transverse.

Or,

$$\frac{ad}{\frac{d}{2} \pm \sqrt{y^2 - \left(\frac{d}{2}\right)^2}} = \text{D}.$$

EXAMPLE.—The conjugate diameter, *ck*, of an ellipse (fig. 81) is 16 (*d*); the ordinate, *ie*, is 7·184 (*y*); and the abscissæ, *bi*, *ig*, are 18 (*a*) and 7 (*a'*); what is the length of the transverse diameter (D)?

$(16 \div 2)^2 - 7{\cdot}184^2 = 3{\cdot}52 =$ *square root of difference of squares of ordinate and semi-conjugate.*
$16 \div 2 + 3{\cdot}52 : 18 :: 16 : 25$; $16 \div 2 - 3{\cdot}52 : 7 :: 16 : 25 =$ *transverse diameter.*

To compute the Conjugate Diameter of an Ellipse, the Transverse Diameter, Ordinate, and Abscissa being given (fig. 81).

RULE.—As the square root of the product of the abscissæ is to the ordinate, so is the transverse diameter to the conjugate.

Or,

$$y\text{D} \div \sqrt{a \times a'} = d.$$

EXAMPLE.—The transverse diameter, *gb*, of an ellipse (fig. 81) is 25 (D); the ordinate, *ie*, is 7·184 (*y*); and the abscissæ, *bi* and *ig*, 18 (*a*) and 7 (*a'*); what is the length (*d*) of the conjugate diameter?

$\sqrt{18 \times 7} = 11{\cdot}225 =$ *square root of product of abscissæ.*
$11{\cdot}225 : 7{\cdot}184 :: 25 : 16 =$ *conjugate diameter.*

To compute the Circumference of an Ellipse (fig. 81).

RULE.—Multiply the square root of half the sum of the squares of the two diameters by 3·1416.

Or,

$$\sqrt{\frac{\text{D}^2 + d^2}{2}} \times 3{\cdot}1416 = \textit{circumference}.$$

EXAMPLE.—The transverse and conjugate diameters, *gb* and *ck*, of an ellipse (fig. 81) are 24 and 20; what is its circumference?

$\frac{24^2 + 20^2}{2} = 488$, and $\sqrt{488} = 22{\cdot}09 =$ *square root of half the sum of the squares of the diameters.*

Hence $22{\cdot}09 \times 3{\cdot}1416 = 69{\cdot}398 =$ *circumference.*

To compute the Area of an Ellipse (fig. 81).

RULE.—Multiply the diameters together, and the product by ·7854. Or, multiply one diameter by ·7854, and the product by the other.

Or,

$$\text{D} \times d \times {\cdot}7854 = \textit{area}.$$

EXAMPLE.—The transverse diameter of an ellipse, *gb*, fig. 81, is 12 (D), and its conjugate, *ck*, 9 (*d*); what is its area?

$12 \times 9 \times {\cdot}7854 = 84{\cdot}8232 =$ *product of diameters and* ·7854 = *area.*

To compute the Area of a Segment of an Ellipse when its Base is parallel to either Axis, as *ein*, fig. 82.

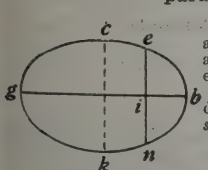


FIG. 82.

Ascertain the segment of the circle described upon the same axis to which the base of the segment is perpendicular. Then, as this axis is to the other axis, so is the circular segment to the elliptical segment.

EXAMPLE.—The axis to which the base of the segment is perpendicular is 50, and the height of the segment, 25. *Also, the area of the segment is one-half of that of a circle of* 50 *diameter*

$$= \frac{1963{\cdot}4954}{2} = 981{\cdot}7477.$$

Hence $50 : 70 :: 981{\cdot}75 : 1374{\cdot}45 =$ *area of elliptic segment.*

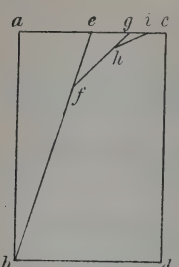


FIG. 83.

THE PARABOLA.

To draw a Parabola, the Base and Height being given (fig. 83).

Required a semi-parabola of which *bd* is an ordinate, the corresponding height being *ab*.

Bisect *ac* and draw *eb*. Make *ef* = one-quarter of *be*. Bisect *ec* and draw *fg*. Make *gh* = one-quarter of *fg* and join *h* to the bisection, *i*, of *gc*. (*C. H. Wingfield.*)

To compute either Ordinate or Abscissa of a Parabola, the other Ordinate and the Abscissæ, or the other Abscissa and the Ordinates, being given (fig. 84).

RULE.—As either abscissa is to the square of its ordinate, so is the other abscissa to the square of its ordinate.

Or,

$$\frac{y^2 \times a'}{a} = y'^2. \qquad \frac{y'^2 \times a}{a'} = y^2.$$

$$\frac{y^2 \times a'}{y'^2} = a. \qquad \frac{y'^2 \times a}{y^2} = a'.$$

Or, as the square root of any abscissa is to its ordinate, so is the square root of any other abscissa to its ordinate. Hence

$$\frac{y \times \sqrt{a'}}{\sqrt{a}} = y'.$$

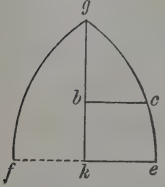


FIG. 84.

EXAMPLE 1.—The abscissa, *gb*, of the parabola, fig. 84, is 9 (*a*); its ordinate, *bc*, 6 (*y*); what is the ordinate, *ke* (*y'*), the abscissa of which, *gk*, is 16 (*a'*).

$9 : 6^2 :: 16 : 64$, and $\sqrt{64} = 8 =$ *length of ordinate.*

Or, $\sqrt{9} : 6 :: \sqrt{16} : 8 =$ *ordinate.*

EXAMPLE 2.—The abscissæ of a parabola are 9 (*a'*) and 16 (*a*), and their corresponding ordinates 6 (*y'*) and 8 (*y*); any three of these being taken, it is required to find the fourth.

$$\sqrt{\frac{6^2 \times 16}{9}} = 8 = \textit{ordinate.} \qquad \sqrt{\frac{8^2 \times 9}{16}} = 6 = \textit{ordinate.}$$

$$\frac{6^2 \times 16}{8^2} = 9 = \textit{lesser abscissa.} \qquad \frac{8^2 \times 9}{6^2} = 16 = \textit{abscissa.}$$

To compute the Length of the Curve of a Parabola cut off by a Double Ordinate (fig. 84).

RULE.—To the square of the ordinate add $\frac{4}{3}$ of the square of the abscissa, and the square root of this sum, multiplied by two, will give the length of the curve nearly.

Or,

$$\sqrt{\left(y^2 + \frac{4a^2}{3}\right)} 2 = \textit{length of curve.}$$

EXAMPLE.—The ordinate, *ke*, fig. 84, is 8 (*y*), and its abscissa, *gk*, 16 (*a*); what is the length of the curve *fge*?

$$8^2 + \frac{4 \times 16^2}{3} = 405{\cdot}333 = \textit{sum of square of the ordinate and } \tfrac{4}{3} \textit{ of the square of the abscissa, and}$$

$\sqrt{405{\cdot}333} = 20{\cdot}133$, which $\times\ 2 = 40{\cdot}267 =$ *length.*

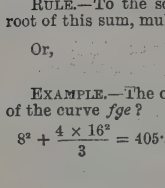


FIG. 85.

To compute the Area of a Parabola (fig. 85).

RULE.—Multiply the base (*d*) by the height (*h*), and take $\frac{2}{3}$ of the product.

Or,

$$\frac{2}{3} d \times h = \textit{area.}$$

EXAMPLE.—What is the area of the parabola *abc*, fig. 85, the height, *bo*, being 16 (*h*), and the base, or double ordinate, *ac*, 16 (*d*)?

$16 \times 16 = 256 =$ *product of base and height, and* $\frac{2}{3}$ *of* $256 = 170{\cdot}667 =$ *area.*

To compute the Area of a Segment of a Parabola (fig. 85).

RULE.—Multiply the difference of the cubes of the two ends of the segment, *ac*, *gf*, by twice its altitude, *eo*, and divide the product by three times the difference of the squares of the ends.

Or,

$$\frac{(l^3 - l'^3)2h}{(l^2 - l'^2)3} = \textit{area, } l \textit{ and } l' \textit{ representing the lengths of the base and lesser ends.}$$

EXAMPLE 1.—The ends of a segment of a parabola, *ac* and *gf*, fig. 85, are 10 (l) and 6 (l'), and the height, *eo*, is 10 (h); what is its area?

$(10^3 - 6^3)(2 \times 10) = 15680 =$ *difference of cubes of the ends* × *twice the height.*
$15680 \div (10^2 - 6^2)3 = 81{\cdot}667 =$ *preceding product* ÷ 3 *times the difference of the squares of the ends* = *area.*

Any parabolic segment is equal to a parabola of the same altitude, the base of which is equal to the base of the segment, increased by a third proportional to the sum of the two ends and the lesser end.

EXAMPLE 2.—In Example 1 the base and end are 10 and 6.

Then $10 + 6 : 6 :: 6 : 2{\cdot}25 =$ *third proportional to the sum of the two ends and the lesser end.*
Hence $10 + 2{\cdot}25 = 12{\cdot}25 =$ *sum of length of base of parabola and third proportional; and the area, the height being* 10, $= 81{\cdot}667$.

THE HYPERBOLA.

To compute the Ordinate of an Hyperbola, the Transverse and Conjugate Diameters and the Abscissæ being given (fig. 86).

RULE.—As the transverse diameter is to the conjugate, so is the square root of the product of the abscissæ to the ordinate required.

Or,

$$\frac{d \times \sqrt{a \times a'}}{\mathrm{D}} = \textit{ordinate.}$$

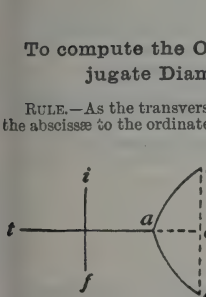


FIG. 86.

EXAMPLE.—The hyperbola *abc*, fig. 86, has a transverse diameter, *at*, of 120 (D); a conjugate, *if*, of 72 (d); and the abscissa *ae* is 40 (a); what is the length of the ordinate *ec*?

$40 + 120 = a' =$ *sum of lesser abscissa and axis = greater abscissa.*

$120 : 72 :: \sqrt{40 \times 160} : 48 =$ *ordinate.*

In hyperbolas the lesser abscissa, added to the axis (the transverse diameter), gives the greater.

The difference of two lines drawn from the *foci* of any hyperbola to any point in the curve is equal to its transverse diameter.

To compute the Abscissa of an Hyperbola, the Transverse and Conjugate Diameters and the Ordinate being given (fig. 86).

RULE.—As the conjugate diameter is to the transverse, so is the square root of the sum of the squares of the ordinate and semi-conjugate to the distance between the ordinate and the centre, or half the sum of the abscissæ. Then the sum of this distance and the semi-transverse will give the greater abscissa, and their difference the lesser abscissa.

Or,

$$\frac{\mathrm{D}\sqrt{y^2 + (d \div 2)^2}}{d} = \frac{a + a'}{2} = \textit{half the sum of the abscissæ.}$$

$$\frac{a + a'}{2} + \frac{t}{2} = a, \quad \text{and } \frac{a + a'}{2} - \frac{t}{2} = a'.$$

EXAMPLE.—The transverse diameter, *at*, of a hyperbola (fig. 86) is 120 (D); the conjugate, *if*, 72 (d); and the ordinate, *ec*, 48 (y); what are the lengths of the abscissæ, *te* and *ae*?

$72 : 120 :: \sqrt{48^2 + (72 \div 2)^2} = 60 : 100 =$ *half the sum of the abscissæ.*
$100 + (120 \div 2) = 160 =$ *above sum added to the semi-transverse = the greater abscissa*; and
$100 - (120 \div 2) = 40 =$ *above sum subtracted from the semi-transverse = the lesser abscissa.*

To compute the Conjugate Diameter of an Hyperbola, the Transverse Diameter, the Abscissæ, and Ordinate being given (fig. 86).

RULE.—As the square root of the product of the abscissæ is to the ordinate, so is the transverse diameter to the conjugate.

Or,

$$\frac{y\mathrm{D}}{\sqrt{a \times a'}} = \textit{conjugate diameter.}$$

EXAMPLE.—The transverse diameter, *at*, of a hyperbola (fig. 86) is 120 (D); the ordinate, *ec*, 8 (*y*); and the abscissæ, *te* and *ae*, 160 (*a*) and 40 (*a'*); what is the length of the conjugate, *if*?

$$\sqrt{40 \times 160} = 80 : 48 :: 120 : 72 = \textit{conjugate.}$$

To compute the Transverse Diameter of an Hyperbola, the Conjugate, the Ordinate, and an Abscissa being given (fig. 86).

RULE.—Add the square of the ordinate to the square of the semi-conjugate, and extract the square root of their sum.

Take the sum or difference of the semi-conjugate and this root, according as the greater or lesser abscissa is used.* Then, as the square of the ordinate is to the product of the abscissa and conjugate, so is the sum or difference above ascertained to the transverse diameter required.

Or,

$$a \text{ or } a' \times d \times \left\{\sqrt{y^2 + (d \div 2)^2} \pm (d \div 2)\right\} \div y^2 = \textit{transverse diameter.}$$

EXAMPLE.—The conjugate diameter, *if*, of a hyperbola (fig. 86) is 72 (*d*); the ordinate *ec*, 48 (*y*); and the lesser abscissa, *ae*, 40 (*a'*); what is the length of the transverse diameter, *at*?

$\sqrt{48^2 + (72 \div 2)^2} = 60 = \textit{square root of the squares of the ordinate and semi-conjugate.}$
$60 + (72 \div 2) = 96 = \textit{sum of above root and the semi-conjugate}$ (the lesser abscissa being used).
$40 \times 72 = 2880 = \textit{product of abscissa and conjugate.}$
$48^2 : 2880 :: 96 : 120 = \textit{transverse diameter.}$

To compute the Length of any Arc of an Hyperbola, commencing at the Vertex (fig. 87).

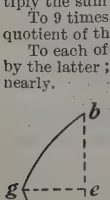
RULE.—To 19 times the transverse diameter add 21 times the parameter of the axis, and multiply the sum by the quotient of the lesser abscissa divided by the transverse diameter.

To 9 times the transverse diameter add 21 times the parameter, and multiply the sum by the quotient of the lesser abscissa divided by the transverse diameter.

To each of the products thus ascertained add 15 times the parameter, and divide the former by the latter; then this quotient, being multiplied by the ordinate, will give the length of the arc nearly.

Or,

$$\frac{(19\mathrm{D} + 21p)\frac{a}{\mathrm{D}} + 15p}{(9\mathrm{D} + 21p)\frac{a}{\mathrm{D}} + 15p} \times y = \textit{arc nearly.}$$



EXAMPLE.—In the hyperbola *gbc*, fig. 87, the transverse diameter is 120 (D), the conjugate 80 (*d*), the ordinate, *ec*, 48 (*y*), and the lesser abscissa, *ge*, 40 (*a'*); what is the length of the arc *gb*?

$$120 : 80 :: 80 : 53{\cdot}3333 = \textit{parameter.}$$

FIG. 87. $\left\{(19 \times 120) + (21 \times 53{\cdot}3333)\right\} \times \frac{40}{120} = 1133{\cdot}3333 = \textit{product of the sum of 19 times the transverse and 21 times the parameter, by the quotient of the lesser abscissa and the transverse.}$

* When the greater abscissa is used, the difference is taken, and *vice versâ*.

$(9 \times 120) + (21 \times 53{\cdot}3333) \times \frac{40}{120} = 733{\cdot}3333 =$ *product of the sum of* 9 *times the transverse and* 21 *times the parameter, by the quotient of the lesser abscissa and transverse.*

$1133{\cdot}333 + (15 \times 53{\cdot}333) \div (733{\cdot}333 + (15 \times 53{\cdot}333)) = 1{\cdot}2609 =$ *quotient of former product and* 15 *times the parameter ÷ latter product and* 15 *times the parameter.*

$1{\cdot}2609 \times 48 = 60{\cdot}5232 =$ *above quotient × the ordinate = length.*

As the transverse diameter is to the conjugate, so is the conjugate to the parameter.

To compute the Area of an Hyperbola, the Transverse, Conjugate, and Lesser Abscissa being given (fig. 87).

RULE.—To the product of the transverse diameter and lesser abscissa add $\frac{5}{7}$ of the square of this abscissa, and multiply the square root of the sum by 21.

Add 4 times the square root of the product of the transverse diameter and lesser abscissa to the product last ascertained, and divide the sum by 75.

Divide 4 times the product of the conjugate diameter and lesser abscissa by the transverse diameter, and this last quotient, multiplied by the former, will give the area nearly.

Or,

$$\frac{21\sqrt{Da' + \frac{5}{7}a'^2} + 4\sqrt{Da'}}{75} \times \frac{4da'}{D} = area.$$

EXAMPLE.—The transverse diameter of an hyperbola (fig. 87) is 60 (D), the conjugate 36 (d), and the lesser abscissa or height, ge, 20 (a'); what is the area of the figure?

$60 \times 20 + \frac{5}{7}$ of $20^2 = 1485{\cdot}7143 =$ *sum of the product of the transverse and abscissa and* $\frac{5}{7}$ *of the square of the abscissa.*

$\sqrt{1485{\cdot}7143} \times 21 = 809{\cdot}424 = 21$ *times the square root of the above sum.*

$\sqrt{60 \times 20} \times 4 + 809{\cdot}424 = 947{\cdot}988 =$ *sum of above result and the root of* 4 *times the product of the transverse and abscissa.*

$947{\cdot}988 \div 75 = 12{\cdot}6398 =$ *quotient of above result ÷* 75.

$\frac{36 \times 20 \times 4}{60} \times 12{\cdot}6398 = 606{\cdot}7104 =$ *product of* 4 *times the product of the conjugate and abscissa ÷ the transverse and the above quotient = area.*

CURVES.

ROULETTES AND CYCLOIDAL CURVES.

(G. A. Burls, M.Inst.C.E.)

Roulettes.

When one curve rolls without slipping upon a second fixed curve, any point fixed in the plane at the rolling curve or 'generator' traces out a curve termed a 'Roulette.'

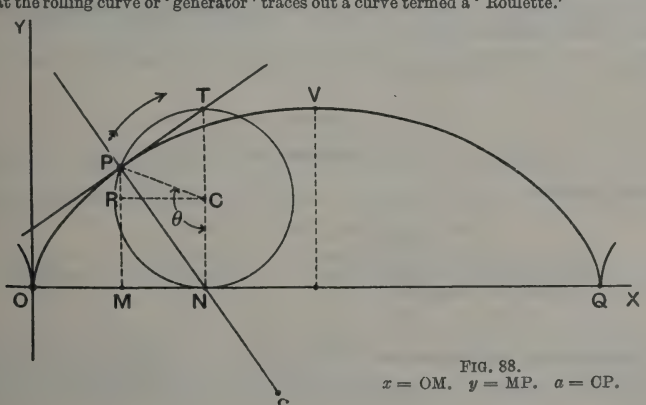


FIG. 88.
$x =$ OM. $y =$ MP. $a =$ CP.

When the fixed and generating curves are circles the corresponding roulettes are termed 'Cycloidal' curves. Of these the simplest is the 'Cycloid,' which is the roulette traced out by any point fixed on the circumference of a generating circle which rolls along a straight line.

The Cycloid.

This curve consists of an infinite number of arches, one of which is shown in fig. 88. Its equation is found from the pair of equations—

$$\left.\begin{aligned} x &= a(\theta - \sin\theta) \\ y &= a(1 - \cos\theta) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Eliminating θ between these two equations gives—

$$x = a\cos^{-1}\left(1 - \frac{y}{a}\right) - \sqrt{2ay - y^2} \quad . \quad . \quad . \quad . \quad (2)$$

By applying the rules given in the section on the calculus (p. 14) the following results relating to the Cycloid are obtained :—

$$\frac{dy}{dx} = \sqrt{\frac{2a - y}{y}} = \cot\tfrac{1}{2}\theta \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{ds}{dx} = \sqrt{\frac{2a}{y}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Join PT ; then PT is tangent to the Cycloid at P.

Join PN ; then PN is normal to the Cycloid at P.

The length of the Cycloidal are OP $= 4a -$ PT ; hence the whole length of the Cycloid OVQ $= 8a =$ eight times the radius of the generating circle.

The area of the Cycloid OVQO is $3\pi a^2$—*i.e.* three times the area of the generating circle.

The radius of curvature at P $=$ SP $=$ 2PN and the evolute of the Cycloid, *i.e.* the locus of S, is an equal Cycloid.

If the Cycloid revolve about its base OQ, the volume of the solid generated is $5^2\pi a^3$; and its surface is $\frac{64}{3} \cdot \pi a^2$.

Curtate and Prolate Cycloids.

If the tracing point lie between the centre and circumference of the generating circle the curve traced is termed a 'Curtate Cycloid' ; and if the tracing point lie outside the circumference, a 'Prolate Cycloid.' These two curves are sometimes termed the 'Interior' and 'Superior' Trochoids respectively.

If m denote the ratio of the radius of the generating circle to the distance of the tracing point from its centre, then the two equations,

$$\left.\begin{aligned} \frac{x}{a} &= \theta - m\sin\theta \\ \frac{y}{a} &= 1 - m\cos\theta \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (1')$$

or the single equation

$$x = a\cos^{-1}\left(\frac{a - y}{ma}\right) - \sqrt{m^2a^2 - (a - y)^2} \quad . \quad . \quad . \quad (2')$$

represent a 'Curtate Cycloid' if n be greater than 1 ; a 'Common Cycloid' if m be equal to 1 : and a 'Prolate Cycloid' if m be less than 1.

Epicycloids, Hypocycloids, Epitrochoids, and Hypotrochoids.

Let O and C (fig. 89) be the centres of the fixed and rolling circles respectively. B their point of contact.

If the generating circle roll *outside* the fixed circle the curve traced is termed :

An ' Epicycloid,' if the tracing point be on the circumference of the rolling circle, as P.
An ' Inferior Epitrochoid,' if the tracing point be within the rolling circle, as Q.
A ' Superior Epitrochoid,' if the tracing point be without the rolling circle, as R.

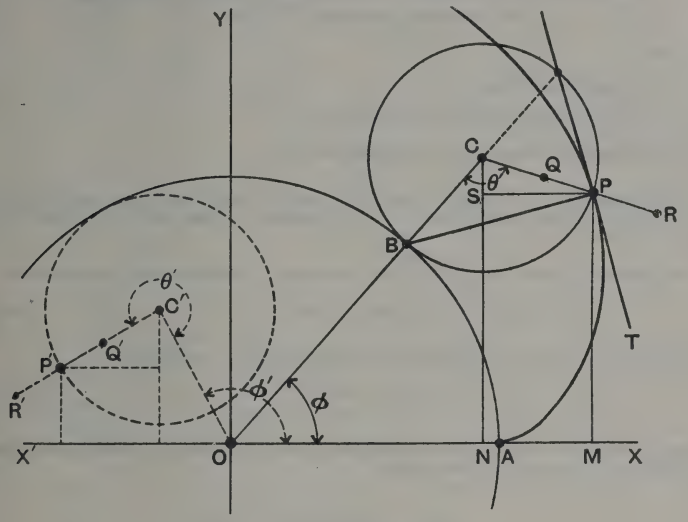


FIG. 89.

OB = b. BC = a.

If the generating circle roll *inside* the fixed circle, the curve traced is termed :

A ' Hypocycloid,' if the tracing point be on the circumference of the rolling circle, as P'.
An ' Inferior Hypotrochoid,' if the tracing point be within the rolling circle, as Q'.
A ' Superior Hypotrochoid,' if the tracing point be without the rolling circle, as R'.

General Equation to the Epicycloid : In fig. 89 let A be the initial position of P, and take OA as the axis of x, and OY, perpendicular to OA, as the axis of y, and complete the figure as indicated. Then $x = OM = ON + NM = ON + SP = (a + b)\cos\phi + a\sin SCP$; $y = MP = NC - SC = (a + b)\sin\phi - a\cos SCP$; and as $a\theta = b\phi$, these easily reduce to

$$\left.\begin{aligned} x &= (a+b)\cos\phi - a\cos\left(\frac{a+b}{a}\right)\phi \\ y &= (a+b)\sin\phi - a\sin\left(\frac{a+b}{a}\right)\phi \end{aligned}\right\} \quad \ldots\ldots (5)$$

It is usually convenient to use both these equations in investigating properties of the Epicycloid. PB is normal to the Epicycloid at P, and PT—at right angles to PB—is the tangent at P.

General Equations to Cycloids and Trochoids : Proceeding as above, the following equations are obtained :—

$$\left.\begin{aligned} x &= (a+b)\cos\phi - ma\cos\left(\frac{a+b}{a}\right)\phi \\ y &= (a+b)\sin\phi - ma\sin\left(\frac{a+b}{a}\right)\phi \end{aligned}\right\} \quad \ldots\ldots (6)$$

where ma denotes the distance of the tracing point from the centre of the rolling circle ; they represent :

(1) An ' Epicycloid,' if $m = 1$.
(2) An ' Inferior Epitrochoid,' if m be less than 1.
(3) A ' Superior Epitrochoid,' if m be greater than 1.

Similarly the equations :—

$$\left.\begin{aligned} x &= (b-a)\cos\phi + ma\cos\left(\frac{b-a}{a}\right)\phi \\ y &= (b-a)\sin\phi - ma\sin\left(\frac{b-a}{a}\right)\phi \end{aligned}\right\} \quad \ldots \quad (7)$$

represent

(1) A ' Hypocycloid,' if $m = 1$.

(2) An ' Inferior Hypotrochoid,' if m be less than 1.

(3) A ' Superior Hypotrochoid,' if m be greater than 1.

In the equations to the Epicycloid and Hypocycloid, if a and b are in the proportion of two whole numbers, ϕ may be eliminated, and the equations to these curves then appear in an algebraical form.

For example, if in the Epicycloid $a = \frac{1}{3}b$, the equation to the curve may be shown to be

$$4(x^2 + y^2 - b^2)^3 = 27b^4y^2 \quad \ldots \quad (8)$$

If in the Hypocycloid $a = \frac{1}{4}b$, the equation to the curve may be expressed :

$$x^{\frac{2}{3}} + y^{\frac{2}{3}} = b^{\frac{2}{3}} \quad \ldots \quad (9)$$

If in the Hypocycloid $a = \frac{1}{2}b$, we have the well-known property that the curve reduces to a straight line, which is a diameter of the fixed circle.

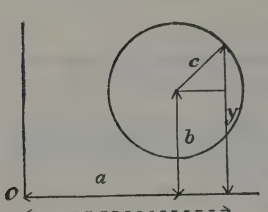


FIG. 90.

Circle.

General equation : $x^2 + y^2 - 2ax - 2by + a^2 + b^2 - c^2 = 0$.

If origin O is on the circumference, then $x^2 + y^2 - 2ax = 0$.

Equation to tangent : $y = mx + c\sqrt{1 + m^2}$,

where $m = -\frac{x'}{y'}$, x' and y' being the co-ordinates of the point on the circle at which the tangent is drawn.

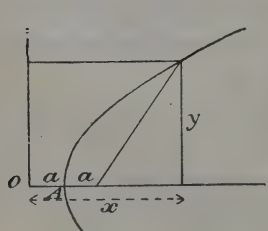


FIG. 90A.

Parabola.

General equation : $y^2 = 4a(x - a)$.

If origin O is at A, then $y^2 = 4ax$.

Equation to tangent: $y = mx + \frac{a}{m}$,

where $m = \frac{2a}{y'}$, y' being the ordinate of the point on the curve at which the tangent is drawn.

Ellipse.

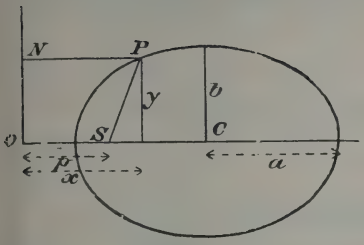


FIG. 91.

$$\frac{SP}{PN} = e = \textit{less than}\ \text{unity}.$$

General equation: $y^2 + (x-p)^2 = e^2x^2$.

If the origin is at the centre, C, then—

$$y^2 = \frac{b^2}{a^2}(a^2 - x^2).$$

Equation to tangent: $y = mx + \sqrt{a^2m^2 + b^2}$, where $-\frac{b^2x'}{a^2y'} = m$, x' and y' being the co-ordinates of the point on the circle at which the tangent is drawn.

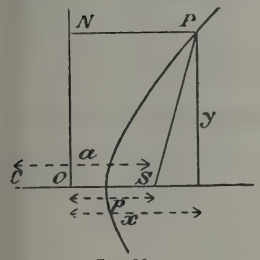


FIG. 92.

Hyperbola.

$$\frac{SP}{PN} = e = \textit{greater than}\ \text{unity}.$$

General equation: $y^2 + (x-p)^2 = e^2x^2$.

If the origin is at the centre, C, then $y^2 = \frac{b^2}{a^2}(x^2 - a^2)$, where $b^2 = (e^2-1)a^2$.

Equation to tangent: $y = mx + \sqrt{m^2a^2 - b^2}$.

The Logarithmic Curve.

In this curve the abscissa is the logarithm of the ordinate.

General equation: $y = a^x$,

where a is the base of the system.

The Catenary.

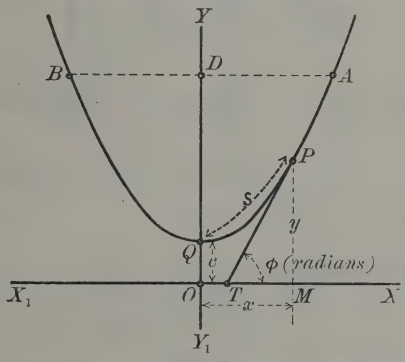


FIG. 93.

This is the curve in which a uniform, perfectly flexible, but inextensible, cord or chain hangs under the action of gravity. The weight of any portion of such a chain is proportional to its length, and accordingly it is usual to take as unit weight that of unit length of the chain.

Let A B (fig. 93) be the points of suspension ; Q the lowest point ; c the length of chain the weight of which is equal to the tension at Q. Take QO = c ; then the equation to the curve referred to OX and OY as axes is :—

$$y = \frac{c}{2}\left\{ e^{\frac{x}{c}} + e^{-\frac{x}{c}} \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

which is very simply expressed in the notation of hyperbolic functions thus :—

$$\frac{y}{c} = \cosh. \frac{x}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

By aid of the table, pp. 119–120, the curve may readily be plotted.

The slope at any point P is given by :—

$$\tan \phi = \frac{dy}{dx} = \sinh. \frac{x}{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and is also at once given by the table.

If the tension at P be equal to the weight of T units of length of the chain, then it is easily shown that :—

$$T = y = PM \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

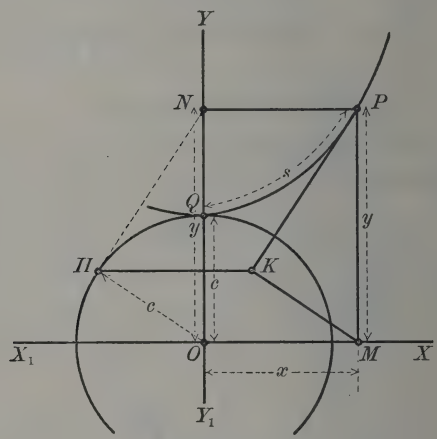


Fig. 94.

If the length of the chain from Q to P be denoted by s, then ;—

$$s = c \sinh. \frac{x}{c} = c \tan \phi \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Another simple and easily established expression for s is :—

$$s^2 = y^2 - c^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

With O as centre (fig. 94) and OQ = c as radius, describe a circle.

Let P $(x\ y)$ be any point on the catenary ; draw the co-ordinates PM and PN.

From N draw NH, touching the circle at H ; and join OH.

Then ON $= y$. OH $= c$. Also as OHN is 90° :—

$$NH^2 = ON^2 - OH^2 = y^2 - c^2 = s^2 = QP^2, \text{ by (6).}$$

Thus NH is equal to the length of the arc QP of the catenary.

Also from (5) :—Tan $\phi = \frac{s}{c} = \frac{NH}{HO} = \tan HON$; thus HON $= \phi$, and accordingly NH is parallel to the tangent to the catenary at P.

Through H draw HK parallel to OX meeting the tangent through P at K ; join KM. Then the triangles PKM and NHO are in all respects equal. And evidently K may be regarded as the free end of a string being unwound from the catenary, starting from Q, since PK = the arcual length PQ. Thus K is a point on the involute of the catenary starting from Q ; this involute is called the tractrix.

To find the catenary of given length, through any two points.

In fig. 95, given :—

$$P_1E = a = x_2 - x_1 ; \quad EP_2 = b = y_2 - y_1 ; \quad P_1P_2 = s$$

to find the axes, and the equation to P_1P_2.

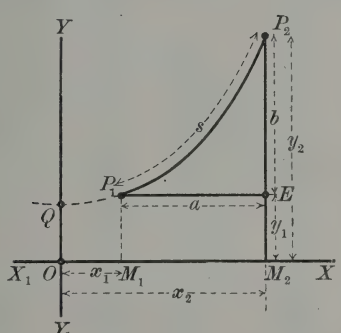


FIG. 95.

The value of c must first be found which satisfies the equation :—

$$\cosh.\frac{a}{c} = 1 + \frac{\frac{1}{2}(s^2 - b^2)}{c^2} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

This is easily done by trial by aid of the table on pp. 119-12 .

Knowing c we next find $(x + x_1)$ from the equation :—

$$\coth.\frac{x_2 + x_1}{2c} = \frac{s}{b} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

and as $x_2 - x_1 = a$, x_2 and x_1 are known.

Then as $y_1 = c \cosh. \frac{x_1}{c}$, $y_2 = c \cosh. \frac{x_2}{c}$, y_1 and y_2 are also known. Thus the axes are located and the equation is found.

s and l (= AB, fig. 93) are commonly known. Let $\frac{s}{l} = k$; then k is known.

c may now be found by aid of the equation:—

$$\frac{\sinh. \left(\frac{l}{2c}\right)}{\left(\frac{l}{2c}\right)} = k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

To facilitate the use of this equation the table on page 47 has been prepared, giving a sufficient range of values of $\frac{\sinh. \theta}{\theta}$ for ordinary practice. From this table, in any specific case θ is at once recognised; then $\frac{l}{2c} = \theta$, so that

$$c = \frac{l}{2\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and is at once determined.

Knowing c, all the quantities connected with the curve are immediately determinable by aid of the equations above given.

Spirals.

The Spiral of Archimedes.—In this spiral the radius vector varies directly as the angle described.

General equation: $r = a\theta$,

where $a = \frac{c}{2\pi}$ if c be the value of r when $\theta = 2\pi$..

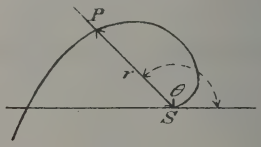


FIG. 96.

Let a line revolve uniformly round S, while a point, P, moves uniformly from S along it; then P will trace the Spiral of Archimedes.

The Logarithmic Spiral.—Here the angle described is the logarithm of the radius vector.

General equation: $r = a^{\theta}$.

It is also called the equiangular spiral, since it cuts the radius at a constant angle.

The Hyperbolic Spiral.—In this spiral as the angle increases at a uniform rate the radius vector decreases at an hyperbolic rate.

General equation: $r = \frac{a}{\theta}$.

TABLE OF VALUES OF $\frac{\text{Sinh. } \theta}{\theta}$.

(G. A. Burls.)

θ	$\frac{\text{Sinh. } \theta}{\theta}$	θ	$\frac{\text{Sinh. } \theta}{\theta}$	θ	$\frac{\text{Sinh. } \theta}{\theta}$	θ	$\frac{\text{Sinh. } \theta}{\theta}$
0	1	·61	1·06318	1·21	1·2626	1·81	1·6427
·01	1·0000167	·62	1·06531	1·22	1·2673	1·82	1·6510
·02	1·0000667	·63	1·06748	1·23	1·2719	1·83	1·6594
·03	1·0001500	·64	1·06968	1·24	1·2767	1·84	1·6678
·04	1·0002667	·65	1·07192	1·25	1·2815	1·85	1·6763
·05	1·0004167	·66	1·07420	1·26	1·2864	1·86	1·6850
·06	1·0006001	·67	1·07651	1·27	1·2913	1·87	1·6936
·07	1·0008169	·68	1·07887	1·28	1·2963	1·88	1·7023
·08	1·0010670	·69	1·08126	1·29	1·3013	1·89	1·7112
·09	1·0013505	·70	1·08369	1·30	1·3064	1·90	1·7201
·10	1·0016675	·71	1·08616	1·31	1·3116	1·91	1·7291
·11	1·0020179	·72	1·08867	1·32	1·3168	1·92	1·7381
·12	1·0024017	·73	1·09122	1·33	1·3220	1·93	1·7472
·13	1·0028190	·74	1·09381	1·34	1·3274	1·94	1·7564
·14	1·0032698	·75	1·09644	1·35	1·3329	1·95	1·7657
·15	1·0037542	·76	1·0991	1·36	1·3380	1·96	1·7751
·16	1·0042721	·77	1·1018	1·37	1·3435	1·97	1·7845
·17	1·0048236	·78	1·1045	1·38	1·3490	1·98	1·7941
·18	1·0054087	·79	1·1073	1·39	1·3546	1·99	1·8037
·19	1·0060275	·80	1·1101	1·40	1·3602	2·0	1·8134
·20	1·0066800	·81	1·1130	1·41	1·3659	2·1	1·9151
·21	1·0073662	·82	1·1159	1·42	1·3716	2·2	2·0259
·22	1·0080862	·83	1·1188	1·43	1·3774	2·3	2·1465
·23	1·0088400	·84	1·1218	1·44	1·3832	2·4	2·2776
·24	1·0096276	·85	1·1249	1·45	1·3891	2·5	2·4201
·25	1·0104492	·86	1·1279	1·46	1·3951	2·6	2·5749
·26	1·01130	·87	1·1310	1·47	1·4011	2·7	2·7430
·27	1·01219	·88	1·1342	1·48	1·4072	2·8	2·9257
·28	1·01312	·89	1·1374	1·49	1·4133	2·9	3·1239
·29	1·01407	·90	1·1406	1·50	1·4195	3·0	3·3393
·30	1·01507	·91	1·1438	1·51	1·4258	3·1	3·5730
·31	1·01609	·92	1·1471	1·52	1·4321	3·2	3·8268
·32	1·01716	·93	1·1505	1·53	1·4384	3·3	4·1024
·33	1·01825	·94	1·1539	1·54	1·4449	3·4	4·4016
·34	1·01938	·95	1·1573	1·55	1·4513	3·5	4·7264
·35	1·02054	·96	1·1608	1·56	1·4579	3·6	5·0793
·36	1·02174	·97	1·1643	1·57	1·4645	3·7	5·4625
·37	1·02297	·98	1·1679	1·58	1·4712	3·8	5·8788
·38	1·02424	·99	1·1715	1·59	1·4779	3·9	6·3310
·39	1·02554	1·0	1·1752	1·60	1·4847	4·0	6·8225
·40	1·02688	1·01	1·1789	1·61	1·4916	4·1	7·357
·41	1·02825	1·02	1·1826	1·62	1·4985	4·2	7·937
·42	1·02966	1·03	1·1864	1·63	1·5055	4·3	8·568
·43	1·03110	1·04	1·1902	1·64	1·5125	4·4	9·254
·44	1·03258	1·05	1·1941	1·65	1·5197	4·5	10·001
·45	1·03409	1·06	1·1980	1·66	1·5269	4·6	10·812
·46	1·03564	1·07	1·2020	1·67	1·5341	4·7	11·696
·47	1·03723	1·08	1·2060	1·68	1·5414	4·8	12·656
·48	1·03885	1·09	1·2101	1·69	1·5489	4·9	13·702
·49	1·04050	1·10	1·2142	1·70	1·5562	5·0	14·841
·50	1·04220	1·11	1·2183	1·71	1·5637	5·1	16·080
51	1·04392	1·12	1·2226	1·72	1·5713	5·2	17·430
·52	1·04568	1·13	1·2268	1·73	1·5790	5·3	18·899
·53	1·04748	1·14	1·2311	1·74	1·5867	5·4	20·500
·54	1·04931	1·15	1·2354	1·75	1·5945	5·5	22·244
·55	1·05118	1·16	1·2398	1·76	1·6024	5·6	24·145
·56	1·05309	1·17	1·2443	1·77	1·6103	5·7	26·216
·57	1·05504	1·18	1·2488	1·78	1·6183	5·8	28·474
·58	1·05702	1·19	1·2533	1·79	1·6264	5·9	30·935
·59	1·05903	1·20	1·2579	1·80	1·6345	6·0	33·619
·60	1·06109						

Involute of a Circle.

This curve is described by the extremity of a string which is uncoiled from the circumference of a circle.

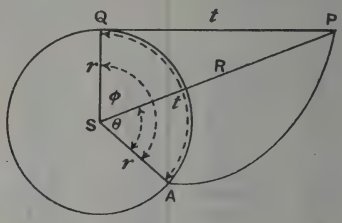


FIG. 97.

A, the point from which the string began to be unwrapped; QP (at right angles to QS), the string once coincident with, and therefore equal to, the arc AQ; ϕ, the angle QSA; θ, the angle PSA; join SP, then $t = \phi r \frac{2\pi}{360}$. in angular measure $= r$, in circular measure; also

$$t = \frac{\sqrt{R^2 - r^2}}{r} - \tan^{-1}\frac{\sqrt{R^2 - r^2}}{r}, \text{ in circular measure.}$$

$\left(\tan^{-1}\frac{\sqrt{R^2-r^2}}{r}\right.$ is the angle (in circular measure) whose tangent is $\left.\frac{\sqrt{R^2-r^2}}{r}\right)$.

THE CIRCLE.

Formulæ.

d = diameter. r = radius. p = periphery or circumference. A = area.
π = ratio of circumference to diameter.

Periphery or Circumference.	*Diameter and Radius.*	*Area.*
$p = \pi d = 3{\cdot}14159d.$	$d = \frac{p}{\pi} = \frac{p}{3{\cdot}14159}.$	$A = \frac{\pi d^2}{4} = 0{\cdot}7854d^2.$
$= 2\pi r = 6{\cdot}2832r.$	$= 2\sqrt{\frac{A}{\pi}} = 1{\cdot}12838\sqrt{A}.$	$= \pi r^2 = 3{\cdot}14159r^2.$
$= 2\sqrt{\pi A} = 3{\cdot}54\sqrt{A}.$		
$= \frac{2A}{r} = \frac{4A}{d}.$	$r = \frac{p}{2\pi} = \frac{p}{6{\cdot}2832}$	$= \frac{p^2}{4\pi} = \frac{p^2}{12{\cdot}566}.$
	$= \sqrt{\frac{A}{\pi}} = 0{\cdot}56419\sqrt{A}.$	$= \frac{pr}{2} = \frac{pd}{4}.$

$\pi = 3\ 1415926536.$

An approximate value of π is $\frac{22}{7}$, but a *much nearer* value is $\frac{355}{113}$, which is true as far as six places of decimals. The last fraction is easily remembered by writing down the first three odd numbers twice and dividing them in the middle, thus, 113 | 355.

$2\pi = 6{\cdot}283185.$	$6\pi = 18\ 849556.$	$\frac{\pi}{2} = 1\ 570796.$	$\frac{\pi}{8} = 0\ 392699.$	$\frac{1}{\pi} = 0{\cdot}318310.$	$\frac{6}{\pi} = 1{\cdot}909859.$
$3\pi = 9{\cdot}424778.$	$7\pi = 21{\cdot}991148.$	$\frac{\pi}{3} = 1\ 047197.$	$\frac{\pi}{12} = 0{\cdot}261799.$	$\frac{2}{\pi} = 0{\cdot}636619.$	$\frac{8}{\pi} = 2{\cdot}546478.$
$4\pi = 12{\cdot}566370.$	$8\pi = 25{\cdot}132741.$	$\frac{\pi}{4} = 0{\cdot}785398.$	$\frac{2\pi}{3} = 2{\cdot}094394.$	$\frac{3}{\pi} = 0{\cdot}954929.$	$\frac{12}{\pi} = 3{\cdot}819718.$
$5\pi = 15{\cdot}707963.$	$9\pi = 28{\cdot}274334.$	$\frac{\pi}{6} = 0{\cdot}523599.$	$\frac{\pi}{360} = 0{\cdot}008726.$	$\frac{4}{\pi} = 1{\cdot}273239.$	$\frac{360}{\pi} = 114{\cdot}5915.$
$\pi^2 = 9{\cdot}869650.$	$\sqrt{\pi} = 1{\cdot}772453.$	$\sqrt{\frac{1}{\pi}} = 0{\cdot}564189.$	$\sqrt{\frac{\pi}{2}} = 1{\cdot}253314.$	$\sqrt{\frac{2}{\pi}} = 0{\cdot}797884$	Log π = 0·49714987.

CIRCUMFERENCE AND AREA OF CIRCLES.

TABLE I.—Diameters advancing by Units.*

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.	Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
1	3·1416	0·7854	61	191·64	2922·5	121	380·13	11499	181	568·63	25730
2	6·2832	3·1416	62	194·78	3019·1	122	383·27	11690	182	571·77	26016
3	9·4248	7·0686	63	197·92	3117·2	123	386·42	11882	183	574·91	26302
4	12·566	12·5664	64	201·06	3217·0	124	389·56	12076	184	578·05	26590
5	15·708	19·6350	65	204·20	3318·3	125	392·70	12272	185	581·19	26880
6	18·850	28·2743	66	207·35	3421·2	126	395·84	12469	186	584·34	27172
7	21·991	38·4845	67	210·49	3525·7	127	398·98	12668	187	587·48	27465
8	25·133	50·2655	68	213·63	3631·7	128	402·12	12868	188	590·62	27759
9	28·274	63·6173	69	216·77	3739·3	129	405·27	13070	189	593·76	28055
10	31·416	78·54	70	219·91	3848·5	130	408·41	13273	190	596·90	28353
11	34·558	95·03	71	223·05	3959·2	131	411·55	13478	191	600·04	28652
12	37·699	113·10	72	226·19	4071·5	132	414·69	13685	192	603·19	28953
13	40·841	132·73	73	229·34	4185·4	133	417·83	13893	193	606·33	29255
14	43·982	153·94	74	232·48	4300·8	134	420·97	14103	194	609·47	29559
15	47·124	176·71	75	235·62	4417·9	135	424·12	14314	195	612·61	29865
16	50·265	201·06	76	238·76	4536·5	136	427·26	14527	196	615·75	30172
17	53·407	226·98	77	241·90	4656·6	137	430·40	14741	197	618·89	30481
18	56·549	254·47	78	245·04	4778·4	138	433·54	14957	198	622·04	30791
19	59·690	283·53	79	248·19	4901·7	139	436·68	15175	199	625·18	31103
20	62·832	314·16	80	251·33	5026·6	140	439·82	15394	200	628·32	31416
21	65·973	346·36	81	254·47	5153·0	141	442·96	15615	201	631·46	31731
22	69·115	380·13	82	257·61	5281·0	142	446·11	15837	202	634·60	32047
23	72·257	415·48	83	260·75	5410·6	143	449·25	16061	203	637·74	32365
24	75·398	452·39	84	263·89	5541·8	144	452·39	16286	204	640·89	32685
25	78·540	490·87	85	267·04	5674·5	145	455·53	16513	205	644·03	33006
26	81·681	530·93	86	270·18	5808·8	146	458·67	16742	206	647·17	33329
27	84·823	572·56	87	273·32	5944·7	147	461·81	16972	207	650·31	33654
28	87·965	615·75	88	276·46	6082·1	148	464·96	17203	208	653·45	33979
29	91·106	660·52	89	279·60	6221·1	149	468·10	17437	209	656·59	34307
30	94·248	706·86	90	282·74	6361·7	150	471·24	17671	210	659·73	34636
31	97·389	754·77	91	285·88	6503·9	151	474·38	17908	211	662·88	34967
32	100·53	804·25	92	289·03	6647·6	152	477·52	18146	212	666·02	35299
33	103·67	855·30	93	292·17	6792·9	153	480·66	18385	213	669·16	35633
34	106·81	907·92	94	295·31	6939·8	154	483·81	18627	214	672·30	35968
35	109·96	962·11	95	298·45	7088·2	155	486·95	18869	215	675·44	36305
36	113·10	1017·88	96	301·59	7238·2	156	490·09	19113	216	678·58	36644
37	116·24	1075·21	97	304·73	7389·8	157	493·23	19359	217	681·73	36984
38	119·38	1134·11	98	307·88	7543·0	158	496·37	19607	218	684·87	37325
39	122·52	1194·59	99	311·02	7697·7	159	499·51	19856	219	688·01	37668
40	125·66	1256·63	100	314·16	7854·0	160	502·65	20106	220	691·15	38013
41	128·81	1320·25	101	317·30	8011·9	161	505·80	20358	221	694·29	38360
42	131·95	1385·44	102	320·44	8171·3	162	508·94	20612	222	697·43	38708
43	135·09	1452·20	103	323·58	8332·3	163	512·08	20867	223	700·58	39057
44	138·23	1520·52	104	326·73	8494·9	164	515·22	21124	224	703·72	39408
45	141·37	1590·43	105	329·87	8659·0	165	518·36	21382	225	706·86	39761
46	144·51	1661·90	106	333·01	8824·7	166	521·50	21642	226	710·00	40115
47	147·65	1734·94	107	336·15	8992·0	167	524·65	21904	227	713·14	40471
48	150·80	1809·55	108	339·29	9160·9	168	527·79	22167	228	716·28	40828
49	153·94	1885·74	109	342·43	9331·3	169	530·93	22432	229	719·42	41187
50	157·08	1963·5	110	345·58	9503·3	170	534·07	22698	230	722·57	41548
51	160·22	2042·8	111	348·72	9676·9	171	537·21	22966	231	725·71	41910
52	163·36	2123·7	112	351·86	9852·0	172	540·35	23235	232	728·85	42273
53	166·50	2206·2	113	355·00	10028·8	173	543·50	23506	233	731·99	42638
54	169·65	2290·2	114	358·14	10207·0	174	546·64	23779	234	735·13	43005
55	172·79	2375·8	115	361·28	10386·9	175	549·78	24053	235	738·27	43374
56	175·93	2463·0	116	364·42	10568·3	176	552·92	24328	236	741·42	43744
57	179·07	2551·8	117	367·57	10751·3	177	556·06	24606	237	744·56	44115
58	182·21	2642·1	118	370·71	10935·9	178	559·20	24885	238	747·70	44488
59	185·35	2734·0	119	373·85	11122·0	179	562·35	25165	239	750·84	44863
60	188·50	2827·4	120	376·99	11310·0	180	565·49	25447	240	753·98	45239

* For Diameters advancing by 'Tenths,' shift the decimal point one place to the left for Circumferences, and two places to the left for Areas.

EXAMPLE.—What is the circumference and the area of a circle whose diameter is 1·7 (i.e. 17 tenths)?
Circumference = 5·3407; Area = 2·2698.

TABLE I. (*continued*).

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.	Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
241	757·12	45617	305	958·19	73062	369	1159·25	106941	433	1360·31	147254
242	760·27	45996	306	961·33	73542	370	1162·39	107521	434	1363·45	147934
243	763·41	46377	307	964·47	74023	371	1165·53	108103	435	1366·59	148617
244	766·55	46759	308	967·61	74506	372	1168·67	108687	436	1369·73	149301
245	769·69	47144	309	970·75	74991	373	1171·81	109272	437	1372·88	149987
246	772·83	47529	310	973·89	75477	374	1174·96	109858	438	1376·02	150674
247	775·97	47916	311	977·04	75964	375	1178·10	110447	439	1379·16	151363
248	779·12	48305	312	980·18	76454	376	1181·24	111036	440	1382·30	152053
249	782·26	48695	313	983·32	76945	377	1184·38	111628	441	1385·44	152745
250	785·40	49087	314	986·46	77437	378	1187·52	112221	442	1388·58	153439
251	788·54	49481	315	989·60	77931	379	1190·66	112815	443	1391·73	154134
252	791·68	49876	316	992·74	78427	380	1193·81	113411	444	1394·87	154830
253	794·82	50273	317	995·88	78924	381	1196·95	114009	445	1398·01	155528
254	797·96	50671	318	999·03	79423	382	1200·09	114608	446	1401·15	156228
255	801·11	51071	319	1002·17	79923	383	1203·23	115209	447	1404·29	156930
256	804·25	51472	320	1005·31	80425	384	1206·37	115812	448	1407·43	157633
257	807·39	51875	321	1008·45	80928	385	1209·51	116416	449	1410·58	158337
258	810·53	52279	322	1011·59	81433	386	1212·65	117021	450	1413·72	159043
259	813·67	52685	323	1014·73	81940	387	1215·80	117628	451	1416·86	159751
260	816·81	53093	324	1017·88	82448	388	1218·94	118237	452	1420·00	160460
261	819·96	53502	325	1021·02	82958	389	1222·08	118847	453	1423·14	161171
262	823·10	53913	326	1024·16	83469	390	1225·22	119459	454	1426·28	161883
263	826·24	54325	327	1027·30	83982	391	1228·36	120072	455	1429·42	162597
264	829·38	54739	328	1030·44	84496	392	1231·50	120687	456	1432·57	163313
265	832·52	55155	329	1033·58	85012	393	1234·65	121304	457	1435·71	164030
266	835·66	55572	330	1036·73	85530	394	1237·79	121922	458	1438·85	164748
267	838·81	55990	331	1039·87	86049	395	1240·93	122542	459	1441·99	165468
268	841·95	56410	332	1043·01	86570	396	1244·07	123163	460	1445·13	166190
269	845·09	56832	333	1046·15	87092	397	1247·21	123786	461	1448·27	166914
270	848·23	57256	334	1049·29	87616	398	1250·35	124410	462	1451·42	167639
271	851·37	57680	335	1052·43	88141	399	1253·50	125036	463	1454·56	168365
272	854·51	58107	336	1055·58	88668	400	1256·64	125664	464	1457·70	169093
273	857·66	58535	337	1058·72	89197	401	1259·78	126293	465	1460·84	169823
274	860·80	58965	338	1061·86	89727	402	1262·92	126923	466	1463·98	170544
275	863·94	59396	339	1065·00	90259	403	1266·06	127556	467	1467·12	171287
276	867·08	59828	340	1068·14	90792	404	1269·20	128190	468	1470·27	172021
277	870·22	60263	341	1071·28	91327	405	1272·35	128825	469	1473·41	172757
278	873·36	60699	342	1074·42	91863	406	1275·49	129462	470	1476·55	173494
279	876·50	61136	343	1077·57	92401	407	1278·63	130100	471	1479·69	174234
280	879·65	61575	344	1080·71	92941	408	1281·77	130741	472	1482·83	174974
281	882·79	62016	345	1083·85	93482	409	1284·91	131382	473	1485·97	175716
282	885·93	62458	346	1086·99	94025	410	1288·05	132025	474	1489·11	176460
283	889·07	62902	347	1090·13	94569	411	1291·19	132670	475	1492·26	177205
284	892·21	63347	348	1093·27	95115	412	1294·34	133317	476	1495·40	177952
285	895·35	63794	349	1096·42	95662	413	1297·48	133965	477	1498·54	178701
286	898·50	64242	350	1099·56	96211	414	1300·62	134614	478	1501·68	179451
287	901·64	64692	351	1102·70	96762	415	1303·76	135265	479	1504·82	180203
288	904·78	65144	352	1105·84	97314	416	1306·90	135918	480	1507·96	180956
289	907·92	65597	353	1108·98	97868	417	1310·04	136572	481	1511·11	181711
290	911·06	66052	354	1112·12	98423	418	1313·19	137228	482	1514·25	182467
291	914·20	66508	355	1115·27	98980	419	1316·33	137885	483	1517·39	183225
292	917·35	66966	356	1118·41	99538	420	1319·47	138544	484	1520·53	183984
293	920·49	67426	357	1121·55	100098	421	1322·61	139205	485	1523·67	184745
294	923·63	67887	358	1124·69	100660	422	1325·75	139867	486	1526·81	185508
295	926·77	68349	359	1127·83	101223	423	1328·89	140531	487	1529·96	186272
296	929·91	68813	360	1130·97	101788	424	1332·04	141196	488	1533·10	187038
297	933·05	69279	361	1134·11	102354	425	1335·18	141863	489	1536·24	187805
298	936·19	69747	362	1137·26	102922	426	1338·32	142531	490	1539·38	188574
299	939·34	70215	363	1140·40	103491	427	1341·46	143201	491	1542·52	189345
300	942·48	70686	364	1143·54	104062	428	1344·60	143872	492	1545·66	190117
301	945·62	71158	365	1146·68	104635	429	1347·74	144545	493	1548·81	190890
302	948·76	71631	366	1149·82	105209	430	1350·88	145220	494	1551·95	191665
303	951·90	72107	367	1152·96	105785	431	1354·03	145896	495	1555·09	192442
304	955·04	72583	368	1156·11	106362	432	1357·17	146574	496	1558·23	193221

TABLE I. (*continued*).

Diameter.	Circum.	Area.
497	1561·37	194000
498	1564·51	194782
499	1567·65	195565
500	1570·80	196350
501	1573·94	197136
502	1577·08	197923
503	1580·22	198713
504	1583·36	199504
505	1586·50	200296
506	1589·65	201090
507	1592·79	201886
508	1595·93	202683
509	1599·07	203482
510	1602·21	204282
511	1605·35	205084
512	1608·50	205887
513	1611·64	206692
514	1614·78	207499
515	1617·92	208307
516	1621·06	209117
517	1624·20	209928
518	1627·35	210741
519	1630·49	211556
520	1633·63	212372
521	1636·77	213189
522	1639·91	214008
523	1643·05	214829
524	1646·20	215651
525	1649·34	216475
526	1652·48	217301
527	1655·62	218128
528	1658·76	218956
529	1661·90	219787
530	1665·04	220618
531	1668·19	221452
532	1671·33	222287
533	1674·47	223123
534	1677·61	223961
535	1680·75	224801
536	1683·89	225642
537	1687·04	226484
538	1690·18	227329
539	1693·32	228175
540	1696·46	229022
541	1699·60	229871
542	1702·74	230722
543	1705·88	231574
544	1709·03	232428
545	1712·17	233283
546	1715·31	234140
547	1718·45	234998
548	1721·59	235858
549	1724·73	236720
550	1727·88	237583
551	1731·02	238448
552	1734·16	239314
553	1737·30	240182
554	1740·44	241051
555	1743·58	241922
556	1746·73	242795
557	1749·87	243669
558	1753·01	244545
559	1756·15	245422
560	1759·29	246301
561	1762·43	247181
562	1765·58	248063
563	1768·72	248947
564	1771·86	249832
565	1775·00	250719
566	1778·14	251607
567	1781·28	252497
568	1784·42	253388
569	1787·57	254281
570	1790·71	255176
571	1793·85	256072
572	1796·99	256970
573	1800·13	257869
574	1803·27	258770
575	1806·42	259672
576	1809·56	260576
577	1812·70	261482
578	1815·84	262389
579	1818·98	263298
580	1822·12	264208
581	1825·27	265120
582	1828·41	266033
583	1831·55	266948
584	1834·69	267865
585	1837·83	268783
586	1840·97	269702
587	1844·11	270624
588	1847·26	271547
589	1850·40	272471
590	1853·54	273397
591	1856·68	274325
592	1859·82	275254
593	1862·96	276184
594	1866·11	277117
595	1869·25	278051
596	1872·39	278986
597	1875·53	279923
598	1878·67	280862
599	1881·81	281802
600	1884·96	282743
601	1888·10	283687
602	1891·24	284631
603	1894·38	285578
604	1897·52	286526
605	1900·66	287475
606	1903·81	288426
607	1906·95	289379
608	1910·09	290333
609	1913·23	291289
610	1916·37	292247
611	1919·51	293206
612	1922·65	294166
613	1925·80	295128
614	1928·94	296092
615	1932·08	297057
616	1935·22	298024
617	1938·36	298992
618	1941·50	299962
619	1944·65	300934
620	1947·79	301907
621	1950·93	302882
622	1954·07	303858
623	1957·21	304836
624	1960·35	305815
625	1963·50	306796
626	1966·64	307779
627	1969·78	308763
628	1972·92	309748
629	1976·06	310736
630	1979·20	311725
631	1982·35	312715
632	1985·49	313707
633	1988·63	314700
634	1991·77	315696
635	1994·91	316692
636	1998·05	317690
637	2001·19	318690
638	2004·34	319692
639	2007·48	320695
640	2010·62	321699
641	2013·67	322705
642	2016·90	323713
643	2020·04	324722
644	2023·19	325733
645	2026·33	326745
646	2029·47	327759
647	2032·61	328775
648	2035·75	329792
649	2038·89	330810
650	2042·04	331831
651	2045·18	332853
652	2048·32	333876
653	2051·46	334901
654	2054·60	335927
655	2057·74	336955
656	2060·88	337985
657	2064·03	339016
658	2067·17	340049
659	2070·31	341083
660	2073·45	342119
661	2076·59	343157
662	2079·73	344196
663	2082·88	345237
664	2086·02	346279
665	2089·16	347323
666	2092·30	348368
667	2095·44	349415
668	2098·58	350464
669	2101·73	351514
670	2104·87	352565
671	2108·01	353618
672	2111·15	354673
673	2114·29	355730
674	2117·43	356788
675	2120·58	357847
676	2123·72	358908
677	2126·86	359971
678	2130·00	361035
679	2133·14	362101
680	2136·28	363168
681	2139·42	364237
682	2142·57	365308
683	2145·71	366380
684	2148·85	367453
685	2151·99	368528
686	2155·13	369605
687	2158·27	370684
688	2161·42	371764
689	2164·56	372845
690	2167·70	373928
691	2170·84	375013
692	2173·98	376099
693	2177·12	377187
694	2180·27	378276
695	2183·41	379367
696	2186·55	380459
697	2189·69	381554
698	2192·83	382649
699	2195·97	383746
700	2199·11	384845
701	2202·26	385945
702	2205·40	387047
703	2208·54	388151
704	2211·68	389256
705	2214·82	390363
706	2217·96	391471
707	2221·11	392580
708	2224·25	393692
709	2227·39	394805
710	2230·53	395919
711	2233·67	397035
712	2236·81	398153
713	2239·96	399272
714	2243·10	400393
715	2246·24	401515
716	2249·38	402639
717	2252·52	403765
718	2255·66	404892
719	2258·81	406020
720	2261·95	407150
721	2265·09	408282
722	2268·23	409416
723	2271·37	410550
724	2274·51	411687
725	2277·65	412825
726	2280·80	413965
727	2283·94	415106
728	2287·08	416248
729	2290·22	417393
730	2293·36	418539
731	2296·50	419686
732	2299·65	420835
733	2302·79	421986
734	2305·93	423139
735	2309·07	424292
736	2312·21	425447
737	2315·35	426604
738	2318·50	427762
739	2321·64	428922
740	2324·78	430084
741	2327·92	431247
742	2331·06	432412
743	2334·30	433578
744	2337·34	434746
745	2340·49	435916
746	2343·63	437087
747	2346·77	438259
748	2349·91	439433
749	2353·05	440609
750	2356·19	441786
751	2359·34	442965
752	2362·48	444146

TABLE I. (*continued*).

Diameter.	Circum.	Area.
753	2365·62	445328
754	2368·76	446511
755	2371·90	447697
756	2375·04	448883
757	2378·19	450072
758	2381·33	451262
759	2384·47	452453
760	2387·61	453646
761	2390·75	454841
762	2393·89	456037
763	2397·04	457234
764	2400·18	458434
765	2403·32	459635
766	2406·46	460837
767	2409·60	462041
768	2412·74	463247
769	2415·88	464454
770	2419·03	465663
771	2422·17	466873
772	2425·31	468085
773	2428·45	469298
774	2431·59	470513
775	2434·73	471730
776	2437·88	472948
777	2441·02	474168
778	2444·16	475389
779	2447·30	476612
780	2450·44	477836
781	2453·58	479062
782	2456·73	480290
783	2459·87	481519
784	2463·01	482750
785	2466·15	483982
786	2469·29	485216
787	2472·43	486451
788	2475·58	487688
789	2478·72	488927
790	2481·86	490167
791	2485·00	491409
792	2488·14	492652
793	2491·28	493897
794	2494·42	495143
795	2497·57	496391
796	2500·71	497641
797	2503·85	498892
798	2506·99	500145
799	2510·13	501399
800	2513·27	502655
801	2516·42	503912
802	2519·56	505171
803	2522·70	506432
804	2525·84	507694
805	2528·98	508958
806	2532·12	510223
807	2535·27	511490
808	2538·41	512758
809	2541·55	514028
810	2544·69	515300
811	2547·83	516573
812	2550·97	517848
813	2554·11	519124
814	2557·26	520402
815	2560·40	521681
816	2563·54	522962
817	2566·68	524245
818	2569·82	525529
819	2572·96	526814
820	2576·11	528102
821	2579·25	529391
822	2582·39	530681
823	2585·53	531973
824	2588·67	533267
825	2591·81	534562
826	2594·96	535858
827	2598·10	537157
828	2601·24	538456
829	2604·38	539758
830	2607·52	541061
831	2610·66	542365
832	2613·81	543671
833	2616·95	544979
834	2620·09	546288
835	2623·23	547599
836	2626·37	548912
837	2629·51	550226
838	2632·65	551541
839	2635·80	552858
840	2638·94	554177
841	2642·08	555497
842	2645·22	556819
843	2648·36	558142
844	2651·50	559467
845	2654·65	560794
846	2657·79	562122
847	2660·93	563452
848	2664·07	564783
849	2667·21	566116
850	2670·35	567450
851	2673·50	568786
852	2676·64	570124
853	2679·78	571463
854	2682·92	572803
855	2686·06	574146
856	2689·20	575490
857	2692·34	576835
858	2695·49	578182
859	2698·63	579530
860	2701·77	580880
861	2704·91	582232
862	2708·05	583585
863	2711·19	584940
864	2714·34	586297
865	2717·48	587655
866	2720·62	589014
867	2723·76	590375
868	2726·90	591738
869	2730·04	593102
870	2733·19	594468
871	2736·33	595835
872	2739·47	597204
873	2742·61	598575
874	2745·75	599947
875	2748·89	601320
876	2752·04	602696
877	2755·18	604073
878	2758·32	605451
879	2761·46	606831
880	2764·60	608212
881	2767·74	609595
882	2770·88	610980
883	2774·03	612366
884	2777·17	613754
885	2780·31	615143
886	2783·45	616534
887	2786·59	617927
888	2789·73	619321
889	2792·88	620717
890	2796·02	622114
891	2799·16	623513
892	2802·30	624913
893	2805·44	626315
894	2808·58	627718
895	2811·73	629124
896	2814·87	630530
897	2818·01	631938
898	2821·15	633348
899	2824·29	634760
900	2827·43	636173
901	2830·58	637587
902	2833·72	639003
903	2836·86	640421
904	2840·00	641840
905	2843·14	643261
906	2846·28	644683
907	2849·42	646107
908	2852·57	647533
909	2855·71	648960
910	2858·85	650388
911	2861·99	651818
912	2865·13	653250
913	2868·27	654684
914	2871·42	656118
915	2874·56	657555
916	2877·70	658993
917	2880·84	660433
918	2883·98	661874
919	2887·12	663317
920	2890·27	664761
921	2893·41	666207
922	2896·55	667654
923	2899·69	669103
924	2902·83	670554
925	2905·97	672006
926	2909·11	673460
927	2912·26	674915
928	2915·40	676372
929	2918·54	677831
930	2921·68	679291
931	2924·82	680752
932	2927·96	682216
933	2931·11	683680
934	2934·25	685147
935	2937·39	686615
936	2940·53	688084
937	2943·67	689555
938	2946·81	691028
939	2949·96	692502
940	2953·10	693978
941	2956·24	695455
942	2959·38	696934
943	2962·52	698415
944	2965·66	699897
945	2968·81	701380
946	2971·95	702865
947	2975·09	704352
948	2978·23	705840
949	2981·37	707330
950	2984·51	708822
951	2987·65	710315
952	2990·80	711809
953	2993·94	713307
954	2997·08	714803
955	3000·22	716303
956	3003·36	717804
957	3006·50	719306
958	3009·65	720810
959	3012·79	722316
960	3015·93	723823
961	3019·07	725332
962	3022·21	726842
963	3025·35	728354
964	3028·50	729867
965	3031·64	731382
966	3034·78	732899
967	3037·92	734417
968	3041·06	735937
969	3044·20	737458
970	3047·34	738981
971	3050·49	740506
972	3053·63	742032
973	3056·77	743559
974	3059·91	745088
975	3063·05	746619
976	3066·19	748151
977	3069·34	749685
978	3072·48	751221
979	3075·62	752758
980	3078·76	754296
981	3081·90	755837
982	3085·04	757378
983	3088·19	758922
984	3091·33	760466
985	3094·47	762013
986	3097·61	763561
987	3100·75	765111
988	3103·89	766662
989	3107·04	768215
990	3110·18	769769
991	3113·32	771325
992	3116·46	772882
993	3119·60	774441
994	3122·74	776002
995	3125·88	777564
996	3129·03	779128
997	3132·17	780693
998	3135·31	782260
999	3138·45	783828

CIRCUMFERENCE AND AREA OF CIRCLES.

TABLE II.—Diameters advancing by 8ths.

Diameter.	Circ.	Area.
1/32	·0981	·00076
1/16	·1963	·00306
3/32	·3926	·01227
1/8	·5890	·02761
5/32	·7854	·04908
3/16	·9817	·07669
7/32	1·178	·1104
1/4	1·374	·1503
9/32	1·570	·1963
5/16	1·767	·2485
11/32	1·963	·3067
3/8	2·159	·3712
13/32	2·356	·4417
7/16	2·552	·5184
15/32	2·748	·6013
1/2	2·945	·6902
17/32	3·141	·7854
9/16	3·534	·9940
19/32	3·927	1·227
5/8	4·319	1·484
21/32	4·712	1·767
11/16	5·105	2·073
23/32	5·497	2·405
3/4	5·890	2·761
25/32	6·283	3·141
13/16	6·675	3·546
27/32	7·068	3·976
7/8	7·461	4·430
29/32	7·854	4·908
15/16	8·246	5·411
31/32	8·639	5·939
1	9·032	6·491
1 1/32	9·424	7·068
1 1/16	9·817	7·669
1 3/32	10·21	8·295
1 1/8	10·60	8·946
1 5/32	10·99	9·621
1 3/16	11·38	10·320
1 7/32	11·78	11·044
1 1/4	12·17	11·793
1 9/32	12·56	12·566
1 5/16	12·95	13·364
1 11/32	13·35	14·186
1 3/8	13·74	15·033
1 13/32	14·13	15·904
1 7/16	14·52	16·800
1 15/32	14·92	17·720
1 1/2	15·31	18·665
1 17/32	15·70	19·635
1 9/16	16·10	20·629
1 19/32	16·49	21·647
1 5/8	16·88	22·690
1 21/32	17·27	23·758
1 11/16	17·67	24·850
1 23/32	18·06	25·967
1 3/4	18·45	27·108
1 25/32	18·84	28·274
1 13/16	19·24	29·464
1 27/32	19·63	30·679
1 7/8	20·02	31·919
1 29/32	20·42	33·183
1 15/16	20·81	34·471
1 31/32	21·20	35·784
2	21·57	37·122
2 1/32	21·99	38·484
2 1/16	22·38	39·871
2 3/32	22·77	41·282
2 1/8	23·16	42·718
2 5/32	23·56	44·178
2 3/16	23·95	45·663
2 7/32	24·34	47·173
2 1/4	24·74	48·707
2 9/32	25·13	50·265
2 5/16	25·52	51·848
2 11/32	25·91	53·456
2 3/8	26·31	55·088
2 13/32	26·70	56·745
2 7/16	27·09	58·426
2 15/32	27·48	60·132
2 1/2	27·88	61·862
2 17/32	28·27	63·617
2 9/16	28·66	65·396
2 19/32	29·05	67·200
2 5/8	29·45	69·029
2 21/32	29·84	70·882
2 11/16	30·23	72·759
2 23/32	30·63	74·662
2 3/4	31·02	76·588
2 25/32	31·41	78·539
2 13/16	31·80	80·515
2 27/32	32·20	82·516
2 7/8	32·59	84·540
2 29/32	32·98	86·590
2 15/16	33·37	88·664
2 31/32	33·77	90·762
3	34·16	92·885
3 1/32	34·55	95·033
3 1/16	34·95	97·205
3 3/32	35·34	99·402
3 1/8	35·73	101·62
3 5/32	36·12	103·86
3 3/16	36·52	106·13
3 7/32	36·91	108·43
3 1/4	37·30	110·75
3 9/32	37·69	113·09
3 5/16	38·09	115·46
3 11/32	38·48	117·85
3 3/8	38·87	120·27
3 13/32	39·27	122·71
3 7/16	39·66	125·18
3 15/32	40·05	127·67
3 1/2	40·44	130·19
3 17/32	40·84	132·73
3 9/16	41·23	135·29
3 19/32	41·62	137·88
3 5/8	42·01	140·50
3 21/32	42·41	143·13
3 11/16	42·80	145·80
3 23/32	43·19	148·48
3 3/4	43·58	151·20
3 25/32	43·98	153·93
3 13/16	44·37	156·69
3 27/32	44·76	159·48
3 7/8	45·16	162·29
3 29/32	45·55	165·13
3 15/16	45·94	167·98
3 31/32	46·33	170·87
4	46·73	173·78
4 1/32	47·12	176·71
4 1/16	47·51	179·67
4 3/32	47·90	182·65
4 1/8	48·30	185·66
4 5/32	48·69	188·69
4 3/16	49·08	191·74
4 7/32	49·48	194·82
4 1/4	49·87	197·93
4 9/32	50·26	201·06
4 5/16	50·65	204·21
4 11/32	51·05	207·39
4 3/8	51·44	210·59
4 13/32	51·83	213·82
4 7/16	52·22	217·07
4 15/32	52·62	220·35
4 1/2	53·01	223·65
4 17/32	53·40	226·98
4 9/16	53·79	230·33
4 19/32	54·19	233·70
4 5/8	54·58	237·10
4 21/32	54·97	240·52
4 11/16	55·37	243·97
4 23/32	55·76	247·45
4 3/4	56·16	250·94
4 25/32	56·54	254·46
4 13/16	56·94	258·01
4 27/32	57·33	261·58
4 7/8	57·72	265·18
4 29/32	58·11	268·80
4 15/16	58·51	272·44
4 31/32	58·90	276·11
5	59·29	279·81
5 1/32	59·69	283·52
5 1/16	60·08	287·27
5 3/32	60·47	291·03
5 1/8	60·86	294·83
5 5/32	61·26	298·64
5 3/16	61·65	302·48
5 7/32	62·04	306·35
5 1/4	62·43	310·24
5 9/32	62·83	314·16
5 5/16	63·22	318·09
5 11/32	63·61	322·06
5 3/8	64·01	326·05
5 13/32	64·40	330·06
5 7/16	64·79	334·10
5 15/32	65·18	338·16
5 1/2	65·58	342·25
5 17/32	65·97	346·36
5 9/16	66·36	350·49
5 19/32	66·75	354·65
5 5/8	67·15	358·84
5 21/32	67·54	363·05
5 11/16	67·93	367·28
5 23/32	68·32	371·54
5 3/4	68·72	375·82
5 25/32	69·11	380·13
5 13/16	69·50	384·46
5 27/32	69·90	388·82
5 7/8	70·29	393·20
5 29/32	70·68	397·60
5 15/16	71·07	402·03
5 31/32	71·47	406·49
6	71·86	410·97
6 1/32	72·25	415·47
6 1/16	72·64	420·00
6 3/32	73·04	424·55
6 1/8	73·43	429·13
6 5/32	73·82	433·73
6 3/16	74·21	438·30
6 7/32	74·61	443·01
6 1/4	75·	447·69
6 9/32	75·39	452·39
6 5/16	75·79	457·11
6 11/32	76·18	461·86
6 3/8	76·57	466·63
6 13/32	76·96	471·43
6 7/16	77·36	476·25
6 15/32	77·75	481·10
6 1/2	78·14	485·97
6 17/32	78·54	490·87
6 9/16	78·93	495·79
6 19/32	79·32	500·74
6 5/8	79·71	505·71
6 21/32	80·10	510·70
6 11/16	80·50	515·72
6 23/32	80·89	520·70
6 3/4	81·28	525·83
6 25/32	81·68	530·93
6 13/16	82·07	536·04
6 27/32	82·46	541·18
6 7/8	82·85	546·35
6 29/32	83·25	551·54
6 15/16	83·64	556·76
6 31/32	84·03	562·00
7	84·43	567·26
7 1/32	84·82	572·55
7 1/16	85·21	577·87
7 3/32	85·60	583·20
7 1/8	86·	588·57
7 5/32	86·39	593·95
7 3/16	86·78	599·37
7 7/32	87·17	604·80
7 1/4	87·57	610·26
7 9/32	87·96	615·75
7 5/16	88·35	621·26
7 11/32	88·75	626·79
7 3/8	89·14	632·35
7 13/32	89·53	637·94
7 7/16	89·92	643·54
7 15/32	90·32	649·18
7 1/2	90·71	654·83
7 17/32	91·10	660·52
7 9/16	91·49	666·22
7 19/32	91·89	671·95
7 5/8	92·28	677·71
7 21/32	92·67	683·49
7 11/16	93·06	689·29
7 23/32	93·46	695·12
7 3/4	93·85	700·98

TABLE II. (*continued*).

Diameter.	Circ.	Area.
30	94·24	706·86
	94·64	712·76
¼	95·03	718·69
	95·42	724·64
½	95·81	730·61
	96·21	736·61
¾	96·60	742·64
	96·99	748·69
31	97·38	754·76
	97·78	760·86
¼	98·17	766·99
	98·56	773·14
½	98·96	779·31
	99·35	785·51
¾	99·74	791·73
	100·1	797·97
32	100·5	804·24
	100·9	810·54
¼	101·3	816·86
	101·7	823·21
½	102·1	829·57
	102·4	835·97
¾	102·8	842·39
	103·2	848·83
33	103·6	855·30
	104·	861·79
¼	104·4	868·30
	104·8	874·84
½	105·2	881·41
	105·6	888·00
¾	106·	894·61
	106·4	901·25
34	106·8	907·92
	107·2	914·61
¼	107·5	921·32
	107·9	928·06
½	108·3	934·82
	108·7	941·60
¾	109·1	948·41
	109·5	955·25
35	109·9	962·11
	110·3	968·99
¼	110·7	975·90
	111·1	982·84
½	111·5	989·80
	111·9	996·78
¾	112·3	1003·7
	112·7	1010·8
36	113·	1017·8
	113·4	1024·9
¼	113·8	1032·0
	114·2	1039·1
½	114·6	1046·3
	115·	1053·5
¾	115·4	1060·7
	115·8	1067·9
37	116·2	1075·2
	116·6	1082·4
¼	117·	1089·7
	117·4	1097·1
½	117·8	1104·4
	118·2	1111·8
¾	118·6	1119·2
	118·9	1126·6
38	119·3	1134·1
	119·7	1141·5
¼	120·1	1149·0
	120·5	1156·6
½	120·9	1164·1
	121·3	1171·7
¾	121·7	1179·3
	122·1	1186·9
39	122·5	1194·5
	122·9	1202·2
¼	123·3	1209·9
	123·7	1217·6
½	124·	1225·4
	124·4	1233·1
¾	124·8	1240·9
	125·2	1248·7
40	125·6	1256·6
	126·	1264·5
¼	126·4	1272·3
	126·8	1280·3
½	127·2	1288·2
	127·6	1296·2
¾	128·	1304·2
	128·4	1312·2
41	128·8	1320·2
	129·1	1328·3
¼	129·5	1336·4
	129·9	1344·5
½	130·3	1352·6
	130·7	1360·8
¾	131·1	1369·0
	131·5	1377·2
42	131·9	1385·4
	132·3	1393·7
¼	132·7	1401·9
	133·1	1410·2
½	133·5	1418·6
	133·9	1426·9
¾	134·3	1435·3
	134·6	1443·7
43	135·	1452·2
	135·4	1460·6
¼	135·8	1469·1
	136·2	1477·6
½	136·6	1486·1
	137·	1494·7
¾	137·4	1503·3
	137·8	1511·9
44	138·2	1520·5
	138·6	1529·1
¼	139·	1537·8
	139·4	1546·5
½	139·8	1555·2
	140·1	1564·0
¾	140·5	1572·8
	140·9	1581·6
45	141·3	1590·4
	141·7	1599·2
¼	142·1	1608·1
	142·5	1617·0
½	142·9	1625·9
	143·3	1634·9
¾	143·7	1643·8
	144·1	1652·8
46	144·5	1661·9
	144·9	1670·9
¼	145·2	1680·0
	145·6	1689·1
½	146·	1698·2
	146·4	1707·3
¾	146·8	1716·5
	147·2	1725·7
47	147·6	1734·9
	148·	1744·1
¼	148·4	1753·4
	148·8	1762·7
½	149·2	1772·0
	149·6	1781·3
¾	150·	1790·7
	150·4	1800·1
48	150·7	1809·5
	150·1	1818·9
¼	151·5	1828·4
	151·9	1837·9
½	152·3	1847·4
	152·7	1856·9
¾	153·1	1866·5
	153·5	1876·1
49	153·9	1885·7
	154·3	1895·3
¼	154·7	1905·0
	155·1	1914·7
½	155·5	1924·4
	155·9	1934·1
¾	156·2	1943·9
	156·6	1953·6
50	157·	1963·5
	157·4	1973·3
¼	157·8	1983·1
	158·2	1993·0
½	158·6	2002·9
	159·	2012·8
¾	159·4	2022·8
	159·8	2032·8
51	160·2	2042·8
	160·6	2052·8
¼	161·	2062·9
	161·3	2072·9
½	161·7	2083·0
	162·1	2093·2
¾	162·5	2103·3
	162·9	2113·5
52	163·3	2123·7
	163·7	2133·9
¼	164·1	2144·1
	164·5	2154·4
½	164·9	2164·7
	165·3	2175·0
¾	165·7	2185·4
	166·1	2195·7
53	166·5	2206·1
	166·8	2216·6
¼	167·2	2227·0
	167·6	2237·5
½	168·	2248·0
	168·4	2258·5
¾	168·8	2269·0
	169·2	2279·6
54	169·6	2290·2
	170·	2300·8
¼	170·4	2311·4
	170·8	2322·1
½	171·2	2332·8
	171·6	2343·5
¾	172·	2354·2
	172·3	2365·0
55	172·7	2375·8
	173·1	2386·6
¼	173·5	2397·4
	173·9	2408·3
½	174·3	2419·2
	174·7	2430·1
¾	175·1	2441·0
	175·5	2452·0
56	175·9	2463·0
	176·3	2474·0
¼	176·7	2485·0
	177·1	2496·1
½	177·5	2507·1
	177·8	2518·2
¾	178·2	2529·4
	178·6	2540·5
57	179·	2551·7
	179·4	2562·9
¼	179·8	2574·1
	180·2	2585·4
½	180·6	2596·7
	181·	2608·0
¾	181·4	2619·3
	181·8	2630·7
58	182·2	2642·0
	182·6	2653·4
¼	182·9	2664·9
	183·3	2676·3
½	183·7	2687·8
	184·1	2699·3
¾	184·5	2710·8
	184·9	2722·4
59	185·3	2733·9
	185·7	2745·5
¼	186·1	2757·1
	186·5	2768·8
½	186·9	2780·5
	187·3	2792·2
¾	187·7	2803·9
	188·1	2815·6
60	188·4	2827·4
	188·8	2839·2
¼	189·2	2851·0
	189·6	2862·8
½	190·	2874·7
	190·4	2886·6
¾	190·8	2898·5
	191·2	2910·5

TABLE II. (*continued*).

Diameter.	Circ.	Area.
61	191·6	2922·4
	192·	2934·4
¼	192·4	2946·4
	192·8	2958·5
½	193·2	2970·5
	193·6	2982·6
¾	193·9	2994·7
	194·3	3006·9
62	194·7	3019·0
	195·1	3031·2
¼	195·5	3043·4
	195·9	3055·7
½	196·3	3067·9
	196·7	3080·2
¾	197·1	3092·5
	197·5	3104·8
63	197·9	3117·2
	198·3	3129·6
¼	198·7	3142·0
	199·	3154·4
½	199·4	3166·9
	199·8	3179·4
¾	200·2	3191·9
	200·6	3204·4
64	201·	3216·9
	201·4	3229·5
¼	201·8	3242·1
	202·2	3254·8
½	202·6	3267·4
	203·	3280·1
¾	203·4	3292·8
	203·8	3305·5
65	204·2	3318·3
	204·5	3331·0
¼	204·9	3343·8
	205·3	3356·7
½	205·7	3369·5
	206·1	3382·4
¾	206·5	3395·3
	206·9	3408·2
66	207·3	3421·2
	207·7	3434·1
¼	208·1	3447·1
	208·5	3460·1
½	208·9	3473·2
	209·3	3486·3
¾	209·7	3499·3
	210·	3512·5
67	210·4	3525·6
	210·8	3538·8
¼	211·2	3552·0
	211·6	3565·2
½	212·	3578·4
	212·4	3591·7
¾	212·8	3605·0
	213·2	3618·3
68	213·6	3631·6
	214·	3645·0
¼	214·4	3658·4
	214·8	3671·8
½	215·1	3685·2
	215·5	3698·7
¾	215·9	3712·2
	216·3	3725·7
69	216·7	3739·2
	217·1	3752·8
¼	217·5	3766·4
	217·9	3780·0
½	218·3	3793·6
	218·7	3807·3
¾	219·1	3821·0
	219·5	3834·7
70	219·9	3848·4
	220·3	3862·2
¼	220·6	3875·9
	221·	3889·8
½	221·4	3903·6
	221·8	3917·4
¾	222·2	3931·3
	222·6	3945·2
71	223·	3959·2
	223·4	3973·1
¼	223·8	3987·1
	224·2	4001·1
½	224·6	4015·1
	225·	4029·2
¾	225·4	4043·2
	225·8	4067·3
72	226·1	4071·5
	226·5	4085·6
¼	226·9	4099·8
	227·3	4114·0
½	227·7	4128·2
	228·1	4142·5
¾	228·5	4156·7
	228·9	4171·0
73	229·3	4185·3
	229·7	4199·7
¼	230·1	4214·1
	230·5	4228·5
½	230·9	4242·9
	231·3	4257·3
¾	231·6	4271·8
	232·	4286·3
74	232·4	4300·8
	232·8	4315·3
¼	233·2	4329·9
	233·6	4344·5
½	234·	4359·1
	234·4	4373·8
¾	234·8	4388·4
	235·2	4403·1
75	235·6	4417·8
	236·	4432·6
¼	236·4	4447·3
	236·7	4462·1
½	237·1	4476·9
	237·5	4491·8
¾	237·9	4506·6
	238·3	4521·5
76	238·7	4536·4
	239·1	4551·4
¼	239·5	4566·3
	239·9	4581·3
½	240·3	4596·3
	240·7	4611·3
¾	241·1	4626·4
	241·5	4641·5
77	241·9	4656·6
	242·2	4671·7
¼	242·6	4686·9
	243·	4702·1
½	243·4	4717·3
	243·8	4732·5
¾	244·2	4747·7
	244·6	4763·0
78	245·	4778·3
	245·4	4793·7
¼	245·8	4809·0
	246·2	4824·4
½	246·6	4839·8
	247·	4855·2
¾	247·4	4870·7
	247·7	4886·1
79	248·1	4901·6
	248·5	4917·2
¼	248·9	4932·7
	249·3	4948·3
½	249·7	4963·9
	250·1	4979·5
¾	250·5	4995·1
	250·9	5010·8
80	251·3	5026·5
	251·7	5042·2
¼	252·1	5058·0
	252·5	5073·7
½	252·8	5089·5
	253·2	5105·4
¾	253·6	5121·2
	254·	5137·1
81	254·4	5153·0
	254·8	5168·9
¼	255·2	5184·8
	255·6	5200·8
½	256·	5216·8
	256·4	5232·8
¾	256·8	5248·8
	257·2	5264·9
82	257·6	5281·0
	258·	5297·1
¼	258·3	5313·2
	258·7	5329·4
½	259·1	5345·6
	259·5	5361·8
¾	259·9	5378·0
	260·3	5394·3
83	260·7	5410·6
	261·1	5426·9
¼	261·5	5443·2
	261·9	5459·6
½	262·3	5476·0
	262·7	5492·4
¾	263·1	5508·8
	263·5	5525·3
84	263·8	5541·7
	264·2	5558·2
¼	264·6	5574·8
	265·	5591·3
½	265·4	5607·9
	265·8	5624·5
¾	266·2	5641·1
	266·6	5657·8
85	267·	5674·5
	267·4	5691·2
¼	267·8	5707·9
	268·2	5724·6
½	268·6	5741·4
	268·9	5758·2
¾	269·3	5775·0
	269·7	5791·9
86	270·1	5808·8
	270·5	5325·7
¼	270·9	5842·6
	271·3	5859·5
½	271·7	5876·5
	272·1	5893·5
¾	272·5	5910·5
	272·9	5927·6
87	273·3	5944·6
	273·7	5961·7
¼	274·1	5978·9
	274·4	5996·0
½	274·8	6013·2
	275·2	6030·4
¾	275·6	6047·6
	276·	6064·8
88	276·4	6082·1
	276·8	6099·4
¼	277·2	6116·7
	277·6	6134·0
½	278·	6151·4
	278·4	6168·8
¾	278·8	6186·2
	279·2	6203·6
89	279·6	6221·1
	279·9	6238·6
¼	280·3	6256·1
	280·7	6273·0
½	281·1	6291·2
	281·5	6308·8
¾	281·9	6326·4
	282·3	6344·0
90	282·7	6361·7
	283·1	6379·4
¼	283·5	6397·1
	283·9	6414·8
½	284·3	6432·6
	284·7	6450·4
¾	285·1	6468·2
	285·4	6486·0
91	285·8	6503·8
	286·2	6521·7
¼	286·6	6539·6
	287·	6557·6
½	287·4	6575·5
	287·8	6593·5
¾	288·2	6611·5
	288·6	6629·5

TABLE II. (*continued*).

Diameter.	Circ.	Area.	Diameter.	Circ.	Area.	Diameter.	Circ.	Area.	Diameter.	Circ.	Area.
92	289·	6647·6	¼	296·	6976·7	½	303·1	7313·8	¾	310·2	7658·8
	289·4	6665·7		296·4	6995·2		303·5	7332·8		310·6	7678·2
¼	289·8	6683·8	½	296·8	7013·8	¾	303·9	7351·7	99	311·	7697·7
	290·2	6701·9		297·2	7032·3		304·3	7370·7		311·4	7717·1
½	290·5	6720·0	¾	297·6	7050·9	97	304·7	7389·8	¼	311·8	7736·6
	290·9	6738·2		298·	7069·5		305·1	7408·8		312·1	7756·1
¾	291·3	6756·4	95	298·4	7088·2	¼	305·5	7427·9	½	312·5	7775·6
	291·7	6776·4		298·8	7106·9		305·9	7447·0		312·9	7795·2
93	292·1	6792·9	¼	299·2	7125·5	½	306·3	7466·2	¾	313·3	7814·7
	292·5	6811·1		299·6	7144·3		306·6	7485·3		313·7	7834·3
¼	292·9	6829·4	½	300·	7163·0	¾	307·	7504·5	100	314·1	7853·9
	293·3	6847·8		300·4	7181·8		307·4	7523·7		314·5	7853·6
½	293·7	6866·1	¾	300·8	7200·5	98	307·8	7542·9	¼	314·9	7893·3
	294·1	6884·5		301·2	7219·4		308·2	7562·2		315·3	7913·1
¾	294·5	6902·9	96	301·5	7238·2	¼	308·6	7581·5	½	315·7	7932·7
	294·9	6921·3		301·9	7257·1		309·	7600·8		316·	7942·4
94	295·3	6939·7	¼	302·3	7275·9	½	309·4	7620·1	¾	316·4	7972·2
	295·7	6958·2		302·7	7294·9		309·8	7639·4		316·8	7991·9

AREA OF CIRCLES AND SQUARES.

TABLE OF THE AREAS OF CIRCLES AND OF THE SIDES OF SQUARES OF THE SAME AREA.

Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.	Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.	Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.
1	·785	·89	17	226·98	15·07	33	855·30	29·25
1½	1·767	1·33	17½	240·53	15·51	33½	881·41	29·69
2	3·142	1·77	18	254·47	15·95	34	907·92	30·13
2½	4·909	2·22	18½	268·80	16·40	34½	934·82	30·57
3	7·069	2·66	19	283·53	16·84	35	962·11	31·02
3½	9·621	3·10	19½	298·65	17·28	35½	989·80	31·46
4	12·566	3·54	20	314·16	17·72	36	1017·88	31·90
4½	15·904	3·99	20½	330·06	18·17	36½	1046·35	32·35
5	19·635	4·43	21	343·36	18·61	37	1075·21	32·79
5½	23·758	4·87	21½	363·05	19·05	37½	1104·47	33·23
6	28·274	5·32	22	380·13	19·50	38	1134·12	33·68
6½	33·183	5·76	22½	397·61	19·94	38½	1164·16	34·12
7	38·485	6·20	23	415·48	20·38	39	1194·59	34·56
7½	44·179	6·65	23½	433·74	20·83	39½	1225·42	35·01
8	50·266	7·09	24	452·39	21·27	40	1256·64	35·45
8½	56·745	7·53	24½	471·44	21·71	40½	1288·25	35·89
9	63·617	7·98	25	490·88	22·16	41	1320·26	36·34
9½	70·882	8·42	25½	510·71	22·60	41½	1352·66	36·78
10	78·540	8·86	26	530·93	23·04	42	1385·45	37·22
10½	86·590	9·30	26½	551·55	23·49	42½	1418·63	37·66
11	95·03	9·75	27	572·56	23·93	43	1452·20	38·11
11½	103·87	10·19	27½	593·96	24·37	43½	1486·17	38·55
12	113·10	10·63	28	615·75	24·81	44	1520·53	38·99
12½	122·72	11·08	28½	637·94	25·26	44½	1555·29	39·44
13	132·73	11·52	29	660·52	25·70	45	1590·43	39·88
13½	143·14	11·96	29½	683·49	26·14	45½	1625·97	40·32
14	153·94	12·41	30	706·86	26·59	46	1661·91	40·77
14½	165·13	12·85	30½	730·62	27·03	46½	1698·23	41·21
15	176·72	13·29	31	754·77	27·47	47	1734·95	41·65
15½	188·69	13·74	31½	779·31	27·92	47½	1772·06	42·10
16	201·06	14·18	32	804·25	28·36	48	1809·56	42·58
16½	213·83	14·62	32½	829·58	28·80	48½	1847·46	42·98

TABLE OF THE AREAS OF CIRCLES AND OF THE SIDES OF SQUARES (*continued*)

Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.	Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.	Diam. of Circle in Ins.	Area of Circle in Sq. Ins.	Sides of Square of same Area in Sq. Ins.
49	1885·75	43·43	53	2206·19	46·97	57	2551·76	50·51
49½	1924·43	43·87	53½	2248·01	47·41	57½	2596·73	50·96
50	1963·50	44·31	54	2290·23	47·86	58	2642·09	51·40
50½	2002·97	44·75	54½	2332·83	48·30	58½	2687·84	51·84
51	2042·83	45·20	55	2375·83	48·74	59	2733·98	52·29
51½	2083·08	45·64	55½	2419·23	49·19	59½	2780·51	52·73
52	2123·72	46·08	56	2463·01	49·63	60	2827·74	53·17
52½	2164·76	46·53	56½	2507·19	50·07	60½	2874·76	53·62

TABLE OF SEGMENTS, CHORDS, ZONES, &c., OF A CIRCLE.

To find the Angle of an Arc of a Circle.

RULE.—Divide the chord of the arc by its height, and find the quotient in the first column. The corresponding number in the *second* column is the angle of the arc in degrees of the circle.

To find the Radius of an Arc of a Circle.

RULE.—Divide the chord of the arc by its height, and find the quotient in the first column. The corresponding number in the *third* column, multiplied by the chord, is the radius of the arc.

To find the Length of an Arc of a Circle.

RULE.—Divide the chord of the arc by its height, and find the quotient in the first column. The corresponding number in the *fourth* column, multiplied by the chord, is the length of the arc.

To find the Area of a Segment of a Circle.

RULE.—Divide the chord of the segment by its height, and find the quotient in the first column. The corresponding number in the *fifth* column, multiplied by the square of the chord, is the area of the segment.

To find the Surface of a Circle Zone.

RULE.—Divide the chord of the zone by its height, and find the quotient in the first column. The corresponding number in the *sixth* column, multiplied by the *square* of the chord, is the surface of the zone.

To find the Solidity of a Circle Zone.

RULE.—Divide the chord of the zone by its height, and find the quotient in the first column. The corresponding number in the *seventh* column, multiplied by the *cube* of the chord, is the solidity of the zone.

To find the Chord of an Arc of a Circle.

RULE.—In column *eight* find the chord corresponding to the angle of the arc given in column two, and multiply the value by the radius of the circle.

FORMULÆ.

The following are the formulæ from which the values in the following tables (pp. 58-63) were calculated :—

Col. 1. $2 \cot \frac{v}{4}$.

Col. 3. $\frac{\operatorname{cosec} \frac{v}{2}}{2}$.

Col. 4. $\frac{\operatorname{cosec} \frac{v}{2}}{2} \times \frac{\pi v}{180}$.

Col. 5. $\frac{\operatorname{cosec}^2 \frac{v}{2}}{8}\left(\frac{\pi v}{180} - \sin v\right)$.

Col. 6. $\frac{\pi}{4 - 2 \operatorname{versin} \frac{v}{2}}$.

Col. 7. $\frac{\pi}{24}\left(\operatorname{cosec} \frac{v}{2} - \cot \frac{v}{2}\right)^2 \left(2 \operatorname{cosec} \frac{v}{2} + \cot \frac{v}{2}\right)$.

Col. 8. Ordinary Table of Chords.

TABLE OF SEGMENTS, CHORDS,

$\frac{c}{h}$ (Chord divided by height.)		Centre Angle v.	Radius r.		Circular Arc b.	
1.	Logarithm.	2.	3.	Logarithm.	4.	Logarithm.
458·3633	2·6612099	1	57·29650	1·7581281	1·000015	·0000067
229·1773	2·3601716	2	28·64934	1·4571147	1·000051	·0000223
152·7800	2·1840666	3	19·10077	1·2810510	1·000097	·0000423
114·5799	2·0591085	4	14·32685	1·1561508	1·000203	·0000883
91·65870	1·9621737	5	11·46278	1·0592904	1·000318	·0001380
76·37692	1·8829621	6	9·553660	·9801698	1·000457	·0001986
65·46053	1·8159795	7	8·190203	·9132947	1·000622	·0002700
57·27251	1·7579462	8	7·167793	·8553855	1·000812	·0003527
50·90340	1·7067468	9	6·372747	·8043267	1·001029	·0004465
45·80753	1·6609369	10	5·736856	·7586740	1·001270	·0005513
41·63766	1·6194863	11	5·216714	·7173971	1·001537	·0006671
38·16227	1·5816342	12	4·783385	·6797354	1·001830	·0007940
35·22112	1·5468031	13	4·416836	·6451112	1·002148	·0009319
32·69971	1·5145439	14	4·102753	·6130755	1·002492	·0010810
30·51410	1·4845006	15	3·830647	·5832723	1·002862	·0012410
28·60133	1·4563863	16	3·592648	·5554147	1·003257	·0014121
26·91325	1·4299662	17	3·382733	·5292679	1·003678	·0015942
25·41241	1·4050458	18	3·196227	·5046376	1·004124	·0017875
24·06924	1·3814625	19	3·029429	·4813608	1·004597	·0019918
22·86010	1·3590782	20	2·879385	·4592998	1·005095	·0022073
21·76584	1·3377755	21	2·743702	·4383370	1·005619	·0024336
20·77079	1·3174531	22	2·620421	·4183712	1·006163	·0026685
19·86202	1·2980234	23	2·507925	·3993147	1·006746	·0029199
19·02873	1·2794098	24	2·404866	·3810911	1·007349	·0031798
18·26187	1·2615452	25	2·310112	·3636332	1·007978	·0034510
17·55377	1·2443705	26	2·222706	·3468820	1·008632	·0037328
16·89791	1·2278331	27	2·141828	·3307847	1·009313	·0040258
16·28869	1·2118862	28	2·066782	·3152948	1·010021	·0043303
15·72128	1·1964880	29	1·996964	·3003704	1·010755	·0046458
15·19151	1·1816009	30	1·931851	·2859738	1·011515	·0049724
14·69572	1·1671909	31	1·870988	·2720712	1·012302	·0053103
14·23074	1·1532275	32	1·813977	·2586319	1·013116	·0056593
13·79376	1·1396827	33	1·760468	·2456282	1·013957	·0060195
13·38231	1·1265312	34	1·710152	·2330347	1·014825	·0063910
12·99421	1·1137498	35	1·662754	·2208282	1·015719	·0067736
12·62750	1·1013175	36	1·618034	·2089876	1·016641	·0071675
12·28046	1·0892147	37	1·575772	·1974936	1·017590	·0075727
11·95153	1·0774235	38	1·535776	·1863281	1·018567	·0079897
11·63931	1·0659274	39	1·497871	·1754747	1·019569	·0084167
11·34256	1·0547112	40	1·461902	·1649183	1·020600	·0088556
11·06014	1·0437608	41	1·427725	·1546447	1·021659	·0093060
10·79103	1·0330631	42	1·395213	·1446408	1·022745	·0097674
10·53430	1·0226058	43	1·364251	·1348946	1·023860	·0102405
10·28911	1·0123777	44	1·334733	·1253946	1·025002	·0107247
10·05468	1·0023682	45	1·306563	·1161303	1·026172	·0112202
9·830314	·9925674	46	1·279652	·1070920	1·027371	·0117272
9·615371	·9829660	47	1·253921	·0982703	1·028598	·0122455
9·409260	·9735555	48	1·229295	·0896567	1·029853	·0127753
9·211441	·9643276	49	1·205710	·0812430	1·031137	·0133165
9·021417	·9552748	50	1·183100	·0730217	1·032450	·0138691
8·838728	·9463898	51	1·161410	·0649856	1·033792	·0144331
8·662952	·9376659	52	1·140585	·0571280	1·035163	·0150087
8·493696	·9290967	53	1·120579	·0494426	1·036563	·0155958
8·320600	·9206763	54	1·101344	·0419232	1·037993	·0161943
8·173325	·9123988	55	1·082840	·0345644	1·039452	·0168046
8·021562	·9042589	56	1·065027	·0273607	1·040941	·0174261
7·875019	·8962516	57	1·047628	·0203071	1·042460	·0180594
7·733426	·8883719	58	1·031333	·0133988	1·044009	·0187042
7·596532	·8806154	59	1·015386	·0066312	1·045588	·0193606
7·464102	·8729775	60	1·000000	·0000000	1·047198	·0200287

ZONES, &c., OF A CIRCLE.

Area of Segment.		Surface of Zone.		Solidity of Zone.		Chord c.	
5.	Logarithm.	6.	Logarithm.	7.	Logarithm.	8.	Logarithm.
·0014642	$\bar{3}$·1655947	·785413	1·8950982	·000855	$\bar{4}$·9321857	·0174530	2·2418701
·0029548	3·4705319	·785458	1·8951229	·001713	$\bar{3}$·2338129	·0349048	2·5428853
·0043562	3·6391063	·785533	1·8951643	·002570	3·4099350	·0523538	2·7189490
·0058293	3·7656199	·785637	1·8952222	·003428	$\bar{3}$·5349925	·0697990	2·8438492
·0072793	3·8620906	·785772	1·8952966	·004285	$\bar{3}$·6319520	·0872388	2·9407096
·0087348	3·9412515	·785937	1·8953875	·005143	$\bar{3}$·7111997	·1046720	1·0198302
·0101893	2·0081472	·786131	1·8954951	·006001	$\bar{3}$·7782223	·1220970	1·0867053
·0116472	2·0662225	·786356	1·8956191	·006860	$\bar{3}$·8362961	·1395130	1·1446145
·0131014	2·1173178	·786611	1·8957598	·007719	$\bar{3}$·8875342	·1569182	1·1956733
·0145601	2·1631631	·786895	1·8959170	·008578	3·9334001	·1743114	1·2413260
·0160182	2·2046145	·787210	1·8960908	·009439	3·9749177	·1916916	1·2826029
·0174809	2·2425642	·787555	1·8962811	·010300	2·0128218	·2090570	1·3202646
·0189407	2·2773969	·787931	1·8964880	·011161	2·0477078	·2264064	1·3548888
·0204028	2·3096895	·788336	1·8967116	·012024	2·0800570	·2437386	1·3869245
·0218670	2·3397892	·788772	1·8969516	·012888	2·1101811	·2610524	1·4167277
·0233309	2·3679317	·789239	1·8972083	·013752	2·1383810	·2783462	1·4445853
·0247990	2·3944348	·789735	1·8974816	·014618	2·1648914	·2956188	1·4707321
·0262660	2·4193942	·790263	1·8977716	·015485	2·1899099	·3128690	1·4953624
·0277361	2·4430448	·790821	1·8980782	·016353	2·2135941	·3300952	1·5186392
·0292078	2·4654999	·791410	1·8984015	·017222	2·2360887	·3472964	1·5407002
·0306814	2·4868762	·792029	1·8987413	·018093	2·2575050	·3644710	1·5616630
·0321556	2·5072573	·792680	1·8990979	·018965	2·2779476	·3816180	1·5816288
·0336335	2·5267721	·793362	1·8994712	·019838	2·2975021	·3987358	1·6006853
·0351121	2·5454567	·794074	1·8998612	·020713	2·3162460	·4158234	1·6189089
·0365937	2·5634069	·794818	1·9002679	·021590	2·3342478	·4328792	1·6363668
·0380773	2·5806663	·795594	1·9006914	·022468	2·3515653	·4499022	1·6531180
·0395629	2·5972882	·796400	1·9011315	·023348	2·3682498	·4668908	1·6692153
·0410512	2·6133265	·797240	1·9015888	·024230	2·3843512	·4838438	1·6847052
·0425422	2·6288197	·798110	1·9020629	·025114	2·3999093	·5007600	1·6996296
·0440360	2·6438076	·799012	1·9025532	·025999	2·4149612	·5176380	1·7140262
·0455323	2·6583195	·799944	1·9030597	·026887	2·4295418	·5344768	1·7279288
·0470316	2·6723902	·800911	1·9035843	·027777	2·4436829	·5512748	1·7413681
·0485336	2·6860426	·801910	1·9041258	·028669	2·4574102	·5680306	1·7543718
·0500391	2·6993092	·802940	1·9046830	·029563	2·4707502	·5847434	1·7669653
·0515472	2·7122049	·804003	1·9052578	·030460	2·4837260	·60141.6	1·7791718
·0530589	2·7247583	·805101	1·9058502	·031359	2·4963593	·6180340	1·7910124
·0545737	2·7369833	·806229	1·9064585	·032260	2·5086679	·6346094	1·8025064
·0560920	2·7489009	·807392	1·9070844	·033164	2·5206716	·6511364	1·8136719
·0576139	2·7605275	·808588	1·9077271	·034071	2·5323857	·6676138	1·8245253
·0591394	2·7718771	·809817	1·9083871	·034981	2·5438268	·6840402	1·8350817
·0606689	2·7829661	·811080	1·9090637	·035893	2·5550075	·7004148	1·8453553
·0622020	2·7938041	·812377	1·9097578	·036808	2·5659411	·7167358	1·8553592
·0637392	2·8044067	·813708	1·9104685	·037726	2·5766411	·7330024	1·8651054
·0652804	2·8147826	·815073	1·9111965	·038647	2·5871177	·7492132	1·8756054
·0668258	2·8249447	·816474	1·9119422	·039571	2·5973819	·7653668	1·8833697
·0683755	2·8349008	·817908	1·9127043	·040499	2·6074438	·7814622	1·8929080
·0699298	2·8446625	·819377	1·9134840	·041430	2·6173122	·7974982	1·9017297
·0714883	2·8542351	·820882	1·9142809	·042364	2·6269960	·8134732	1·9103433
·0730516	2·8636299	·822423	1·9150951	·043302	2·6365038	·8293864	1·9187570
·0746196	2·8728529	·823999	1·9159267	·044243	2·6458425	·8452366	1·9269783
·0761941	2·8819212	·825612	1·9167757	·045188	2·6550198	·8610222	1·9350144
·0777702	2·8908134	·827260	1·9176422	·046136	2·6640413	·8767422	1·9428720
·0793532	2·8995645	·828945	1·9185256	·047089	2·6729168	·8923956	1·9505574
·0809413	2·9081701	·830667	1·9194270	·048045	2·6816485	·9079810	1·9580768
·0825347	2·9166367	·832426	1·9203458	·049005	2·6902441	·9234972	1·9654356
·0841336	2·9249696	·834222	1·9212817	·049970	2·6987084	·9389432	1·9726393
·0857380	2·9331735	·836056	1·9222354	·050939	2·7070465	·9543176	1·9796929
·0873483	2·9412545	·837928	1·9232068	·051912	2·7152636	·9696192	1·9866012
·0889642	2·9492153	·839838	1·9241957	·052889	2·7233648	·9848472	1·9933688
·0905861	2·9570616	·841788	1·9252025	·053871	2·7313527	1·0000000	0·0000000

TABLE OF SEGMENTS, CHORDS,

$\frac{c}{h}$ (Chord divided by height.)	Logarithm.	Centre Angle v.	Radius r.	Logarithm.	Circular Arc b.	Logarithm.
1.		2.	3.		4.	
7·335915	·8654543	61	·9851470	1·9935011	1·048838	·0207083
7·211767	·8580417	62	·9708020	1·9871307	1·050509	·0213997
7·091465	·8507360	63	·9569404	1·9808849	1·052211	·0221028
6·974829	·8435336	64	·9435400	1·9747603	1·053945	·0228178
6·861689	·8364310	65	·9305796	1·9687535	1·055709	·0235443
6·751887	·8294252	66	·9180392	1·9628612	1·057505	·0242824
6·645272	·8225028	67	·9059004	1·9570805	1·059334	·0250329
6·541705	·8156910	68	·8941456	1·9514083	1·061194	·0257946
6·441053	·8089569	69	·8827588	1·9458420	1·063086	·0265684
6·343190	·8023077	70	·8717234	1·9403787	1·065012	·0273544
6·247998	·7957409	71	·8610256	1·9350160	1·066969	·0281520
6·155367	·7892540	72	·8506507	1·9297513	1·068959	·0289612
6·065191	·7828445	73	·8405863	1·9245824	1·070983	·0297827
5·977370	·7765101	74	·8308202	1·9195070	1·073041	·0306163
5·891810	·7702487	75	·8213397	1·9145229	1·075132	·0314616
5·808422	·7640581	76	·8121343	1·9096280	1·077256	·0323190
5·727120	·7579363	77	·8031939	1·9048204	1·079416	·0331887
5·647826	·7518813	78	·7945077	1·9000982	1·081610	·0340706
5·570461	·7458912	79	·7860669	1·8954595	1·083837	·0349640
5·494955	·7399641	80	·7778620	1·8909025	1·086100	·0358697
5·421237	·7340984	81	·7698845	1·8864256	1·088399	·0367882
5·349243	·7282923	82	·7621265	1·8820271	1·090732	·0377184
5·278910	·7225442	83	·7545801	1·8777054	1·093102	·0386608
5·210178	·7168526	84	·7472383	1·8734591	1·095508	·0396159
5·142991	·7112158	85	·7400936	1·8692867	1·097951	·0405831
5·077296	·7056325	86	·7330890	1·8651567	1·100354	·0415326
5·013040	·7001011	87	·7263080	1·8611578	1·102946	·0425543
4·950174	·6946204	88	·7197786	1·8571987	1·105501	·0435590
4·888651	·6891891	89	·7133590	1·8533082	1·108090	·0445755
4·828427	·6838057	90	·7071068	1·8494850	1·110720	·0456048
4·769459	·6784691	91	·7010160	1·8457279	1·113388	·0466468
4·711705	·6731781	92	·6950868	1·8420359	1·116094	·0477011
4·655126	·6679315	93	·6892991	1·8384078	1·118840	·0487681
4·599685	·6627281	94	·6836636	1·8348425	1·121625	·0498478
4·545346	·6575669	95	·6781707	1·8313391	1·124450	·0509401
4·492074	·6524469	96	·6728163	1·8278965	1·127314	·0520451
4·439835	·6473669	97	·6675963	1·8245139	1·130220	·0531630
4·388599	·6423259	98	·6625063	1·8211901	1·133166	·0542936
4·338335	·6373231	99	·6575434	1·8179245	1·136153	·0554371
4·289014	·6323575	100	·6527036	1·8147160	1·139182	·0565934
4·240607	·6274280	101	·6479834	1·8115639	1·142253	·0577627
4·193087	·6225339	102	·6433797	1·8084674	1·145367	·0589450
4·146429	·6176743	103	·6388930	1·8054256	1·148524	·0601402
4·100608	·6128482	104	·6345091	1·8024379	1·151724	·0613486
4·055599	·6080550	105	·6302361	1·7995033	1·154968	·0625700
4·011379	·6032937	106	·6260678	1·7966214	1·158256	·0638047
3·967927	·5985637	107	·6220012	1·7937913	1·161588	·0650525
3·925221	·5938641	108	·6180340	1·7910124	1·164967	·0663136
3·883240	·5891942	109	·6141635	1·7882840	1·168390	·0675879
3·841964	·5845533	110	·6103872	1·7856055	1·171859	·0688756
3·801375	·5799407	111	·6067031	1·7829763	1·175375	·0701767
3·761453	·5753556	112	·6031090	1·7803958	1·178938	·0714912
3·722181	·5707975	113	·5996024	1·7778634	1·182549	·0728192
3·683542	·5662656	114	·5961816	1·7753786	1·186208	·0741609
3·645519	·5617593	115	·5928445	1·7729408	1·189914	·0755160
3·608096	·5572780	116	·5895891	1·7705495	1.193671	·0768849
3·571257	·5528211	117	·5864138	1·7682042	1·197477	·0782674
3·534988	·5483880	118	·5833168	1·7659044	1·201334	·0796639
3·499274	·5439780	119	·5802961	1·7636496	1·205241	·0810740
3·464102	·5395906	120	·5773502	1·7614394	1·209200	·0824980

ZONES, &c., OF A CIRCLE (*continued*).

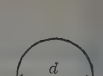
Area of Segment.		Surface of Zone.		Solidity of Zone.		Chord c.	
5.	Logarithm.	6.	Logarithm.	7.	Logarithm.	8.	Logarithm.
·0922141	2·9647972	·843775	1·9262265	·054857	2·7392346	1·0150768	·0064989
·0938482	2·9724261	·845802	1·9272689	·055849	2·7470117	1·0300762	·0128693
·0954887	2·9799522	·847869	1·9283286	·056845	2·7546888	1·0449972	·0191151
·0971356	2·9873783	·849976	1·9294067	·057845	2·7622693	1·0598386	·0252397
·0987883	2·9947054	·852123	1·9305026	·058851	2·7697568	1·0745992	·0312465
·1004493	1·0019472	·854311	1·9316159	·059862	2·7771536	1·0892780	·0371388
·1021166	1·0090962	·856540	1·9327476	·060879	2·7844656	1·1038740	·0429195
·1037906	1·0161582	·858810	1·9338971	·061900	2·7916935	1·1183858	·0485917
·1054720	1·0231370	·861123	1·9350651	·062928	2·7988412	1·1328124	·0541580
·1071606	1·0300352	·863477	1·9362510	·063960	2·8059104	1·1471528	·0596213
·1088565	1·0368544	·865875	1·9374552	·064999	2·8129048	1·1614060	·0649840
·1105601	1·0435983	·868315	1·9386772	·066043	2·8198266	1·1755706	·0702487
·1122713	1·0502690	·870799	1·9399178	·067093	2·8266780	1·1896456	·0754176
·1139905	1·0568689	·873327	1·9411768	·068150	2·8334669	1·2036300	·0804930
·1157177	1·0634001	·875899	1·9424542	·069212	2·8401800	1·2175228	·0854771
·1174531	1·0698645	·878516	1·9437497	·070281	2·8468350	1·2313230	·0903720
·1191968	1·0762646	·881179	1·9450639	·071356	2·8534287	1·2450292	·0951796
·1209490	1·0826023	·883887	1·9463967	·072437	2·8599628	1·2586408	·0999018
·1227097	1·0888794	·886642	1·9477483	·073526	2·8664402	1·2721564	·1045405
·1244795	1·0950979	·889443	1·9491183	·074621	2·8728619	1·2855752	·1090975
·1262583	1·1012598	·892292	1·9505071	·075723	2·8792303	1·2988960	·1135744
·1280460	1·1073663	·895189	1·9519146	·076833	2·8855469	1·3121180	·1179729
·1298431	1·1134190	·898134	1·9533410	·077950	2·8918135	1·3252400	·1222946
·1316500	1·1194204	·901128	1·9547865	·079073	2·8980307	1·3382612	·1265409
·1334661	1·1253711	·904172	1·9562509	·080205	2·9042026	1·3511804	·1307133
·1352923	1·1312732	·907265	1·9577342	·081345	2·9103285	1·3639968	·1348133
·1371284	1·1371277	·910409	1·9592366	·082492	2·9164105	1·3767092	·1388422
·1389748	1·1429361	·913604	1·9607581	·083647	2·9224500	1·3893168	·1428013
·1408316	1·1487004	·916852	1·9622992	·084810	2·9284487	1·4018186	·1466918
·1426990	1·1544211	·920151	1·9638591	·085982	2·9344078	1·4142136	·1505150
·1445772	1·1601000	·923504	1·9654386	·087162	2·9403284	1·4265008	·1542721
·1464664	1·1657380	·926910	1·9670376	·088351	2·9462122	1·4386796	·1579641
·1483668	1·1713367	·930371	1·9686563	·089549	2·9520600	1·4507488	·1615922
·1502784	1·1768966	·933887	1·9702942	·090756	2·9578736	1·4627074	·1651575
·1522017	1·1824196	·937459	1·9719521	·091972	2·9636535	1·4745546	·1686609
·1541368	1·1879065	·941087	1·9736295	·093197	2·9694015	1·4862896	·1721035
·1560839	1·1933582	·944772	1·9753270	·094432	2·9751177	1·4979114	·1754861
·1580432	1·1987759	·948516	1·9770447	·095676	2·9808048	1·5094192	·1788099
·1600146	1·2041598	·952317	1·9787814	·096931	2·9864623	1·5208120	·1820755
·1619994	1·2095134	·956177	1·9805384	·098196	2·9920920	1·5320888	·1852840
·1639967	1·2148351	·960099	1·9823158	·099471	2·9976949	1·5432492	·1884361
·1660072	1·2201269	·964080	1·9841133	·100756	1·0032722	1·5542920	·1915326
·1680310	1·2253893	·968125	1·9859313	·102053	1·0088238	1·5652164	·1945744
·1700684	1·2306238	·972231	1·9877697	·103360	1·0143517	1·5760216	·1975621
·1721196	1·2358303	·976401	1·9896282	·104678	1·0198564	1·5867066	·2004967
·1741849	1·2410106	·980635	1·9915076	·106008	1·0253391	1·5972710	·2033786
·1762645	1·2461650	·984935	1·9934075	·107350	1·0308003	1·6077138	·2062087
·1783590	1·2512948	·989300	1·9953281	·108703	1·0362411	1·6180340	·2089876
·1804680	1·2564001	·993735	1·9972707	·110068	1·0416620	1·6282310	·2117160
·1825916	1·2614810	·998233	1·9992321	·111446	1·0470646	1·6383040	·2143945
·1847318	1·2665417	1·00280	·0012156	·112836	1·0524488	1·6482524	·2170237
·1868871	1·2715793	1·00744	·0032201	·114239	1·0578163	1·6580752	·2196042
·1890582	1·2765957	1·01215	·0052458	·115656	1·0631668	1·6677716	·2221366
·1912457	1·2815918	1·01693	·0072930	·117085	1·0685023	1·6773412	·2246214
·1934497	1·2865682	1·02179	·0093614	·118528	1·0738225	1·6867828	·2270592
·1956705	1·2915254	1·02672	·0114513	·119986	1·0791289	1·6960962	·2294505
·1979185	1·2964646	1·03172	·0135630	·121457	1·0844217	1·7052804	·2317958
·2001639	1·3013858	1·03680	·0156963	·122942	1·0897016	1·7143346	·2340956
·2024370	1·3062900	1·04196	·0178515	·124443	1·0949696	1·7232584	·2363504
·2047282	1·3111778	1·04720	·0200292	·125958	1·1002270	1·7320508	·2385606

$\frac{c}{h}$ (Chord divided by height.)		Centre Angle v.	Radius r.		Circular Arc b.	
1.	Logarithm.	2.	3	Logarithm.	4.	Logarithm.
3·429457	·5352253	121	·5744776	1·7592732	1·213210	·0839359
3·395326	·5308815	122	·5716770	1·7571507	1·217272	·0853880
3·361698	·5265587	123	·5689465	1·7550715	1·221389	·0868541
3·328560	·5222563	124	·5662850	1·7530351	1·225558	·0883341
3·295898	·5179738	125	·5636910	1·7510411	1·229782	·0898286
3·263703	·5137107	126	·5611631	1·7490891	1·234062	·0913371
3·231964	·5094665	127	·5587001	1·7471788	1·238396	·0928599
3·200669	·5052408	128	·5563009	1·7453098	1·242788	·0943971
3·169808	·5010330	129	·5539642	1·7434818	1·247236	·0959490
3·139371	·4968427	130	·5516890	1·7416943	1·251742	·0975150
3·109348	·4926694	131	·5494738	1·7399471	1·256306	·0990957
3·079730	·4885126	132	·5473181	1·7382398	1·260930	·1006913
3·050507	·4843720	133	·5452205	1·7365722	1·265614	·1023013
3·021670	·4802471	134	·5431808	1·7349439	1·270357	·1039261
2·993212	·4761374	135	·5411961	1·7333547	1·275163	·1055660
2·965122	·4720426	136	·5392672	1·7318041	1·280030	·1072204
2·937393	·4679621	137	·5373931	1·7302921	1·284960	·1088900
2·910018	·4638957	138	·5355726	1·7288183	1·289955	·1105748
2·882988	·4598429	139	·5338046	1·7273824	1·295014	·1122746
2·856296	·4558032	140	·5320888	1·7259842	1·300138	·1139897
2·829935	·4517764	141	·5304242	1·7246234	1·305329	·1157199
2·803897	·4477620	142	·5288102	1·7232999	1·310284	·1173658
2·778175	·4437596	143	·5272461	1·7220134	1·315912	·1192269
2·752764	·4397690	144	·5257311	1·7207637	1·321306	·1210036
2·727656	·4357896	145	·5242646	1·7195505	1·326770	·1227958
2·702845	·4318211	146	·5228458	1·7183737	1·332306	·1246041
2·678325	·4278632	147	·5214744	1·7172330	1·337912	·1264277
2·654090	·4239156	148	·5201497	1·7161284	1·343591	·1282675
2·630134	·4199778	149	·5188711	1·7150595	1·349345	·1301233
2·606451	·4160495	150	·5176381	1·7140262	1·355173	·1319949
2·583036	·4121304	151	·5164501	1·7130284	1.361076	·1338827
2·559883	·4082202	152	·5153069	1·7120659	1·367057	·1357868
2·536988	·4043184	153	·5142074	1·7111385	1·373116	·1377074
2·514345	·4004248	154	·5131521	1·7102461	1·379253	·1396441
2·491948	·3965390	155	·5121397	1·7093885	1·385471	·1415976
2·469794	·3926608	156	·5111702	1·7085656	1·391770	·1435676
2·447878	·3887897	157	·5102432	1·7077773	1·398152	·1455545
2·426194	·3849255	158	·5093582	1·7070234	1·404616	·1475579
2·404739	·3810679	159	·5085151	1·7063039	1·411167	·1495785
2·383507	·3772165	160	·5077132	1·7056185	1·417802	·1516159
2·362495	·3733710	161	·5069525	1·7049673	1·424526	·1536706
2·341699	·3695311	162	·5062325	1·7043501	1·431338	·1557425
2·321114	·3656965	163	·5055530	1·7037667	1·438241	·1578317
2·300737	·3618669	164	·5049136	1·7032172	1·445234	·1599385
2·280563	·3580421	165	·5043143	1·7027014	1·452321	·1620626
2·260589	·3542216	166	·5037548	1·7022193	1·459502	·1642049
2·240811	·3504052	167	·5032348	1·7017707	1·466778	·1663646
2·221225	·3465926	168	·5027541	1·7013557	1·474152	·1685423
2·201828	·3427835	169	·5023125	1·7009740	1·481623	·1707380
2·182617	·3389775	170	·5019100	1·7006258	1·489196	·1729521
2·163588	·3351745	171	·5015461	1·7003109	1·496871	·1751844
2·144737	·3313741	172	·5012209	1·7000292	1·504648	·1774350
2·126063	·3275761	173	·5009343	1·6997808	1·512531	·1797044
2·107560	·3237800	174	·5006862	1·6995656	1·520520	·1819923
2·089227	·3199857	175	·5004763	1·6993835	1·528617	·1842988
2·071061	·3161928	176	·5003046	1·6992346	1·536826	·1866248
2·053057	·3124011	177	·5001714	1·6991189	1·545145	·1889695
2·035215	·3086103	178	·5000762	1·6990362	1·553580	·1913335
2·017530	·3048200	179	·5000190	1·6989865	1·562129	·1937169
2·000000	·3010300	180	·5000000	1·6989700	1·570796	·1961199

ZONES, &C., OF A CIRCLE—(*continued*).

Area of Segment.		Surface of Zone.		Solidity of Zone.		Chord *c*.	
5.	Logarithm.	6.	Logarithm.	7.	Logarithm.	8.	Logarithm.
·2070378	I·3160498	1·05251	·0222277	·127489	I·1054730	1·7407114	·2407268
·2093661	I·3209065	1·05791	·0244490	·129036	I·1107095	1·7492394	·2428493
·2117135	I·3257487	1·06339	·0266927	·130598	I·1159369	1·7576342	·2449285
·2140804	I·3305770	1·06895	·0289588	·132177	I·1211554	1·7658952	·2469649
·2164670	I·3353918	1·07460	·0312472	·133772	I·1263658	1·7740216	·2489589
·2188736	I·3401935	1·08033	·0335582	·135385	I·1315695	1·7820130	·2509109
·2213008	I·3449831	1·08616	·0358923	·137014	I·1367662	1·7898688	·2528212
·2237490	I·3497610	1·09207	·0382490	·138662	I·1419567	1·7975880	·2546902
·2262183	I·3545279	1·09807	·0406289	·140327	I·1471420	1·8051706	·2565182
·2287093	I·3592839	1·10416	·0430315	·142011	I·1523227	1·8126156	·2583057
·2312223	I·3640299	1·11034	·0454576	·143714	I·1574990	1·8199226	·2600529
·2337578	I·3687662	1·11662	·0479071	·145436	I·1626719	1·8270910	·2617602
·2363162	I·3734936	1·12300	·0503800	·147178	I·1678417	1·8341202	·2634278
·2388978	I·3782122	1·12948	·0528768	·148939	I·1730095	1·8410098	·2650561
·2415033	I·3829231	1·13605	·0553973	·150721	I·1781750	1·8477590	·2666453
·2441327	I·3876261	1·14273	·0579414	·152525	I·1833396	1·8543678	·2681959
·2467870	I·3923223	1·14950	·0605100	·154349	I·1885034	1·8608352	·2697079
·2494664	I·3970120	1·15639	·0631027	·156195	I·1936671	1·8671608	·2711817
·2521711	I·4016954	1·16337	·0657194	·158064	I·1988318	1·8733444	·2726176
·2549020	I·4063732	1·17047	·0683609	·159955	I·2039972	1·8793852	·2740158
·2576593	I·4110459	1·17768	·0710269	·161869	I·2091643	1·8852830	·2753766
·2604444	I·4157151	1·18500	·0737178	·163808	I·2143337	1·8910372	·2767001
·2632558	I·4203781	1·19243	·0764336	·165770	I·2195060	1·8966474	·2779866
·2660960	I·4250383	1·19998	·0791747	·167757	I·2246815	1·9021130	·2792363
·2689646	I·4296953	1·20765	·0819408	·169770	I·2298611	1·9074340	·2804495
·2718626	I·4343495	1·21544	·0847325	·171809	I·2350449	1·9126096	·2816263
·2747904	I·4390015	1·22335	·0875496	·173874	I·2402342	1·9176394	·2827670
·2777482	I·4436513	1·23138	·0903928	·175966	I·2454289	1·9225234	·2838716
·2807370	I·4482996	1·23954	·0932617	·178086	I·2506298	1·9272610	·2849405
·2837573	I·4529471	1·24783	·0961566	·180234	I·2558374	1·9318516	·2859738
·2868098	I·4575941	1·25626	·0990779	·182411	I·2610520	1·9362952	·2869716
·2898950	I·4622406	1·26481	·1020257	·184618	I·2662749	1·9405914	·2879341
·2930138	I·4668880	1·27350	·1050000	·186856	I·2715059	1·9447398	·2888615
·2961664	I·4715358	1·28233	·1080012	·189124	I·2767458	1·9487402	·2897539
·2993536	I·4761847	1·29131	·1110294	·191423	I·2819943	1·9525920	·2906115
·3025768	I·4808357	1·30042	·1140847	·193756	I·2872544	1·9562952	·2914344
·3058357	I·4854882	1·30969	·1171676	·196121	I·2925247	1·9598494	·2922227
·3091315	I·4901433	1·31910	·1202777	·198521	I·2978058	1·9632544	·2929766
·3124651	I·4948015	1·32867	·1234160	·200955	I·3030986	1·9665098	·2936961
·3158368	I·4994628	1·33839	·1265818	·203425	I·3084036	1·9696156	·2943815
·3192480	I·5041281	1·34827	·1297762	·205931	I·3137215	1·9725712	·2950327
·3226990	I·5087976	1·35831	·1329990	·208475	I·3190531	1·9753766	·2956499
·3261910	I·5134718	1·36851	·1362500	·211056	I·3243979	1·9780318	·2962333
·3297241	I·5181508	1·37889	·1395301	·213677	I·3297582	1·9805362	·2967828
·3333002	I·5228356	1·38944	·1428392	·216338	I·3351328	1·9828898	·2972986
·3369194	I·5275261	1·40016	·1461776	·219040	I·3405234	1·9830924	·2977807
·3405830	I·5322229	1·41106	·1495452	·221784	I·3459305	1·9871438	·2982293
·3442921	I·5369271	1·42214	·1529430	·224571	I·3513541	1·9890438	·2986443
·3480468	I·5416378	1·43341	·1563704	·227403	I·3567953	1·9907924	·2990260
·3518490	I·5463565	1·44487	·1598282	·230279	I·3622543	1·9923894	·2993742
·3556993	I·5510831	1·45652	·1633163	·233202	I.3677319	1·9938346	·2996891
·3595990	I·5558186	1·46837	·1668349	·236172	I·3732290	1·9951281	·2999708
·3635486	I·5605626	1·48042	·1703847	·239191	I·3787456	1·9962696	·3002192
·3675496	I·5653160	1·49267	·1739654	·242261	I·3842826	1·9972590	·3004344
·3716031	I·5700794	1·50514	·1775777	·245381	I·3898411	1·9980964	·3006165
·3757104	I·5748533	1·51782	·1812216	·248554	I·3954205	1·9987816	·3007654
·3798722	I·5796376	1·53073	·1848979	·251781	I·4010229	1·9993146	·3008811
·3840814	I·5844233	1·54385	·1886059	·255063	I·4066474	1·9996954	·3009638
·3883651	I·5892403	1·55721	·1923464	·258402	I·4122959	1·9999238	·3010135
·3926989	I·5940597	1·57080	·1961199	·261799	I·4179687	2·0000000	·3010300

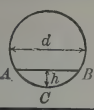
Area of segment ABC = tabular value a corresponding to $\frac{h}{d}$, multiplied by d^2.



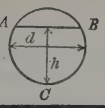
Example:—If $d = 48$ ins., $h = 5$ ins.; then $\frac{h}{d} = \frac{5}{48} = \cdot104$; tabular value a corresponding to $\cdot104 = \cdot04330$; then area of segment ABC = $\cdot04330 \times 48 \times 48 = 99\cdot76$ sq. ins.

$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a
·001	·000042	·057	·01783	·112	·04826	·168	·08704	·223	·1306	·279	·1791
·002	·000119	·058	·01830	·113	·04889	·169	·08779	·224	·1314	·280	·1800
·003	·000219	·059	·01877	·114	·04953	·170	·08854	·225	·1323		
·004	·000337	·060	·01924	·115	·05017			·226	·1331	·281	·1809
·005	·000470			·116	·05080	·171	·08929	·227	·1339	·282	·1818
·006	·000618	·061	·01972	·117	·05115	·172	·09004	·228	·1348	·283	·1827
·007	·000779	·062	·02020	·118	·05209	·173	·09080	·229	·1356	·284	·1836
·008	·000951	·063	·02068	·119	·05274	·174	·09155	·230	·1365	·285	·1845
·009	·001135	·064	·02117	·120	·05339	·175	·09231			·286	·1854
·010	·001329	·065	·02166			·176	·09307	·231	·1373	·287	·1863
		·066	·02215	·121	·05405	·177	·09384	·232	·1382	·288	·1872
·011	·001533	·067	·02265	·122	·05469	·178	·09460	·233	·1390	·289	·1881
·012	·001746	·068	·02315	·123	·05535	·179	·09537	·234	·1398	·290	·1890
·013	·001968	·069	·02366	·124	·05600	·180	·09613	·235	·1407		
·014	·002199	·070	·02417	·125	·05666			·236	·1415	·291	·1900
·015	·002438			·126	·05733	·181	·09690	·237	·1424	·292	·1909
·016	·002685	·071	·02468	·127	·05799	·182	·09767	·238	·1432	·293	·1918
·017	·002940	·072	·02520	·128	·05866	·183	·09845	·239	·1441	·294	·1927
·018	·003202	·073	·02571	·129	·05933	·184	·09922	·240	·1449	·295	·1936
·019	·003471	·074	·02624	·130	·06000	·185	·1000			·296	·1945
·020	·003748	·075	·02676			·186	·1008	·241	·1458	·297	·1954
		·076	·02729	·131	·06067	·187	·1016	·242	·1467	·298	·1963
·021	·004031	·077	·02782	·132	·06135	·188	·1023	·243	·1475	·299	·1973
·022	·004322	·078	·02836	·133	·06203	·189	·1031	·244	·1484	·300	·1982
·023	·004618	·079	·02889	·134	·06271	·190	·1039	·245	·1492		
·024	·004921	·080	·02944	·135	·06339			·246	·1501	·301	·1991
·025	·005230			·136	·06407	·191	·1047	·247	·1510	·302	·2000
·026	·005546	·081	·02998	·137	·06476	·192	·1055	·248	·1518	·303	·2010
·027	·005867	·082	·03053	·138	·06545	·193	·1063	·249	·1527	·304	·2018
·028	·006194	·083	·03108	·139	·06614	·194	·1071	·250	·1535	·305	·2028
·029	·006527	·084	·03163	·140	·06683	·195	·1078			·306	·2037
·030	·006865	·085	·03219			·196	·1086	·251	·1544	·307	·2046
		·086	·03275	·141	·06753	·197	·1094	·252	·1553	·308	·2055
·031	·007209	·087	·03331	·142	·06823	·198	·1102	·253	·1561	·309	·2065
·032	·007558	·088	·03387	·143	·06892	·199	·1110	·254	·1570	·310	·2074
·033	·007913	·089	·03444	·144	·06963	·200	·1118	·255	·1579		
·034	·008273	·090	·03501	·145	·07033			·256	·1588	·311	·2083
·035	·008638			·146	·07103	·201	·1126	·257	·1596	·312	·2092
·036	·009008	·091	·03559	·147	·07174	·202	·1134	·258	·1605	·313	·2102
·037	·009383	·092	·03616	·148	·07245	·203	·1142	·259	·1614	·314	·2111
·038	·009763	·093	·03674	·149	·07316	·204	·1150	·260	·1623	·315	·2120
·039	·01015	·094	·03732	·150	·07387	·205	·1158			·316	·2129
·040	·01054	·095	·03791			·206	·1167	·261	·1631	·317	·2139
		·096	·03850	·151	·07459	·207	·1175	·262	·1640	·318	·2148
·041	·01093	·097	·03909	·152	·07531	·208	·1183	·263	·1649	·319	·2157
·042	·01133	·098	·03968	·153	·07603	·209	·1191	·264	·1658	·320	·2167
·043	·01173	·099	·04028	·154	·07675	·210	·1199	·265	·1667		
·044	·01214	·100	·04088	·155	·07747			·266	·1675	·321	·2176
·045	·01255			·156	·07819	·211	·1207	·267	·1684	·322	·2185
·046	·01297	·101	·04148	·157	·07892	·212	·1215	·268	·1693	·323	·2195
·047	·01339	·102	·04208	·158	·07965	·213	·1223	·269	·1702	·324	·2204
·048	·01382	·103	·04269	·159	·08038	·214	·1232	·270	·1711	·325	·2213
·049	·01425	·104	·04330	·160	·08111	·215	·1240			·326	·2223
·050	·01468	·105	·04391			·216	·1248	·271	·1720	·327	·2232
		·106	·04452	·161	·08185	·217	·1256	·272	·1729	·328	·2242
·051	·01512	·107	·04514	·162	·08258	·218	·1265	·273	·1738	·329	·2251
·052	·01556	·108	·04576	·163	·08332	·219	·1273	·274	·1746	·330	·2260
·053	·01601	·109	·04638	·164	·08406	·220	·1281	·275	·1755		
·054	·01646	·110	·04701	·165	·08480			·276	·1764	·331	·2270
·055	·01691			·166	·08554	·221	·1289	·277	·1773	·332	·2279
·056	·01737	·111	·04763	·167	·08629	·222	·1298	·278	·1782	·333	·2289

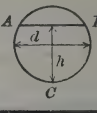
$\frac{h}{d}$ less than ·500



$\frac{h}{d}$ greater than ·500



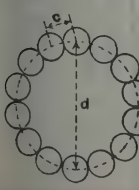
$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a
·334	·2298	·391	·2846	·448	·3408	·504	·3967	·561	·4535	·618	·5096
·335	·2307	·392	·2855	·449	·3418	·505	·3977	·562	·4545	·619	·5106
·336	·2317	·393	·2865	·450	·3428	·506	·3987	·563	·4555	·620	·5115
·337	·2326	·394	·2875			·507	·3997	·564	·4565		
·338	·2336	·395	·2885	·451	·3438	·508	·4007	·565	·4575	·621	·5125
·339	·2345	·396	·2895	·452	·3448	·509	·4017	·566	·4585	·622	·5135
·340	·2355	·397	·2904	·453	·3458	·510	·4027	·567	·4595	·623	·5144
		·398	·2914	·454	·3468			·568	·4605	·624	·5154
·341	·2364	·399	·2924	·455	·3478	·511	·4037	·569	·4615	·625	·5164
·342	·2374	·400	·2934	·456	·3488	·512	·4047	·570	·4625	·626	·5174
·343	·2383			·457	·3498	·513	·4057			·627	·5183
·344	·2393	·401	·2943	·458	·3507	·514	·4067	·571	·4635	·628	·5193
·345	·2402	·402	·2953	·459	·3517	·515	·4077	·572	·4645	·629	·5203
·346	·2412	·403	·2963	·460	·3527	·516	·4087	·573	·4654	·630	·5212
·347	·2421	·404	·2973			·517	·4097	·574	·4664		
·348	·2431	·405	·2983	·461	·3537	·518	·4107	·575	·4674	·631	·5222
·349	·2440	·406	·2993	·462	·3547	·519	·4117	·576	·4684	·632	·5232
·350	·2450	·407	·3002	·463	·3557	·520	·4127	·577	·4694	·633	·5241
		·408	·3012	·464	·3567			·578	·4704	·634	·5251
·351	·2459	·409	·3022	·465	·3577	·521	·4137	·579	·4714	·635	·5260
·352	·2469	·410	·3032	·466	·3587	·522	·4147	·580	·4724	·636	·5270
·353	·2478			·467	·3597	·523	·4157			·637	·5280
·354	·2488	·411	·3042	·468	·3607	·524	·4167	·581	·4733	·638	·5289
·355	·2498	·412	·3052	·469	·3617	·525	·4177	·582	·4743	·639	·5299
·356	·2507	·413	·3061	·470	·3627	·526	·4187	·583	·4753	·640	·5308
·357	·2517	·414	·3071			·527	·4197	·584	·4763		
·358	·2526	·415	·3081	·471	·3637	·528	·4207	·585	·4773	·641	·5318
·359	·2536	·416	·3091	·472	·3647	·529	·4217	·586	·4783	·642	·5328
·360	·2546	·417	·3101	·473	·3657	·530	·4227	·587	·4793	·643	·5337
		·418	·3111	·474	·3667			·588	·4802	·644	·5347
·361	·2555	·419	·3121	·475	·3677	·531	·4237	·589	·4812	·645	·5356
·362	·2565	·420	·3130	·476	·3687	·532	·4247	·590	·4822	·646	·5366
·363	·2574			·477	·3697	·533	·4257			·647	·5376
·364	·2584	·421	·3140	·478	·3707	·534	·4267	·591	·4832	·648	·5385
·365	·2594	·422	·3150	·479	·3717	·535	·4277	·592	·4842	·649	·5395
·366	·2603	·423	·3160	·480	·3727	·536	·4287	·593	·4852	·650	·5404
·367	·2613	·424	·3170			·537	·4297	·594	·4861		
·368	·2622	·425	·3180	·481	·3737	·538	·4307	·595	·4871	·651	·5414
·369	·2632	·426	·3190	·482	·3747	·539	·4317	·596	·4881	·652	·5423
·370	·2642	·427	·3200	·483	·3757	·540	·4327	·597	·4891	·653	·5433
		·428	·3209	·484	·3767			·598	·4901	·654	·5442
·371	·2651	·429	·3219	·485	·3777	·541	·4337	·599	·4910	·655	·5452
·372	·2661	·430	·3229	·486	·3787	·542	·4347	·600	·4920	·656	·5461
·373	·2671			·487	·3797	·543	·4356			·657	·5471
·374	·2680	·431	·3239	·488	·3807	·544	·4366	·601	·4930	·658	·5480
·375	·2690	·432	·3249	·489	·3817	·545	·4376	·602	·4940	·659	·5490
·376	·2700	·433	·3259	·490	·3827	·546	·4386	·603	·4950	·660	·5499
·377	·2710	·434	·3269			·547	·4396	·604	·4959		
·378	·2719	·435	·3279	·491	·3837	·548	·4406	·605	·4969	·661	·5509
·379	·2729	·436	·3289	·492	·3847	·549	·4416	·606	·4981	·662	·5518
·380	·2739	·437	·3300	·493	·3857	·550	·4426	·607	·4989	·663	·5528
		·438	·3309	·494	·3867			·608	·4999	·664	·5537
·381	·2748	·439	·3319	·495	·3877	·551	·4436	·609	·5008	·665	·5547
·382	·2758	·440	·3328	·496	·3887	·552	·4446	·610	5018	·666	·5556
·383	·2768			·497	·3897	·553	·4456			·667	·5565
·384	·2777	·441	·3338	·498	·3907	·554	·4466	·611	5028	·668	·5575
·385	·2787	·442	·3348	·499	·3917	·555	·4476	·612	5038	·669	·5584
·386	·2797	·443	·3358	·500	·3927	·556	·4486	·613	5047	·670	5594
·387	·2807	·444	·3368			·557	·4496	·614	·5057		
·388	·2816	·445	·3378	·501	·3937	·558	·4506	·615	·5067	·671	·5603
·389	·2826	·446	·3388	·502	·3947	·559	·4516	·616	·5077	·672	·5612
·390	·2836	·447	·3398	·503	·3957	·560	·4526	·617	·5086	·673	·5622



$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a	$\frac{h}{d}$	a
·674	·5631	·730	·6143	·785	·6614	·841	·7050	·897	·7427	·952	·7716
·675	·5640			·786	·6622	·842	·7058	·898	·7433	·953	·7720
·676	·5650	·731	·6152	·787	·6631	·843	·7065	·899	·7439	·954	·7724
·677	·5659	·732	·6161	·788	·6639	·844	·7072	·900	·7445	·955	·7728
·678	·5669	·733	·6170	·789	·6647	·845	·7079			·956	·7733
·679	·5678	·734	·6179	·790	·6655	·846	·7087	·901	·7451	·957	·7737
·680	·5687	·735	·6187			·847	·7094	·902	·7457	·958	·7741
		·736	·6196	·791	·6663	·848	·7101	·903	·7463	·959	·7745
·681	·5699	·737	·6205	·792	·6671	·849	·7108	·904	·7469	·960	·7749
·682	·5706	·738	·6214	·793	·6679	·850	·7115	·905	·7475		
·683	·5715	·739	·6223	·794	·6687			·906	·7481	·961	·7753
·684	·5725	·740	·6231	·795	·6696	·851	·7122	·907	·7487	·962	·7756
·685	·5734			·796	·6704	·852	·7129	·908	·7492	·963	·7760
·686	·5743	·741	·6240	·797	·6712	·853	·7137	·909	·7498	·964	·7764
·687	·5752	·742	·6249	·798	·6720	·854	·7144	·910	·7504	·965	·7768
·688	·5762	·743	·6258	·799	·6728	·855	·7151			·966	·7771
·689	·5771	·744	·6266	·800	·6736	·856	·7158	·911	·7510	·967	·7775
·690	·5780	·745	·6275			·857	·7165	·912	·7515	·968	·7778
		·746	·6284	·801	·6744	·858	·7172	·913	·7521	·969	·7782
·691	·5799	·747	·6292	·802	·6752	·859	·7179	·914	·7527	·970	·7785
·692	·5808	·748	·6301	·803	·6760	·860	·7186	·915	·7532		
·693	·5817	·749	·6310	·804	·6768			·916	·7538	·971	·7789
·694	·5826	·750	·6319	·805	·6776	·861	·7193	·917	·7543	·972	·7792
·695	·5836			·806	·6783	·862	·7199	·918	·7549	·973	·7795
·696	·5845	·751	·6327	·807	·6791	·863	·7206	·919	·7554	·974	·7799
·697	·5854	·752	·6336	·808	·6799	·864	·7213	·920	·7560	·975	·7802
·698	·5863	·753	·6344	·809	·6807	·865	·7220			·976	·7805
·699	·5872	·754	·6353	·810	·6815	·866	·7227	·921	·7565	·977	·7808
·700	·5872	·755	·6362			·867	·7234	·922	·7570	·978	·7811
		·756	·6370	·811	·6823	·868	·7241	·923	·7576	·979	·7814
·701	·5881	·757	·6379	·812	·6831	·869	·7247	·924	·7581	·980	·7817
·702	·5891	·758	·6387	·813	·6838	·870	·7254	·925	·7586		
·703	·5900	·759	·6396	·814	·6846			·926	·7592	·981	·7819
·704	·5909	·760	·6405	·815	·6854	·871	·7261	·927	·7597	·982	·7822
·705	·5918			·818	·6862	·872	·7267	·928	·7602	·983	·7825
·706	·5927	·761	·6413	·817	·6870	·873	·7274	·929	·7607	·984	·7827
·707	·5936	·762	·6422	·818	·6877	·874	·7281	·930	·7612	·985	·7830
·708	·5945	·763	·6430	·819	·6885	·875	·7287			·986	·7832
·709	·5954	·764	·6439	·820	·6893	·876	·7294	·931	·7617	·987	·7834
·710	·5964	·765	·6447			·877	·7301	·932	·7622	·988	·7837
		·766	·6456	·821	·6900	·878	·7307	·933	·7627	·989	·7839
·711	·5973	·767	·6464	·822	·6908	·879	·7314	·934	·7632	·990	·7841
·712	·5982	·768	·6472	·823	·6916	·880	·7320	·935	·7637		
·713	·5991	·769	·6481	·824	·6923			·936	·7642	·991	·7843
·714	·6000	·770	·6489	·825	·6931	·881	·7327	·937	·7647	·992	·7844
·715	·6009			·826	·6938	·882	·7333	·938	·7652	·993	·7846
·716	·6018	·771	·6498	·827	·6946	·883	·7340	·939	·7657	·994	·7848
·717	·6027	·772	·6506	·828	·6954	·884	·7346	·940	·7662	·995	·7849
·718	·6036	·773	·6515	·829	·6961	·885	·7352			·996	·7851
·719	·6045	·774	·6523	·830	·6969	·886	·7359	·941	·7666	·997	·7852
·720	·6054	·775	·6531			·887	·7365	·942	·7671	·998	·7853
		·776	·6540	·831	·6976	·888	·7371	·943	·7676	·999	·7854
·721	·6063	·777	·6548	·832	·6984	·889	·7378	·944	·7680	1·000	·7854
·722	·6072	·778	·6556	·833	·6991	·890	·7384	·945	·7685		
·723	·6081	·779	·6565	·834	·6999			·946	·7689		
·724	·6090	·780	·6573	·835	·7006	·891	·7390	·947	·7694		
·725	·6099			·836	·7013	·892	·7396	·948	·7698		
·726	·6107	·781	·6581	·837	·7021	·893	·7403	·949	·7703		
·727	·6116	·782	·6589	·838	·7028	·894	·7409	·950	·7707		
·728	·6125	·783	·6598	·839	·7036	·895	·7415				
·729	·6134	·784	·6606	·840	·7043	·896	·7421	·951	·7712		

CIRCLE SPACING TABLE FOR NUMBER OF SIDES FROM 3 TO 500.

0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
—	—	—	·866025	·707107	·587785	·500000	·433884	·382683	·342020
·309017	·281733	·258819	·239316	·222521	·207912	·195090	·183750	·173648	·164595
·156434	·149042	·142315	·136167	·130526	·125333	·120537	·116093	·111964	·108119
·104528	·101168	·098017	·095056	·092268	·089639	·087156	·084806	·082579	·080467
·078459	·076549	·074730	·072995	·071339	·069757	·068242	·066793	·065403	·064070
·062791	·061561	·060378	·059241	·058145	·057089	·056070	·055088	·054139	·053222
·052336	·051479	·050649	·049846	·049068	·048313	·047582	·046872	·046183	·045515
·044865	·044233	·043619	·043222	·042449	·041876	·041325	·040789	·040266	·039757
·039260	·038775	·038303	·037841	·037391	·036952	·036522	·036102	·035692	·035291
·034900	·034516	·034141	·033774	·033415	·033063	·032719	·032382	·032052	·031728
·031411	·031100	·030795	·030496	·030203	·029915	·029633	·029356	·029085	·028818
·028556	·028299	·028046	·027798	·027554	·027315	·027079	·026848	·026620	·026397
·026177	·025961	·025748	·025539	·025333	·025130	·024931	·024734	·024541	·024351
·024164	·023979	·023798	·023619	·023443	·023269	·023098	·022929	·022763	·022599
·022438	·022279	·022122	·021967	·021815	·021664	·021516	·021370	·021225	·021083
·020942	·020809	·020667	·020532	·020399	·020267	·020137	·020009	·019882	·019757
·019634	·019512	·019391	·019272	·019155	·019039	·018924	·018811	·018699	·018588
·018479	·018371	·018264	·018158	·018054	·017951	·017849	·017748	·017648	·017550
·017452	·017356	·017261	·017166	·017073	·016981	·016889	·016799	·016710	·016621
·016534	·016447	·016362	·016277	·016193	·016110	·016028	·015946	·015866	·015786
·015707	·015629	·015552	·015475	·015399	·015324	·015250	·015176	·015103	·015031
·014960	·014889	·014818	·014749	·014680	·014616	·014544	·014477	·014410	·014345
·014279	·014215	·014151	·014087	·014025	·013962	·013900	·013839	·013779	·013718
·013659	·013600	·013541	·013483	·013425	·013368	·013312	·013255	·013209	·013144
·013090	·013035	·012981	·012928	·012875	·012823	·012770	·012719	·012667	·012617
·012566	·012516	·012466	·012417	·012368	·012320	·012272	·012224	·012176	·012129
·012083	·012037	·011991	·011945	·011907	·011855	·011810	·011766	·011722	·011679
·011635	·011592	·911550	·011507	·011465	·011424	·011382	·011341	·011300	·011260
·011220	·011180	·011140	·011101	·011062	·011023	·010984	·010946	·010908	·010870
·010833	·010796	·010759	·010722	·010686	·010649	·010613	·010578	·010542	·010507
·010472	·010437	·010402	·010368	·010334	·010300	·010267	·010233	·010200	·010167
·010134	·010101	·010069	·010037	·010005	·009973	·009942	·009910	·009879	·009848
·009817	·009787	·009756	·009726	·009696	·009666	·009637	·009607	·009578	·009549
·009520	·009491	·009463	·009434	·009406	·009378	·009350	·009322	·009295	·009267
·009240	·009213	·009186	·009159	·009132	·009106	·009080	·009053	·009027	·009002
·008976	·008950	·008925	·008906	·008874	·008849	·008825	·008800	·008775	·008751
·008727	·008702	·008678	·008654	·008631	·008607	·008584	·008560	·008537	·008514
·008491	·008468	·008445	·008422	·008400	·008378	·008355	·008333	·008311	·008289
·008267	·008246	·008224	·008203	·008181	·008160	·008139	·008118	·008097	·008076
·008055	·008035	·008014	·007994	·007974	·007953	·007933	·007913	·007893	·007874
·007854	·007834	·007815	·007795	·007776	·007757	·007738	·007719	·007700	·007681
·007662	·007644	·007625	·007607	·007588	·007570	·007552	·007534	·007516	·007498
·007480	·007462	·007444	·007427	·007409	·007392	·007375	·007357	·007340	·007323
·007306	·007289	·007272	·007255	·007239	·007222	·007205	·007189	·007173	·007156
·007140	·007124	·007108	·007092	·007076	·007060	·007044	·007028	·007012	·006997
·006981	·006966	·006950	·006935	·006920	·006905	·006889	·006874	·006859	·006844
·006830	·006815	·006800	·006785	·006771	·006756	·006742	·006727	·006713	·006699
·006684	·006670	·006656	·006642	·006628	·006614	·006600	·006586	·006572	·006557
·006545	·006531	·006518	·006504	·006491	·006478	·006464	·006451	·006438	·006425
·006411	·006398	·006385	·006372	·006359	·006347	·006334	·006321	·006308	·006296
·006283	·006271	·006258	·006246	·006233	·006221	·006209	·006196	·006184	·006172



To find the chordal pitch, c, or distance from centre to centre of points spaced on a circle, multiply the factor corresponding to the number of sides by the diameter, d, of the pitch circle. Thus, for 14 sides (see fig.) or spacings on a 12-in. circle, we have $c = 0{\cdot}222521 \times 12 = 2{\cdot}67024$. The table is of service for spacing bolt or rivet holes; also in electrical constructional work in connection with commutator building, the spacing of slots on armature rotors and stators, etc., where considerable accuracy is required.

(*'Mechanical World,'* March 18, 1927.)

TRIGONOMETRY.

Measurement of Angles.

In practice the *right angle*, or some fraction of it, is always taken as the unit of angular measurement. It is divided into 90 equal parts, called degrees (°), each degree into 60 minutes (′), and each minute into 60 seconds (″). The *centesimal* method, in which the right angle is divided into 100 equal parts (grades), etc., is not used even in France, where it was first proposed.

In theoretical investigations, what is termed the *Circular measure* of angles is frequently employed. In this system the unit of measurement is the *Radian*.

RADIANS.

The *Radian*, or Unit Angle, is the angle in which the length of the arc subtended is equal to the length of the radius, *i.e.* where the length of the arc AB (fig. 98) is equal to the length of the radius AO. The actual value of the angle O is

$$\frac{180°}{\pi} = 57°\cdot29578 = 57°\ 17'\ 44\cdot8''. \quad \text{Log. } 57\cdot29578 = 1\cdot7581226.$$

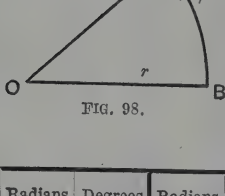


FIG. 98.

The value of a radian (r) expressed in degrees ($\alpha°$) is

$$\alpha° = 57°\cdot29578 \times r.$$

The value of degrees ($\alpha°$) expressed in radians (r) is

$$r = \frac{\alpha°}{57\cdot29578} = \cdot0174533 \times \alpha°. \quad \text{Log } \cdot0174533 = 2\cdot2418774.$$

The following tables give the conversion values of radians and degrees :—

RADIANS TO DEGREES.

$$(\alpha° = 57°\cdot295798 \times r)$$

Radians (r)	Degrees ($\alpha°$)	Radians (r)	Degrees ($\alpha°$)	Radians (r)	Degrees ($\alpha°$)	Radians (r)	Degrees ($\alpha°$)	Radians (r)	Degrees ($\alpha°$)
·01	0·57	·33	18·91	·65	37·24	·97	55·58	1·29	73·91
·02	1·15	·34	19·48	·66	37·82	·98	56·15	1·30	74·48
·03	1·72	·35	20·05	·67	38·39	·99	56·72	1·31	75·06
·04	2·29	·36	20·63	·68	38·96	**1·00**	**57·30**	1·32	75·63
·05	2·86	·37	21·20	·69	39·53	1·01	57·87	1·33	76·20
·06	3·44	·38	21·77	·70	40·11	1·02	58·44	1·34	76·78
·07	4·01	·39	22·34	·71	40·68	1·03	59·01	1·35	77·35
·08	4·58	·40	22·92	·72	41·25	1·04	59·59	1·36	77·92
·09	5·16	·41	23·49	·73	41·83	1·05	60·16	1·37	78·50
·10	5·73	·42	24·06	·74	42·40	1·06	60·73	1·38	79·07
·11	6·30	·43	24·64	·75	42·97	1·07	61·31	1·39	79·64
·12	6·88	·44	25·21	·76	43·54	1·08	61·88	1·40	80·21
·13	7·45	·45	25·78	·77	44·12	1·09	62·45	1·41	80·79
·14	8·02	·46	26·36	·78	44·69	1·10	63·03	1·42	81·36
·15	8·59	·47	26·93	·79	45·26	1·11	63·60	1·43	81·93
·16	9·17	·48	27·50	·80	45·84	1·12	64·17	1·44	82·51
·17	9·74	·49	28·07	·81	46·41	1·13	64·74	1·45	83·08
·18	10·31	·50	28·65	·82	46·98	1·14	65·32	1·46	83·65
·19	10·89	·51	29·22	·83	47·56	1·15	65·89	1·47	84·23
·20	11·46	·52	29·79	·84	48·13	1·16	66·46	1·48	84·80
·21	12·03	·53	30·37	·85	48·70	1·17	67·04	1·49	85·37
·22	12·61	·54	30·94	·86	49·27	1·18	67·61	1·50	85·94
·23	13·18	·55	31·51	·87	49·85	1·19	68·18	1·51	86·52
·24	13·75	·56	32·09	·88	50·42	1·20	68·75	1·52	87·09
·25	14·32	·57	32·66	·89	50·99	1·21	69·33	1·53	87·66
·26	14·90	·58	33·23	·90	51·57	1·22	69·90	1·54	88·24
·27	15·47	·59	33·80	·91	52·14	1·23	70·47	1·55	88·81
·28	16·04	·60	34·38	·92	52·71	1·24	71·05	1·56	89·38
·29	16·62	·61	34·95	·93	53·29	1·25	71·62	1·57	89·95
·30	17·19	·62	35·52	·94	53·86	1·26	72·19	$\pi/2$	90·00
·31	17·76	·63	36·10	·95	54·43	1·27	72·77		
·32	18·33	·64	36·67	·96	55·00	1·28	73·34		

DEGREES TO RADIANS.

($r = \cdot0174533 \times a°$)

Degrees ($a°$)	Radian (r)	Degrees ($a°$)	Radians (r)	Degrees ($a°$)	Radians (r)	Degrees ($a°$)	Radians (r)	Degrees ($a°$)	Radians (r)
1	·0175	37	·6458	73	1·274	109	1·902	145	2·530
2	·0349	38	·6632	74	1·291	110	1·920	146	2·548
3	·0524	39	·6807	75	1·309	111	1·937	147	2·565
4	·0698	40	·6981	76	1·326	112	1·954	148	2·583
5	·0873	41	·7156	77	1·344	113	1·972	149	2·600
6	·1047	42	·7330	78	1·361	114	1·989	150	2·618
7	·1222	43	·7505	79	1·379	115	2·007	151	2·635
8	·1396	44	·7679	80	1·396	116	2·024	152	2·652
9	·1571	45	·7854	81	1·413	117	2·042	153	2·670
10	·1745	46	·8029	82	1·431	118	2·059	154	2·687
11	·1920	47	·8203	83	1·448	119	2·077	155	2·705
12	·2094	48	·8378	84	1·466	120	2·094	156	2·722
13	·2269	49	·8552	85	1·483	121	2·112	157	2·740
14	·2443	50	·8727	86	1·501	122	2·129	158	2·757
15	·2618	51	·8901	87	1·518	123	2·146	159	2·775
16	·2793	52	·9076	88	1·536	124	2·164	160	2·792
17	·2967	53	·9250	89	1·553	125	2·181	161	2·810
18	·3142	54	·9425	90	1·571	126	2·199	162	2·827
19	·3316	55	·9599	91	1·588	127	2·216	163	2·844
20	·3491	56	·9774	92	1·605	128	2·234	164	2·862
21	·3665	57	·9948	93	1·623	129	2·251	165	2·879
22	·3840	58	1·012	94	1·640	130	2·269	166	2·897
23	·4014	59	1·030	95	1·658	131	2·286	167	2·914
24	·4189	60	1·047	76	1·675	132	2·304	168	2·932
25	·4363	61	1·064	97	1·693	133	2·321	169	2·945
26	·4538	62	1·082	98	1·710	134	2·338	170	2·967
27	·4712	63	1·099	99	1·728	135	2·356	171	2·984
28	·4887	64	1·117	100	1·745	136	2·373	172	3·001
29	·5061	65	1·134	101	1·762	137	2·391	173	3·019
30	·5236	66	1·152	102	1·780	138	2·408	174	3·036
31	·5410	67	1·169	103	1·797	139	2·426	175	3·054
32	·5585	68	1·187	104	1·815	140	2·443	176	3·071
33	·5760	69	1·204	105	1·832	141	2·460	177	3·089
34	·5934	70	1·222	106	1·850	142	2·478	178	3·106
35	·6109	71	1·239	107	1·867	143	2·495	179	3·124
36	·6283	72	1·256	108	1·884	144	2·513	180	3·141

Triangles.

A triangle contains seven quantities—namely, three sides, three angles, and the surface. When any three of these quantities are given, the four remaining ones can by them be ascertained (one side or the area must be one of the given quantities). This operation is called *solving the triangle*, and is simply an application of arithmetic to geometrical objects.

SOLUTION OF TRIANGLES.

For the foundation of the above-mentioned solution there are assumed eight *trigonometrical functions*, as follows :—

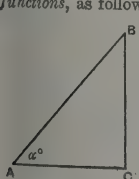


FIG. 98A.

Let ABC (fig. 98A) be a right-angled triangle, C being the right angle ; then

$\frac{BC}{AB}$, or $\frac{\text{perpendicular}}{\text{hypotenuse}}$ = sine $a°$; $\frac{AC}{AB}$, or $\frac{\text{base}}{\text{hypotenuse}}$ = cosine $a°$;

$\frac{BC}{AC}$, or $\frac{\text{perpendicular}}{\text{base}}$ = tangent $a°$; $\frac{AC}{BC}$, or $\frac{\text{base}}{\text{perpendicular}}$ = cotangent $a°$;

$\frac{AB}{AC}$, or $\frac{\text{hypotenuse}}{\text{base}}$ = secant $a°$; $\frac{AB}{BC}$, or $\frac{\text{hypotenuse}}{\text{perpendicular}}$ = cosecant $a°$.

If the cosine of $\alpha°$ is subtracted from unity, the remainder is called the *versed sine* of $\alpha°$

$$1 - \cos \alpha° = \text{versin } \alpha°.$$

If the sine of $\alpha°$ is subtracted from unity, the remainder is called the *coversed sine* of $\alpha°$; i.e.,

$$1 - \sin \alpha° = \text{coversin } \alpha°;$$

the latter is rarely used in practice.

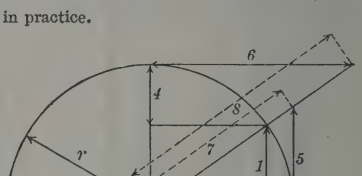


FIG. 99.

If in the figure (fig. 99) the radius r is unity, the values of the different lengths 1, 2, 3, 4, 5, 6, 7, 8, represent the values of the trigonometrical functions of the angle $\alpha°$ as follows :—

1 represents the value of	sine $\alpha°$.	5 represents the value of	tan $\alpha°$.
2 " " "	cosine $\alpha°$.	6 " " "	cot $\alpha°$.
3 " " "	versin $\alpha°$.	7 " " "	sec $\alpha°$.
4 " " "	coversin $\alpha°$.	8 " " "	cosec $\alpha°$.

The *complement* of an angle $\alpha° = 90° - \alpha°$. The *supplement* of an angle $\alpha° = 180° - \alpha°$.

Relations of Trigonometrical Functions to each other.

$$\text{cosec } \alpha = \frac{1}{\sin \alpha}. \qquad \sec \alpha = \frac{1}{\cos \alpha}. \qquad \cot \alpha = \frac{1}{\tan \alpha}.$$

$$\tan \alpha = \frac{\sin \alpha}{\cos \alpha}. \qquad \cot \alpha = \frac{\cos \alpha}{\sin \alpha}. \qquad \sin^2 \alpha + \cos^2 \alpha = 1.$$

$$\tan^2 \alpha + 1 = \sec^2 \alpha. \qquad \cot^2 \alpha + 1 = \text{cosec}^2 \alpha.$$

$$\sin \alpha = \sqrt{1 - \cos^2 \alpha} = \frac{1}{\sqrt{1 + \cot^2 \alpha}} = \frac{\tan \alpha}{\sqrt{1 + \tan^2 \alpha}}. \qquad \cos \alpha = \sqrt{1 - \sin^2 \alpha} = \frac{1}{\sqrt{1 + \tan^2 \alpha}}.$$

$$\tan \alpha = \frac{\sin \alpha}{\sqrt{1 - \sin^2 \alpha}}. \qquad \cot \alpha = \frac{\sqrt{1 - \sin^2 \alpha}}{\sin \alpha}. \qquad \text{cosec } \alpha = \sqrt{1 + \cot^2 \alpha} = \frac{\sqrt{1 + \tan^2 \alpha}}{\tan \alpha}.$$

$$\sec \alpha = \sqrt{1 + \tan^2 \alpha}. \qquad \text{versin } \alpha = 1 - \frac{1}{\sqrt{1 + \tan^2 \alpha}}.$$

$$\sin \alpha = \sin (180 - \alpha) = -\sin (180 + \alpha).$$
$$\cos \alpha = -\cos (180 - \alpha) = -\cos (180 + \alpha).$$
$$\tan \alpha = -\tan (180 - \alpha) = \tan (180 + \alpha).$$
$$\cot \alpha = -\cot (180 - \alpha) = \cot (180 + \alpha).$$
$$\sec \alpha = -\sec (180 - \alpha) = -\sec (180 + \alpha).$$
$$\text{cosec } \alpha = \text{cosec } (180 - \alpha) = -\text{cosec } (180 + \alpha).$$
$$\text{versin } (180 - \alpha) = 1 + \cos \alpha.$$
$$\sin \alpha = -\cos (90 + \alpha). \qquad \cos \alpha = \sin (90 + \alpha).$$

$$\sin (\alpha + \beta) = \sin \alpha \cos \beta + \cos \alpha \sin \beta. \qquad \cos (\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta.$$
$$\sin (\alpha - \beta) = \sin \alpha \cos \beta - \cos \alpha \sin \beta. \qquad \cos (\alpha - \beta) = \cos \alpha \cos \beta + \sin \alpha \sin \beta.$$

$$\tan (\alpha + \beta) = \frac{\tan \alpha + \tan \beta}{1 - \tan \alpha \tan \beta}. \qquad \tan (\alpha - \beta) = \frac{\tan \alpha - \tan \beta}{1 + \tan \alpha \tan \beta}.$$

$$\sin (\alpha + \beta) \sin (\alpha - \beta) = \sin^2 \alpha - \sin^2 \beta = \cos^2 \beta - \cos^2 \alpha.$$
$$\cos (\alpha + \beta) \cos (\alpha - \beta) = \cos^2 \alpha - \sin^2 \beta = \cos^2 \beta - \sin^2 \alpha.$$

$$\sin 2\alpha = 2\sin\alpha\cos\alpha = \frac{2\tan\alpha}{1+\tan^2\alpha};$$

$$\cos 2\alpha = \cos^2\alpha - \sin^2\alpha = 1 - 2\sin^2\alpha = 2\cos^2\alpha - 1 = \frac{1-\tan^2\alpha}{1+\tan^2\alpha};$$

$$\tan 2\alpha = \frac{2\tan\alpha}{1-\tan^2\alpha};\quad \cot 2\alpha = \frac{\cot^2\alpha - 1}{2\cot\alpha};\quad \sin 3\alpha = 3\sin\alpha - 4\sin^3\alpha;\quad \cos 3\alpha = 4\cos^3\alpha - 3\cos\alpha;$$

$$\tan 3\alpha = \frac{3\tan\alpha - \tan^3\alpha}{1-3\tan^2\alpha}.$$

$$\sin\frac{\alpha}{2} = \sqrt{\frac{1-\cos\alpha}{2}}. \qquad \cos\frac{\alpha}{2} = \sqrt{\frac{1+\cos\alpha}{2}}.$$

$$\tan\frac{\alpha}{2} = \sqrt{\frac{1-\cos\alpha}{1+\cos\alpha}} = \frac{1-\cos\alpha}{\sin\alpha} = \frac{-1\pm\sqrt{1+\tan^2\alpha}}{\tan\alpha}.$$

CHANGES IN VALUE AND SIGN OF TRIGONOMETRICAL RATIOS.

Ratio	0° . . . 90°	90° . . . 180°	180° . . . 270°	270° . . . 360°
Sine	positive 0 . . . 1	positive 1 . . 0	negative 0 . . . −1	negative −1 . . . 0
Cosine . . .	positive 1 . . . 0	negative 0 . . . −1	negative −1 . . . 0	positive 0 . . . 1
Tangent . .	positive 0 . . . ∞	negative ∞ . . . 0	positive 0 . . . ∞	negative ∞ . . . 0
Cosecant . .	positive ∞ . . . 1	positive 1 . . . ∞	negative ∞ . . . −1	negative −1 . . . ∞
Secant . . .	positive 1 . . . ∞	negative ∞ . . . −1	negative −1 . . . ∞	positive ∞ . . . 1
Cotangent . .	positive ∞ . . . 0	negative 0 . . . ∞	positive ∞ . . . 0	negative 0 . . . ∞

TABLE OF VALUES OF TRIGONOMETRICAL RATIOS OF ANGLES.

Ratio	0°	30°	45°	60°	90°	120°	135°	150°	180°
Sine . .	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
Cosine . .	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	−1
Tangent . .	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	$-\sqrt{3}$	−1	$-\frac{1}{\sqrt{3}}$	0
Cotangent .	∞	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	$-\frac{1}{\sqrt{3}}$	−1	$-\sqrt{3}$	∞
Secant . .	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞	−2	$-\sqrt{2}$	$-\frac{2}{\sqrt{3}}$	−1
Cosecant . .	∞	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞
Circular Measure	$\frac{\pi}{\infty}$	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{\pi}{2}$	$\frac{2\pi}{3}$	$\frac{3\pi}{4}$	$\frac{5\pi}{6}$	π

Formulæ for Right-angled Triangles.

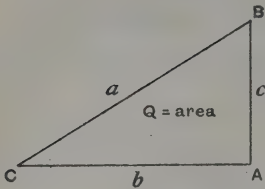


FIG. 100.

$$a = \sqrt{b^2+c^2} = \frac{c}{\sin C} = \frac{b}{\cos C} = 2\sqrt{\frac{Q}{\sin 2C}}.$$

$$b = a\cos C = c\cot C = a\sin B = c\tan B = \sqrt{\frac{2Q}{\tan C}}$$

$$Q = \frac{a^2\sin 2C}{4} = \frac{b^2\tan C}{2} = \frac{c^2\sin 2C}{2} = \frac{c\sqrt{(a+c)(a-c)}}{2}.$$

$$\sin C = \frac{c}{a};\ \cos C = \frac{b}{a};\ \tan C = \frac{c}{b} = \frac{2Q}{b^2};\ \sin 2C = \frac{4Q}{a^2}.$$

Formulæ for Oblique-angled Triangles.

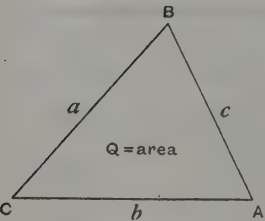


FIG. 101.

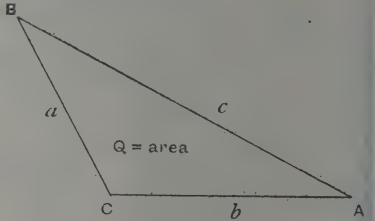


FIG. 102.

(1) Given the lengths of the three sides, a, b, c.

$$s = \tfrac{1}{2}(a+b+c).$$

$$\sin\frac{A}{2} = \sqrt{\frac{(s-b)(s-c)}{bc}};\ \sin\frac{B}{2} = \sqrt{\frac{(s-a)(s-c)}{ac}};\ \sin\frac{C}{2} = \sqrt{\frac{(s-a)(s-b)}{ab}}.$$

$$\cos\frac{A}{2} = \sqrt{\frac{s(s-a)}{bc}};\quad \cos\frac{B}{2} = \sqrt{\frac{s(s-b)}{ac}};\quad \cos\frac{C}{2} = \sqrt{\frac{s(s-c)}{ab}}.$$

$$\tan\frac{A}{2} = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}};\ \tan\frac{B}{2} = \sqrt{\frac{(s-a)(s-c)}{s(s-b)}};\ \tan\frac{C}{2} = \sqrt{\frac{(s-a)(s-b)}{s(s-c)}}.$$

(2) Given one side and two adjacent angles, viz. a, B, C.

$$A = 180 - (B+C);\qquad b = a\frac{\sin B}{\sin A};\qquad c = a\frac{\sin C}{\sin A}.$$

(3) Given two sides and the included angle, viz. b, c, A.

$\tan\frac{B-C}{2} = \frac{b-c}{b+c}\cot\frac{A}{2}$, from which $\frac{B-C}{2}$ can be determined; then $B = \frac{B-C}{2} + 90 - \frac{A}{2}$.

(4) Given two sides and the angle opposite one of them, viz. a, b, A.

$$\sin B = \frac{b}{a}\sin A;\qquad C = 180 - (A+B);\qquad c = a\frac{\sin C}{\sin A},$$

which if

A is not less than 90°	C must be acute;
a is less than $c\sin A$	there is no solution;
a equals $c\sin A$	C is a right angle;
a is greater than $c\sin A$	C may be acute or obtuse;
a equals or is greater than c	C must be acute.

$$Q = \frac{bc\sin A}{2} = \frac{ac\sin B}{2} = \frac{ab\sin C}{2} = \frac{c^2\sin A\sin B}{2\sin(A+B)} = \sqrt{s(s-a)(s-b)(s-c)}.$$

$$a = \sqrt{\frac{2Q\sin A}{\sin B\sin(A+B)}};\qquad b = \sqrt{\frac{2Q\sin B}{\sin C\sin(B+C)}};\qquad c = \sqrt{\frac{2Q\sin C}{\sin A\sin(A+C)}}$$

$$a = \sqrt{b^2+c^2-2bc\cos A}.$$

NATURAL SINES, TANGENTS, &c.

	Sine.	Tang.	Cotang.	Cosine.	
0 Deg.					
0′	·0000000	·000000	Infinite	1·000000	60
1	·0002909	·000291	3437·746	1·000000	59
2	·0005818	·000582	1718·873	·9999998	58
3	·0008727	·000872	1145·915	·9999996	57
4	·0011636	·001163	859·4363	·9999993	56
5	·0014544	·001454	687·5488	·9999989	55
6	·0017453	·001745	572·9572	·9999985	54
7	·0020362	·002036	491·1060	·9999979	53
8	·0023271	·002327	429·7175	·9999973	52
9	·0026180	·002618	381·9709	·9999966	51
10	·0029089	·002908	343·7737	·9999958	50
11	·0031998	·003199	312·5213	·9999949	49
12	·0034907	·003490	286·4777	·9999939	48
13	·0037815	·003781	264·4408	·9999928	47
14	·0040724	·004072	245·5519	·9999917	46
15	·0043633	·004363	229·1816	·9999905	45
16	·0046542	·004654	214·8576	·9999892	44
17	·0049451	·004945	202·2187	·9999878	43
18	·0052360	·005236	190·9841	·9999863	42
19	·0055268	·005526	180·9322	·9999847	41
20	·0058177	·005817	171·8854	·9999831	40
21	·0061086	·006108	163·7001	·9999813	39
22	·0063995	·006399	156·2590	·9999795	38
23	·0066904	·006690	149·4650	·9999776	37
24	·0069813	·006981	143·2371	·9999756	36
25	·0072721	·007272	137·5075	·9999736	35
26	·0075630	·007563	132·2185	·9999714	34
27	·0078539	·007854	127·3213	·9999692	33
28	·0081448	·008145	122·7739	·9999668	32
29	·0084357	·008436	118·5401	·9999644	31
30	·0087265	·008726	114·5886	·9999619	30
31	·0090174	·009017	110·8920	·9999593	29
32	·0093083	·009308	107·4264	·9999567	28
33	·0095992	·009599	104·1709	·9999539	27
34	·0098900	·009890	101·1069	·9999511	26
35	·0101809	·010181	98·21794	·9999482	25
36	·0104718	·010472	95·48947	·9999452	24
37	·0107627	·010763	92·90848	·9999421	23
38	·0110535	·011054	90·46333	·9999389	22
39	·0113444	·011345	88·14357	·9999357	21
40	·0116353	·011636	85·93979	·9999323	20
41	·0119261	·011927	83·84350	·9999289	19
42	·0122170	·012217	81·84704	·9999254	18
43	·0125079	·012508	79·94343	·9999218	17
44	·0127987	·012799	78·12634	·9999181	16
45	·0130896	·013090	76·39000	·9999143	15
46	·0133805	·013381	74·72916	·9999105	14
47	·0136713	·013672	73·13899	·9999065	13
48	·0139622	·013963	71·61507	·9999025	12
49	·0142530	·014254	70·15334	·9998984	11
50	·0145439	·014545	68·75008	·9998942	10
51	·0148348	·014836	67·40185	·9998900	9
52	·0151256	·015127	66·10547	·9998856	8
53	·0154165	·015418	64·85800	·9998812	7
54	·0157073	·015709	63·65674	·9998766	6
55	·0159982	·016000	62·49915	·9998720	5
56	·0162890	·016291	61·38290	·9998673	4
57	·0165799	·016582	60·30582	·9998625	3
58	·0168707	·016873	59·26587	·9998577	2
59	·0171616	·017164	58·26117	·9998527	1
60	·0174524	·017455	57·28996	·9998477	0′
					89 Deg.

	Sine.	Tang.	Cotang.	Cosine.	
1 Deg.					
0′	·0174524	·017455	57·28996	·9998477	60
5	·0189066	·018910	52·88211	·9998213	55
10	·0203608	·020365	49·10388	·9997927	50
15	·0218149	·021820	45·82935	·9997620	45
20	·0232690	·023275	42·96407	·9997292	40
25	·0247230	·024730	40·43583	·9996943	35
30	·0261769	·026185	38·18845	·9996573	30
35	·0276309	·027641	36·17759	·9996182	25
40	·0290847	·029097	34·36777	·9995770	20
45	·0305385	·030552	32·73026	·9995336	15
50	·0319922	·032008	31·24157	·9994881	10
55	·0334459	·033464	29·88229	·9994405	5
60	·0348995	·034920	28·63625	·9993908	0′
					88 Deg.
2 Deg.					
0′	·0348955	·034920	28·63625	·9993908	60
5	·0363530	·036377	27·48985	·9993390	55
10	·0378065	·037833	26·43160	·9992851	50
15	·0392598	·039290	25·45170	·9992290	45
20	·0407131	·040746	24·54175	·9991709	40
25	·0421663	·042203	23·69453	·9991106	35
30	·0436194	·043660	22·90376	·9990482	30
35	·0450724	·045118	22·16398	·9989837	25
40	·0465253	·046575	21·47040	·9989171	20
45	·0479781	·048033	20·81882	·9988484	15
50	·0494308	·049491	20·20555	·9987775	10
55	·0508835	·050949	19·62729	·9987046	5
60	·0523360	·052407	19·08113	·9986295	0′
					87 Deg.
3 Deg.					
0′	·0523360	·052407	19·08113	·9986295	60
5	·0537883	·053866	18·56447	·9985524	55
10	·0552406	·055325	18·07497	·9984731	50
15	·0566928	·056784	17·61055	·9983917	45
20	·0581448	·058243	17·16933	·9983082	40
25	·0595967	·059702	16·74961	·9982225	35
30	·0610485	·061162	16·34985	·9981348	30
35	·0625002	·062622	15·96866	·9980450	25
40	·0639517	·064082	15·60478	·9979530	20
45	·0654031	·065543	15·25705	·9978589	15
50	·0668544	·067004	14·92441	·9977627	10
55	·0683055	·068465	14·60591	·9976645	5
60	·0697565	·069926	14·30066	·9975641	0′
					86 Deg.
4 Deg.					
0′	·0697565	·069926	14·30066	·9975641	60
5	·0712073	·071388	14·00785	·9974615	55
10	·0726580	·072850	13·72673	·9973569	50
15	·0741085	·074312	13·45662	·9972502	45
20	·0755589	·075775	13·19688	·9971413	40
25	·0770091	·077238	12·94692	·9970304	35
30	·0784591	·078701	12·70620	·9969173	30
35	·0799090	·080165	12·47422	·9968022	25
40	·0813587	·081629	12·25050	·9966849	20
45	·0828082	·083093	12·03462	·9965655	15
50	·0842576	·084558	11·82616	·9964440	10
55	·0857067	·086023	11·62476	·9963204	5
60	·0871557	·087488	11·43005	·9961947	0′
					85 Deg.

Cosine.	Cotan.	Tang.	Sine.

NATURAL SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
5 Deg.					
0′	·0871557	·087488	11·43005	·9961947	60
5	·0886046	·088954	11·24171	·9960669	55
10	·0900532	·090420	11·05943	·9959370	50
15	·0915016	·091887	10·88292	·9958049	45
20	·0929499	·093354	10·71191	·9956708	40
25	·0943979	·094821	10·54615	·9955345	35
30	·0958458	·096289	10·38539	·9953962	30
35	·0972934	·097757	10·22942	·9952557	25
40	·0987408	·099225	10·07803	·9951132	20
45	·1001881	·100694	9·931008	·9949685	15
50	·1016351	·102164	9·788173	·9948217	10
55	·1030819	·103634	9·649347	·9946729	5
60	·1045285	·105104	9·514364	·9945219	0′
					84 Deg.
6 Deg.					
0′	·1045285	·105104	9·514364	·9945219	60
5	·1059748	·106575	9·383066	·9943688	55
10	·1074210	·108046	9·255303	·9942136	50
15	·1088669	·109517	9·130934	·9940563	45
20	·1103126	·110989	9·009826	·9938969	40
25	·1117580	·112462	8·891850	·9937355	35
30	·1132032	·113935	8·776887	·9935719	30
35	·1146482	·115409	8·664822	·9934062	25
40	·1160929	·116883	8·555546	·9932384	20
45	·1175374	·118357	8·448957	·9930685	15
50	·1189816	·119832	8·344955	·9928965	10
55	·1204256	·121308	8·243448	·9927224	5
60	·1218693	·122784	8·144346	·9925462	0′
					83 Deg.
7 Deg.					
0′	·1218693	·122784	8·144346	·9925462	60
5	·1233128	·124261	8·047564	·9923679	55
10	·1247560	·125738	7·953022	·9921874	50
15	·1261990	·127216	7·860642	·9920049	45
20	·1276416	·128694	7·770350	·9918204	40
25	·1290841	·130173	7·682076	·9916337	35
30	·1305262	·131652	7·595754	·9914449	30
35	·1319681	·133132	7·511317	·9912540	25
40	·1334096	·134612	7·428706	·9910610	20
45	·1348509	·136094	7·347861	·9908659	15
50	·1362919	·137575	7·268725	·9906687	10
55	·1377327	·139058	7·191245	·9904694	5
60	·1391731	·140540	7·115369	·9902681	0′
					82 Deg.
8 Deg.					
0′	·1391731	·140540	7·115369	·9902681	60
5	·1406132	·142024	7·041048	·9900646	55
10	·1420531	·143508	6·968233	·9898590	50
15	·1434926	·144993	6·896879	·9896514	45
20	·1449319	·146478	6·826943	·9894416	40
25	·1463708	·147964	6·758382	·9892298	35
30	·1478094	·149451	6·691156	·9890159	30
35	·1492477	·150938	6·625225	·9887998	25
40	·1506857	·152426	6·560553	·9885817	20
45	·1521234	·153914	6·497104	·9883615	15
50	·1535607	·155404	6·434842	·9881392	10
55	·1549978	·156893	6·373735	·9879148	5
60	·1564345	·158384	6·313751	·9876883	0′
					81 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
9 Deg.					
0′	·1564345	·158384	6·313751	·9876883	60
5	·1578708	·159875	6·254858	·9874598	55
10	·1593069	·161367	6·197027	·9872291	50
15	·1607426	·162860	6·140230	·9869964	45
20	·1621779	·164353	6·084438	·9867615	40
25	·1636129	·165847	6·029624	·9865246	35
30	·1650476	·167342	5·975764	·9862856	30
35	·1664819	·168838	5·922832	·9860445	25
40	·1679159	·170334	5·870804	·9858013	20
45	·1693495	·171831	5·819657	·9855561	15
50	·1707828	·173329	5·769368	·9853087	10
55	·1722156	·174827	5·719917	·9850593	5
60	·1736482	·176327	5·671281	·9848078	0′
					80 Deg.
10 Deg.					
0′	·1736482	·176327	5·671281	·9848078	60
5	·1750803	·177827	5·623442	·9845542	55
10	·1765121	·179327	5·576378	·9842985	50
15	·1779435	·180829	5·530072	·9840407	45
20	·1793746	·182331	5·484505	·9837808	40
25	·1808052	·183835	5·439659	·9835189	35
30	·1822355	·185339	5·395517	·9832549	30
35	·1836654	·186843	5·352062	·9829888	25
40	·1850949	·188349	5·309279	·9827206	20
45	·1865240	·189855	5·267151	·9824504	15
50	·1879528	·191363	5·225664	·9821781	10
55	·1893811	·192871	5·184803	·9819037	5
60	·1908090	·194380	5·144554	·9816272	0′
					79 Deg.
11 Deg.					
0′	·1908090	·194380	5·144554	·9816272	60
5	·1922365	·195890	5·104902	·9813486	55
10	·1936636	·197400	5·065835	·9810680	50
15	·1950903	·198912	5·027339	·9807853	45
20	·1965166	·200424	4·989402	·9805005	40
25	·1979425	·201938	4·952012	·9802136	35
30	·1993679	·203452	4·915157	·9799247	30
35	·2007930	·204967	4·878824	·9796337	25
40	·2022176	·206483	4·843004	·9793406	20
45	·2036418	·208000	4·807685	·9790455	15
50	·2050655	·209518	4·772856	·9787483	10
55	·2064888	·211036	4·738508	·9784490	5
60	·2079117	·212556	4·704630	·9781476	0′
					78 Deg.
12 Deg.					
0′	·2079117	·212556	4·704630	·9781476	60
5	·2093341	·214077	4·671212	·9778441	55
10	·2107561	·215598	4·638245	·9775386	50
15	·2121777	·217121	4·605720	·9772311	45
20	·2135988	·218644	4·573628	·9769215	40
25	·2150194	·220169	4·541960	·9766098	35
30	·2164396	·221694	4·510708	·9762960	30
35	·2178593	·223221	4·479863	·9759802	25
40	·2192786	·224748	4·449418	·9756623	20
45	·2206974	·226276	4·419364	·9753423	15
50	·2221158	·227806	4·389694	·9750203	10
55	·2235337	·229336	4·360400	·9746962	5
60	·2249511	·230868	4·331475	·9743701	0′
					77 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

NATURAL SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
13 Deg.					
0′	·2249511	·230868	4·331475	·9743701	60
5	·2263680	·232400	4·302913	·9740419	55
10	·2277844	·233934	4·274706	·9737116	50
15	·2292004	·235468	4·246848	·9733792	45
20	·2306159	·237004	4·219331	·9730449	40
25	·2320309	·238541	4·192151	·9727084	35
30	·2334454	·240078	4·165299	·9723699	30
35	·2348594	·241617	4·138771	·9720294	25
40	·2362729	·243157	4·112561	·9716867	20
45	·2376859	·244698	4·086662	·9713421	15
50	·2390984	·246240	4·061070	·9709953	10
55	·2405104	·247783	4·035777	·9706466	5
60	·2419219	·249328	4·010780	·9702957	0′
					76 Deg.
14 Deg.					
0′	·2419219	·249328	4·010780	·9702957	60
5	·2433329	·250873	3·986073	·9699428	55
10	·2447433	·252420	3·961651	·9695879	50
15	·2461533	·253967	3·937509	·9692309	45
20	·2475627	·255516	3·913642	·9688719	40
25	·2489716	·257066	3·890044	·9685108	35
30	·2503800	·258617	3·866713	·9681476	30
35	·2517879	·260169	3·843642	·9677825	25
40	·2531952	·261723	3·820828	·9674152	20
45	·2546019	·263278	3·798266	·9670459	15
50	·2560082	·264833	3·775951	·9666746	10
55	·2574139	·266390	3·753881	·9663012	5
60	·2588190	·267949	3·732050	·9659258	0′
					75 Deg.
15 Deg.					
0′	·2588190	·267949	3·732050	·9659258	60
5	·2602237	·269508	3·710455	·9655484	55
10	·2616277	·271069	3·689092	·9651689	50
15	·2630312	·272631	3·667957	·9647873	45
20	·2644342	·274194	3·647046	·9644037	40
25	·2658366	·275758	3·626356	·9640181	35
30	·2672384	·277324	3·605883	·9636305	30
35	·2686396	·278891	3·585624	·9632408	25
40	·2700403	·280459	3·565574	·9628490	20
45	·2714404	·282029	3·545732	·9624552	15
50	·2728400	·283599	3·526093	·9620594	10
55	·2742390	·285172	3·506655	·9616616	5
60	·2756374	·286745	3·487414	·9612617	0′
					74 Deg.
16 Deg.					
0′	·2756374	·286745	3·487414	·9612617	60
5	·2770352	·288320	3·468367	·9608598	55
10	·2784324	·289896	3·449512	·9604558	50
15	·2798290	·291473	3·430844	·9600499	45
20	·2812251	·293052	3·412362	·9596418	40
25	·2826205	·294632	3·394063	·9592318	35
30	·2840153	·296213	3·375943	·9588197	30
35	·2854096	·297796	3·358000	·9584056	25
40	·2868032	·299380	3·340232	·9579895	20
45	·2881963	·300965	3·322636	·9575714	15
50	·2895887	·302552	3·305209	·9571512	10
55	·2909805	·304141	3·287948	·9567290	5
60	·2923717	·305730	3·270852	·9563048	0′
					73 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
17 Deg.					
0′	·2923717	·305730	3·270852	·9563048	60
5	·2937623	·307321	3·253918	·9558785	55
10	·2951522	·308914	3·237143	·9554502	50
15	·2965416	·310508	3·220526	·9550199	45
20	·2979303	·312103	3·204063	·9545876	40
25	·2993184	·313700	3·187754	·9541533	35
30	·3007058	·315298	3·171594	·9537170	30
35	·3020926	·316898	3·155584	·9532786	25
40	·3034788	·318499	3·139719	·9528382	20
45	·3048643	·320102	3·123999	·9523958	15
50	·3062492	·321706	3·108421	·9519514	10
55	·3076334	·323312	3·092983	·9515050	5
60	·3090170	·324919	3·077683	·9510565	0′
					72 Deg.
18 Deg.					
0′	·3090170	·324919	3·077683	·9510565	60
5	·3103999	·326528	3·062520	·9506061	55
10	·3117822	·328138	3·047491	·9501536	50
15	·3131638	·329750	3·032595	·9496991	45
20	·3145448	·331363	3·017830	·9492426	40
25	·3159250	·332978	3·003193	·9487842	35
30	·3173047	·334595	2·988685	·9483237	30
35	·3186836	·336213	2·974301	·9478612	25
40	·3200619	·337833	2·960042	·9473966	20
45	·3214395	·339454	2·945905	·9469301	15
50	·3228164	·341077	2·931888	·9464616	10
55	·3241926	·342701	2·917990	·9459911	5
60	·3255682	·344327	2·904210	·9455186	0′
					71 Deg.
19 Deg.					
0′	·3255682	·344327	2·904210	·9455186	60
5	·3269430	·345955	2·890546	·9450441	55
10	·3283172	·347584	2·876997	·9445675	50
15	·3296906	·349215	2·863560	·9440890	45
20	·3310634	·350848	2·850234	·9436085	40
25	·3324355	·352482	2·837019	·9431260	35
30	·3338069	·354118	2·823912	·9426415	30
35	·3351775	·355756	2·810913	·9421550	25
40	·3365475	·357395	2·798019	·9416665	20
45	·3379167	·359036	2·785230	·9411760	15
50	·3392852	·360679	2·772544	·9406835	10
55	·3406531	·362324	2·759960	·9401891	5
60	·3420201	·363970	2·747477	·9396926	0′
					70 Deg.
20 Deg.					
0′	·3420201	·363970	2·747477	·9396926	60
5	·3433865	·365618	2·735093	·9391942	55
10	·3447521	·367268	2·722807	·9386938	50
15	·3461171	·368919	2·710618	·9381913	45
20	·3474812	·370572	2·698525	·9376869	40
25	·3488447	·372227	2·686526	·9371806	35
30	·3502074	·373884	2·674621	·9366722	30
35	·3515693	·375543	2·662808	·9361618	25
40	·3529306	·377203	2·651086	·9356495	20
45	·3542910	·378866	2·639454	·9351352	15
50	·3556508	·380530	2·627912	·9346189	10
55	·3570097	·382196	2·616457	·9341007	5
60	·3583679	·383864	2·605089	·9335804	0′
					69 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

Natural Signs, Tangents, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.			Sine.	Tang.	Cotang.	Cosine.	
21 Deg.						25 Deg.					
0′	·3583679	·383864	2·605089	·9335804	60	0′	·4226183	·466307	2·144506	·9063078	60
5	·3597254	·385533	2·593806	·9330582	55	5	·4239360	·468079	2·136389	·9056922	55
10	·3610821	·387205	2·582609	·9325340	50	10	·4252528	·469853	2·128321	·9050746	50
15	·3624380	·388878	2·571495	·9320079	45	15	·4265687	·471630	2·120303	·9044551	45
20	·3637932	·390554	2·560464	·9314797	40	20	·4278838	·473409	2·112334	·9038338	40
25	·3651476	·392231	2·549516	·9309496	35	25	·4291979	·475191	2·104415	·9032105	35
30	·3665012	·393910	2·538647	·9304176	30	30	·4305111	·476975	2·096543	·9025853	30
35	·3678541	·395591	2·527859	·9298835	25	35	·4318234	·478762	2·088720	·9019582	25
40	·3692061	·397274	2·517150	·9293475	20	40	·4331348	·480551	2·080943	·9013292	20
45	·3705574	·398959	2·506519	·9288096	15	45	·4344453	·482342	2·073214	·9006982	15
50	·3719079	·400646	2·495966	·9282696	10	50	·4357548	·484136	2·065531	·9000654	10
55	·3732577	·402335	2·485488	·9277277	5	55	·4370634	·485933	2·057895	·8994307	5
60	·3746066	·404026	2·475086	·9271839	0′	60	·4383711	·487732	2·050303	·8987940	0′
					68 Deg.						64 Deg.
22 Deg.						26 Deg.					
0′	·3746066	·404026	2·475086	·9271839	60	0′	·4383711	·487732	2·050303	·8987940	60
5	·3759547	·405719	2·464759	·9266380	55	5	·4396779	·489534	2·042757	·8981555	55
10	·3773021	·407413	2·454506	·9260902	50	10	·4409838	·491338	2·035256	·8975151	50
15	·3786486	·409110	2·444325	·9255405	45	15	·4422887	·493145	2·027799	·8968727	45
20	·3799944	·410809	2·434217	·9249888	40	20	·4435927	·494954	2·020386	·8962285	40
25	·3813393	·412510	2·424180	·9244351	35	25	·4448957	·496766	2·013016	·8955824	35
30	·3826834	·414213	2·414213	·9238795	30	30	·4461978	·498581	2·005689	·8949344	30
35	·3840268	·415918	2·404316	·9233220	25	35	·4474990	·500398	1·998405	·8942844	25
40	·3853693	·417625	2·394488	·9227624	20	40	·4487992	·502218	1·991163	·8936326	20
45	·3867110	·419334	2·384729	·9222010	15	45	·4500984	·504041	1·983963	·8929789	15
50	·3880518	·421046	2·375037	·9216375	10	50	·4513967	·505866	1·976805	·8923234	10
55	·3893919	·422759	2·365411	·9210722	5	55	·4526941	·507694	1·969687	·8916659	5
60	·3907311	·424474	2·355852	·9205049	0′	60	·4539905	·509525	1·962610	·8910065	0′
					67 Deg.						63 Deg.
23 Deg.						27 Deg.					
0′	·3907311	·424474	2·355852	·9205049	60	0′	·4539905	·509525	1·962610	·8910065	60
5	·3920695	·426192	2·346358	·9199356	55	5	·4552859	·511358	1·955573	·8903453	55
10	·3934071	·427912	2·336928	·9193644	50	10	·4565804	·513195	1·948577	·8896822	50
15	·3947439	·429633	2·327563	·9187912	45	15	·4578739	·515033	1·941620	·8890171	45
20	·3960798	·431357	2·318260	·9182161	40	20	·4591665	·516875	1·934702	·8883503	40
25	·3974148	·433084	2·309020	·9176391	35	25	·4604580	·518719	1·927822	·8876815	35
30	·3987491	·434812	2·299842	·9170601	30	30	·4617486	·520567	1·920982	·8870108	30
35	·4000825	·436542	2·290725	·9164791	25	35	·4630382	·522417	1·914179	·8863383	25
40	·4014150	·438275	2·281669	·9158963	20	40	·4643269	·524269	1·907414	·8856639	20
45	·4027467	·440010	2·272672	·9153115	15	45	·4656145	·526125	1·900687	·8849876	15
50	·4040775	·441747	2·263735	·9147247	10	50	·4669012	·527983	1·893997	·8843095	10
55	·4054075	·443487	2·254857	·9141361	5	55	·4681869	·529845	1·887343	·8836295	5
60	·4067366	·445228	2·246036	·9135455	0′	60	·4694716	·531709	1·880726	·8829476	0′
					66 Deg.						62 Deg.
24 Deg.						28 Deg.					
0′	·4067366	·445228	2·246036	·9135455	60	0′	·4694716	·531709	1·880726	·8829476	60
5	·4080649	·446972	2·237273	·9129529	55	5	·4707553	·533576	1·874145	·8822638	55
10	·4093923	·448718	2·228567	·9123584	50	10	·4720380	·535446	1·867600	·8815782	50
15	·4107189	·450467	2·219917	·9117620	45	15	·4733197	·537319	1·861090	·8808907	45
20	·4120445	·452217	2·211323	·9111637	40	20	·4746004	·539195	1·854615	·8802014	40
25	·4133693	·453970	2·202784	·9105635	35	25	·4758801	·541074	1·848176	·8795102	35
30	·4146932	·455726	2·194299	·9099613	30	30	·4771588	·542955	1·841770	·8788171	30
35	·4160163	·457483	2·185869	·9093572	25	35	·4784364	·544840	1·835399	·8781222	25
40	·4173385	·459243	2·177492	·9087511	20	40	·4797131	·546728	1·829062	·8774254	20
45	·4186597	·461006	2·169167	·9081432	15	45	·4809888	·548618	1·822759	·8767268	15
50	·4199801	·462771	2·160895	·9075333	10	50	·4822634	·550512	1·816489	·8760263	10
55	·4212996	·464538	2·152675	·9069215	5	55	·4835370	·552409	1·810252	·8753239	5
60	·4226183	·466307	2·144506	·9063078	0′	60	·4848096	·554309	1·804047	·8746197	0′
					65 Deg.						61 Deg.
	Cosine.	Cotan.	Tang.	Sine.			Cosine.	Cotan.	Tang.	Sine.	

NATURAL SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
29 Deg.					
0′	·4848096	·554309	1·804047	·8746197	60
5	·4860812	·556211	1·797875	·8739137	55
10	·4873517	·558117	1·791736	·8732058	50
15	·4886212	·560026	1·785628	·8724960	45
20	·4898897	·561939	1·779552	·8717844	40
25	·4911572	·563854	1·773507	·8710710	35
30	·4924236	·565772	1·767494	·8703557	30
35	·4936889	·567694	1·761511	·8696386	25
40	·4949532	·569619	1·755559	·8689196	20
45	·4962165	·571547	1·749637	·8681988	15
50	·4974787	·573478	1·743745	·8674762	10
55	·4987399	·575412	1·737883	·8667517	5
60	·5000000	·577350	1·732050	·8660254	0′
					60 Deg.
30 Deg.					
0′	·5000000	·577350	1·732050	·8660254	60
5	·5012591	·579291	1·726247	·8652973	55
10	·5025170	·581235	1·720473	·8645673	50
15	·5037740	·583182	1·714728	·8638355	45
20	·5050298	·585133	1·709011	·8631019	40
25	·5062846	·587087	1·703323	·8623664	35
30	·5075384	·589045	1·697663	·8616292	30
35	·5087910	·591005	1·692030	·8608901	25
40	·5100426	·592969	1·686426	·8601491	20
45	·5112931	·594937	1·680848	·8594064	15
50	·5125425	·596908	1·675298	·8586619	10
55	·5137908	·598882	1·669775	·8579155	5
60	·5150381	·600860	1·664279	·8571673	0′
					59 Deg.
31 Deg.					
0′	·5150381	·600860	1·664279	·8571673	60
5	·5162842	·602841	1·658809	·8564173	55
10	·5175293	·604826	1·653366	·8556655	50
15	·5187733	·606814	1·647949	·8549119	45
20	·5200161	·608806	1·642557	·8541564	40
25	·5212579	·610801	1·637191	·8533992	35
30	·5224986	·612800	1·631851	·8526402	30
35	·5237381	·614803	1·626536	·8518793	25
40	·5249766	·616809	1·621246	·8511167	20
45	·5262139	·618818	1·615982	·8503522	15
50	·5274502	·620832	1·610741	·8495860	10
55	·5286853	·622848	1·605526	·8488179	5
60	·5299193	·624860	1·600334	·8480481	0′
					58 Deg.
32 Deg.					
0′	·5299193	·624869	1·600334	·8480481	60
5	·5311521	·626893	1·595167	·8472765	55
10	·5323839	·628921	1·590023	·8465030	50
15	·5336145	·630953	1·584904	·8457278	45
20	·5348440	·632988	1·579807	·8449508	40
25	·5360724	·635027	1·574735	·8441720	35
30	·5372996	·637070	1·569685	·8433914	30
35	·5385257	·639116	1·564659	·8426091	25
40	·5397507	·641167	1·559655	·8418249	20
45	·5409745	·643221	1·554674	·8410390	15
50	·5421971	·645279	1·549715	·8402513	10
55	·5434187	·647341	1·544779	·8394618	5
60	·5446390	·649407	1·539865	·8386706	0′
					57 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
33 Deg.					
0′	·5446390	·649407	1·539865	·8386706	60
5	·5458583	·651477	1·534972	·8378775	55
10	·5470763	·653551	1·530102	·8370827	50
15	·5482932	·655628	1·525253	·8362862	45
20	·5495090	·657710	1·520426	·8354878	40
25	·5507236	·659796	1·515620	·8346877	35
30	·5519370	·661885	1·510835	·8338858	30
35	·5531492	·663979	1·506071	·8330822	25
40	·5543603	·666076	1·501328	·8322768	20
45	·5555702	·668178	1·496605	·8314696	15
50	·5567790	·670284	1·491903	·8306607	10
55	·5579865	·672394	1·487222	·8298500	5
60	·5591929	·674508	1·482561	·8290376	0′
					56 Deg.
34 Deg.					
0′	·5591929	·674508	1·482561	·8290376	60
5	·5603981	·676626	1·477919	·8282234	55
10	·5616021	·678749	1·473298	·8274074	50
15	·5628049	·680875	1·468696	·8265897	45
20	·5640066	·683006	1·464114	·8257703	40
25	·5652070	·685141	1·459552	·8249491	35
30	·5664062	·687281	1·455009	·8241262	30
35	·5676043	·689424	1·450485	·8233015	25
40	·5688011	·691572	1·445980	·8224751	20
45	·5699968	·693724	1·441494	·8216469	15
50	·5711912	·695881	1·437026	·8208170	10
55	·5723844	·698042	1·432578	·8199854	5
60	·5735764	·700207	1·428148	·8191520	0′
					55 Deg.
35 Deg.					
0′	·5735764	·700207	1·428148	·8191520	60
5	·5747672	·702377	1·423736	·8183169	55
10	·5759568	·704551	1·419342	·8174801	50
15	·5771452	·706730	1·414967	·8166416	45
20	·5783323	·708913	1·410609	·8158013	40
25	·5795183	·711100	1·406270	·8149593	35
30	·5807030	·713293	1·401948	·8141155	30
35	·5818864	·715489	1·397644	·8132701	25
40	·5830687	·717691	1·393357	·8124229	20
45	·5842497	·719897	1·389087	·8115740	15
50	·5854294	·722107	1·384835	·8107234	10
55	·5866080	·724322	1·380600	·8098710	5
60	·5877853	·726542	1·376381	·8090170	0′
					54 Deg.
36 Deg.					
0′	·5877853	·726542	1·376381	·8090170	60
5	·5889613	·728767	1·372180	·8081612	55
10	·5901361	·730996	1·367995	·8073038	50
15	·5913096	·733230	1·363827	·8064446	45
20	·5924819	·735469	1·359676	·8055837	40
25	·5936530	·737712	1·355541	·8047211	35
30	·5948228	·739961	1·351422	·8038569	30
35	·5959913	·742214	1·347319	·8029909	25
40	·5971586	·744472	1·343233	·8021232	20
45	·5983246	·746735	1·339162	·8012538	15
50	·5994893	·749003	1·335107	·8003827	10
55	·6006528	·751276	1·331068	·7995100	5
60	·6018150	·753554	1·327044	·7986355	0′
					53 Deg.
	Cosine.	Cotan.	Tang.	Sine.	

NATURAL SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
37 Deg.					
0′	·6018150	·753554	1·327044	·7986355	60
5	·6029760	·755836	1·323036	·7977594	55
10	·6041356	·758124	1·319044	·7968815	50
15	·6052940	·760417	1·315066	·7960020	45
20	·6064511	·762715	1·311104	·7951208	40
25	·6076069	·765018	1·307157	·7942379	35
30	·6087614	·767327	1·303225	·7933533	30
35	·6099147	·769640	1·299308	·7924671	25
40	·6110666	·771958	1·295405	·7915792	20
45	·6122173	·774282	1·291517	·7906896	15
50	·6133666	·776611	1·287644	·7897983	10
55	·6145147	·778946	1·283786	·7889054	5
60	·6156615	·781285	1·279941	·7880108	0′
				52 Deg.	
38 Deg.					
0′	·6156615	·781285	1·279941	·7880108	60
5	·6168069	·783630	1·276111	·7871145	55
10	·6179511	·785980	1·272295	·7862165	50
15	·6190939	·788336	1·268494	·7853169	45
20	·6202355	·790697	1·264706	·7844157	40
25	·6213757	·793064	1·260932	·7835127	35
30	·6225146	·795435	1·257172	·7826082	30
35	·6236522	·797813	1·253426	·7817019	25
40	·6247885	·800196	1·249693	·7807940	20
45	·6259235	·802584	1·245974	·7798845	15
50	·6270571	·804979	1·242268	·7789733	10
55	·6281894	·807378	1·238576	·7780604	5
60	·6293204	·809784	1·234897	·7771460	0′
				51 Deg.	
39 Deg.					
0′	·6293204	·809784	1·234897	·7771460	60
5	·6304500	·812195	1·231231	·7762298	55
10	·6315784	·814611	1·227578	·7753121	50
15	·6327053	·817034	1·223938	·7743926	45
20	·6338310	·819462	1·220312	·7734716	40
25	·6349553	·821896	1·216698	·7725489	35
30	·6360782	·824336	1·213097	·7716246	30
35	·6371998	·826782	1·209508	·7706986	25
40	·6383201	·829233	1·205932	·7697710	20
45	·6394390	·831691	1·202369	·7688418	15
50	·6405566	·834154	1·198818	·7679110	10
55	·6416728	·836624	1·195279	·7669785	5
60	·6427876	·839099	1·191753	·7660444	0′
				50 Deg.	
40 Deg.					
0′	·6427876	·839099	1·191753	·7660444	60
5	·6439011	·841581	1·188239	·7651087	55
10	·6450132	·844068	1·184737	·7641714	50
15	·6461240	·846562	1·181247	·7632325	45
20	·6472334	·849062	1·177769	·7622919	40
25	·6483414	·851568	1·174303	·7613497	35
30	·6494480	·854080	1·170849	·7604060	30
35	·6505533	·856599	1·167407	·7594606	25
40	·6516572	·859124	1·163976	·7585136	20
45	·6527598	·861655	1·160557	·7575650	15
50	·6538609	·864192	1·157149	·7566148	10
55	·6549607	·866736	1·153753	·7556630	5
60	·6560590	·869286	1·150368	·7547096	0′
				49 Deg.	

	Sine.	Tang.	Cotang.	Cosine.	
41 Deg.					
0′	·6560590	·869286	1·150368	·7547096	60
5	·6571560	·871843	1·146994	·7537546	55
10	·6582516	·874406	1·143632	·7527980	50
15	·6593458	·876976	1·140281	·7518398	45
20	·6604386	·879552	1·136941	·7508800	40
25	·6615300	·882135	1·133612	·7499187	35
30	·6626200	·884725	1·130294	·7489557	30
35	·6637087	·887321	1·126987	·7479912	25
40	·6647959	·889924	1·123690	·7470251	20
45	·6658817	·892534	1·120405	·7460574	15
50	·6669661	·895150	1·117130	·7450881	10
55	·6680490	·897773	1·113866	·7441173	5
60	·6691306	·900404	1·110612	·7431448	0′
					48 Deg.
42 Deg.					
0′	·6691306	·900404	1·110612	·7431448	60
5	·6702108	·903041	1·107369	·7421708	55
10	·6712895	·905685	1·104136	·7411953	50
15	·6723668	·908336	1·100914	·7402181	45
20	·6734427	·910994	1·097702	·7392394	40
25	·6745172	·913659	1·094500	·7382592	35
30	·6755902	·916331	1·091308	·7372773	30
35	·6766618	·919010	1·088126	·7362940	25
40	·6777320	·921696	1·084955	·7353090	20
45	·6788007	·924390	1·081793	·7343225	15
50	·6798681	·927091	1·078642	·7333345	10
55	·6809339	·929799	1·075500	·7323449	5
60	·6819984	·932515	1·072368	·7313537	0′
					47 Deg.
43 Deg.					
0′	·6819984	·932515	1·072368	·7313537	60
5	·6830613	·935238	1·069246	·7303610	55
10	·6841229	·937968	1·066134	·7293668	50
15	·6851830	·940706	1·063031	·7283710	45
20	·6862416	·943451	1·059938	·7273736	40
25	·6872988	·946204	1·056854	·7263748	35
30	·6883546	·948964	1·053780	·7253744	30
35	·6894089	·951732	1·050715	·7243724	25
40	·6904617	·954508	1·047659	·7233690	20
45	·6915131	·957291	1·044613	·7223640	15
50	·6925630	·960082	1·041576	·7213574	10
55	·6936114	·962881	1·038548	·7203494	5
60	·6946584	·965688	1·035530	·7193398	0′
					46 Deg.
44 Deg.					
0′	·6946584	·965688	1·035530	·7193398	60
5	·6957039	·968503	1·032520	·7183287	55
10	·6967479	·971326	1·029520	·7173161	50
15	·6977905	·974156	1·026528	·7163019	45
20	·6988315	·976995	1·023546	·7152863	40
25	·6998711	·979842	1·020572	·7142691	35
30	·7009093	·982697	1·017607	·7132504	30
35	·7019459	·985560	1·014651	·7122303	25
40	·7029811	·988431	1·011703	·7112086	20
45	·7040147	·991311	1·008764	·7101854	15
50	·7050469	·994199	1·005834	·7091607	10
55	·7060776	·997095	1·002913	·7081345	5
60	·7071068	1·00000	1·000000	·7071068	0′
					45 Deg.

Cosine.	Cotan.	Tang.	Sine.
Cosine.	Cotan.	Tang.	Sine.

LOGARITHMIC SINES, TANGENTS, &c.

Deg.	Sine.	Tang.	Cotang.	Cosine.	
0′	1nf Neg	Inf. Neg.	Infinite	10·00000	60
1	6·46373	6·46373	13·53627	10·00000	59
2	6·76476	6·76476	13·23524	10·00000	58
3	6·94085	6·94085	13·05915	10·00000	57
4	7·06579	7·06579	12·93421	10·00000	56
5	7·16270	7·16270	12·83730	10·00000	55
6	7·24188	7·24188	12·75812	10·00000	54
7	7·30882	7·30882	12·69118	10·00000	53
8	7·36682	7·36682	12·63318	10·00000	52
9	7·41797	7·41797	12·58203	10·00000	51
10	7·46373	7·46373	12·53627	10·00000	50
11	7·50512	7·50512	12·49488	10·00000	49
12	7·54291	7·54291	12·45709	10·00000	48
13	7·57767	7·57767	12·42233	10·00000	47
14	7·60985	7·60986	12·39014	10·00000	46
15	7·63982	7·63982	12·36018	10·00000	45
16	7·66784	7·66785	12·33215	10·00000	44
17	7·69417	7·69418	12·30582	9·99999	43
18	7·71900	7·71900	12·28100	9·99999	42
19	7·74248	7·74248	12·25752	9 99999	41
20	7·76475	7·76476	12·23524	9·99999	40
21	7·78594	7·78595	12·21405	9·99999	39
22	7·80615	7·80615	12·19385	9·99999	38
23	7·82545	7·82546	12·17454	9·99999	37
24	7·84393	7·84394	12·15606	9·99999	36
25	7·86166	7·86167	12·13833	9·99999	35
26	7·87870	7·87871	12·12129	9·99999	34
27	7·89509	7·89510	12·10490	9·99999	33
28	7·91088	7·91089	12·08911	9·99999	32
29	7·92612	7 92613	12·07387	9·99998	31
30	7·94084	7·94086	12·05914	9·99998	30
31	7·95508	7·95510	12·04490	9·99998	29
32	7·96887	7·96889	12·03111	9·99998	28
33	7·98223	7·98225	12·01775	9·99998	27
34	7·99520	7·99522	12·00478	9·99998	26
35	8·00779	8·00781	11·99219	9·99998	25
36	8·02002	8·02004	11·97996	9·99998	24
37	8·03192	8·03194	11·96806	9 99997	23
38	8·04350	8·04353	11·95647	9·99997	22
39	8·05478	8·05481	11·94519	9·99997	21
40	8·06578	8·06581	11·93419	9·99997	20
41	8·07650	8·07653	11·92347	9·99997	19
42	8·08696	8·08700	11·91300	9·99997	18
43	8·09718	8·09722	11·90278	9·99997	17
44	8·10717	8·10720	11·89280	9·99996	16
45	8·11693	8·11696	11·88304	9 99996	15
46	8·12647	8·12651	11·87349	9·99996	14
47	8·13581	8·13585	11·86415	9·99996	13
48	8·14495	8·14500	11·85500	9·99996	12
49	8·15391	8·15395	11·84605	9·99996	11
50	8·16268	8·16273	11·83727	9·99995	10
51	8·17128	8·17133	11·82867	9·99995	9
52	8·17971	8·17976	11·82024	9·99995	8
53	8·18798	8·18804	11·81196	9·99995	7
54	8·19610	8·19616	11·80384	9·99995	6
55	8·20407	8·20413	11·79587	9·99994	5
56	8·21189	8·21195	11·78805	9·99994	4
57	8·21958	8·21964	11·78036	9·99994	3
58	8·22713	8·22720	11·77280	9·99994	2
59	8·23456	8·23462	11·76538	9·99994	1
60	8·24186	8·24192	11·75808	9·99993	0′
					89 Deg.
	Cosine.	Cotang.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
1 Deg.					
0′	8·24186	8·24192	11·75808	9·99993	60
5	8·27661	8·27669	11·72331	9·99992	55
10	8·30879	8·30888	11·69112	9·99991	50
15	8·33875	8·33886	11·66114	9·99990	45
20	8·36678	8·36689	11·63311	9·99988	40
25	8·39310	8·39323	11·60677	9·99987	35
30	8·41792	8·41807	11·58193	9·99985	30
35	8·44139	8·44156	11·55844	9·99983	25
40	8·46366	8·46385	11·53615	9·99982	20
45	8·48485	8·48505	11·51495	9·99980	15
50	8·50504	8·50527	11·49473	9·99978	10
55	8·52434	8·52459	11·47541	9·99976	5
60	8·54282	8·54308	11·45692	9·99974	0′
					88 Deg.
2 Deg.					
0′	8·54282	8·54308	11·45692	9·99974	60
5	8·56054	8·56083	11·43917	9·99971	55
10	8·57757	8·57788	11·42212	9·99969	50
15	8·59395	8·59428	11·40572	9·99967	45
20	8·60973	8·61009	11·38991	9·99964	40
25	8·62497	8·62535	11·37465	9·99961	35
30	8·63968	8·64009	11·35991	9·99959	30
35	8·65391	8·65135	11·34565	9·99956	25
40	8·66769	8·66816	11·33184	9·99953	20
45	8·68104	8·68154	11·31846	9·99950	15
50	8·69400	8·69453	11·30547	9·99947	10
55	8·70658	8·70714	11·29286	9·99944	5
60	8·71880	8·71940	11·28060	9·99940	0′
					87 Deg.
3 Deg.					
0′	8·71880	8·71940	11·28060	9·99940	60
5	8·73069	8·73132	11·26868	9·99937	55
10	8·74226	8·74292	11·25708	9·99934	50
15	8·75353	8·75423	11·24577	9·99930	45
20	8·76451	8·76525	11·23475	9·99926	40
25	8·77522	8·77600	11·22400	9·99923	35
30	8·78568	8·78649	11·21351	9·99919	30
35	8·79588	8·79673	11·20327	9·99915	25
40	8·80585	8·80674	11·19326	9·99911	20
45	8·81560	8·81653	11·18347	9·99907	15
50	8·82513	8·82610	11·17390	9·99903	10
55	8·83446	8·83547	11·16453	9·99898	5
60	8·84358	8·84464	11·15536	9·99894	0′
					86 Deg.
4 Deg.					
0′	8·84358	8·84464	11·15536	9·99894	60
5	8·85252	8·85363	11·14637	9·99890	55
10	8·86128	8·86243	11·13757	9·99885	50
15	8·86987	8·87106	11·12894	9·99880	45
20	8·87829	8·87953	11·12047	9·99876	40
25	8·88654	8·88783	11·11217	9·99871	35
30	8·89464	8·89598	11·10402	9·99866	30
35	8·90260	8·90399	11·09601	9·99861	25
40	8·91040	8·91185	11·08815	9·99856	20
45	8·91807	8·91957	11·08043	9·99851	15
50	8·92561	8·92716	11·07284	9·99845	10
55	8·93301	8·93462	11·06538	9·99840	5
60	8·94030	8·94195	11·05805	9·99834	0′
					85 Deg.
	Cosine	Cotang.	Tang.	Sine.	

LOGARITHMIC SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
5 Deg.					
0′	8·94030	8·94195	11·05805	9·99834	60
5	8·94746	8·94917	11·05083	9·99829	55
10	8·95450	8·95627	11·04373	9·99823	50
15	8·96143	8·96325	11·03675	9·99817	45
20	8·96825	8·97013	11·02987	9·99812	40
25	8·97496	8·97691	11·02309	9·99806	35
30	8·98157	8·98358	11·01642	9·99800	30
35	8·98808	8·99015	11·00985	9·99793	25
40	8·99450	8·99662	11·00338	9·99787	20
45	9·00082	9·00301	10·99699	9·99781	15
50	9·00704	9·00930	10·99070	9·99775	10
55	9·01318	9·01550	10·98450	9·99768	5
60	9·01923	9·02162	10·97838	9·99761	0′
					84 Deg.
6 Deg.					
0′	9·01923	9·02162	10·97838	9·99761	60
5	9·02520	9·02766	10·97234	9·99755	55
10	9·03109	9·03361	10·96639	9·99748	50
15	9·03690	9·03948	10·96052	9·99741	45
20	9·04262	9·04528	10·95472	9·99734	40
25	9·04828	9·05101	10·94899	9·99727	35
30	9·05386	9·05666	10·94334	9·99720	30
35	9·05937	9·06224	10·93776	9·99713	25
40	9·06481	9·06775	10·93225	9·99705	20
45	9·07018	9·07320	10·92680	9·99698	15
50	9·07548	9·07858	10·92142	9·99690	10
55	9·08072	9·08389	10·91611	9·99683	5
60	9·08589	9·08914	10·91086	9·99675	0′
					83 Deg.
7 Deg.					
0′	9·08589	9·08914	10·91086	9·99675	60
5	9·09101	9·09434	10·90566	9·99667	55
10	9·09606	9·09947	10·90053	9·99659	50
15	9·10106	9·10454	10·89546	9·99651	45
20	9·10599	9·10956	10·89044	9·99643	40
25	9·11087	9·11452	10·88548	9·99635	35
30	9·11570	9·11943	10·88057	9·99627	30
35	9·12047	9·12428	10·87572	9·99618	25
40	9·12519	9·12909	10·87091	9·99610	20
45	9·12985	9·13384	10·86616	9·99601	15
50	9·13447	9·13854	10·86146	9·99593	10
55	9·13904	9·14320	10·85680	9·99584	5
60	9·14356	9·14780	10·85220	9·99575	0′
					82 Deg.
8 Deg.					
0′	9·14356	9·14780	10·85220	9·99575	60
5	9·14803	9·15236	10·84764	9·99566	55
10	9·15245	9·15688	10·84312	9·99557	50
15	9·15683	9·16135	10·83865	9·99548	45
20	9·16116	9·16577	10·83423	9·99539	40
25	9·16545	9·17016	10·82984	9·99530	35
30	9·16970	9·17450	10·82550	9·99520	30
35	9·17391	9·17880	10·82120	9·99511	25
40	9·17807	9·18306	10·81694	9·99501	20
45	9·18220	9·18728	10·81272	9·99492	15
50	9·18628	9·19146	10·80854	9·99482	10
55	9·19033	9·19561	10·80439	9·99472	5
60	9·19433	9·19971	10·80029	9·99462	0′
					81 Deg.

	Cosine.	Cotang.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
9 Deg.					
0′	9·19433	9·19971	10·80029	0·99462	60
5	9·19830	9·20378	10·79622	9·99452	55
10	9·20223	9·20789	10·79218	9·99442	50
15	9·20613	9·21182	10·78818	9·99432	45
20	9·20999	9·21578	10·78422	9·99421	40
25	9·21382	9·21971	10·78029	9·99411	35
30	9·21761	9·22361	10·77639	9·99400	30
35	9·22137	9·22747	10·77253	9·99390	25
40	9·22509	9·23130	10·76870	9·99379	20
45	9·22878	9·23510	10·76490	9·99368	15
50	9·23244	9·23887	10·76113	9·99257	10
55	9·23607	9·24261	10·75739	9·99346	5
60	9·23967	9·24632	10·75368	9·99335	0′
					80 De
10 Deg.					
0′	9·23967	9·24632	10·75368	9·99335	60
5	9·24324	9·25000	10·75000	9·99324	55
10	9·24677	9·25365	10·74635	9·99313	50
15	9·25028	9·25727	10·74273	9·99301	45
20	9·25376	9·26086	10·73914	9·99290	40
25	9·25721	9·26443	10·73557	9·99278	35
30	9·26063	9·26797	10·73203	9·99267	30
35	9·26403	9·27148	10·72852	9·99255	25
40	9·26739	9·27496	10·72504	9·99243	20
45	9·27073	9·27842	10·72158	9·99231	15
50	9·27405	9·28186	10·71814	9·99219	10
55	9·27734	9·28527	10·71473	9·99207	5
60	9·28060	9·28865	10·71135	9·99195	0
					79 De
11 Deg.					
0′	9·28060	9·28865	10·71135	9·99195	60
5	9·28384	9·29201	10·70799	9·99182	55
10	9·28705	9·29535	10·70465	9·99170	50
15	9·29024	9·29866	10·70134	9·99157	45
20	9·29340	9·30195	10·69805	9·99145	40
25	9·29654	9·30522	10·69478	9·99132	35
30	9·29966	9·30846	10·69154	9·99119	30
35	9·30275	9·31168	10·68832	9·99106	25
40	9·30582	9·31489	10·68511	9·99093	20
45	9·30887	9·31806	10·68194	9·99080	15
50	9·31189	9·32122	10·67878	9·99067	10
55	9·31490	9·32436	10·67564	9·99054	5
60	9·31788	9·32747	10·67253	9·99040	0
					78 D
12 Deg.					
0′	9·31788	9·32747	10·67253	9·99040	60
5	9·32084	9·33057	10·66943	9·99027	55
10	9·32378	9·33365	10·66635	9·99013	50
15	9·32670	9·33670	10·66330	9·99000	45
20	9·32960	9·33974	10·66026	9·98986	40
25	9·33248	9·34276	10·65724	9·98972	35
30	9·33534	9·34576	10·65424	9·98958	30
35	9·33818	9·34874	10·65126	9·98944	25
40	9·34100	9·35170	10·64830	9·98930	20
45	9·34380	9·35464	10·64536	9·98916	15
50	9·34658	9·35757	10·64243	9·98901	10
55	9·34934	9·36047	10·63953	9·98887	5
60	9·35209	9·36336	10·63664	9·98872	0
					77 D

	Cosine.	Cotang.	Tang.	Sine.	

LOGARITHMIC SINES, TANGENTS, &C. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
3 Deg.					
0′	9·35209	9·36336	10·63664	9·98872	60
5	9·35481	9·36624	10·63376	9·98858	55
10	9·35752	9·36909	10·63091	9·98843	50
15	9·36022	9·37193	10·62807	9·98828	45
20	9·36289	9·37476	10·62524	9·98813	40
25	9·36555	9·37756	10·62244	9·98798	35
30	9·36819	9·38035	10·61965	9·98783	30
35	9·37081	9·38313	10·61687	9·98768	25
40	9·37341	9·38589	10·61411	9·98753	20
45	9·37600	9·38863	10·61137	9·98737	15
50	9·37858	9·39136	10·60864	9·98722	10
55	9·38113	9·39407	10·60593	9·98706	5
60	9·38368	9·39677	10·60323	9·98690	0′
					76 Deg.
4 Deg.					
0′	9·38368	9·39677	10·60323	9·98690	60
5	9·38620	9·39945	10·60055	9·98675	55
10	9·38871	9·40212	10·59788	9·98659	50
15	9·39121	9·40478	10·59522	9·98643	45
20	9·39369	9·40742	10·59258	9·98627	40
25	9·39615	9·41005	10·58995	9·98610	35
30	9·39860	9·41266	10·58734	9·98594	30
35	9·40103	9·41526	10·58474	9·98578	25
40	9·40346	9·41784	10·58216	9·98561	20
45	9·40586	9·42041	10·57959	9·98545	15
50	9·40825	9·42297	10·57703	9·98528	10
55	9·41063	9·42552	10·57448	9·98511	5
60	9·41300	9·42805	10·57195	9·98494	0′
					75 Deg.
5 Deg.					
0′	9·41300	9·42805	10·57195	9·98494	60
5	9·41535	9·43057	10·56943	9·98477	55
10	9·41768	9·43308	10·56692	9·98460	50
15	9·42001	9·43558	10·56442	9·98443	45
20	9·42232	9·43806	10·56194	9·98426	40
25	9·42461	9·44053	10·55947	9·98409	35
30	9·42690	9·44299	10·55701	9·98391	30
35	9·42917	9·44544	10·55456	9·98373	25
40	9·43143	9·44787	10·55213	9·98356	20
45	9·43367	9·45029	10·54971	9·98338	15
50	9·43591	9·45271	10·54729	9·98320	10
55	9·43813	9·45511	10·54489	9·98302	5
60	9·44034	9·45750	10·54250	9·98284	0′
					74 Deg.
6 Deg.					
0′	9·44034	9·45750	10·54250	9·98284	60
5	9·44253	9·45987	10·54013	9·98266	55
10	9·44472	9·46224	10·53776	9·98248	50
15	9·44689	9·46460	10·53540	9·98229	45
20	9·44905	9·46694	10·53306	9·98211	40
25	9·45120	9·46928	10·53072	9·98192	35
30	9·45334	9·47160	10·52840	9·98174	30
35	9·45547	9·47392	10·52608	9·98155	25
40	9·45758	9·47622	10·52378	9·98136	20
45	9·45969	9·47852	10·52148	9·98117	15
50	9·46178	9·48080	10·51920	9·98098	10
55	9·46386	9·48307	10·51693	9·98079	5
60	9·46594	9·48534	10·51466	9·98060	0′
					73 Deg.
	Cosine.	Cotang.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
17 Deg.					
0′	9·46594	9·48534	10·51466	9·98060	60
5	9·46800	9·48759	10·51241	9·98040	55
10	9·47005	9·48984	10·51016	9·98021	50
15	9·47209	9·49207	10·50793	9·98001	45
20	9·47411	9·49430	10·50570	9·97982	40
25	9·47613	9·49652	10·50348	9·97962	35
30	9·47814	9·49872	10·50128	9·97942	30
35	9·48014	9·50092	10·49908	9·97922	25
40	9·48213	9·50311	10·49689	9·97902	20
45	9·48411	9·50529	10·49471	9·97882	15
50	9·48607	9·50746	10·49254	9·97861	10
55	9·48803	9·50962	10·49038	9·97841	5
60	9·48998	9·51178	10·48822	9·97821	0′
					72 Deg.
18 Deg.					
0′	9·48998	9·51178	10·48822	9·97821	60
5	9·49192	9·51392	10·48608	9·97800	55
10	9·49385	9·51606	10·48394	9·97779	50
15	9·49577	9·51819	10·48181	9·97759	45
20	9·49768	9·52031	10·47969	9·97738	40
25	9·49958	9·52242	10·47758	9·97717	35
30	9·50148	9·52452	10·47548	9·97696	30
35	9·50336	9·52661	10·47339	9·97674	25
40	9·50523	9·52870	10·47130	9·97653	20
45	9·50710	9·53078	10·46922	9·97632	15
50	9·50896	9·53285	10·46715	9·97610	10
55	9·51080	9·53492	10·46508	9·97589	5
60	9·51264	9·53697	10·46303	9·97567	0′
					71 Deg.
19 Deg.					
0′	9·51264	9·53697	10·46503	9·97567	60
5	9·51447	9·53902	10·46098	9·97545	55
10	9·51629	9·54106	10·45894	9·97523	50
15	9·51811	9·54309	10·45691	9·97501	45
20	9·51991	9·54512	10·45488	9·97479	40
25	9·52171	9·54714	10·45286	9·97457	35
30	9·52350	9·54915	10·45085	9·97435	30
35	9·52527	9·55115	10·44885	9·97412	25
40	9·52705	9·55315	10·44685	9·97390	20
45	9·52881	9·55514	10·44486	9·97367	15
50	9·53056	9·55712	10·44288	9·97344	10
55	9·53231	9·55910	10·44090	9·97322	5
60	9·53405	9·56107	10·43893	9·97299	0′
					70 Deg.
20 Deg.					
0′	9·53405	9·56107	10·43893	9·97299	60
5	9·53578	9·56303	10·43697	9·97276	55
10	9·53751	9·56498	10·43502	9·97252	50
15	9·53922	9·56693	10·43307	9·97229	45
20	9·54093	9·56887	10·43113	9·97206	40
25	9·54263	9·57081	10·42919	9·97182	35
30	9·54433	9·57274	10·42726	9·97159	30
35	9·54601	9·57466	10·42534	9·97135	25
40	9·54769	9·57658	10·42342	9·97111	20
45	9·54936	9·57849	10·42151	9·97087	15
50	9·55102	9·58039	10·41961	9·97063	10
55	9·55268	9·58229	10·41771	9·97039	5
60	9·55433	9·58418	10·41582	9·97015	0′
					69 Deg.
	Cosine.	Cotang.	Tang.	Sine.	

LOGARITHMIC SINES, TANGENTS, &c. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.			Sine.	Tang.	Cotang.	Cosine.	
21 Deg.						25 Deg.					
0′	9·55433	9·58418	10·41582	9·97015	60	0′	9·62595	9·66867	10·33133	9·95728	60
5	9·55597	9·58606	10·41394	9·96991	55	5	9·62730	9·67032	10·32968	9·95698	55
10	9·55761	9·58794	10·41206	9·96966	50	10	9·62865	9·67196	10·32804	9·95668	50
15	9·55923	9·58981	10·41019	9·96942	45	15	9·62999	9·67360	10·32640	9·95639	45
20	9·56085	9·59168	10·40832	9·96917	40	20	9·63133	9·67524	10·32476	9·95609	40
25	9·56247	9·59354	10·40646	9·96893	35	25	9·63266	9·67687	10·32313	9·95579	35
30	9·56408	9·59540	10·40460	9·96868	30	30	9·63398	9 67850	10·32150	9·95549	30
35	9·56568	9·59725	10·40275	9·96843	25	35	9·63531	9·68012	10·31988	9·95519	25
40	9·56727	9·59909	10·40091	9·96818	20	40	9·63662	9·68174	10·31826	9·95488	20
45	9·56886	9·60093	10·39907	9·96793	15	45	9·63794	9·68336	10·31664	9·95458	15
50	9·57044	9·60276	10·39724	9·96767	10	50	9·63924	9·68497	10·31503	9·95427	10
55	9·57201	9·60459	10·39541	9·96742	5	55	9·64054	9·68658	10·31342	9·95397	5
60	9·57358	9·60641	10·39359	9·96717	0′	60	9·64184	9·68818	10·31182	9·95366	0′
					68 Deg.						64 De
22 Deg.						26 Deg.					
0′	9·57358	9·60641	10·39359	9·96717	60	0′	9·64184	9·68818	10·31182	9·95366	60
5	9·57514	9·60823	10·39177	9·96691	55	5	9·64313	9·68978	10·31022	9·95335	55
10	9·57669	9·61004	10·38996	9·96665	50	10	9·64442	9·69138	10·30862	9·95304	50
15	9·57824	9·61184	10·38816	9·96640	45	15	9·64571	9·69298	10·30702	9·95273	45
20	9·57978	9·61364	10·38636	9·96614	40	20	9·64698	9·69457	10·30543	9·95242	40
25	9·58131	9·61544	10·38456	9·96588	35	25	9·64826	9·69615	10·30385	9·95211	35
30	9·58284	9·61722	10·38278	9·96562	30	30	9·64953	9·69774	10·30226	9·95179	30
35	9·58436	9·61901	10·38099	9·96535	25	35	9·65079	9·69932	10·30068	9·95148	25
40	9·58588	9·62079	10·37921	9·96509	20	40	9·65205	9·70089	10·29911	9·95116	20
45	9·58739	9·62256	10·37744	9·96483	15	45	9·65331	9·70247	10·29753	9·95084	15
50	9·58889	9·62433	10·37567	9·96456	10	50	9·65456	9·70404	10·29596	9·95052	10
55	9·59039	9·62609	10·37391	9·96429	5	55	9·65580	9·70560	10·29440	9·95020	5
60	9·59188	9·62785	10·37215	9·96403	0′	60	9·65705	9·70717	10·29283	9·94988	0′
					67 Deg.						63 De
23 Deg.						27 Deg.					
0′	9·59188	9·62785	10·37215	9·96403	60	0′	9·65705	9·70717	10·29283	9·94988	60
5	9·59336	9·62961	10·37039	9·96376	55	5	9·65828	9·70873	10·29127	9·94956	55
10	9·59484	9·63135	10·36865	9·96349	50	10	9·65952	9·71028	10·28972	9·94923	50
15	9·59632	9·63310	10·36690	9·96322	45	15	9·66075	9·71184	10·28816	9·94891	45
20	9·59778	9·63484	10·36516	9·96294	40	20	9·66197	9·71339	10·28661	9·94858	40
25	9·59924	9·63657	10·36343	9·96267	35	25	9·66319	9·71493	10·28507	9·94826	35
30	9·60070	9·63830	10·36170	9·96240	30	30	9·66441	9·71648	10·28352	9·94793	30
35	9·60215	9·64003	10·35997	9·96212	25	35	9·66562	9·71802	10·28198	9·94760	25
40	9·60359	9·64175	10·35825	9·96185	20	40	9·66682	9·71955	10·28045	9·94727	20
45	9·60503	9·64346	10·35654	9·96157	15	45	9·66803	9·72109	10·27891	9·94694	15
50	9·60646	9·64517	10·35483	9·96129	10	50	9·66922	9·72262	10·27738	9·94660	10
55	9·60789	9·64688	10·35312	9·96101	5	55	9·67042	9·72415	10·27585	9·94627	5
60	9·60931	9·64858	10·35142	9·96073	0′	60	9·67161	9·72567	10·27433	9·94593	0′
					66 Deg.						62 De
24 Deg.						28 Deg.					
0′	9·60931	9·64858	10·35142	9·96073	60	0′	9·67161	9·72567	10·27433	9·94593	60
5	9·61073	9·65028	10·34972	9·96045	55	5	9·67280	9·72720	10·27280	9·94560	55
10	9·61214	9·65197	10·34803	9·96017	50	10	9·67398	9·72872	10·27128	9·94526	50
15	9·61354	9·65366	10·34634	9·95988	45	15	9·67515	9·73023	10·26977	9·94492	45
20	9·61494	9·65535	10·34465	9·95960	40	20	9·67633	9·73175	10·26825	9·94458	40
25	9·61634	9·65703	10·34297	9·95931	35	25	9·67750	9·73326	10·26674	9·94424	35
30	9·61773	9·65870	10·34130	9·95902	30	30	9·67866	9·73476	10·26524	9·94390	30
35	9·61911	9·66038	10·33962	9·95873	25	35	9·67982	9·73627	10·26373	9·94355	25
40	9·62049	9·66204	10·33796	9·95844	20	40	9·68098	9·73777	10·26223	9·94321	20
45	9·62186	9·66371	10·33629	9·95815	15	45	9·68213	9·73927	10·26073	9·94286	15
50	9·62323	9·66537	10·33463	9·95786	10	50	9·68328	9·74077	10·25923	9·94252	10
55	9·62459	9·66702	10·33298	9·95757	5	55	9·68443	9·74226	10·25774	9·94217	5
60	9·62595	9·66867	10·33133	9·95728	0′	60	9·68557	9·74375	10·25625	9·94182	0
					65 Deg.						61 De
	Cosine.	Cotang.	Tang.	Sine.			Cosine.	Cotang.	Tang.	Sine.	

LOGARITHMIC SINES, TANGENTS, &C. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
eg.					33 Deg.
′	9·68557	9·74375	10·25625	9·94182	60
5	9·68671	9·74524	10·25476	9·94147	55
0	9·68784	9·74673	10·25327	9·94112	50
5	9·68897	9·74821	10·25179	9·94076	45
0	9·69010	9·74969	10·25031	9·94041	40
5	9·69122	9·75117	10·24883	9·94005	35
0	9·69234	9·75264	10·24736	9·93970	30
5	9·69345	9·75411	10·24589	9·93934	25
0	9·69456	9·75558	10·24442	9·93898	20
5	9·69567	9·75705	10·24295	9·93862	15
0	9·69677	9·75852	10·24148	9·93826	10
5	9·69787	9·75998	10·24002	9·93789	5
0	9·69897	9·76144	10·23856	9·93753	0′
					60 Deg.
eg.					34 Deg.
0′	9·69897	9·76144	10·23856	9·93753	60
5	9·70006	9·76290	10·23710	9·93717	55
0	9·70115	9·76435	10·23565	9·93680	50
5	9·70224	9·76580	10·23420	9·93643	45
0	9·70332	9·76725	10·23275	9·93606	40
5	9·70439	9·76870	10·23130	9·93569	35
0	9·70547	9·77015	10·22985	9·93532	30
5	9·70654	9·77159	10·22841	9·93495	25
0	9·70761	9·77303	10·22697	9·93457	20
5	9·70867	9·77447	10·22553	9·93420	15
0	9·70973	9·77591	10·22409	9·93382	10
5	9·71079	9·77734	10·22266	9·93344	5
0	9·71184	9·77877	10·22123	9·93307	0′
					59 Deg.
eg.					35 Deg.
0′	9·71184	9·77877	10·22123	9·93307	60
5	9·71289	9·78020	10·21980	9·93269	55
0	9·71393	9·78163	10·21837	9·93230	50
5	9·71498	9·78306	10·21694	9·93192	45
0	9·71602	9·78448	10·21552	9·93154	40
5	9·71705	9·78590	10·21410	9·93115	35
0	9·71809	9·78732	10·21268	9·93077	30
5	9·71911	9·78874	10·21126	9·93038	15
0	9·72014	9·79015	10·20985	9·92999	20
5	9·72116	9·79156	10·20844	9·92960	15
0	9·72218	9·79297	10·20703	9·92921	10
5	9·72320	9·79438	10·20562	9·92881	5
0	9·72421	9·79579	10·20421	9·92842	0′
					58 Deg.
eg.					36 Deg.
0′	9·72421	9·79579	10·20421	9·92842	60
5	9·72522	9·79719	10·20281	9·92803	55
0	9·72622	9·79860	10·20140	9·92763	50
5	9·72723	9·80000	10·20000	9·92723	45
0	9·72823	9·80140	10·19860	9·92683	40
5	9·72922	9·80279	10·19721	9·92643	35
0	9·73022	9·80419	10·19581	9·92603	30
5	9·73121	9·80558	10·19442	9·92563	25
0	9·73219	9·80697	10·19303	9·92522	20
5	9·73318	9·80836	10·19164	9·92482	15
0	9·73416	9·80975	10·19025	9·92441	10
5	9·73513	9·81113	10·18887	9·92400	5
0	9·73611	9·81252	10·18748	9·92359	0′
					57 Deg.

	Sine.	Tang.	Cotang.	Cosine.	
					33 Deg.
0′	9·73611	9·81252	10·18748	9·92359	60
5	9·73708	9·81390	10·18610	9·92318	55
10	9·73805	9·81528	10·18472	9·92277	50
15	9·73901	9·81666	10·18334	9·92235	45
20	9·73997	9·81803	10·18197	9·92194	40
25	9·74093	9·81941	10·18059	9·92152	35
30	9·74189	9·82078	10·17922	9·92111	30
35	9·74284	9·82215	10·17785	9·92069	25
40	9·74379	9·82352	10·17648	9·92027	20
45	9·74474	9·82489	10·17511	9·91985	15
50	9·74568	9·82626	10·17374	9·91942	10
55	9·74662	9·82762	10·17238	9·91900	5
60	9·74756	9·82899	10·17101	9·91857	0′
					56 Deg.
					34 Deg.
0′	9·74756	9·82899	10·17101	9·91857	60
5	9·74850	9·83035	10·16965	9·91815	55
10	9·74943	9·83171	10·16829	9·91772	50
15	9·75036	9·83307	10·16693	9·91729	45
20	9·75128	9·83442	10·16558	9·91686	40
25	9·75221	9·83578	10·16422	9·91643	35
30	9·75313	9·83713	10·16287	9·91599	30
35	9·75405	9·83849	10·16151	9·91556	25
40	9·75496	9·83984	10·16016	9·91512	20
45	9·75587	9·84119	10·15881	9·91469	15
50	9·75678	9·84254	10·15746	9·91425	10
55	9·75769	9·84388	10·15612	9·91381	5
60	9·75859	9·84523	10·15477	9·91336	0′
					55 Deg.
					35 Deg.
0′	9·75859	9·84523	10·15477	9·91336	60
5	9·75949	9·84657	10·15343	9·91292	55
10	9·76039	9·84791	10·15209	9·91248	50
15	9·76129	9·84925	10·15075	9·91203	45
20	9·76218	9·85059	10·14941	9·91158	40
25	9·76307	9·85193	10·14807	9·91114	35
30	9·76395	9·85327	10·14673	9·91069	30
35	9·76484	9·85460	10·14540	9·91023	25
40	9·76572	9·85594	10·14406	9·90978	20
45	9·76660	9·85727	10·14273	9·90933	15
50	9·76747	9·85860	10·14140	9·90887	10
55	9·76835	9·85993	10·14007	9·90842	5
60	9·76922	9·86126	10·13874	9·90796	0′
					54 Deg.
					36 Deg.
0′	9·76922	9·86126	10·13874	9·90796	60
5	9·77009	9·86259	10·13741	9·90750	55
10	9·77095	9·86392	10·13608	9·90704	50
15	9·77181	9·86524	10·13476	9·90657	45
20	9·77268	9·86656	10·13344	9·90611	40
25	9·77353	9·86789	10·13211	9·90565	35
30	9·77439	9·86921	10·13079	9·90518	30
35	9·77524	9·87053	10·12947	9·90471	25
40	9·77609	9·87185	10·12815	9·90424	20
45	9·77694	9·87317	10·12683	9·90377	15
50	9·77778	9·87448	10·12552	9·90330	10
55	9·77862	9·87580	10·12420	9·90282	5
60	9·77946	9·87711	10·12289	9·90235	0′
					53 Deg.

	Cosine.	Cotang.	Tang.	Sine.	

LOGARITHMIC SINES, TANGENTS, &C. (*continued*).

	Sine.	Tang.	Cotang.	Cosine.	
37 Deg.					
0′	9·77946	9·87711	10·12289	9·90235	60
5	9·78030	9·87843	10·12157	9·90187	55
10	9·78113	9·87974	10·12026	9·90139	50
15	9·78197	9·88105	10·11895	9·90091	45
20	9·78280	9·88236	10·11764	9·90043	40
25	9·78362	9·88367	10·11633	9·89995	35
30	9·78445	9·88498	10·11502	9·89947	30
35	9·78527	9·88629	10·11371	9·89898	25
40	9·78609	9·88759	10·11241	9·89849	20
45	9·78691	9·88890	10·11110	9·89801	15
50	9·78772	9·89020	10·10980	9·89752	10
55	9·78853	9·89151	10·10849	9·89702	5
60	9·78934	9·89281	10.10719	9·89653	0′
					52 Deg.
38 Deg.					
0′	9·78934	9·89281	10·10719	9·89653	60
5	9·79015	9·89411	10·10589	9·89604	55
10	9·79095	9·89541	10·10459	9·89554	50
15	9·79176	9·89671	10·10329	9·89504	45
20	9·79256	9·89801	10·10199	9·89455	40
25	9·79335	9·89931	10·10069	9·89405	35
30	9·79415	9·90061	10·09939	9·89354	30
35	9·79494	9·90190	10·09810	9·89304	25
40	9·79573	9·90320	10·09680	9·89254	20
45	9·79652	9·90449	10·09551	9·89203	15
50	9·79731	9·90578	10·09422	9·89152	10
55	9·79809	9·90708	10·09292	9·89101	5
60	9·79887	9·90837	10·09163	9·89050	0′
					51 Deg.
39 Deg.					
0′	9·79887	9·90837	10·09163	9·89050	60
5	9·79965	9·90966	10·09034	9·88999	55
10	9·80043	9·91095	10·08905	9·88948	50
15	9·80120	9·91224	10·08776	9·88896	45
20	9·80197	9·91353	10·08647	9·88844	40
25	9·80274	9·91482	10·08518	9·88793	35
30	9·80351	9·91610	10·08390	9·88741	30
35	9·80428	9·91739	10·08261	9·88688	25
40	9·80504	9·91868	10·08132	9·88636	20
45	9·80580	9·91996	10·08004	9·88584	15
50	9·80656	9·92125	10·07875	9·88531	10
55	9·80731	9·92253	10·07747	9·88478	5
60	9·80807	9·92381	10·07619	9·88425	0′
					50 Deg.
40 Deg.					
0	9·80807	9·92381	10·07619	9·88425	60
5	9·80882	9·92510	10·07490	9·88372	55
10	9·80957	9·92638	10·07362	9·88319	50
15	9·81032	9·92766	10·07234	9·88266	45
20	9·81106	9·92894	10·07106	9·88212	40
25	9·81180	9·93022	10·06978	9·88158	35
30	9·81254	9·93150	10·06850	9·88105	30
35	9·81328	9·93278	10·06722	9·88051	25
40	9 81402	9·93406	10·06594	9·87996	20
45	9·81475	9·93533	10·06467	9·87942	15
50	9·81549	9·93661	10·06339	9·87887	10
55	9·81622	9·93789	10·06211	9·87833	5
60	9·81694	9·93916	10·06084	9·87778	0′
					49 Deg.
	Cosine.	Cotang.	Tang.	Sine.	

	Sine.	Tang.	Cotang.	Cosine.	
41 Deg.					
0′	9·81694	9·93916	10·06084	9·87778	
5	9·81767	9·94044	10·05956	9·87723	
10	9·81839	9·94171	10·05829	9·87668	
15	9·81911	9·94299	10·05701	9·87613	
20	9·81983	9·94426	10·05574	9·87557	
25	9·82055	9·94554	10·05446	9·87501	
30	9·82126	9·94681	10·05319	9·87446	
35	9·82198	9·94808	10·05192	9·87390	
40	9·82269	9·94935	10·05065	9·87334	
45	9·82340	9·95062	10·04938	9·87277	
50	9·82410	9·95190	10·04810	9·87221	
55	9·82481	9·95317	10·04683	9·87164	
60	9·82551	9·95444	10·04556	9·87107	
					48
42 Deg.					
0′	9·82551	9·95444	10·04556	9·87107	
5	9·82621	9·95571	10·04429	9·87050	
10	9·82691	9·95698	10·04302	9·86993	
15	9·82761	9·95825	10·04175	9·86936	
20	9·82830	9·95952	10·04048	9·86879	
25	9·82899	9·96078	10·03922	9·86821	
30	9·82968	9·96205	10·03795	9·86763	
35	9·83037	9·96332	10·03668	9·86705	
40	9·83106	9·96459	10·03541	9·86647	
45	9·83174	9·96586	10·03414	9·86589	
50	9·83242	9·96712	10·03288	9·86530	
55	9·83310	9·96839	10·03161	9·86472	
60	9·83378	9·96966	10·03034	9·86413	
					47
43 Deg.					
0′	9·83378	9·96966	10·03034	9·86413	
5	9·83446	9·97092	10·02908	9·86354	
10	9·83513	9·97219	10·02781	9·86295	
15	9·83581	9·97345	10·02655	9·86235	
20	9·83648	9·97472	10·02528	9·86176	
25	9·83715	9·97598	10·02402	9·86116	
30	9·83781	9·97725	10·02275	9·86056	
35	9·83848	9·97851	10·02149	9·85996	
40	9·83914	9·97978	10·02022	9·85936	
45	9·83980	9·98104	10·01896	9·85876	
50	9·84046	9·98231	10·01769	9·85815	
55	9·84112	9·98357	10·01643	9·85754	
60	9·84177	9·98484	10·01516	9·85692	
					46
44 Deg.					
0′	9·84177	9·98484	10·01516	9·85693	
5	9·84242	9·98610	10·01390	9·85632	
10	9·84308	9·98737	10·01263	9·85571	
15	9·84373	9·98863	10·01137	9·85510	
20	9·84437	9·98989	10·01011	9·85448	
25	9·84502	9·99116	10·00884	9·85386	
30	9·84566	9·99242	10·00758	9·85324	
35	9·84630	9·99368	10·00632	9·85262	
40	9·84694	9·99495	10·00505	9·85200	
45	9·84758	9·99621	10·00379	9·85137	
50	9·84822	9·99747	10·00253	9·85074	
55	9·84885	9·99874	10·00126	9·85012	
60	9·84949	10·00000	10·00000	9·84949	
					45
	Cosine.	Cotang.	Tang.	Sine.	

SPHERICAL TRIGONOMETRY.

Spherical Trigonometry treats of triangles which are drawn (or imagined to be) on the surface of a sphere. Their sides are arcs of the great circle of the sphere, and are measured by the angle of the arc. Therefore the trigonometrical functions bear quite a different relation to the sides.

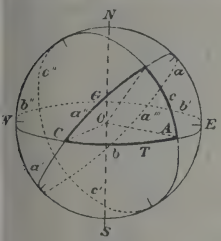


FIG. 103

Every section of a sphere cut by a plane is a *circle*. A line drawn through the centre and at right angles to the sectional circle is called an *axis*, and the two points where the axis meets the surface of the sphere are called the *poles* of the sectional circle.

When the cutting-plane goes through the centre of the sphere, it will pass through the great circle, and is then called the *Equator* for the poles. Axis = NS. Equator = GETW.

Three great circle-planes, $a\ a'\ a''\ a'''$, $b\ b'\ b''$, and $c\ c'\ c''$, cutting a sphere, NESW, will form a solid angle at the centre O, and a triangle ABC on the surface of the sphere, in which the arcs a, b, c, are the sides. The angles formed by each two planes are congruent to each of the appertinent angles A, B, and C.

Spherical Distances.

For the spherical distances, let

l = lower latitude, in degrees from the equator.
l' = highest latitude " " "
C = course, from the latitude l to l'.
C′ = course, from the latitude l' to l.
d = shortest distance between l and l', in degrees of the great circle.
L = difference in longitude between l and l', in degrees, or time.
$\tan m = \cot l' \cos \mathrm{L}$.
$n = 90 \mp l - m$.
ϕ $-l$, when l and l' are on one side of the equator.
$+l$, when l is on one side, and l' on the other. Then

$$\cos d = \frac{\sin l' \cos n}{\cos m}. \qquad \sin \mathrm{C} = \frac{\sin \mathrm{L} \cos l'}{\sin d}. \qquad \sin \mathrm{C}' = \frac{\sin \mathrm{L} \cos l}{\sin d}.$$

Formulæ for Right-angled Spherical Triangles.

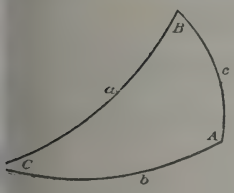


FIG. 104.

$$\sin b = \sin a \sin \mathrm{B}. \qquad \tan c = \tan a \cos \mathrm{B}.$$
$$\cot \mathrm{C} = \cos a \tan \mathrm{B}. \qquad \tan c = \sin b \tan \mathrm{C}.$$
$$\cos a = \cos b \cos c. \qquad \cos \mathrm{B} = \cos b \sin \mathrm{C}.$$
$$\tan a = \frac{\tan b}{\cos \mathrm{C}}. \qquad \sin c = \frac{\tan b}{\tan \mathrm{B}}.$$
$$\sin a = \frac{\sin b}{\sin \mathrm{B}}. \qquad \sin \mathrm{C} = \frac{\cos \mathrm{B}}{\cos b}.$$
$$\cos c = \frac{\cos a}{\cos b}. \qquad \sin \mathrm{B} = \frac{\sin b}{\sin a}.$$
$$\cos \mathrm{C} = \frac{\tan b}{\tan a}. \qquad \tan \mathrm{C} = \frac{\tan c}{\sin b}.$$

$$\tan \mathrm{B} = \frac{\tan b}{\sin c}. \qquad \cos c = \frac{\cos \mathrm{C}}{\sin \mathrm{B}}. \qquad \cos b = \frac{\cos \mathrm{B}}{\sin \mathrm{C}}. \qquad \cos a = \frac{\cot \mathrm{C}}{\tan \mathrm{B}}.$$

Formulæ for Oblique-angled Spherical Triangles.

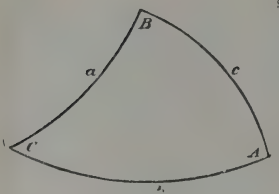


FIG. 105.

$$\sin a : \sin b = \sin A : \sin B. \qquad \sin b : \sin c = \sin B : \sin C.$$

$$\sin a = \frac{\sin b \sin A}{\sin B}. \qquad \sin b = \frac{\sin c \sin B}{\sin C}.$$

$$\tan \tfrac{1}{2}(a + b) = \tan \tfrac{1}{2}c \, \frac{\cos \tfrac{1}{2}(A - B)}{\cos \tfrac{1}{2}(A + B)}.$$

$$\tan \tfrac{1}{2}(a - b) = \tan \tfrac{1}{2}c \, \frac{\sin \tfrac{1}{2}(A - B)}{\sin \tfrac{1}{2}(A + B)}.$$

$$\tan \tfrac{1}{2}(B + C) = \cot \tfrac{1}{2}A \, \frac{\cos \tfrac{1}{2}(b - c)}{\cos \tfrac{1}{2}(b + c)}.$$

$$\tan \tfrac{1}{2}(B - C) = \cot \tfrac{1}{2}A \, \frac{\sin \tfrac{1}{2}(b - c)}{\sin \tfrac{1}{2}(b + c)}.$$

$$\cot \tfrac{1}{2}A = \tan \tfrac{1}{2}(B - C) \frac{\sin \tfrac{1}{2}(b + c)}{\sin \tfrac{1}{2}(b - c)}. \qquad \tan \tfrac{1}{2}c = \tan \tfrac{1}{2}(a - b) \frac{\sin \tfrac{1}{2}(A + B)}{\sin \tfrac{1}{2}(A - B)}.$$

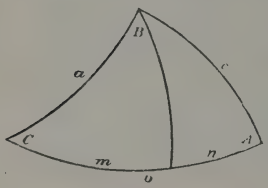


FIG. 106.

$$\tan \tfrac{1}{2}(m + n) \tan \tfrac{1}{2}(m - n) = \tan \tfrac{1}{2}(a + c) \tan \tfrac{1}{2}(a - c).$$

$$\tan m = \tan a \cos C. \qquad \tan C = \frac{\sin (b - m) \tan A}{\sin m}.$$

$$\cos C = \frac{\cos a \cos (b - m)}{\cos m}. \qquad \cos n = \frac{\cos c \cos m}{\cos c}.$$

$$b = m \pm n.$$

$$s = \tfrac{1}{2}(a + b + c). \qquad S = \tfrac{1}{2}(A + B + C).$$

$$\sin \tfrac{1}{2}A = \sqrt{\frac{\sin (s - c) \sin (s - b)}{\sin b \sin c}}. \qquad \sin \tfrac{1}{2}a = \sqrt{\frac{\cos S \cos (S - A)}{\sin B \sin C}}.$$

To find the Area of a Spherical Triangle.

Let Q be the area of the triangle in square degrees ; if R = radius of the sphere, the length of one degree will be

$$= \frac{2\pi R}{360}, \text{ or one square degree} = \frac{R^2}{3285{\cdot}58}.$$

$$\cot \tfrac{1}{2}Q = \frac{\cot \tfrac{1}{2}c \cot \tfrac{1}{2}a + \cos B}{\sin B}. \qquad \sin \tfrac{1}{2}Q = \frac{\sin \tfrac{1}{2}c \sin \tfrac{1}{2}a \sin B}{\cos \tfrac{1}{2}b}.$$

The sum of the three angles in a spherical triangle is greater than two right angles, and less than six right angles.

SQUARES—CUBES—ROOTS—RECIPROCALS.

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS, OF NUMBERS FROM 1 TO 1,000.

Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.
1	1	1	1·0000000	1·0000000	1·000000000	81	6561	531441	9·0000000	4·3267487	·012345679
2	4	8	1·4142136	1·2599210	·500000000	82	6724	551368	9·0553851	4·3444815	·012195122
3	9	27	1·7320508	1·4422496	·333333333	83	6889	571787	9·1104336	4·3620707	·012048193
4	16	64	2·0000000	1·5874011	·250000000	84	7056	592704	9·1651514	4·3795191	·011904762
5	25	125	2·2360680	1·7099759	·200000000	85	7225	614125	9·2195445	4·3968296	·011764706
6	36	216	2·4494897	1·8171206	·166666666	86	7396	636056	9·2736185	4·4140049	·011627907
7	49	343	2·6457513	1·9129312	·142857143	87	7569	658503	9·3273791	4·4310476	·011494253
8	64	512	2·8284271	2·0000000	·125000000	88	7744	681472	9·3808315	4·4479692	·011363636
9	81	729	3·0000000	2·0800837	·111111111	89	7921	704969	9·4339811	4·4647451	·011235955
10	100	1000	3·1622777	2·1544347	·100000000	90	8100	729000	9·4868330	4·4814047	·011111111
11	121	1331	3·3166248	2·2239801	·090909091	91	8281	753571	9·5393920	4·4979414	·010989011
12	144	1728	3·4641016	2·2894286	·083333333	92	8464	778688	9·5916630	4·5143574	·010869565
13	169	2197	3·6055513	2·3513347	·076923077	93	8649	804357	9·6436508	4·5306549	·010752688
14	196	2744	3·7416574	2·4101422	·071428571	94	8836	830584	9·6953597	4·5468359	·010638298
15	225	3375	3·8729833	2·4662121	·066666667	95	9025	857375	9·7467943	4·5629026	·010526316
16	256	4096	4·0000000	2·5198421	·062500000	96	9216	884736	9·7979590	4·5788570	·010416667
17	289	4913	4·1231056	2·5712816	·058823529	97	9409	912673	9·8488578	4·5947009	·010309278
18	324	5832	4·2426407	2·6207414	·055555556	98	9604	941192	9·8994949	4·6104363	·010204082
19	361	6859	4·3588989	2·6684016	·052631579	99	9801	970299	9·9498744	4·6260650	·010101010
20	400	8000	4·4721360	2·7144177	·050000000	100	10000	1000000	10·0000000	4·6415888	·010000000
21	441	9261	4·5825757	2·7589243	·047619048	101	10201	1030301	10·0498756	4·6570095	·009900990
22	484	10648	4·6904158	2·8020393	·045454545	102	10404	1061208	10·0995049	4·6723287	·009803922
23	529	12167	4·7958315	2·8438670	·043478261	103	10609	1092727	10·1488916	4·6875482	·009708738
24	576	13824	4·8989795	2·8844991	·041666667	104	10816	1124864	10·1980390	4·7026694	·009615385
25	625	15625	5·0000000	2·9240177	·040000000	105	11025	1157625	10·2469508	4·7176940	·009523810
26	676	17576	5·0990195	2·9624960	·038461538	106	11236	1191016	10·2956301	4·7326235	·009433962
27	729	19683	5·1961524	3·0000000	·037037037	107	11449	1225043	10·3440804	4·7474594	·009345794
28	784	21952	5·2915026	3·0365889	·035714286	108	11664	1259712	10·3923048	4·7622032	·009259259
29	841	24389	5·3851648	3·0723168	·034482759	109	11881	1295029	10·4403065	4·7768562	·009174312
30	900	27000	5·4772256	3·1072325	·033333333	110	12100	1331000	10·4880885	4·7914199	·009090909
31	961	29791	5·5677644	3·1413806	·032258065	111	12321	1367631	10·5356538	4·8058995	·009009009
32	1024	32768	5·6568542	3·1748021	·031250000	112	12544	1404928	10·5830052	4·8202845	·008928571
33	1089	35937	5·7445626	3·2075343	·030303030	113	12769	1442897	10·6301458	4·8345881	·008849558
34	1156	39304	5·8309519	3·2396118	·029411765	114	12996	1481544	10·6770783	4·8488076	·008771930
35	1225	42875	5·9160798	3·2710663	·028571429	115	13225	1520875	10·7238053	4·8629442	·008695652
36	1296	46656	6·0000000	3·3019272	·027777778	116	13456	1560896	10·7703296	4·8769990	·008620690

37	1369	50653	6·0827625	3·3322218	·027027027	117	13689	1601613	10·8166538	4·8909732	·008547009
38	1444	54872	6·1644140	3·3619754	·026315789	118	13924	1643032	10·8627805	4·9048681	·008474576
39	1521	59319	6·2449980	3·3912114	·025641026	119	14161	1685159	10·9087121	4·9186847	·008403361
40	1600	64000	6·3245553	3·4199519	·025000000	120	14400	1728000	10·9544512	4·9324242	·008333333
41	1681	68921	6·4031242	3·4482172	·024390244	121	14641	1771561	11·0000000	4·9460874	·008264463
42	1764	74088	6·4807407	3·4760266	·023809524	122	14884	1815848	11·0453610	4·9596757	·008196721
43	1849	79507	6·5574385	3·5033981	·023255814	123	15129	1860867	11·0905365	4·9731898	·008130081
44	1936	85184	6·6332496	3·5303483	·022727273	124	15376	1906624	11·1355287	4·9866310	·008064516
45	2025	91125	6·7082039	3·5568933	·022222222	125	15625	1953125	11·1803399	5·0000000	·008000000
46	2116	97336	6·7823300	3·5830479	·021739130	126	15876	2000376	11·2249722	5·0132979	·007936508
47	2209	103823	6·8556546	3·6088261	·021276600	127	16129	2048383	11·2694277	5·0265257	·007874016
48	2304	110592	6·9282032	3·6342411	·020833333	128	16384	2097152	11·3137085	5·0396842	·007812500
49	2401	117649	7·0000000	3·6593057	·020408163	129	16641	2146689	11·3578167	5·0527743	·007751938
50	2500	125000	7·0710678	3·6840314	·020000000	130	16900	2197000	11·4017543	5·0657970	·007692308
51	2601	132651	7·1414284	3·7084298	·019607843	131	17161	2248091	11·4455231	5·0787531	·007633588
52	2704	140608	7·2111026	3·7325111	·019230769	132	17424	2299968	11·4891253	5·0916434	·007575758
53	2809	148877	7·2801099	3·7562858	·018867925	133	17689	2352637	11·5325626	5·1044687	·007518797
54	2916	157464	7·3484692	3·7797631	·018518519	134	17956	2406104	11·5758369	5·1172299	·007462687
55	3025	166375	7·4161985	3·8029525	·018181818	135	18225	2460375	11·6189500	5·1299278	·007407407
56	3136	175616	7·4833148	3·8258624	·017857143	136	18496	2515456	11·6619038	5·1425632	·007352941
57	3249	185193	7·5498344	3·8485011	·017543860	137	18769	2571353	11·7046999	5·1551367	·007299270
58	3364	195112	7·6157731	3·8708766	·017241379	138	19044	2628072	11·7473401	5·1676493	·007246377
59	3481	205379	7·6811457	3·8929965	·016949153	139	19321	2685619	11·7898261	5·1801015	·007194245
60	3600	216000	7·7459667	3·9148676	·016666667	140	19600	2744000	11·8321596	5·1924941	·007142857
61	3721	226981	7·8102497	3·9364972	·016393443	141	19881	2803221	11·8743421	5·2048279	·007092199
62	3844	238328	7·8740079	3·9578915	·016129032	142	20164	2863288	11·9163753	5·2171034	·007042254
63	3969	250047	7·9372539	3·9790571	·015873016	143	20449	2924207	11·9582607	5·2293215	·006993007
64	4096	262144	8·0000000	4·0000000	·015625000	144	20736	2985984	12·0000000	5·2414828	·006944444
65	4225	274625	8·0622577	4·0207256	·015384615	145	21025	3048625	12·0415946	5·2535879	·006896552
66	4356	287496	8·1240384	4·0412401	·015151515	146	21316	3112136	12·0830460	5·2656374	·006849315
67	4489	300763	8·1853528	4·0615480	·014925373	147	21609	3176523	12·1243557	5·2776321	·006802721
68	4624	314432	8·2462113	4·0816551	·014705882	148	21904	3241792	12·1655251	5·2895725	·006756757
69	4761	328509	8·3066239	4·1015661	·014492754	149	22201	3307949	12·2065556	5·3014592	·006711409
70	4900	343000	8·3666003	4·1212853	·014285714	150	22500	3375000	12·2474487	5·3132928	·006666667
71	5041	357911	8·4261498	4·1408178	·014084517	151	22801	3442951	12·2882057	5·3250740	·006622517
72	5184	373248	8·4852814	4·1601676	·013888889	152	23104	3511808	12·3288280	5·3368033	·006578947
73	5329	389017	8·5440037	4·1793390	·013698630	153	23409	3581577	12·3693169	5·3484812	·006535948
74	5476	405224	8·6023253	4·1983364	·013513514	154	23716	3652264	12·4096736	5·3601084	·006493506
75	5625	421875	8·6602540	4·2171633	·013333333	155	24025	3723875	12·4498996	5·3716854	·006451613
76	5776	438976	8·7177979	4·2358236	·013157895	156	24336	3796416	12·4899960	5·3832126	·006410256
77	5929	456533	8·7749644	4·2543210	·012987013	157	24649	3869893	12·5299641	5·3946907	·006369427
78	6084	474552	8·8317609	4·2726586	·012820513	158	24964	3944312	12·5698051	5·4061202	·006329114
79	6241	493039	8·8881944	4·2908404	·012658228	159	25281	4019679	12·6095202	5·4175015	·006289308
80	6400	512000	8·9442719	4·3088695	·012500000	160	25600	4096000	12·6491106	5·4288352	·006250000

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS (*continued*).

Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.
161	25921	4173281	12·6885775	5·4401218	·006211180	245	60025	14706125	15·6524758	6·2573248	·004081633
162	26244	4251528	12·7279221	5·4513618	·006172840	246	60516	14886936	15·6843871	6·2658266	·004065041
163	26569	4330747	12·7671453	5·4625556	·006134969	247	61009	15069223	15·7162336	6·2743054	·004048583
164	26896	4410944	12·8062485	5·4737037	·006097561	248	61504	15252992	15·7480157	6·2827613	·004032258
165	27225	4492125	12·8452326	5·4848066	·006060606	249	62001	15438249	15·7797338	6·2911946	·004016064
166	27556	4574296	12·8840987	5·4958647	·006024096	250	62500	15625000	15·8113883	6·2996053	·004000000
167	27889	4657463	12·9228480	5·5068784	·005988024	251	63001	15813251	15·8429795	6·3079935	·003984064
168	28224	4741632	12·9614814	5·5178484	·005952381	252	63504	16003008	15·8745079	6·3163596	·003968254
169	28561	4826809	13·0000000	5·5287748	·005917160	253	64009	16194277	15·9059737	6·3247035	·003952569
170	28900	4913000	13·0384048	5·5396583	·005882353	254	64516	16387064	15·9373775	6·3330256	·003937008
171	29241	5000211	13·0766968	5·5504991	·005847953	255	65025	16581375	15·9687194	6·3413257	·003921569
172	29584	5088448	13·1148770	5·5612978	·005813953	256	65536	16777216	16·0000000	6·3496042	·003906250
173	29929	5177717	13·1529464	5·5720546	·005780347	257	66049	16974593	16·0312195	6·3578611	·003891051
174	30276	5268024	13·1909060	5·5827702	·005747126	258	66564	17173512	16·0623784	6·3660968	·003875969
175	30625	5359375	13·2287566	5·5934447	·005714286	259	67081	17373979	16·0934769	6·3743111	·003861004
176	30976	5451776	13·2664992	5·6040787	·005681818	260	67600	17576000	16·1245155	6·3825043	·003846154
177	31329	5545233	13·3041347	5·6146724	·005649718	261	68121	17779581	16·1554944	6·3906765	·003831418
178	31684	5639752	13·3416641	5·6252263	·005617978	262	68644	17984728	16·1864141	6·3988279	·003816794
179	32041	5735339	13·3790882	5·6357408	·005586592	263	69169	18191447	16·2172747	6·4069585	·003802281
180	32400	5832000	13·4164079	5·6462162	·005555556	264	69696	18399744	16·2480768	6·4150687	·003787879
181	32761	5929741	13·4536240	5·6566528	·005524862	265	70225	18609625	16·2788206	6·4231583	·003773585
182	33124	6028568	13·4907376	5·6670511	·005494505	266	70756	18821096	16·3095064	6·4312276	·003759398
183	33489	6128487	13·5277493	5·6774114	·005464481	267	71289	19034163	16·3401346	6·4392767	·003745318
184	33856	6229504	13·5646600	5·6877340	·005434783	268	71824	19248832	16·3707055	6·4473057	·003731343
185	34225	6331625	13·6014705	5·6980192	·005405405	269	72361	19465109	16·4012195	6·4553148	·003717472
186	34596	6434856	13·6381817	5·7082675	·005376344	270	72900	19683000	16·4316767	6·4633041	·003703704
187	34969	6539203	13·6747943	5·7184791	·005347594	271	73441	19902511	16·4620776	6·4712736	·003690037
188	35344	6644672	13·7113092	5·7286543	·005319149	272	73984	20123648	16·4924225	6·4792236	·003676471
189	35721	6751269	13·7477271	5·7387936	·005291005	273	74529	20346417	16·5227116	6·4871541	·003663004
190	36100	6859000	13·7840488	5·7488971	·005263158	274	75076	20570824	16·5529454	6·4950653	·003649635
191	36481	6967871	13·8202750	5·7589652	·005235602	275	75625	20796875	16·5831240	6·5029572	·003636364
192	36864	7077888	13·8564065	5·7689982	·005208333	276	76176	21024576	16·6132477	6·5108300	·003623188
193	37249	7189057	13·8924440	5·7789966	·005181347	277	76729	21253933	16·6433170	6·5186839	·003610108
194	37636	7301384	13·9283883	5·7889604	·005154639	278	77284	21484952	16·6733320	6·5265189	·003597122
195	38025	7414875	13·9642400	5·7988900	·005128205	279	77841	21717639	16·7032931	6·5343351	·003584229
196	38416	7529536	14·0000000	5·8087857	·005102041	280	78400	21952000	16·7332005	6·5421326	·003571429
197	38809	7645373	14·0356688	5·8186479	·005076142	281	78961	22188041	16·7630546	6·5499116	·003558719
198	39204	7762392	14·0712473	5·8284867	·005050505	282	79524	22425768	16·7928556	6·5576722	·003546099
199	39601	7880599	14·1067360	5·8382725	·005025126	283	80089	22665187	16·8226038	6·5654144	·003533569
200	40000	8000000	14·1421356	5·8480355	·005000000	284	80656	22906304	16·8522995	6·5731385	·003521127

201	40401	8120601	14·1774469	5·8577660	·00497512
202	40804	8242408	14·2126704	5·8674673	·00495049
203	41209	8365427	14·2478068	5·8771307	·00492610
204	41616	8489664	14·2828569	5·8867653	·00490196
205	42025	8615125	14·3178211	5·8963685	·00487804
206	42436	8741816	14·3527001	5·9059406	·00485436
207	42849	8869743	14·3874946	5·9154817	·00483091
208	43264	8998912	14·4222051	5·9249921	·00480769
209	43681	9129329	14·4568323	5·9344721	·00478469
210	44100	9261000	14·4913767	5·9439220	·00476190
211	44521	9393931	14·5258390	5·9533418	·00473933
212	44944	9528128	14·5602198	5·9627320	·00471698
213	45369	9663597	14·5945195	5·9720926	·00469484
214	45796	9800344	14·6287388	5·9814240	·00467289
215	46225	9938375	14·6628783	5·9907264	·00465116
216	46656	10077696	14·6969385	6·0000000	·00462963
217	47089	10218313	14·7309199	6·0092450	·00460829
218	47524	10360232	14·7648231	6·0184617	·00458716
219	47961	10503459	14·7986486	6·0276502	·00456621
220	48400	10648000	14·8323970	6·0368107	·00454545
221	48841	10793861	14·8660687	6·0459435	·00452488
222	49284	10941048	14·8996644	6·0550489	·00450450
223	49729	11089567	14·9331845	6·0641270	·00448430
224	50176	11239424	14·9666295	6·0731779	·00446429
225	50625	11390625	15·0000000	6·0822020	·00444444
226	51076	11543176	15·0332964	6·0911994	·00442479
227	51529	11697083	15·0665192	6·1001702	·00440528
228	51984	11852352	15·0996689	6·1091147	·00438596
229	52441	12008989	15·1327460	6·1180332	·00436681
230	52900	12167000	15·1657509	6·1269257	·00434783
231	53361	12326391	15·1986842	6·1357924	·00432900
232	53824	12487168	15·2315462	6·1446337	·00431035
233	54289	12649337	15·2643375	6·1534495	·00429185
234	54756	12812904	15·2970585	6·1622401	·00427350
235	55225	12977875	15·3297097	6·1710058	·00425531
236	55696	13144256	15·3622915	6·1797466	·00423728
237	56169	13312053	15·3948043	6·1884628	·00421940
238	56644	13481272	15·4272486	6·1971544	·00420168
239	57121	13651919	15·4596248	6·2058218	·00418410
240	57600	13824000	15·4919334	6·2144650	·00416667
241	58081	13997521	15·5241747	6·2230843	·00414938
242	58564	14172488	15·5563492	6·2316797	·00413223
243	59049	14348907	15·5884573	6·2402515	·00411523
244	59536	14526784	15·6204994	6·2487998	·00409836
285	81225	23149125	16·8819430	6·5808443	·00350877
286	81796	23393656	16·9115345	6·5885323	·00349650
287	82369	23639903	16·9410743	6·5962023	·00348432
288	82944	23887872	16·9705627	6·6038545	·00347222
289	83521	24137569	17·0000000	6·6114890	·00346020
290	84100	24389000	17·0293864	6·6191060	·00344828
291	84681	24642171	17·0587221	6·6267054	·00343643
292	85264	24897088	17·0880075	6·6342874	·00342466
293	85849	25153757	17·1172428	6·6418522	·00341297
294	86436	25412184	17·1464282	6·6493998	·00340136
295	87025	25672375	17·1755640	6·6569302	·00338983
296	87616	25934336	17·2046505	6·6644437	·00337838
297	88209	26198073	17·2336879	6·6719403	·00336700
298	88804	26463592	17·2626765	6·6794200	·00335570
299	89401	26730899	17·2916165	6·6868831	·00334448
300	90000	27000000	17·3205081	6·6943295	·00333333
301	90601	27270901	17·3493516	6·7017593	·00332226
302	91204	27543608	17·3781472	6·7091729	·00331126
303	91809	27818127	17·4068952	6·7165700	·00330033
304	92416	28094464	17·4355958	6·7239508	·00328947
305	93025	28372625	17·4642492	6·7313155	·00327869
306	93636	28652616	17·4928557	6·7386641	·00326797
307	94249	28934443	17·5214155	6·7459967	·00325733
308	94864	29218112	17·5499288	6·7533134	·00324675
309	95481	29503629	17·5783958	6·7606143	·00323624
310	96100	29791000	17·6068169	6·7678995	·00322581
311	96721	30080231	17·6351921	6·7751690	·00321543
312	97344	30373128	17·6635217	6·7824229	·00320513
313	97969	30664297	17·6918060	6·7896613	·00319488
314	98596	30959144	17·7200451	6·7968844	·00318471
315	99225	31255875	17·7482393	6·8040921	·00317460
316	99856	31554496	17·7763888	6·8112847	·00316456
317	100489	31855013	17·8044938	6·8184620	·00315457
318	101124	32157432	17·8325545	6·8256242	·00314464
319	101761	32461759	17·8605711	6·8327714	·00313480
320	102400	32768000	17·8885438	6·8399037	·00312500
321	103041	33076161	17·9164729	6·8470213	·00311526
322	103684	33386248	17·9443584	6·8541240	·00310559
323	104329	33698267	17·9722008	6·8612120	·00309598
324	104976	34012224	18·0000000	6·8682855	·00308642
325	105625	34328125	18·0277564	6·8753443	·00307692
326	106276	34645976	18·0554701	6·8823888	·00306748
327	106929	34965783	18·0831413	6·8894188	·00305810
328	107584	35287552	18·1107703	6·8964345	·00304878

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS (*continued*).

Number.	Squares.	Cubes.	$\sqrt{}$ Roots.	$\sqrt[3]{}$ Roots.	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{}$ Roots.	$\sqrt[3]{}$ Roots.	Reciprocals.
329	108241	35611289	18·1383571	6·9034359	·003039514	413	170569	70444997	20·3224014	7·4470343	·002421308
330	108900	35937000	18·1659021	6·9104232	·003030303	414	171396	70957944	20·3469899	7·4530399	·002415469
331	109561	36264691	18·1934054	6·9173964	·003021148	415	172225	71473375	20·3715488	7·4590359	·002409639
332	110224	36594368	18·2208672	6·9243556	·003012048	416	173056	71991296	20·3960781	7·4650223	·002406846
333	110889	36926037	18·2482876	6·9313008	·003003003	417	173889	72511713	20·4205779	7·4709991	·002398082
334	111556	37259704	18·2756669	6·9382321	·002994012	418	174724	73034632	20·4450483	7·4769664	·002392344
335	112225	37595375	18·3030052	6·9451496	·002985075	419	175561	73560059	20·4694895	7·4829242	·002386635
336	112896	37933056	18·3303028	6·9520533	·002976190	420	176400	74088000	20·4939015	7·4888724	·002380952
337	113569	38272753	18·3575598	6·9589434	·002967359	421	177241	74618461	20·5182845	7·4948113	·002375297
338	114244	38614472	18·3847763	6·9658198	·002958580	422	178084	75151448	20·5426386	7·5007406	·002369668
339	114921	38958219	18·4119526	6·9726826	·002949853	423	178929	75686967	20·5669638	7·5066607	·002364066
340	115600	39304000	18·4390889	6·9795321	·002941176	424	179776	76225024	20·5912603	7·5125715	·002358491
341	116281	39651821	18·4661853	6·9863681	·002932551	425	180625	76765625	20·6155281	7·5184730	·002352941
342	116964	40001688	18·4932420	6·9931906	·002923977	426	181476	77308776	20·6397674	7·5243652	·002347418
343	117649	40353607	18·5202592	7·0000000	·002915452	427	182329	77854483	20·6639783	7·5302482	·002341920
344	118336	40707584	18·5472370	7·0067962	·002906977	428	183184	78402752	20·6881609	7·5361221	·002336449
345	119025	41063625	18·5741756	7·0135791	·002898551	429	184041	78953589	20·7123152	7·5419867	·002331002
346	119716	41421736	18·6010752	7·0203490	·002890173	430	184900	79507000	20·7364414	7·5478423	·002325581
347	120409	41781923	18·6279360	7·0271058	·002881844	431	185761	80062991	20·7605395	7·5536888	·002320186
348	121104	42144192	18·6547581	7·0338497	·002873563	432	186624	80621568	20·7846097	7·5595263	·002314815
349	121801	42508549	18·6815417	7·0405806	·002865330	433	187489	81182737	20·8086520	7·5653548	·002309469
350	122500	42875000	18·7082869	7·0472987	·002857143	434	188356	81746504	20·8326667	7·5711743	·002304147
351	123201	43243551	18·7349940	7·0540041	·002849003	435	189225	82312875	20·8566536	7·5769849	·002298851
352	123904	43614208	18·7616630	7·0606967	·002840909	436	190096	82881856	20·8806130	7·5827865	·002293578
353	124609	43986977	18·7882942	7·0673767	·002832861	437	190969	83453453	20·9045450	7·5885793	·002288330
354	125316	44361864	18·8148877	7·0740440	·002824859	438	191844	84027672	20·9284495	7·5943633	·002283105
355	126025	44738875	18·8414437	7·0806988	·002816901	439	192721	84604519	20·9523268	7·6001385	·002277904
356	126736	45118016	18·8679623	7·0873411	·002808989	440	193600	85184000	20·9761770	7·6059049	·002272727
357	127449	45499293	18·8944436	7·0939709	·002801120	441	194481	85766121	21·0000000	7·6116626	·002267574
358	128164	45882712	18·9208879	7·1005885	·002793296	442	195364	86350888	21·0237960	7·6174116	·002262443
359	128881	46268279	18·9472953	7·1071937	·002785515	443	196249	86938307	21·0475652	7·6231519	·002257336
360	129600	46656000	18·9736660	7·1137866	·002777778	444	197136	87528384	21·0713075	7·6288837	·002252252
361	130321	47045881	19·0000000	7·1203674	·002770082	445	198025	88121125	21·0950231	7·6346067	·002247191
362	131044	47437928	19·0262976	7·1269360	·002762431	446	198916	88716536	21·1187121	7·6403213	·002242152
363	131769	47832147	19·0525589	7·1334925	·002754821	447	199809	89314623	21·1423745	7·6460272	·002237136
364	132496	48228544	19·0787840	7·1400370	·002747253	448	200704	89915392	21·1660105	7·6517247	·002232143
365	133225	48627125	19·1049732	7·1465695	·002739726	449	201601	90518849	21·1896201	7·6574138	·002227171
366	133956	49027896	19·1311265	7·1530901	·002732240	450	202500	91125000	21·2132034	7·6630943	·002222222
367	134689	49430863	19·1572441	7·1595988	·002724796	451	203401	91733851	21·2367606	7·6687665	·002217295
368	135424	49836032	19·1833261	7·1660957	·002717391	452	204304	92345408	21·2602916	7·6744303	·002212389

369	136161	50243409	19·2093727	7·1725809	·002710027
370	136900	50653000	19·2353841	7·1790544	·002702703
371	137641	51064811	19·2613603	7·1855162	·002695418
372	138384	51478848	19·2873015	7·1919663	·002688172
373	139129	51895117	19·3132079	7·1984050	·002680965
374	139876	52313624	19·3390796	7·2048322	·002673797
375	140625	52734375	19·3649167	7·2112479	·002666667
376	141376	53157376	19·3907194	7·2176522	·002659574
377	142129	53582633	19·4164878	7·2240450	·002652520
378	142884	54010152	19·4422221	7·2304268	·002645503
379	143641	54439939	19·4679223	7·2367972	·002638521
380	144400	54872000	19·4935887	7·2431565	·002631579
381	145161	55306341	19·5192213	7·2495045	·002624672
382	145924	55742968	19·5448203	7·2558415	·002617801
383	146689	56181887	19·5703858	7·2621675	·002610966
384	147456	56623104	19·5959179	7·2684824	·002604167
385	148225	57066625	19·6214169	7·2747864	·002597403
386	148996	57512456	19·6468827	7·2810794	·002590674
387	149769	57960603	19·6723156	7·2873617	·002583979
388	150544	58411072	19·6977156	7·2936330	·002577320
389	151321	58863869	19·7230829	7·2998936	·002570694
390	152100	59319000	19·7484177	7·3061436	·002564103
391	152881	59776471	19·7737199	7·3123828	·002557545
392	153664	60236288	19·7989899	7·3186114	·002551020
393	154449	60698457	19·8242276	7·3248295	·002544529
394	155236	61162984	19·8494332	7·3310369	·002538071
395	156025	61629875	19·8746069	7·3372339	·002531646
396	156816	62099136	19·8997487	7·3434205	·002525253
397	157609	62570773	19·9248588	7·3495966	·002518892
398	158404	63044792	19·9499373	7·3557624	·002512563
399	159201	63521199	19·9749844	7·3619178	·002506266
400	160000	64000000	20·0000000	7·3680630	·002500000
401	160801	64481201	20·0249844	7·3741979	·002493766
402	161604	64964808	20·0499377	7·3803227	·002487562
403	162409	65450827	20·0748599	7·3864373	·002481390
404	163216	65939264	20·0997512	7·3925418	·002475248
405	164025	66430125	20·1246118	7·3986363	·002469136
406	164836	66923416	20·1494417	7·4047206	·002463054
407	165649	67419143	20·1742410	7·4107950	·002457002
408	166464	67917312	20·1990099	7·4168595	·002450980
409	167281	68417929	20·2237484	7·4229142	·002444988
410	168100	68921000	20·2484567	7·4289589	·002439024
411	168921	69426531	20·2731349	7·4349938	·002433090
412	169744	69934528	20·2977831	7·4410189	·002427184
453	205209	92959677	21·2837967	7·6800857	·002207506
454	206116	93576664	21·3072758	7·6857328	·002202643
455	207025	94196375	21·3307290	7·6913717	·002197802
456	207936	94818816	21·3541565	7·6970023	·002192982
457	208849	95443993	21·3775583	7·7026246	·002188184
458	209764	96071912	21·4009346	7·7082388	·002183406
459	210681	96702579	21·4242853	7·7138448	·002178649
460	211600	97336000	21·4476106	7·7194426	·002173913
461	212521	97972181	21·4709106	7·7250325	·002169197
462	213444	98611128	21·4941853	7·7306141	·002164502
463	214369	99252847	21·5174348	7·7361877	·002159827
464	215296	99897344	21·5406592	7·7417532	·002155172
465	216225	100544625	21·5638587	7·7473109	·002150538
466	217156	101194696	21·5870331	7·7528606	·002145923
467	218089	101847563	21·6101828	7·7584023	·002141328
468	219024	102503232	21·6333077	7·7639361	·002136752
469	219961	103161709	21·6564078	7·7694620	·002132196
470	220900	103823000	21·6794834	7·7749801	·002127660
471	221841	104487111	21·7025344	7·7804904	·002123142
472	222784	105154048	21·7255610	7·7859928	·002118644
473	223729	105828817	21·7485632	7·7914875	·002114165
474	224676	106496424	21·7715411	7·7969745	·002109705
475	225625	107171875	21·7944947	7·8024538	·002105263
476	226576	107850176	21·8174242	7·8079254	·002100840
477	227529	108531333	21·8403297	7·8133892	·002096486
478	228484	109215352	21·8632111	7·8188456	·002092050
479	229441	109902239	21·8860686	7·8242942	·002087683
480	230400	110592000	21·9089023	7·8297353	·002083333
481	231361	111284641	21·9317122	7·8351688	·002079002
482	232324	111980168	21·9544984	7·8405949	·002074689
483	233289	112678587	21·9772610	7·8460134	·002070393
484	234256	113379904	22·0000000	7·8514244	·002066116
485	235225	114084125	22·0227155	7·8568281	·002061856
486	236196	114791256	22·0454077	7·8622242	·002057613
487	237169	115501303	22·0680765	7·8676130	·002053388
488	238144	116214272	22·0907220	7·8729944	·002049180
489	239121	116930169	22·1133444	7·8783684	·002044990
490	240100	117649000	22·1359436	7·8837352	·002040816
491	241081	118370771	22·1585198	7·8890946	·002036660
492	242064	119095488	22·1810730	7·8944468	·002032520
493	243049	119823157	22·2036033	7·8997917	·002028398
494	244036	120553784	22·2261108	7·9051294	·002024291
495	245025	121287375	22·2485955	7·9104599	·002020202
496	246016	122023936	22·2710575	7·9157832	·002016129

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS (*continued*).

Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.
497	247009	122763473	22·2934968	7·9210994	·002012072	581	337561	196122941	24·1039416	8·3443410	·001721170
498	248004	123505992	22·3159136	7·9264085	·002008032	582	338724	197137368	24·1246762	8·3491256	·001718213
499	249001	124251499	22·3383079	7·9317104	·002004008	583	339889	198155287	24·1453929	8·3539047	·001715266
500	250000	125000000	22·3606798	7·9370053	·002000000	584	341056	199176704	24·1660919	8·3586784	·001712329
501	251001	125751501	22·3830293	7·9422931	·001996008	585	342225	200201625	24·1867732	8·3634466	·001709402
502	252004	126506008	22·4053565	7·9475739	·001992032	586	343396	201230056	24·2074369	8·3682095	·001706485
503	253009	127263527	22·4276615	7·9528477	·001988072	587	344569	202262003	24·2280829	8·3729668	·001703578
504	254016	128024064	22·4499443	7·9581144	·001984127	588	345744	203297472	24·2487113	8·3777188	·001700680
505	255025	128787625	22·4722051	7·9633743	·001980198	589	346921	204336469	24·2693222	8·3824653	·001697793
506	256036	129554216	22·4944438	7·9686271	·001976285	590	348100	205379000	24·2899156	8·3872065	·001694915
507	257049	130323843	22·5166605	7·9738731	·001972387	591	349281	206425071	24·3104916	8·3919428	·001692047
508	258064	131096512	22·5388553	7·9791122	·001968504	592	350464	207474688	24·3310501	8·3966729	·001689189
509	259081	131872229	22·5610283	7·9843444	·001964637	593	351649	208527857	24·3515913	8·4013981	·001686341
510	260100	132651000	22·5831796	7·9895697	·001960784	594	352836	209584584	24·3721152	8·4061180	·001683502
511	261121	133432831	22·6053091	7·9947883	·001956947	595	354025	210644875	24·3926218	8·4108326	·001680672
512	262144	134217728	22·6274170	8·0000000	·001953125	596	355216	211708736	24·4131112	8·4155419	·001677852
513	263169	135005697	22·6495033	8·0052049	·001949318	597	356409	212776173	24·4335834	8·4202460	·001675042
514	264196	135796744	22·6715681	8·0104032	·001945525	598	357604	213847192	24·4540385	8·4249448	·001672241
515	265225	136590875	22·6936114	8·0155946	·001941748	599	358801	214921799	24·4744765	8·4296383	·001669449
516	266256	137388096	22·7156334	8·0207794	·001937984	600	360000	216000000	24·4948974	8·4343267	·001666667
517	267289	138188413	22·7376341	8·0259574	·001934236	601	361201	217081801	24·5153013	8·4390098	·001663894
518	268324	138991832	22·7596134	8·0311287	·001930502	602	362404	218167208	24·5356883	8·4436877	·001661130
519	269361	139798359	22·7815715	8·0362935	·001926782	603	363609	219256227	24·5560583	8·4483605	·001658375
520	270400	140608000	22·8035085	8·0414515	·001923077	604	364816	220348864	24·5764115	8·4530281	·001655629
521	271411	141420761	22·8254244	8·0466030	·001919386	605	366025	221445125	24·5967478	8·4576906	·001652893
522	272484	142236648	22·8473193	8·0517479	·001915709	606	367236	222545016	24·6170673	8·4623479	·001650165
523	273529	143055667	22·8691933	8·0568862	·001912046	607	368449	223648543	24·6373700	8·4670001	·001647446
524	274576	143877824	22·8910463	8·0620180	·001908397	608	369664	224755712	24·6576560	8·4716471	·001644737
525	275625	144703125	22·9128785	8·0671432	·001904762	609	370881	225866529	24·6779254	8·4762892	·001642036
526	276676	145531576	22·9346899	8·0722620	·001901141	610	372100	226981000	24·6981781	8·4809261	·001639344
527	277729	146363183	22·9564806	8·0773743	·001897533	611	373321	228099131	24·7184142	8·4855579	·001636661
528	278784	147197952	22·9782506	8·0824800	·001893939	612	374544	229220928	24·7386338	8·4901848	·001633987
529	279841	148035889	23·0000000	8·0875794	·001890359	613	375769	230346397	24·7588368	8·4948065	·001631321
530	280900	148877000	23·0217289	8·0926723	·001886792	614	376996	231475544	24·7790234	8·4994233	·001628664
531	281961	149721291	23·0434372	8·0977589	·001883239	615	378225	232608375	24·7991935	8·5040350	·001626016
532	283024	150568768	23·0651252	8·1028390	·001879699	616	379456	233744896	24·8193473	8·5086417	·001623377
533	284089	151419437	23·0867928	8·1079128	·001876173	617	380689	234885113	24·8394847	8·5132435	·001620746
534	285156	152273304	23·1084400	8·1129803	·001872659	618	381924	236029032	24·8596058	8·5178403	·001618123
535	286225	153130375	23·1300670	8·1180414	·001869159	619	383161	237176659	24·8797106	8·5224331	·001615509
536	287296	153990656	23·1516738	8·1230962	·001865672	620	384400	238328000	24·8997992	8·5270189	·001612903

537	288369	154854153	23·1732605	8·1281447	·001862197
538	289444	155720872	23·1948270	8·1331870	·001858736
539	290521	156590819	23·2163735	8·1382230	·001855288
540	291600	157464000	23·2379001	8·1432529	·001851852
541	292681	158340421	23·2594067	8·1482765	·001848429
542	293764	159220088	23·2808935	8·1532939	·001845018
543	294849	160103007	23·3023604	8·1583051	·001841621
544	295936	160989184	23·3238076	8·1633102	·001838235
545	297025	161878625	23·3452351	8·1683092	·001834862
546	298116	162771336	23·3666429	8·1733020	·001831502
547	299209	163667323	23·3880311	8·1782888	·001828154
548	300304	164566592	23·4093998	8·1832695	·001824818
549	301401	165469149	23·4307490	8·1882441	·001821494
550	302500	166375000	23·4520788	8·1932127	·001818182
551	303601	167284151	23·4733892	8·1981753	·001814882
552	304704	168196608	23·4946802	8·2031319	·001811594
553	305809	169112377	23·5159520	8·2080825	·001808318
554	306916	170031464	23·5372046	8·2130271	·001805054
555	308025	170953875	23·5584380	8·2179657	·001801802
556	309136	171879616	23·5796522	8·2228985	·001798561
557	310249	172808693	23·6008474	8·2278254	·001795332
558	311364	173741112	23·6220236	8·2327463	·001792115
559	312481	174676879	23·6431808	8·2376614	·001788909
560	313600	175616000	23·6643191	8·2425706	·001785714
561	314721	176558481	23·6854386	8·2474740	·001782531
562	315844	177504328	23·7065392	8·2523715	·001779359
563	316969	178453547	23·7276210	8·2572635	·001776199
564	318096	179406144	23·7486842	8·2621492	·001773050
565	319225	180362125	23·7697286	8·2670294	·001769912
566	320356	181321496	23·7907545	8·2719039	·001766784
567	321489	182284263	23·8117618	8·2767726	·001763668
568	322624	183250432	23·8327506	8·2816355	·001760563
569	323761	184220009	23·8537209	8·2864928	·001757469
570	324900	185193000	23·8746728	8·2913444	·001754386
571	326041	186169411	23·8956063	8·2961903	·001751313
572	327184	187149248	23·9165215	8·3010304	·001748252
573	328329	188132517	23·9374184	8·3058651	·001745201
574	329476	189119224	23·9582971	8·3106941	·001742160
575	330625	190109375	23·9791576	8·3155175	·001739130
576	331776	191102976	24·0000000	8·3203353	·001736111
577	332929	192100033	24·0208243	8·3251475	·001733102
578	334084	193100552	24·0416306	8·3299542	·001730104
579	335241	194104539	24·0624188	8·3347553	·001727116
580	336400	195112000	24·0831891	8·3395509	·001724138
621	385641	239483061	24·9198716	8·5316009	·001610306
622	386884	240641848	24·9399278	8·5361780	·001607717
623	388129	241804367	24·9599679	8·5407501	·001605136
624	389376	242970624	24·9799920	8·5453173	·001602564
625	390625	244140625	25·0000000	8·5498797	·001600000
626	391876	245314376	25·0199920	8·5544372	·001597444
627	393129	246491883	25·0399681	8·5589899	·001594896
628	394384	247673152	25·0599282	8·5635377	·001592357
629	395641	248858189	25·0798724	8·5680807	·001589825
630	396900	250047000	25·0998008	8·5726189	·001587302
631	398161	251239591	25·1197134	8·5771523	·001584786
632	399424	252435968	25·1396102	8·5816809	·001582278
633	400689	253636137	25·1594913	8·5862047	·001579779
634	401956	254840104	25·1793566	8·5907238	·001577287
635	403225	256047875	25·1992063	8·5952380	·001574803
636	404496	257259456	25·2190404	8·5997476	·001572327
637	405769	258474853	25·2388589	8·6042525	·001569859
638	407044	259694072	25·2586619	8·6087526	·001567398
639	408321	260917119	25·2784493	8·6132480	·001564945
640	409600	262144000	25·2982213	8·6177388	·001562500
641	410881	263374721	25·3179778	8·6222248	·001560062
642	412164	264609288	25·3377189	8·6267063	·001557632
643	413449	265847707	25·3574447	8·6311830	·001555210
644	414736	267089984	25·3771551	8·6356551	·001552795
645	416025	268336125	25·3968502	8·6401226	·001550388
646	417316	269585136	25·4165302	8·6445855	·001547988
647	418609	270840023	25·4361947	8·6490437	·001545595
648	419904	272097792	25·4558441	8·6534974	·001543210
649	421201	273359449	25·4754784	8·6579465	·001540832
650	422500	274625000	25·4950976	8·6623911	·001538462
651	423801	275894451	25·5147016	8·6668310	·001536098
652	425104	277167808	25·5342907	8·6712665	·001533742
653	426409	278445077	25·5538647	8·6756974	·001531394
654	427716	279726264	25·5734237	8·6801237	·001529052
655	429025	281011375	25·5929678	8·6845456	·001526718
656	430336	282300416	25·6124969	8·6889630	·001524390
657	431649	283593393	25·6320112	8·6933759	·001522070
658	432964	284890312	25·6515107	8·6977843	·001519751
659	434281	286191179	25·6709953	8·7021882	·001517451
660	435600	287496000	25·6904652	8·7065877	·001515152
661	436921	288804781	25·7099203	8·7109827	·001512859
662	438244	290117528	25·7293607	8·7153734	·001510574
663	439569	291434247	25·7487864	8·7197596	·001508296
664	440896	292754944	25·7681975	8·7241414	·001506024

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS (*continued*).

Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.
665	442225	294079625	25·7875939	8·7285187	·001503759	749	561001	420189749	27·3678644	9·0815631	·001335113
666	443556	295408296	25·8069758	8·7328918	·001501502	750	562500	421875000	27·3861279	9·0856030	·001333333
667	444889	296740963	25·8263431	8·7372604	·001499250	751	564001	423564751	27·4043792	9·0896392	·001331558
668	446224	298077632	25·8456960	8·7416246	·001497006	752	565504	425259008	27·4226184	9·0936719	·001329787
669	447561	299418309	25·8650343	8·7459846	·001494768	753	567009	426957777	27·4408455	9·0977010	·001328021
670	448900	300763000	25·8843582	8·7503401	·001492537	754	568516	428661064	27·4590604	9·1017265	·001326260
671	450241	302111711	25·9036677	8·7546913	·001490313	755	570025	430368875	27·4772633	9·1057485	·001324503
672	451584	303464448	25·9229628	8·7590383	·001488095	756	571536	432081216	27·4954542	9·1097669	·001322751
673	452929	304821217	25·9422435	8·7633809	·001485884	757	573049	433798093	27·5136330	9·1137818	·001321004
674	454276	306182024	25·9615100	8·7677192	·001483680	758	574564	435519512	27·5317998	9·1177931	·001319261
675	455625	307546875	25·9807621	8·7720532	·001481481	759	576081	437245479	27·5499546	9·1218010	·001317523
676	456976	308915776	26·0000000	8·7763830	·001479290	760	577600	438976000	27·5680975	9·1258053	·001315789
677	458329	310288733	26·0192237	8·7807084	·001477105	761	579121	440711081	27·5862284	9·1298061	·001314060
678	459684	311665752	26·0384331	8·7850296	·001474926	762	580644	442450728	27·6043475	9·1338034	·001312336
679	461041	313046839	26·0576284	8·7893466	·001472754	763	582169	444194947	27·6224546	9·1377971	·001310616
680	462400	314432000	26·0768096	8·7936593	·001470588	764	583696	445943744	27·6405499	9·1417874	·001308901
681	463761	315821241	26·0959767	8·7979679	·001468429	765	585225	447697125	27·6586334	9·1457742	·001307190
682	465124	317214568	26·1151297	8·8022721	·001466276	766	586756	449455096	27·6767050	9·1497576	·001305483
683	466489	318611987	26·1342687	8·8065722	·001464129	767	588289	451217663	27·6947648	9·1537375	·001303781
684	467856	320013504	26·1533937	8·8108681	·001461988	768	589824	452984832	27·7128129	9·1577139	·001302083
685	469225	321419125	26·1725047	8·8151598	·001459854	769	591361	454756609	27·7308492	9·1616869	·001300390
686	470596	322828856	26·1916017	8·8194474	·001457726	770	592900	456533000	27·7488739	9·1656565	·001298701
687	471969	324242703	26·2106848	8·8237307	·001455604	771	594441	458314011	27·7668868	9·1696225	·001297017
688	473344	325660672	26·2297541	8·8280099	·001453488	772	595984	460099648	27·7848880	9·1735852	·001295337
689	474721	327082769	26·2488095	8·8322850	·001451379	773	597529	461889917	27·8028775	9·1775445	·001293661
690	476100	328509000	26·2678511	8·8365559	·001449275	774	599076	463684824	27·8208555	9·1815003	·001291990
691	477481	329939371	26·2868789	8·8408227	·001447178	775	600625	465484375	27·8388218	9·1854527	·001290323
692	478864	331373888	26·3058929	8·8450854	·001445087	776	602176	467288576	27·8567766	9·1894018	·001288660
693	480249	332812557	26·3248932	8·8493440	·001443001	777	603729	469097433	27·8747197	9·1933474	·001287001
694	481636	334255384	26·3438797	8·8535985	·001440922	778	605284	470910952	27·8926514	9·1972897	·001285347
695	483025	335702375	26·3628527	8·8578489	·001438849	779	606841	472729139	27·9105715	9·2012286	·001283697
696	484416	337153536	26·3818119	8·8620952	·001436782	780	608400	474552000	27·9284801	9·2051641	·001282051
697	485809	338608873	26·4007576	8·8663375	·001434720	781	609961	476379541	27·9463772	9·2090962	·001280410
698	487204	340068392	26·4196896	8·8705757	·001432665	782	611524	478211768	27·9642629	9·2130250	·001278772
699	488601	341532099	26·4386081	8·8748099	·001430615	783	613089	480048687	27·9821372	9·2169505	·001277139
700	490000	343000000	26·4575131	8·8790400	·001428571	784	614656	481890304	28·0000000	9·2208726	·001275510
701	491401	344472101	26·4764046	8·8832661	·001426534	785	616225	483736625	28·0178515	9·2247914	·001273885
702	492804	345948408	26·4952826	8·8874882	·001424501	786	617796	485587656	28·0356915	9·2287068	·001272265
703	494209	347428927	26·5141472	8·8917063	·001422475	787	619369	487443403	28·0535203	9·2326189	·001270648
704	495616	348913664	26·5329983	8·8959204	·001420455	788	620944	489303872	28·0713377	9·2365277	·001269036

705	497025	350402625	26·5518361	8·9001304	·001418440
706	498436	351895816	26·5706605	8·9043366	·001416431
707	499849	353393243	26·5894716	8·9085387	·001414427
708	501264	354894912	26·6082694	8·9127369	·001412429
709	502681	356400829	26·6270539	8·9169311	·001410437
710	504100	357911000	26·6458252	8·9211214	·001408451
711	505521	359425431	26·6645833	8·9253078	·001406470
712	506944	360944128	26·6833281	8·9294902	·001404494
713	508369	362467097	26·7020598	8·9336687	·001402525
714	509796	363994344	26·7207784	8·9378433	·001400560
715	511225	365525875	26·7394839	8·9420140	·001398601
716	512656	367061696	26·7581763	8·9461809	·001396648
717	514089	368601813	26·7768557	8·9503438	·001394700
718	515524	370146232	26·7955220	8·9545029	·001392758
719	516961	371694959	26·8141754	8·9586581	·001390821
720	518400	373248000	26·8328157	8·9628095	·001388889
721	519841	374805361	26·8514432	8·9669570	·001386963
722	521284	376367048	26·8700577	8·9711007	·001385042
723	522729	377933067	26·8886593	8·9752406	·001383126
724	524176	379503424	26·9072481	8·9793766	·001381215
725	525625	381078125	26·9258240	8·9835089	·001379310
726	527076	382657176	26·9443872	8·9876373	·001377410
727	528529	384240583	26·9629375	8·9917620	·001375516
728	529984	385828352	26·9814751	8·9958829	·001373626
729	531441	387420489	27·0000000	9·0000000	·001371742
730	532900	389017000	27·0185122	9·0041134	·001369863
731	534361	390617891	27·0370117	9·0082229	·001367989
732	535824	392223168	27·0554985	9·0123288	·001366120
733	537289	393832837	27·0739727	9·0164309	·001364256
734	538756	395446904	27·0924344	9·0205293	·001362398
735	540225	397065375	27·1108834	9·0246239	·001360544
736	541696	398688256	27·1293199	9·0287149	·001358696
737	543169	400315553	27·1477149	9·0328021	·001356852
738	544644	401947272	27·1661554	9·0368857	·001355014
739	546121	403583419	27·1845544	9·0409655	·001353180
740	547600	405224000	27·2029140	9·0450419	·001351351
741	549081	406869021	27·2213152	9·0491142	·001349528
742	550564	408518488	27·2396769	9·0531831	·001347709
743	552049	410172407	27·2580263	9·0572482	·001345895
744	553536	411830784	27·2763634	9·0613098	·001344086
745	555025	413493625	27·2946881	9·0653677	·001342282
746	556516	415160936	27·3130006	9·0694220	·001340483
747	558009	416832723	27·3313007	9·0734726	·001338688
748	559504	418508992	27·3495887	9·0775197	·001336898
789	622521	491169069	28·0891438	9·2404333	·001267427
790	624100	493039000	28·1069386	9·2443355	·001265823
791	625681	494913671	28·1247222	9·2482344	·001264223
792	627264	496793088	28·1424946	9·2521300	·001262626
793	628849	498677257	28·1602557	9·2560224	·001261034
794	630436	500566184	28·1780056	9·2599114	·001259446
795	632025	502459875	28·1957444	9·2637973	·001257862
796	633616	504358336	28·2134720	9·2676798	·001256281
797	635209	506261573	28·2311884	9·2715592	·001254705
798	636804	508169592	28·2488938	9·2754352	·001253133
799	638401	510082399	28·2665881	9·2793081	·001251564
800	640000	512000000	28·2842712	9·2831777	·001250000
801	641601	513922401	28·3019434	9·2870444	·001248439
802	643204	515849608	28·3196045	9·2909072	·001246883
803	644809	517781627	28·3372546	9·2947671	·001245330
804	646416	519718464	28·3548938	9·2986239	·001243781
805	648025	521660125	28·3725219	9·3024775	·001242236
806	649636	523606616	28·3901391	9·3063278	·001240695
807	651249	525557943	28·4077454	9·3101750	·001239157
808	652864	527514112	28·4253408	9·3140190	·001237624
809	654481	529475129	28·4429253	9·3178599	·001236094
810	656100	531441000	28·4604989	9·3216975	·001234568
811	657721	533411731	28·4780617	9·3255320	·001233046
812	659344	535387328	28·4956137	9·3293634	·001231527
813	660969	537367797	28·5131549	9·3331916	·001230012
814	662596	539353144	28·5306852	9·3370167	·001228501
815	664225	541343375	28·5482048	9·3408386	·001226994
816	665856	543338496	28·5657137	9·3446575	·001225499
817	667489	545338513	28·5832119	9·3484731	·001223990
818	669124	547343432	28·6006993	9·3522857	·001222494
819	670761	549353259	28·6181760	9·3560952	·001221001
820	672400	551368000	28·6356421	9·3599016	·001219512
821	674041	553387661	28·6530976	9·3637049	·001218027
822	675684	555412248	28·6705424	9·3675051	·001216545
823	677329	557441767	28·6879766	9·3713022	·001215067
824	678976	559476224	28·7054002	9·3750963	·001213592
825	680625	561515625	28·7228132	9·3788873	·001212121
826	682276	563559976	28·7402157	9·3826752	·001210654
827	683929	565609283	28·7576077	9·3864600	·001209190
828	685584	567663552	28·7749891	9·3902419	·001207729
829	687241	569722789	28·7923601	9·3940206	·001206273
830	688900	571787000	28·8097206	9·3977964	·001204819
831	690561	573856191	28·8270706	9·4015691	·001203369
832	692224	575930368	28·8444102	9·4053387	·001201923

TABLE OF SQUARES, CUBES, SQUARE AND CUBE ROOTS, AND RECIPROCALS (*continued*).

Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.	Number.	Squares.	Cubes.	$\sqrt{\text{Roots.}}$	$\sqrt[3]{\text{Roots.}}$	Reciprocals.
833	693889	578009537	28·8617394	9·4091054	·001200480	917	840889	771095213	30·2820079	9·7153051	·001090513
834	695556	580093704	28·8790582	9·4128690	·001199041	918	842724	773620632	30·2985148	9·7188354	·001089325
835	697225	582182875	28·8963666	9·4166297	·001197605	919	844561	776151559	30·3150128	9·7223631	·001088139
836	698896	584277056	28·9136646	9·4203873	·001196172	920	846400	778688000	30·3315018	9·7258883	·001086957
837	700569	586376253	28·9309523	9·4241420	·001194743	921	848241	781229961	30·3479818	9·7294109	·001085776
838	702244	588480472	28·9482297	9·4278936	·001193317	922	850084	783777448	30·3644529	9·7329309	·001084599
839	703921	590589719	28·9654967	9·4316423	·001191895	923	851929	786330467	30·3809151	9·7364484	·001083423
840	705600	592704000	28·9827535	9·4353880	·001190476	924	853776	788889024	30·3973683	9·7399634	·001082251
841	707281	594823321	29·0000000	9·4391307	·001189061	925	855625	791453125	30·4138127	9·7434758	·001081081
842	708964	596947688	29·0172363	9·4428704	·001187648	926	857476	794022776	30·4302481	9·7469857	·001079914
843	710649	599077107	29·0344623	9·4466072	·001186240	927	859329	796597983	30·4466747	9·7504930	·001078749
844	712336	601211584	29·0516781	9·4503410	·001184834	928	861184	799178752	30·4630924	9·7539979	·001077586
845	714025	603351125	29·0688837	9·4540719	·001183432	929	863041	801765089	30·4795013	9·7575002	·001076426
846	715716	605495736	29·0860791	9·4577999	·001182033	930	864900	804357000	30·4959014	9·7610001	·001075269
847	717409	607645423	29·1032644	9·4615249	·001180638	931	866761	806954491	30·5122926	9·7644974	·001074114
848	719104	609800192	29·1204396	9·4652470	·001179245	932	868624	809557568	30·5286750	9·7679922	·001072961
849	720801	611960049	29·1376046	9·4689661	·001177856	933	870489	812166237	30·5450487	9·7714845	·001071811
850	722500	614125000	29·1547595	9·4726824	·001176471	934	872356	814780504	30·5614136	9·7749743	·001070664
851	724201	616295051	29·1719043	9·4763957	·001175088	935	874225	817400375	30·5777697	9·7784616	·001069519
852	725904	618470208	29·1890390	9·4801061	·001173709	936	876096	820025856	30·5941171	9·7819466	·001068376
853	727609	620650477	29·2061637	9·4838136	·001172333	937	877969	822656953	30·6104557	9·7854288	·001067236
854	729316	622835864	29·2232784	9·4875182	·001170960	938	879844	825293672	30·6267857	9·7889087	·001066098
855	731025	625026375	29·2403830	9·4912200	·001169591	939	881721	827936019	30·6431069	9·7923861	·001064963
856	732736	627222016	29·2574777	9·4949188	·001168224	940	883600	830584000	30·6594194	9·7958611	·001063830
857	734449	629422793	29·2745623	9·4986147	·001166861	941	885481	833237621	30·6757233	9·7993336	·001062699
858	736164	631628712	29·2916370	9·5023078	·001165501	942	887364	835896888	30·6920185	9·8028036	·001061571
859	737881	633839779	29·3087018	9·5059980	·001164144	943	889249	838561807	30·7083051	9·8062711	·001060445
860	739600	636056000	29·3257566	9·5096854	·001162791	944	891136	841232384	30·7245830	9·8097362	·001059322
861	741321	638277381	29·3428015	9·5133699	·001161440	945	893025	843908625	30·7408523	9·8131989	·001058201
862	743044	640503928	29·3598365	9·5170515	·001160093	946	894916	846590536	30·7571130	9·8166591	·001057082
863	744769	642735647	29·3768616	9·5207303	·001158749	947	896809	849278123	30·7733651	9·8201169	·001055966
864	746496	644972544	29·3938769	9·5244063	·001157407	948	898704	851971392	30·7896086	9·8235723	·001054852
865	748225	647214625	29·4108823	9·5280794	·001156069	949	900601	854670349	30·8058436	9·8270252	·001053741
866	749956	649461896	29·4278779	9·5317497	·001154734	950	902500	857375000	30·8220700	9·8304757	·001052632
867	751689	651714363	29·4448637	9·5354172	·001153403	951	904401	860085351	30·8382879	9·8339238	·001051525
868	753424	653972032	29·4618397	9·5390818	·001152074	952	906304	862801408	30·8544972	9·8373695	·001050420
869	755161	656234909	29·4788059	9·5427437	·001150748	953	908209	865523177	30·8706981	9·8408127	·001049318
870	756900	658503000	29·4957624	9·5464027	·001149425	954	910116	868250664	30·8868904	9·8442536	·001048218
871	758641	660776311	29·5127091	9·5500589	·001148106	955	912025	870983875	30·9030743	9·8476920	·001047120
872	760384	663054848	29·5296461	9·5537123	·001146789	956	913936	873722816	30·9192497	9·8511280	·001046025

873	762129	665338617	29·5465734	9·5573630	·001145475	957	915849	876467493	30·9354166	9·8545617	·001044932
874	763876	667627624	29·5634910	9·5610108	·001144165	958	917764	879217912	30·9515751	9·8579929	·001043841
875	765625	669921875	29·5803989	9·5646559	·001142857	959	919681	881974079	30·9677251	9·8614218	·001042753
876	767376	672221376	29·5972972	9·5682982	·001141553	960	921600	884736000	30·9838668	9·8648483	·001041667
877	769129	674526133	29·6141858	9·5719377	·001140251	961	923521	887503681	31·0000000	9·8682724	·001040583
878	770884	676836152	29·6310648	9·5755745	·001138952	962	925444	890277128	31·0161248	9·8716941	·001039501
879	772641	679151439	29·6479342	9·5792085	·001137656	963	927369	893056347	31·0322413	9·8751135	·001038422
880	774400	681472000	29·6647939	9·5828397	·001136364	964	929296	895841344	31·0483494	9·8785305	·001037344
881	776161	683797841	29·6816442	9·5864682	·001135074	965	931225	898632125	31·0644491	9·8819451	·001036269
882	777924	686128968	29·6984848	9·5900937	·001133787	966	933156	901428696	31·0805405	9·8853574	·001035197
883	779689	688465387	29·7153159	9·5937169	·001132503	967	935089	904231063	31·0966236	9·8887673	·001034126
884	781456	690807104	29·7321375	9·5973373	·001131222	968	937024	907039232	31·1126984	9·8921749	·001033058
885	783225	693154125	29·7489496	9·6009548	·001129944	969	938961	909853209	31·1287648	9·8955801	·001031992
886	784996	695506456	29·7657521	9·6045696	·001128668	970	940900	912673000	31·1448230	9·8989830	·001030928
887	786769	697864103	29·7825452	9·6081817	·001127396	971	942841	915498611	31·1608729	9·9023835	·001029866
888	788544	700227072	29·7993289	9·6117911	·001126126	972	944784	918330048	31·1769145	9·9057817	·001028807
889	790321	702595369	29·8161030	9·6153977	·001124859	973	946729	921167317	31·1929479	9·9091776	·001027749
890	792100	704969000	29·8328678	9·6190017	·001123596	974	948676	924010424	31·2089731	9·9125712	·001026694
891	793881	707347971	29·8496231	9·6226030	·001122334	975	950625	926859375	31·2249900	9·9159624	·001025641
892	795664	709732288	29·8663690	9·6262016	·001121076	976	952576	929714176	31·2409987	9·9193513	·001024590
893	797449	712121957	29·8831056	9·6297975	·001119821	977	954529	932574833	31·2569992	9·9227379	·001023541
894	799236	714516984	29·8998328	9·6333907	·001118568	978	956484	935441352	31·2729915	9·9261222	·001022495
895	801025	716917375	29·9165506	9·6369812	·001117818	979	958441	938313739	31·2889757	9·9295042	·001021450
896	802816	719323136	29·9332591	9·6405690	·001116071	980	960400	941192000	31·3049517	9·9328839	·001020408
897	804609	721734273	29·9499583	9·6441542	·001114827	981	962361	944076141	31·3209195	9·9362613	·001019168
898	806404	724150792	29·9666481	9·6477367	·001113586	982	964324	946966168	31·3368792	9·9396363	·001018330
899	808201	726572699	29·9833287	9·6513166	·001112347	983	966289	949862087	31·3528308	9·9430092	·001017294
900	810000	729000000	30·0000000	9·6548938	·001111111	984	968256	952763904	31·3687743	9·9463797	·001016260
901	811801	731432701	30·0166621	9·6584684	·001109878	985	970225	955671625	31·3847097	9·9497479	·001015228
902	813604	733870808	30·0333148	9·6620403	·001108647	986	972196	958585256	31·4006369	9·9531138	·001014199
903	815409	736314327	30·0499584	9·6656096	·001107420	987	974169	961504803	31·4165561	9·9564775	·001013171
904	817216	738763264	30·0665928	9·6691762	·001106195	988	976144	964430272	31·4324673	9·9598389	·001012146
905	819025	741217625	30·0832179	9·6727403	·001104972	989	978121	967361669	31·4483704	9·9631981	·001011122
906	820836	743677416	30·0998339	9·6763017	·001103753	990	980100	970299000	31·4642654	9·9665549	·001010101
907	822649	746142643	30·1164407	9·6798604	·001102536	991	982081	973242271	31·4801525	9·9699095	·001009082
908	824464	748613312	30·1330383	9·6834166	·001101322	992	984064	976191488	31·4960315	9·9732619	·001008065
909	826281	751089429	30·1496269	9·6869701	·001100110	993	986049	979146657	31·5119025	9·9766120	·001007049
910	828100	753571000	30·1662063	9·6905211	·001098901	994	988036	982107784	31·5277655	9·9799599	·001006036
911	829921	756058031	30·1827765	9·6940694	·001097695	995	990025	985074875	31·5436206	9·9833055	·001005025
912	831744	758550528	30·1993377	9·6976151	·001096491	996	992016	988047936	31·5594677	9·9866488	·001004016
913	833569	761048497	30·2158899	9·7011583	·001095290	997	994009	991026973	31·5753068	9·9899900	·001003009
914	835396	763551944	30·2324329	9·7046989	·001094092	998	996004	994011992	31·5911380	9·9933289	·001002004
915	837225	766060875	30·2489669	9·7082369	·001092896	999	998001	997002999	31·6069613	9·9966656	·001001001
916	839056	768575296	30·2654919	9·7117723	·001091703	1000	1000000	1000000000	31·6227766	10·0000000	·001000000

TABLE OF FOURTH POWERS.

Numbers.	Fourth Powers.	Numbers.	Fourth Powers.	Numbers.	Fourth Powers.	Numbers.	Fourth Powers.
1·00	1	9·00	6561	17·00	83521	24·75	375232·8164
1·25	2·4414	9·25	7320·9414	17·25	88543·4414	25·00	390625
1·50	5·0625	9·50	8145·0625	17·50	93789·0625	25·25	406485·9414
1·75	9·3789	9·75	9036·8789	17·75	99264·3789	25·50	422825·0625
2·00	16	10·00	10000	18·00	104976	25·75	439651·8789
2·25	25·6289	10·25	11038·1289	18·25	110930·6289	26·00	456976
2·5	39·0625	10·50	12155·0625	18·50	117135·0625	26·25	474807·1289
2·75	57·1914	10·75	13354·6914	18·75	123596·1914	26·50	493155·0625
3·00	81	11·00	14641	19·00	130321	26·75	512029·6914
3·25	111·5664	11·25	16018·0664	19·25	137316·5664	27·00	531441
3·50	150·0625	11·50	17490·0625	19·50	144590·0625	27·25	551399·0664
3·75	197·7539	11·75	19061·2539	19·75	152148·7539	27·50	571914·0625
4·00	256	12·00	20736	20·00	160000	27·75	592996·2539
4·25	326·2539	12·25	22518·7539	20·25	168151·2539	28·00	614656
4·50	410·0625	12·50	24414·0625	20·50	176610·0625	28·25	636903·7539
4·75	509·0064	12·75	26426·5664	20·75	185384·0664	28·50	659750·0625
5·00	625	13·00	28561	21·00	194481	28·75	683205·5664
5·25	759·6914	13·25	30822·1914	21·25	203908·6914	29·00	707281
5·50	915·0625	13·50	33215·0625	21·50	213675·0625	29·25	731987·1914
5·75	1093·1289	13·75	35744·6289	21·75	223788·1289	29·50	757335·0625
6·00	1296	14·00	38416	22·00	234256	29·75	783335·6289
6·25	1525·8789	14·25	41234·3789	22·25	245086·8789	30·00	810000
6·50	1785·0625	14·50	44205·0625	22·50	256289·0625	30·25	837339·3789
6·75	2075·9414	14·75	47333·4414	22·75	267870·9414	30·50	865365·0625
7·00	2401	15·00	50625	23·00	279841	30·75	894088·4414
7·25	2762·8164	15·25	54085·3164	23·25	292207·8164	31·00	923521
7·50	3164·0625	15·50	57720·0625	23·50	304980·0625	31·25	953674·3164
7·75	3607·5039	15·75	61535·0039	23·75	318166·5039	31·50	984560·0625
8·00	4096	16·00	65536	24·00	331776	31·75	1016190·0039
8·25	4632·5039	16·25	69729·0039	24·25	345817·5039	32·00	1048576
8·50	5220·0625	16·50	74120·0625	24·50	360300·0625	32·25	1081730·0039
8·75	5861·8164	16·75	78715·3164				

LOGARITHMS.

COMMON LOGARITHMS OF NUMBERS, FROM 1 TO 9,999.

No.	0	1	2	3	4	5	6	7	8	9	
0	—	000000	301030	477121	602060	698970	778151	845098	903090	954243	
1	000000	041393	079181	113943	146128	176091	204120	230449	255273	278754	
2	301030	322219	342423	361728	380211	397940	414973	431364	447158	462398	
3	477121	491362	505150	518514	531479	544068	556303	568202	579784	591065	
4	602060	612784	623249	633468	643453	653213	662758	672098	681241	690196	
5	698970	707570	716003	724276	732394	740363	748188	755875	763428	770852	
6	778151	785330	792392	799341	806180	812913	819544	826075	832509	838849	
7	845098	851258	857332	863323	869232	875061	880814	886491	892095	897627	
8	903090	908485	913814	919078	924279	929419	934498	939519	944483	949390	
9	954243	959041	963788	968483	973128	977724	982271	986772	991226	995635	

No.	0	1	2	3	4	5	6	7	8	9	D.
100	000000	000434	000868	001301	001734	002166	002598	003029	003461	003891	432
101	004321	004751	005181	005609	006038	006466	006894	007321	007748	008174	428
102	008600	009026	009451	009876	010300	010724	011147	011570	011993	012415	424
103	012837	013259	013680	014100	014521	014940	015360	015779	016197	016616	419
104	017033	017451	017868	018284	018700	019116	019532	019947	020361	020775	415
105	021189	021603	022013	022428	022841	023252	023664	024075	024486	024896	411
106	025306	025715	026125	026533	026942	027350	027757	028164	028571	028978	408
107	029384	029789	030195	030600	031004	031408	031812	032216	032619	033021	404

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
108	033424	033826	034227	034628	035029	035430	035830	036230	036629	037028	400
109	037426	037825	038223	038620	039017	039414	039811	040207	040602	040998	396
110	041393	041787	042182	042576	042969	043362	043755	044148	044540	044932	393
111	045323	045714	046105	046495	046885	047275	047664	048053	048442	048830	389
112	049218	049606	049993	050380	050766	051153	051538	051924	052309	052694	386
113	053078	053463	053846	054230	054613	054996	055378	055760	056142	056524	383
114	056905	057286	057666	058046	058426	058805	059185	059563	059942	060320	379
115	060698	061075	061452	061829	062206	062582	062958	063333	063709	064083	376
116	064458	064832	065206	065580	065953	066326	066699	067071	067443	067815	373
117	068186	068557	068928	069298	069668	070038	070407	070776	071145	071514	369
118	071882	072250	072617	072985	073352	073718	074085	074451	074816	075182	366
119	075547	075912	076276	076640	077004	077368	077731	078094	078457	078819	363
120	079181	079543	079904	080266	080626	080987	081347	081707	082067	082426	360
121	082785	083144	083503	083861	084219	084576	084934	085291	085647	086004	357
122	086360	086716	087071	087426	087781	088136	088490	088845	089198	089552	354
123	089905	090258	090611	090963	091315	091667	092018	092370	092721	093071	351
124	093422	093772	094122	094471	094820	095169	095518	095866	096215	096562	349
125	096910	097257	097604	097951	098298	098644	098990	099335	099681	100026	346
126	100371	100715	101059	101403	101747	102091	102434	102777	103119	103462	343
127	103804	104146	104487	104828	105169	105510	105851	106191	106531	106871	340
128	107210	107549	107888	108227	108565	108903	109241	109579	109916	110253	338
129	110590	110926	111263	111599	111934	112270	112605	112940	113275	113609	335
130	113943	114277	114611	114944	115278	115611	115943	116276	116608	116940	332
131	117271	117603	117934	118265	118595	118926	119256	119586	119915	120245	330
132	120574	120903	121231	121560	121888	122216	122544	122871	123198	123525	327
133	123852	124178	124504	124830	125156	125481	125806	126131	126456	126781	325
134	127105	127429	127753	128076	128399	128722	129045	129368	129690	130012	322
135	130334	130655	130977	131298	131619	131939	132260	132580	132900	133219	320
136	133539	133858	134177	134496	134814	135133	135451	135769	136086	136403	318
137	136721	137037	137354	137671	137987	138303	138618	138934	139249	139564	315
138	139879	140194	140508	140822	141136	141450	141763	142076	142389	142702	313
139	143015	143327	143639	143951	144263	144574	144885	145196	145507	145818	311
140	146128	146438	146748	147058	147367	147676	147985	148294	148603	148911	309
141	149219	149527	149835	150142	150449	150756	151063	151370	151676	151982	308
142	152288	152594	152900	153205	153510	153815	154120	154424	154728	155032	304
143	155336	155640	155943	156246	156549	156852	157154	157457	157759	158061	302
144	158362	158664	158965	159266	159567	159868	160168	160469	160769	161068	300
145	161368	161667	161967	162266	162564	162863	163161	163460	163758	164055	298
146	164353	164650	164947	165244	165541	165838	166134	166430	166726	167022	296
147	167317	167613	167908	168203	168497	168792	169086	169380	169674	169968	294
148	170262	170555	170848	171141	171434	171726	172019	172311	172603	172895	292
149	173186	173478	173769	174060	174351	174641	174932	175222	175512	175802	290
150	176091	176381	176670	176959	177248	177536	177825	178113	178401	178689	288
151	178977	179264	179552	179839	180126	180413	180699	180986	181272	181558	286
152	181844	182129	182415	182700	182985	183270	183555	183839	184123	184407	284
153	184691	184975	185259	185542	185825	186108	186391	186674	186956	187239	282
154	187521	187803	188084	188366	188647	188928	189209	189490	189771	190051	281
155	190332	190612	190892	191171	191451	191730	192010	192289	192567	192846	279
156	193125	193403	193681	193959	194237	194514	194792	195069	195346	195623	277
157	195900	196176	196453	196729	197005	197281	197556	197832	198107	198382	275
158	198657	198932	199206	199481	199755	200029	200303	200577	200850	201124	274
159	201397	201670	201943	202216	202488	202761	203033	203305	203577	203848	272
160	204120	204391	204663	204934	205204	205475	205746	206016	206286	206556	270
161	206826	207096	207365	207634	207904	208173	208441	208710	208979	209247	269
162	209515	209783	210051	210319	210586	210853	211121	211388	211654	211921	267
163	212188	212454	212720	212986	213252	213518	213783	214049	214314	214579	266
164	214844	215109	215373	215638	215902	216166	216430	216694	216957	217221	264
165	217484	217747	218010	218273	218536	218798	219060	219323	219585	219846	262
166	220108	220370	220631	220892	221153	221414	221675	221936	222196	222456	260
167	222716	222976	223236	223496	223755	224015	224274	224533	224792	225051	259

COMMON LOGARITHMS OF NUMBERS (*continued*).

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169	227887	228144	228400	228657	228913	229170	229426	229682	229938	230193	256
170	230449	230704	230960	231215	231470	231724	231979	232234	232488	232742	254
171	232996	233250	233504	233757	234011	234264	234517	234770	235023	235276	253
172	235528	235781	236033	236285	236537	236789	237041	237292	237544	237795	251
173	238046	238297	238548	238799	239049	239299	239550	239800	240050	240300	250
174	240549	240799	241048	241297	241546	241795	242044	242293	242541	242790	249
175	243038	243286	243534	243782	244030	244277	244525	244772	245019	245266	247
176	245513	245759	246006	246252	246499	246745	246991	247237	247482	247728	246
177	247973	248219	248464	248709	248954	249198	249443	249687	249932	250176	244
178	250420	250664	250908	251151	251395	251638	251881	252125	252368	252610	243
179	252853	253096	253338	253580	253822	254064	254306	254548	254790	255031	242
180	255273	255514	255755	255996	256237	256477	256718	256958	257198	257439	240
181	257679	257918	258158	258398	258637	258877	259116	259355	259594	259833	239
182	260071	260310	260548	260787	261025	261263	261501	261739	261976	262214	238
183	262451	262688	262925	263162	263399	263636	263873	264109	264346	264582	236
184	264818	265054	265290	265525	265761	265996	266232	266467	266702	266937	235
185	267172	267406	267641	267875	268110	268344	268578	268812	269046	269279	234
186	269513	269746	269980	270213	270446	270679	270912	271144	271377	271609	233
187	271842	272074	272306	272538	272770	273001	273233	273464	273696	273927	232
188	274158	274389	274620	274850	275081	275311	275542	275772	276002	276232	230
189	276462	276692	276921	277151	277380	277609	277838	278067	278296	278525	229
190	278754	278982	279211	279439	279667	279895	280123	280351	280578	280806	228
191	281033	281261	281488	281715	281942	282169	282396	282622	282849	283075	227
192	283301	283527	283753	283979	284205	284431	284656	284882	285107	285332	225
193	285557	285782	286007	286232	286456	286681	286905	287130	287354	287578	224
194	287802	288026	288249	288473	288696	288920	289143	289366	289589	289812	223
195	290035	290257	290480	290702	290925	291147	291369	291591	291813	292034	222
196	292256	292478	292699	292920	293141	293363	293584	293804	294025	294246	221
197	294466	294687	294907	295127	295347	295567	295787	296007	296226	296446	219
198	296665	296884	297104	297323	297542	297761	297979	298198	298416	298635	218
199	298853	299071	299289	299507	299725	299943	300161	300378	300595	300813	217
200	301030	301247	301464	301681	301898	302114	302331	302547	302764	302980	216
201	303196	303412	303628	303844	304059	304275	304491	304706	304921	305136	215
202	305351	305566	305781	305996	306211	306425	306639	306854	307068	307282	214
203	307496	307710	307924	308137	308351	308564	308778	308991	309204	309417	213
204	309630	309843	310056	310268	310481	310693	310906	311118	311330	311542	212
205	311754	311966	312177	312389	312600	312812	313023	313234	313445	313656	211
206	313867	314078	314289	314499	314710	314920	315130	315340	315551	315760	210
207	315970	316180	316390	316599	316809	317018	317227	317436	317646	317854	209
208	318063	318272	318481	318689	318898	319106	319314	319522	319730	319938	208
209	320146	320354	320562	320769	320977	321184	321391	321598	321805	322012	207
210	322219	322426	322633	322839	323046	323252	323458	323665	323871	324077	206
211	324282	324488	324694	324899	325105	325310	325516	325721	325926	326131	205
212	326336	326541	326745	326950	327155	327359	327563	327767	327972	328176	205
213	328380	328583	328787	328991	329194	329398	329601	329805	330008	330211	203
214	330414	330617	330819	331022	331225	331427	331630	331832	332034	332236	202
215	332438	332640	332842	333044	333246	333447	333649	333850	334051	334253	201
216	334454	334655	334856	335057	335257	335458	335658	335859	336059	336260	200
217	336460	336660	336860	337060	337260	337459	337659	337858	338058	338257	199
218	338456	338656	338855	339054	339253	339451	339650	339849	340047	340246	198
219	340444	340642	340841	341039	341237	341435	341632	341830	342028	342225	197
220	342423	342620	342817	343014	343212	343409	343606	343802	343999	344196	197
221	344392	344589	344785	344981	345178	345374	345570	345766	345962	346157	196
222	346353	346549	346744	346939	347135	347330	347525	347720	347915	348110	195
223	348305	348500	348694	348889	349083	349278	349472	349666	349860	350054	194
224	350248	350442	350636	350829	351023	351216	351410	351603	351796	351989	193
225	352183	352375	352568	352761	352954	353147	353339	353532	353724	353916	192
226	354108	354301	354493	354685	354876	355068	355260	355452	355643	355834	191
227	356026	356217	356408	356599	356790	356981	357172	357363	357554	357744	191

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
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229	359835	360025	360215	360404	360593	360783	360972	361161	361350	361539	189
230	361728	361917	362105	362294	362482	362671	362859	363048	363236	363424	188
231	363612	363800	363988	364176	364363	364551	364739	364926	365113	365301	187
232	365488	365675	365862	366049	366236	366423	366610	366796	366983	367169	187
233	367356	367542	367729	367915	368101	368287	368473	368659	368845	369030	186
234	369216	369401	369587	369772	369958	370143	370328	370513	370698	370883	185
235	371068	371253	371437	371622	371806	371991	372175	372360	372544	372728	184
236	372912	373096	373280	373464	373647	373831	374015	374198	374382	374565	184
237	374748	374932	375115	375298	375481	375664	375846	376029	376212	376394	183
238	376577	376759	376942	377124	377306	377488	377670	377852	378034	378216	182
239	378398	378580	378761	378943	379124	379306	379487	379668	379849	380030	181
240	380211	380392	380573	380754	380934	381115	381296	381476	381656	381837	181
241	382017	382197	382377	382557	382737	382917	383097	383277	383456	383636	179
242	383815	383995	384174	384353	384533	384712	384891	385070	385249	385428	179
243	385606	385785	385964	386142	386321	386499	386677	386856	387034	387212	178
244	387390	387568	387746	387923	388101	388279	388456	388634	388811	388989	177
245	389166	389343	389520	389698	389875	390051	390228	390405	390582	390759	177
246	390935	391112	391288	391464	391641	391817	391993	392169	392345	392521	176
247	392697	392873	393048	393224	393400	393575	393751	393926	394101	394277	175
248	394452	394627	394802	394977	395152	395326	395501	395676	395850	396025	175
249	396199	396374	396548	396722	396896	397071	397245	397419	397592	397766	174
250	397940	398114	398287	398461	398634	398808	398981	399154	399328	399501	173
251	399674	399847	400020	400192	400365	400538	400711	400883	401056	401228	173
252	401401	401573	401745	401917	402089	402261	402433	402605	402777	402949	172
253	403121	403292	403464	403635	403807	403978	404149	404320	404492	404663	171
254	404834	405005	405176	405346	405517	405688	405858	406029	406199	406370	171
255	406540	406710	406881	407051	407221	407391	407561	407731	407901	408070	170
256	408240	408410	408579	408749	408918	409087	409257	409426	409595	409764	169
257	409933	410102	410271	410440	410609	410777	410946	411114	411283	411451	169
258	411620	411788	411956	412124	412293	412461	412629	412796	412964	413132	168
259	413300	413467	413635	413803	413970	414137	414305	414472	414639	414806	167
260	414973	415140	415307	415474	415641	415808	415974	416141	416308	416474	167
261	416641	416807	416973	417139	417306	417472	417638	417804	417970	418135	166
262	418301	418467	418633	418798	418964	419129	419295	419460	419625	419791	165
263	419956	420121	420286	420451	420616	420781	420945	421110	421275	421439	165
264	421604	421768	421933	422097	422261	422426	422590	422754	422918	423082	164
265	423246	423410	423574	423737	423901	424065	424228	424392	424555	424718	163
266	424882	425045	425208	425371	425534	425697	425860	426023	426186	426349	163
267	426511	426674	426836	426999	427161	427324	427486	427648	427811	427973	162
268	428135	428297	428459	428621	428783	428944	429106	429268	429429	429591	162
269	429752	429914	430075	430236	430398	430559	430720	430881	431042	431203	161
270	431364	431525	431685	431846	432007	432167	432328	432488	432649	432809	160
271	432969	433130	433290	433450	433610	433770	433930	434090	434249	434409	160
272	434569	434729	434888	435048	435207	435367	435526	435685	435844	436004	159
273	436163	436322	436481	436640	436799	436957	437116	437275	437433	437592	159
274	437751	437909	438067	438226	438384	438542	438701	438859	439017	439175	158
275	439333	439491	439648	439806	439964	440122	440279	440437	440594	440752	157
276	440909	441066	441224	441381	441538	441695	441852	442009	442166	442323	157
277	442480	442637	442793	442950	443106	443263	443419	443576	443732	443889	156
278	444045	444201	444357	444513	444669	444825	444981	445137	445293	445449	156
279	445604	445760	445915	446071	446226	446382	446537	446692	446848	447003	155
280	447158	447313	447468	447623	447778	447933	448088	448242	448397	448552	155
281	448706	448861	449015	449170	449324	449478	449633	449787	449941	450095	154
282	450249	450403	450557	450711	450865	451018	451172	451326	451479	451633	154
283	451786	451940	452093	452247	452400	452553	452706	452859	453012	453165	153
284	453318	453471	453624	453777	453930	454082	454235	454387	454540	454692	153
285	454845	454997	455150	455302	455454	455606	455758	455910	456062	456214	152
286	456366	456518	456670	456821	456973	457125	457276	457428	457579	457731	152
287	457882	458033	458184	458336	458487	458638	458789	458940	459091	459242	151

COMMON LOGARITHMS OF NUMBERS (*continued*).

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289	460898	461048	461198	461348	461499	461649	461799	461948	462098	462248	150
290	462398	462548	462697	462847	462997	463146	463296	463445	463594	463744	149
291	463893	464042	464191	464340	464490	464639	464788	464936	465085	465234	149
292	465383	465532	465680	465829	465977	466126	466274	466423	466571	466719	148
293	466868	467016	467164	467312	467460	467608	467756	467904	468052	468200	148
294	468347	468495	468643	468790	468938	469085	469233	469380	469527	469675	147
295	469822	469969	470116	470263	470410	470557	470704	470851	470998	471145	147
296	471292	471438	471585	471732	471878	472025	472171	472318	472464	472610	146
297	472756	472903	473049	473195	473341	473487	473633	473779	473925	474071	146
298	474216	474362	474508	474653	474799	474944	475090	475235	475381	475526	146
299	475671	475816	475962	476107	476252	476397	476542	476687	476832	476976	145
300	477121	477266	477411	477555	477700	477844	477989	478133	478278	478422	145
301	478566	478711	478855	478999	479143	479287	479431	479575	479719	479863	144
302	480007	480151	480294	480438	480582	480725	480869	481012	481156	481299	144
303	481443	481586	481729	481872	482016	482159	482302	482445	482588	482731	143
304	482874	483016	483159	483302	483445	483587	483730	483872	484015	484157	143
305	484300	484442	484585	484727	484869	485011	485153	485295	485437	485579	142
306	485721	485863	486005	486147	486289	486430	486572	486714	486855	486997	142
307	487138	487280	487421	487563	487704	487845	487986	488127	488269	488410	141
308	488551	488692	488833	488974	489114	489255	489396	489537	489677	489818	141
309	489958	490099	490239	490380	490520	490661	490801	490941	491081	491222	140
310	491362	491502	491642	491782	491922	492062	492201	492341	492481	492621	140
311	492760	492900	493040	493179	493319	493458	493597	493737	493876	494015	139
312	494155	494294	494433	494572	494711	494850	494989	495128	495267	495406	139
313	495544	495683	495822	495960	496099	496238	496376	496515	496653	496791	138
314	496930	497068	497206	497344	497483	497621	497759	497897	498035	498173	138
315	498311	498448	498586	498724	498862	498999	499137	499275	499412	499550	138
316	499687	499824	499962	500099	500236	500374	500511	500648	500785	500922	137
317	501059	501196	501333	501470	501607	501744	501880	502017	502154	502291	137
318	502427	502564	502700	502837	502973	503109	503246	503382	503518	503655	136
319	503791	503927	504063	504199	504335	504471	504607	504743	504878	505014	136
320	505150	505286	505421	505557	505693	505828	505964	506099	506234	506370	136
321	506505	506640	506776	506911	507046	507181	507316	507451	507586	507721	135
322	507856	507991	508126	508260	508395	508530	508664	508799	508934	509068	135
323	509203	509337	509471	509606	509740	509874	510009	510143	510277	510411	134
324	510545	510679	510813	510947	511081	511215	511349	511482	511616	511750	134
325	511883	512017	512151	512284	512418	512551	512684	512818	512951	513084	133
326	513218	513351	513484	513617	513750	513883	514016	514149	514282	514415	133
327	514548	514681	514813	514946	515079	515211	515344	515476	515609	515741	133
328	515874	516006	516139	516271	516403	516535	516668	516800	516932	517064	132
329	517196	517328	517460	517592	517724	517855	517987	518119	518251	518382	132
330	518514	518646	518777	518909	519040	519171	519303	519434	519566	519697	131
331	519828	519959	520090	520221	520353	520484	520615	520745	520876	521007	131
332	521138	521269	521400	521530	521661	521792	521922	522053	522183	522314	131
333	522444	522573	522705	522835	522966	523096	523226	523356	523486	523616	130
334	523746	523876	524006	524136	524266	524396	524526	524656	524785	524915	130
335	525045	525174	525304	525434	525563	525693	525822	525951	526081	526210	129
336	526339	526469	526598	526727	526856	526985	527114	527243	527372	527501	129
337	527630	527759	527888	528016	528145	528274	528402	528531	528660	528788	129
338	528917	529045	529174	529302	529430	529559	529687	529815	529943	530072	128
339	530200	530328	530456	530584	530712	530840	530968	531096	531223	531351	128
340	531479	531607	531734	531862	531990	532117	532245	532372	532500	532627	128
341	532754	532882	533009	533136	533264	533391	533518	533645	533772	533899	127
342	534026	534153	534280	534407	534534	534661	534787	534914	535041	535167	127
343	535294	535421	535547	535674	535800	535927	536053	536179	536306	536432	126
344	536558	536685	536811	536937	537063	537189	537315	537441	537567	537693	126
345	537819	537945	538071	538197	538322	538448	538574	538699	538825	538951	126
346	539076	539202	539327	539452	539578	539703	539829	539954	540079	540204	125
347	540329	540455	540580	540705	540830	540955	541080	541205	541330	541454	125

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
348	541579	541704	541829	541953	542078	542203	542327	542452	542576	542701	125
349	542825	542950	543074	543199	543323	543447	543571	543696	543820	543944	124
350	544068	544192	544316	544440	544564	544688	544812	544936	545060	545183	124
351	545307	545431	545555	545678	545802	545925	546049	546172	546296	546419	124
352	546543	546666	546789	546913	547036	547159	547282	547405	547529	547652	123
353	547775	547898	548021	548144	548267	548389	548512	548635	548758	548881	123
354	549003	549126	549249	549371	549494	549616	549739	549861	549984	550106	123
355	550228	550351	550473	550595	550717	550840	550962	551084	551206	551328	122
356	551450	551572	551694	551816	551938	552060	552181	552303	552425	552547	122
357	552668	552790	552911	553033	553155	553276	553398	553519	553640	553762	121
358	553883	554004	554126	554247	554368	554489	554610	554731	554852	554973	121
359	555094	555215	555336	555457	555578	555699	555820	555940	556061	556182	121
360	556303	556423	556544	556664	556785	556905	557026	557146	557267	557387	120
361	557507	557627	557748	557868	557988	558108	558228	558349	558469	558589	120
362	558709	558829	558948	559068	559188	559308	559428	559548	559667	559787	120
363	559907	560026	560146	560265	560385	560504	560624	560743	560863	560982	119
364	561101	561221	561340	561459	561578	561698	561817	561936	562055	562174	119
365	562293	562412	562531	562650	562769	562887	563006	563125	563244	563362	119
366	563481	563600	563718	563837	563955	564074	564192	564311	564429	564548	119
367	564666	564784	564903	565021	565139	565257	565376	565494	565612	565730	118
368	565848	565966	566084	566202	566320	566437	566555	566673	566791	566909	118
369	567026	567144	567262	567379	567497	567614	567732	567849	567967	568084	118
370	568202	568319	568436	568554	568671	568788	568905	569023	569140	569257	117
371	569374	569491	569608	569725	569842	569959	570076	570193	570309	570426	117
372	570543	570660	570776	570893	571010	571126	571243	571359	571476	571592	117
373	571709	571825	571942	572058	572174	572291	572407	572523	572639	572755	116
374	572872	572988	573104	573220	573336	573452	573568	573684	573800	573915	116
375	574031	574147	574263	574379	574494	574610	574726	574841	574957	575072	116
376	575188	575303	575419	575534	575650	575765	575880	575996	576111	576226	115
377	576341	576457	576572	576687	576802	576917	577032	577147	577262	577377	115
378	577492	577607	577722	577836	577951	578066	578181	578295	578410	578525	115
379	578639	578754	578868	578983	579097	579212	579326	579441	579555	579669	114
380	579784	579898	580012	580126	580241	580355	580469	580583	580697	580811	114
381	580925	581039	581153	581267	581381	581495	581608	581722	581836	581950	114
382	582063	582177	582291	582404	582518	582631	582745	582858	582972	583085	114
383	583199	583312	583426	583539	583652	583765	583879	583992	584105	584218	113
384	584331	584444	584557	584670	584783	584896	585009	585122	585235	585348	113
385	585461	585574	585686	585799	585912	586024	586137	586250	586362	586475	113
386	586587	586700	586812	586925	587037	587149	587262	587374	587486	587599	112
387	587711	587823	587935	588047	588160	588272	588384	588496	588608	588720	112
388	588832	588944	589056	589167	589279	589391	589503	589615	589726	589838	112
389	589950	590061	590173	590284	590396	590507	590619	590730	590842	590953	112
390	591065	591176	591287	591399	591510	591621	591732	591843	591955	592066	111
391	592177	592288	592399	592510	592621	592732	592843	592954	593064	593175	111
392	593286	593397	593508	593618	593729	593840	593950	594061	594171	594282	111
393	594393	594503	594614	594724	594834	594945	595055	595165	595276	595386	110
394	595496	595606	595717	595827	595937	596047	596157	596267	596377	596487	110
395	596597	596707	596817	596927	597037	597146	597256	597366	597476	597586	110
396	597695	597805	597914	598024	598134	598243	598353	598462	598572	598681	110
397	598791	598900	599009	599119	599228	599337	599446	599556	599665	599774	109
398	599883	599992	600101	600210	600319	600428	600537	600646	600755	600864	109
399	600973	601082	601191	601299	601408	601517	601625	601734	601843	601951	109
400	602060	602169	602277	602386	602494	602603	602711	602819	602928	603036	108
401	603144	603253	603361	603469	603577	603686	603794	603902	604010	604118	108
402	604226	604334	604442	604550	604658	604766	604874	604982	605089	605197	108
403	605305	605413	605521	605628	605736	605844	605951	606059	606166	606274	108
404	606381	606489	606596	606704	606811	606919	607026	607133	607241	607348	107
405	607455	607562	607669	607777	607884	607991	608098	608205	608312	608419	107
406	608526	608633	608740	608847	608954	609061	609167	609274	609381	609488	107
407	609594	609701	609808	609914	610021	610128	610234	610341	610447	610554	107

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
408	610660	610767	610873	610979	611086	611192	611298	611405	611511	611617	106
409	611723	611829	611936	612042	612148	612254	612360	612466	612572	612678	106
410	612784	612890	612996	613102	613207	613313	613419	613525	613630	613736	106
411	613842	613947	614053	614159	614264	614370	614475	614581	614686	614792	106
412	614897	615003	615108	615213	615319	615424	615529	615634	615740	615845	105
413	615950	616055	616160	616265	616370	616476	616581	616686	616790	616895	105
414	617000	617105	617210	617315	617420	617525	617629	617734	617839	617943	105
415	618048	618153	618257	618362	618466	618571	618676	618780	618884	618989	105
416	619093	619198	619302	619406	619511	619615	619719	619824	619928	620032	104
417	620136	620240	620344	620448	620552	620656	620760	620864	620968	621072	104
418	621176	621280	621384	621488	621592	621695	621799	621903	622007	622110	104
419	622214	622318	622421	622525	622628	622732	622835	622939	623042	623146	104
420	623249	623353	623456	623559	623663	623766	623869	623973	624076	624179	103
421	624282	624385	624488	624591	624695	624798	624901	625004	625107	625210	103
422	625312	625415	625518	625621	625724	625827	625929	626032	626135	626238	103
423	626340	626443	626546	626648	626751	626853	626956	627058	627161	627263	103
424	627366	627468	627571	627673	627775	627878	627980	628082	628185	628287	102
425	628389	628491	628593	628695	628797	628900	629002	629104	629206	629308	102
426	629410	629512	629613	629715	629817	629919	630021	630123	630224	630326	102
427	630428	630530	630631	630733	630835	630936	631038	631139	631241	631342	102
428	631444	631545	631647	631748	631849	631951	632052	632153	632255	632356	101
429	632457	632559	632660	632761	632862	632963	633064	633165	633266	633367	101
430	633468	633569	633670	633771	633872	633973	634074	634175	634276	634376	101
431	634477	634578	634679	634779	634880	634981	635081	635182	635283	635383	101
432	635484	635584	635685	635785	635886	635986	636087	636187	636287	636388	100
433	636488	636588	636688	636789	636889	636989	637089	637189	637290	637390	100
434	637490	637590	637690	637790	637890	637990	638090	638190	638290	638389	100
435	638489	638589	638689	638789	638888	638988	639088	639188	639287	639387	100
436	639486	639586	639686	639785	639885	639984	640084	640183	640283	640382	100
437	640481	640581	640680	640779	640879	640978	641077	641177	641276	641375	99
438	641474	641573	641672	641771	641871	641970	642069	642168	642267	642366	99
439	642465	642563	642662	642761	642860	642959	643058	643156	643255	643354	99
440	643453	643551	643650	643749	643847	643946	644044	644143	644242	644340	98
441	644439	644537	644636	644734	644832	644931	645029	645127	645226	645324	98
442	645422	645521	645619	645717	645815	645913	646011	646110	646208	646306	98
443	646404	646502	646600	646698	646796	646894	646992	647089	647187	647285	98
444	647383	647481	647579	647676	647774	647872	647969	648067	648165	648262	98
445	648360	648458	648555	648653	648750	648848	648945	649043	649140	649237	97
446	649335	649432	649530	649627	649724	649821	649919	650016	650113	650210	97
447	650308	650405	650502	650599	650696	650793	650890	650987	651084	651181	97
448	651278	651375	651472	651569	651666	651762	651859	651956	652053	652150	97
449	652246	652343	652440	652536	652633	652730	652826	652923	653019	653116	97
450	653213	653309	653405	653502	653598	653695	653791	653888	653984	654080	96
451	654177	654273	654369	654465	654562	654658	654754	654850	654946	655042	96
452	655138	655235	655331	655427	655523	655619	655715	655810	655906	656002	96
453	656098	656194	656290	656386	656482	656577	656673	656769	656864	656960	96
454	657056	657152	657247	657343	657438	657534	657629	657725	657820	657916	96
455	658011	658107	658202	658298	658393	658488	658584	658679	658774	658870	95
456	658965	659060	659155	659250	659346	659441	659536	659631	659726	659821	95
457	659916	660011	660106	660201	660296	660391	660486	660581	660676	660771	95
458	660865	660960	661055	661150	661245	661339	661434	661529	661623	661718	95
459	661813	661907	662002	662096	662191	662286	662380	662475	662569	662663	94
460	662758	662852	662947	663041	663135	663230	663324	663418	663512	663607	94
461	663701	663795	663889	663983	664078	664172	664266	664360	664454	664548	94
462	664642	664734	664830	664924	665018	665112	665206	665299	665393	665487	94
463	665581	665675	665769	665862	665956	666050	666143	666237	666331	666424	94
464	666518	666612	666705	666799	666892	666986	667079	667173	667266	667360	94
465	667453	667546	667640	667733	667826	667920	668013	668106	668199	668293	93
466	668386	668479	668572	668665	668759	668852	668945	669038	669131	669224	93
467	669317	669410	669503	669596	669689	669782	669875	669967	670060	670153	93

COMMON LOGARITHMS OF NUMBERS (*continued*).

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469	671173	671265	671358	671451	671543	671636	671728	671821	671913	672005	92
470	672098	672190	672283	672375	672467	672560	672652	672744	672836	672929	92
471	673021	673113	673205	673297	673390	673482	673574	673666	673758	673850	92
472	673942	674034	674126	674218	674310	674402	674494	674586	674677	674769	92
473	674861	674953	675045	675137	675228	675320	675412	675503	675595	675687	92
474	675778	675870	675962	676053	676145	676236	676328	676419	676511	676602	92
475	676694	676785	676876	676968	677059	677151	677242	677333	677424	677516	91
476	677607	677698	677789	677881	677972	678063	678154	678245	678336	678427	91
477	678518	678609	678700	678791	678882	678973	679064	679155	679246	679337	91
478	679428	679519	679610	679700	679791	679882	679973	680063	680154	680245	91
479	680336	680426	680517	680607	680698	680789	680879	680970	681060	681151	91
480	681241	681332	681422	681513	681603	681693	681784	681874	681964	682055	90
481	682145	682235	682326	682416	682506	682596	682686	682777	682867	682957	90
482	683047	683137	683227	683317	683407	683497	683587	683677	683767	683857	90
483	683947	684037	684127	684217	684307	684396	684486	684576	684666	684756	90
484	684845	684935	685025	685114	685204	685294	685383	685473	685563	685652	90
485	685742	685831	685921	686010	686100	686189	686279	686368	686458	686547	90
486	686636	686726	686815	686904	686994	687083	687172	687261	687351	687440	89
487	687529	687618	687707	687796	687886	687975	688064	688153	688242	688331	89
488	688420	688509	688598	688687	688776	688865	688953	689042	689131	689220	89
489	689309	689398	689486	689575	689664	689753	689841	689930	690019	690107	89
490	690196	690285	690373	690462	690550	690639	690728	690816	690905	690993	89
491	691081	691170	691258	691347	691435	691524	691612	691700	691789	691877	88
492	691965	692053	692142	692230	692318	692406	692494	692583	692671	692759	88
493	692847	692935	693023	693111	693199	693287	693375	693463	693551	693639	88
494	693727	693815	693903	693991	694078	694166	694254	694342	694430	694517	88
495	694605	694693	694781	694868	694956	695044	695131	695219	695307	695394	88
496	695482	695569	695657	695744	695832	695919	696007	696094	696182	696269	87
497	696356	696444	696531	696618	696706	696793	696880	696968	697055	697142	87
498	697229	697317	697404	697491	697578	697665	697752	697839	697926	698014	87
499	698101	698188	698275	698362	698449	698535	698622	698709	698796	698883	87
500	698970	699057	699144	699231	699317	699404	699491	699578	699664	699751	87
501	699838	699924	700011	700098	700184	700271	700358	700444	700531	700617	87
502	700704	700790	700877	700963	701050	701136	701222	701309	701395	701482	86
503	701568	701654	701741	701827	701913	701999	702086	702172	702258	702344	86
504	702431	702517	702603	702689	702775	702861	702947	703033	703119	703205	86
505	703291	703377	703463	703549	703635	703721	703807	703893	703979	704065	86
506	704151	704236	704322	704408	704494	704579	704665	704751	704837	704922	86
507	705008	705094	705179	705265	705350	705436	705522	705607	705693	705778	86
508	705864	705949	706035	706120	706206	706291	706376	706462	706547	706632	85
509	706718	706803	706888	706974	707059	707144	707229	707315	707400	707485	85
510	707570	707655	707740	707826	707911	707996	708081	708166	708251	708336	85
511	708421	708506	708591	708676	708761	708846	708931	709015	709100	709185	85
512	709270	709355	709440	709524	709609	709694	709679	709863	709948	710033	85
513	710117	710202	710287	710371	710456	710540	710625	710710	710794	710879	85
514	710963	711048	711132	711217	711301	711385	711470	711554	711639	711723	84
515	711807	711892	711976	712060	712144	712229	712313	712397	712481	712566	84
516	712650	712734	712818	712902	712986	713070	713154	713238	713323	713407	84
517	713491	713575	713659	713742	713826	713910	713994	714078	714162	714246	84
518	714330	714414	714497	714581	714665	714749	714833	714916	715000	715084	84
519	715167	715251	715335	715418	715502	715586	715669	715753	715836	715920	84
520	716003	716087	716170	716254	716337	716421	716504	716588	716671	716754	83
521	716838	716921	717004	717088	717171	717254	717338	717421	717504	717587	83
522	717671	717754	717837	717920	718003	718086	718169	718253	718336	718419	83
523	718502	718585	718668	718751	718834	718917	719000	719083	719165	719248	83
524	719331	719414	719497	719580	719663	719745	719828	719911	719994	720077	83
525	720159	720242	720325	720407	720490	720573	720655	720738	720821	720903	83
526	720986	721068	721151	721233	721316	721398	721481	721563	721646	721728	83
527	721811	721893	721975	722058	722140	722222	722305	722387	722469	722552	82

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
528	722634	722716	722798	722881	722963	723045	723127	723209	723291	723374	82
529	723456	723538	723620	723702	723784	723866	723948	724030	724112	724194	82
530	724276	724358	724440	724522	724604	724685	724767	724849	724931	725013	82
531	725095	725176	725258	725340	725422	725503	725585	725667	725748	725830	82
532	725912	725993	726075	726156	726238	726320	726401	726483	726564	726646	82
533	726727	726809	726890	726972	727053	727134	727216	727297	727379	727460	81
534	727541	727623	727704	727785	727866	727948	728029	728110	728191	728273	81
535	728354	728435	728516	728597	728678	728759	728841	728922	729003	729084	81
536	729165	729246	729327	729408	729489	729570	729651	729732	729813	729893	81
537	729974	730055	730136	730217	730298	730378	730459	730540	730621	730702	81
538	730782	730863	730944	731024	731105	731186	731266	731347	731428	731508	81
539	731589	731669	731750	731830	731911	731991	732072	732152	732233	732313	81
540	732394	732474	732555	732635	732715	732796	732876	732956	733037	733117	80
541	733197	733278	733358	733438	733518	733598	733679	733759	733839	733919	80
542	733999	734079	734160	734240	734320	734400	734480	734560	734640	734720	80
543	734800	734880	734960	735040	735120	735200	735279	735359	735439	735519	80
544	735599	735679	735759	735838	735918	735998	736078	736157	736237	736317	80
545	736397	736476	736556	736635	736715	736795	736874	736954	737034	737113	80
546	737193	737272	737352	737431	737511	737590	737670	737749	737829	737908	79
547	737987	738067	738146	738225	738305	738384	738463	738543	738622	738701	79
548	738781	738860	738939	739018	739097	739177	739256	739335	739414	739493	79
549	739572	739651	739731	739810	739889	739968	740047	740126	740205	740284	79
550	740363	740442	740521	740600	740678	740757	740836	740915	740994	741073	79
551	741152	741230	741309	741388	741467	741546	741624	741703	741782	741860	79
552	741939	742018	742096	742175	742254	742332	742411	742489	742568	742647	79
553	742725	742804	742882	742961	743039	743118	743196	743275	743353	743431	78
554	743510	743588	743667	743745	743823	743902	743980	744058	744136	744215	78
555	744293	744371	744449	744528	744606	744684	744762	744840	744919	744997	78
556	745075	745153	745231	745309	745387	745465	745543	745621	745699	745777	78
557	745855	745933	746011	746089	746167	746245	746323	746401	746479	746556	78
558	746634	746712	746790	746868	746945	747023	747101	747179	747256	747334	78
559	747412	747489	747567	747645	747722	747800	747878	747955	748033	748110	78
560	748188	748266	748343	748421	748498	748576	748653	748731	748808	748885	77
561	748963	749040	749118	749195	749272	749350	749427	749504	749582	749659	77
562	749736	749814	749891	749968	750045	750123	750200	750277	750354	750431	77
563	750508	750586	750663	750740	750817	750894	750971	751048	751125	751202	77
564	751279	751356	751433	751510	751587	751664	751741	751818	751895	751972	77
565	752048	752125	752202	752279	752356	752433	752509	752586	752663	752740	77
566	752816	752893	752970	753047	753123	753200	753277	753353	753430	753506	77
567	753583	753660	753736	753813	753889	753966	754042	754119	754195	754272	77
568	754348	754425	754501	754578	754654	754730	754807	754883	754960	755036	76
569	755112	755189	755265	755341	755417	755494	755570	755646	755722	755799	76
570	755875	755951	756027	756103	756180	756256	756332	756408	756484	756560	76
571	756636	756712	756788	756864	756940	757016	757092	757168	757244	757320	76
572	757396	757472	757548	757624	757700	757775	757851	757927	758003	758079	76
573	758155	758230	758306	758382	758458	758533	758609	758685	758761	758836	76
574	758912	758988	759063	759139	759214	759290	759366	759441	759517	759592	76
575	759668	759743	759819	759894	759970	760045	760121	760196	760272	760347	75
576	760422	760498	760573	760649	760724	760799	760875	760950	761025	761101	75
577	761176	761251	761326	761402	761477	761552	761627	761702	761778	761853	75
578	761928	762003	762078	762153	762228	762303	762378	762453	762529	762604	75
579	762679	762754	762829	762904	762978	763053	763128	763203	763278	763353	75
580	763428	763503	763578	763653	763727	763802	763877	763952	764027	764101	75
581	764176	764251	764326	764400	764475	764550	764624	764699	764774	764848	75
582	764923	764998	765072	765147	765221	765296	765370	765445	765520	765594	75
583	765669	765743	765818	765892	765966	766041	766115	766190	766264	766338	74
584	766413	766487	766562	766636	766710	766785	766859	766933	767007	767082	74
585	767156	767230	767304	767379	767453	767527	767601	767675	767749	767823	74
586	767898	767972	768046	768120	768194	768268	768342	768416	768490	768564	74
587	768638	768712	768786	768860	768934	769008	769082	769156	769230	769303	74

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
588	769377	769451	769525	769599	769673	769746	769820	769894	769968	770042	74
589	770115	770189	770263	770336	770410	770484	770557	770631	770705	770778	74
590	770852	770926	770999	771073	771146	771220	771293	771367	771440	771514	74
591	771587	771661	771734	771808	771881	771955	772028	772102	772175	772248	73
592	772322	772395	772468	772542	772615	772688	772762	772835	772908	772981	73
593	773055	773128	773201	773274	773348	773421	773494	773567	773640	773713	73
594	773786	773860	773933	774006	774079	774152	774225	774298	774371	774444	73
595	774517	774590	774663	774736	774809	774882	774955	775028	775100	775173	73
596	775246	775319	775392	775465	775538	775610	775683	775756	775829	775902	73
597	775974	776047	776120	776193	776265	776338	776411	776483	776556	776629	73
598	776701	776774	776846	776919	776992	777064	777137	777209	777282	777354	73
599	777427	777499	777572	777644	777717	777789	777862	777934	778006	778079	72
600	778151	778224	778296	778368	778441	778513	778585	778658	778730	778802	72
601	778874	778947	779019	779091	779163	779236	779308	779380	779452	779524	72
602	779596	779669	779741	779813	779885	779957	780029	780101	780173	780245	72
603	780317	780389	780461	780533	780605	780677	780749	780821	780893	780965	72
604	781037	781109	781181	781253	781324	781396	781468	781540	781612	781684	72
605	781755	781827	781899	781971	782042	782114	782186	782258	782329	782401	72
606	782473	782544	782616	782688	782759	782831	782902	782974	783046	783117	72
607	783189	783260	783332	783403	783475	783546	783618	783689	783761	783832	71
608	783904	783975	784046	784118	784189	784261	784332	784403	784475	784546	71
609	784617	784689	784760	784831	784902	784974	785045	785116	785187	785259	71
610	785330	785401	785472	785543	785615	785686	785757	785828	785899	785970	71
611	786041	786112	786183	786254	786325	786396	786467	786538	786609	786680	71
612	786751	786822	786893	786964	787035	787106	787177	787248	787319	787390	71
613	787460	787531	787602	787673	787744	787815	787885	787956	788027	788098	71
614	788168	788239	788310	788381	788451	788522	788593	788663	788734	788804	71
615	788875	788946	789016	789087	789157	789228	789299	789369	789440	789510	71
616	789581	789651	789722	789792	789863	789933	790004	790074	790144	790215	70
617	790285	790356	790426	790496	790567	790637	790707	790778	790858	790918	70
618	790988	791059	791129	791199	791269	791340	791410	791480	791550	791620	70
619	791691	791761	791831	791901	791971	792041	792111	792181	792252	792322	70
620	792392	792462	792532	792602	792672	792742	792812	792882	792952	793022	70
621	793092	793162	793231	793301	793371	793441	793511	793581	793651	793721	70
622	793790	793860	793930	794000	794070	794139	794209	794279	794349	794418	70
623	794488	794558	794627	794697	794767	794836	794906	794976	795045	795115	70
624	795185	795254	795324	795393	795463	795532	795602	795672	795741	795811	70
625	795880	795949	796019	796088	796158	796227	796297	796366	796436	796505	69
626	796574	796644	796713	796782	796852	796921	796990	797060	797129	797198	69
627	797268	797337	797406	797475	797545	797614	797683	797752	797821	797890	69
628	797960	798029	798098	798167	798236	798305	798374	798443	798513	798582	69
629	798651	798720	798789	798858	798927	798996	799065	799134	799203	799272	69
630	799341	799409	799478	799547	799616	799685	799754	799823	799892	799961	69
631	800029	800098	800167	800236	800305	800373	800442	800511	800580	800648	69
632	800717	800786	800854	800923	800992	801061	801129	801198	801266	801335	69
633	801404	801472	801541	801609	801678	801747	801815	801884	801952	802021	69
634	802089	802158	802226	802295	802363	802432	802500	802568	802637	802705	69
635	802774	802842	802910	802979	803047	803116	803184	803252	803321	803389	68
636	803457	803525	803594	803662	803730	803798	803867	803935	804003	804071	68
637	804139	804208	804276	804344	804412	804480	804548	804616	804685	804753	68
638	804821	804889	804957	805025	805093	805161	805229	805297	805365	805433	68
639	805501	805569	805637	805705	805773	805841	805908	805976	806044	806112	68
640	806180	806248	806316	806384	806451	806519	806587	806655	806723	806790	68
641	806858	806926	806994	807061	807129	807197	807264	807332	807400	807467	68
642	807535	807603	807670	807738	807806	807873	807941	808008	808076	808143	68
643	808211	808279	808346	808414	808481	808549	808616	808684	808751	808818	67
644	808886	808953	809021	809088	809156	809223	809290	809358	809425	809492	67
645	809560	809627	809694	809762	809829	809896	809964	810031	810098	810165	67
646	810233	810300	810367	810434	810501	810569	810636	810703	810770	810837	67
647	810904	810971	811039	811106	811173	811240	811307	811374	811441	811508	67

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
648	811575	811642	811709	811776	811843	811910	811977	812044	812111	812178	67
649	812245	812312	812379	812445	812512	812579	812646	812713	812780	812847	67
650	812913	812980	813047	813114	813181	813247	813314	813381	813448	813514	67
651	813581	813648	813714	813781	813848	813914	813981	814048	814114	814181	67
652	814248	814314	814381	814447	814514	814581	814647	814714	814780	814847	67
653	814913	814980	815046	815113	815179	815246	815312	815378	815445	815511	66
654	815578	815544	815711	815777	815843	815910	815976	816042	816109	816175	66
655	816241	816308	816374	816440	816506	816573	816639	816705	816771	816838	66
656	816904	816970	817036	817102	817169	817235	817301	817367	817433	817499	66
657	817565	817631	817698	817764	817830	817896	817962	818028	818094	818160	66
658	818226	818292	818358	818424	818490	818556	818622	818688	818754	818820	66
659	818885	818951	819017	819083	819149	819215	819281	819346	819412	819478	66
660	819544	819610	819676	819741	819807	819873	819939	820004	820070	820136	66
661	820201	820267	820333	820399	820464	820530	820595	820661	820727	820792	66
662	820858	820924	820989	821055	821120	821186	821251	821317	821382	821448	66
663	821514	821579	821645	821710	821775	821841	821906	821972	822037	822103	65
664	822168	822233	822299	822364	822430	822495	822560	822626	822691	822756	65
665	822822	822887	822952	823018	823083	823148	823213	823279	823344	823409	65
666	823474	823539	823605	823670	823735	823800	823865	823930	823996	824061	65
667	824126	824191	824256	824321	824386	824451	824516	824581	824646	824711	65
668	824776	824841	824906	824971	825036	825101	825166	825231	825296	825361	65
669	825426	825491	825556	825621	825686	825751	825815	825880	825945	826010	65
670	826075	826140	826204	826269	826334	826399	826464	826528	826593	826658	65
671	826723	826787	826852	826917	826981	827046	827111	827175	827240	827305	65
672	827369	827434	827499	827563	827628	827692	827757	827821	827886	827951	65
673	828015	828080	828144	828209	828273	828338	828402	828467	828531	828595	64
674	828660	828724	828789	828853	828918	828982	829046	829111	829175	829239	64
675	829304	829368	829432	829497	829561	829625	829690	829754	829818	829882	64
676	829947	830011	830075	830139	830204	830268	830332	830396	830460	830525	64
677	830589	830653	830717	830781	830845	830909	830973	831037	831102	831166	64
678	831230	831294	831358	831422	831486	831550	831614	831678	831742	831806	64
679	831870	831934	831998	832062	832126	832189	832253	832317	832381	832445	64
680	832509	832573	832637	832700	832764	832828	832892	832956	833020	833083	64
681	833147	833211	833275	833338	833402	833466	833530	833593	833657	833721	64
682	833784	833848	833912	833975	834039	834103	834166	834230	834294	834357	64
683	834421	834484	834548	834611	834675	834739	834802	834866	834929	834993	64
684	835056	835120	835183	835247	835310	835373	835437	835500	835564	835627	63
685	835691	835754	835817	835881	835944	836007	836071	836134	836197	836261	63
686	836324	836387	836451	836514	836577	836641	836704	836767	836830	836894	63
687	836957	837020	837083	837146	837210	837273	837336	837399	837462	837525	63
688	837588	837652	837715	837778	837841	837904	837967	838030	838093	838156	63
689	838219	838282	838345	838408	838471	838534	838597	838660	838723	838786	63
690	838849	838912	838975	839038	839101	839164	839227	839289	839352	839415	63
691	839478	839541	839604	839667	839729	839792	839855	839918	839981	840043	63
692	840106	840169	840232	840294	840357	840420	840482	840545	840608	840671	63
693	840733	840796	840859	840921	840984	841046	841109	841172	841234	841297	63
694	841359	841422	841485	841547	841610	841672	841735	841797	841860	841922	63
695	841985	842047	842110	842172	842235	842297	842360	842422	842484	842547	62
696	842609	842672	842734	842796	842859	842921	842983	843046	843108	843170	62
697	843233	843295	843357	843420	843482	843544	843606	843669	843731	843793	62
698	843855	843918	843980	844042	844104	844166	844229	844291	844353	844415	62
699	844477	844539	844601	844664	844726	844788	844850	844912	844974	845036	62
700	845098	845160	845222	845284	845346	845408	845470	845532	845594	845656	62
701	845718	845780	845842	845904	845966	846028	846090	846151	846213	846275	62
702	846337	846399	846461	846523	846585	846646	846708	846770	846832	846894	62
703	846955	847017	847079	847141	847202	847264	847326	847388	847449	847511	62
704	847573	847634	847696	847758	847819	847881	847943	848004	848066	848128	62
705	848189	848251	848312	848374	848435	848497	848559	848620	848682	848743	62
706	848805	848866	848928	848989	849051	849112	849174	849235	849297	849358	61
707	849419	849481	849542	849604	849665	849726	849788	849849	849911	849972	61

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
708	850033	850095	850156	850217	850279	850340	850401	850462	850524	850585	61
709	850646	850707	850769	850830	850891	850952	851014	851075	851136	851197	61
710	851258	851320	851381	851442	851503	851564	851625	851686	851747	851809	61
711	851870	851931	851992	852053	852114	852175	852236	852297	852358	852419	61
712	852480	852541	852602	852663	852724	852785	852846	852907	852968	853029	61
713	853090	853150	853211	853272	853333	853394	853455	853516	853577	853637	61
714	853698	853759	853820	853881	853941	854002	854063	854124	854185	854245	61
715	854306	854367	854428	854488	854549	854610	854670	854731	854792	854852	61
716	854913	854974	855034	855095	855156	855216	855277	855337	855398	855459	61
717	855519	855580	855640	855701	855761	855822	855882	855943	856003	856064	61
718	856124	856185	856245	856306	856366	856427	856487	856548	856608	856668	60
719	856729	856789	856850	856910	856970	857031	857091	857152	857212	857272	60
720	857332	857393	857453	857513	857574	857634	857694	857755	857815	857875	60
721	857935	857995	858056	858116	858176	858236	858297	858357	858417	858477	60
722	858537	858597	858657	858718	858778	858838	858898	858958	859018	859078	60
723	859138	859198	859258	859318	859379	859439	859499	859559	859619	859679	60
724	859739	859799	859859	859918	859978	860038	860098	860158	860218	860278	60
725	860338	860398	860458	860518	860578	860637	860697	860757	860817	860877	60
726	860937	860996	861056	861116	861176	861236	861295	861355	861415	861475	60
727	861534	861594	861654	861714	861773	861833	861893	861952	862012	862072	60
728	862131	862191	862251	862310	862370	862430	862489	862549	862608	862668	60
729	862728	862787	862847	862906	862966	863025	863085	863144	863204	863263	60
730	863323	863382	863442	863501	863561	863620	863680	863739	863799	863858	59
731	863917	863977	864036	864096	864155	864214	864274	864333	864392	864452	59
732	864511	864570	864630	864689	864748	864808	864867	864926	864985	865045	59
733	865104	865163	865222	865282	865341	865400	865459	865519	865578	865637	59
734	865696	865755	865814	865874	865933	865992	866051	866110	866169	866228	59
735	866287	866346	866405	866465	866524	866583	866642	866701	866760	866819	59
736	866878	866937	866996	867055	867114	867173	867232	867291	867350	867409	59
737	867467	867526	867585	867644	867703	867762	867821	867880	867939	867998	59
738	868056	868115	868174	868233	868292	868350	868409	868468	868527	868586	59
739	868644	868703	868762	868821	868879	868938	868997	869056	869114	869173	59
740	869232	869290	869349	869408	869466	869525	869585	869642	869701	869760	59
741	869818	869877	869935	869994	870053	870111	870170	870228	870287	870345	59
742	870404	870462	870521	870579	870638	870696	870755	870813	870872	870930	58
743	870989	871047	871106	871164	871223	871281	871339	871398	871456	871515	58
744	871573	871631	871690	871748	871806	871865	871923	871981	872040	872098	58
745	872156	872215	872273	872331	872389	872448	872506	872564	872622	872681	58
746	872739	872797	872855	872913	872972	873030	873088	873146	873204	873262	58
747	873321	873379	873437	873495	873553	873611	873669	873727	873785	873844	58
748	873902	873960	874018	874076	874134	874192	874250	874208	874366	874424	58
749	874482	874540	874598	874656	874714	874772	874830	874888	874945	875003	58
750	875061	875119	875177	875235	875293	875351	875409	875466	875524	875582	58
751	875640	875698	875756	875813	875871	875929	875987	876045	876102	876160	58
752	876218	876276	876333	876391	876449	876507	876564	876622	876680	876737	58
753	876795	876853	876910	876968	877026	877083	877141	877199	877256	877314	58
754	877371	877429	877487	877544	877602	877659	877717	877774	877832	877889	58
755	877947	878004	878062	878119	878177	878234	878292	878349	878407	878464	57
756	878522	878579	878637	878694	878752	878809	878866	878924	878981	879039	57
757	879096	879153	879211	879268	879325	879383	879440	879497	879555	879612	57
758	879669	879726	879784	879841	879898	879956	880013	880070	880127	880185	57
759	880242	880299	880356	880413	880471	880528	880585	880642	880699	880756	57
760	880814	880871	880928	880985	881042	881099	881156	881213	881271	881328	57
761	881385	881442	881499	881556	881613	881670	881727	881784	881841	881898	57
762	881955	882012	882068	882126	882183	882240	882297	882354	882411	882468	57
763	882525	882581	882639	882695	882752	882809	882866	882923	882980	883037	57
764	883093	883150	883207	883264	883321	883377	883434	883491	883548	883605	57
765	883661	883718	883775	883832	883888	883945	884002	884059	884115	884172	57
766	884229	884285	884342	884399	884455	884512	884569	884625	884682	884739	57
767	884795	884852	884909	884965	885022	885078	885135	885192	885248	885305	57

COMMON LOGARITHMS OF NUMBERS *(continued)*.

No.	0	1	2	3	4	5	6	7	8	9	D.
768	885361	885418	885474	885531	885587	885644	885700	885757	885813	885870	57
769	885926	885983	886039	886096	886152	886209	886265	886321	886378	886434	56
770	886491	886547	886604	886660	886716	886773	886829	886885	886942	886996	56
771	887054	887111	887167	887223	887280	887336	887392	887449	887505	887561	56
772	887617	887674	887730	887786	887842	887898	887955	888011	888067	888123	56
773	888179	888236	888292	888348	888404	888460	888516	888573	888629	888685	56
774	888741	888797	888853	888909	888965	889021	889077	889134	889190	889246	56
775	889302	889358	889414	889470	889526	889582	889638	889694	889750	889806	56
776	889862	889918	889974	890030	890086	890141	890197	890253	890309	890365	56
777	890421	890477	890533	890589	890645	890700	890756	890812	890868	890924	56
778	890980	891035	891091	891147	891203	891259	891314	891370	891426	891482	56
779	891537	891593	891649	891705	891760	891816	891872	891928	891983	892039	56
780	892095	892150	892206	892262	892317	892373	892429	892484	892540	892595	56
781	892651	892707	892762	892818	892873	892929	892985	893040	893096	893151	56
782	893207	893262	893318	893373	893429	893484	893540	893595	893651	893706	56
783	893762	893817	893873	893928	893984	894039	894094	894150	894205	894261	55
784	894316	894371	894427	894482	894538	894593	894648	894704	894759	894814	55
785	894870	894925	894980	895036	895091	895146	895201	895257	895312	895367	55
786	895423	895478	895533	895588	895644	895699	895754	895809	895864	895920	55
787	895975	896030	896085	896140	896195	896251	896306	896361	896416	896471	55
788	896526	896581	896636	896692	896747	896802	896857	896912	896967	897022	55
789	897077	897132	897187	897242	897297	897352	897407	897462	897517	897572	55
790	897627	897682	897737	897792	897847	897902	897957	898012	898067	898122	55
791	898176	898231	898286	898341	898396	898451	898506	898561	898615	898670	55
792	898725	898780	898835	898890	898944	898999	899054	899109	899164	899218	55
793	899273	899328	899383	899437	899492	899547	899602	899656	899711	899766	55
794	899821	899875	899930	899985	900039	900094	900149	900203	900258	900312	55
795	900367	900422	900476	900531	900586	900640	900695	900749	900804	900859	55
796	900913	900968	901022	901077	901131	901186	901240	901295	901349	901404	55
797	901458	901513	901567	901622	901676	901731	901785	901840	901894	901948	54
798	902003	902057	902112	902166	902221	902275	902329	902384	902438	902492	54
799	902547	902601	902655	902710	902764	902818	902873	902927	902981	903036	54
800	903090	903144	903199	903253	903307	903361	903416	903470	903524	903578	54
801	903633	903687	903741	903795	903849	903904	903958	904012	904066	904120	54
802	904174	904229	904283	904337	904391	904445	904499	904553	904607	904661	54
803	904716	904770	904824	904878	904932	904986	905040	905094	905148	905202	54
804	905256	905310	905364	905418	905472	905526	905580	905634	905688	905742	54
805	905796	905850	905904	905958	906012	906066	906119	906173	906227	906281	54
806	906335	906389	906443	906497	906551	906604	906658	906712	906766	906820	54
807	906874	906927	906981	907035	907089	907143	907196	907250	907304	907358	54
808	907411	907465	907519	907573	907626	907680	907734	907787	907841	907895	54
809	907949	908002	908056	908110	908163	908217	908270	908324	908378	908431	54
810	908485	908539	908592	908646	908699	908753	908807	908860	908914	908967	54
811	909021	909074	909128	909181	909235	909289	909342	909396	909449	909503	54
812	909556	909610	909663	909716	909770	909823	909877	909930	909984	910037	53
813	910091	910144	910197	910251	910304	910358	910411	910464	910518	910571	53
814	910624	910678	910731	910784	910838	910891	910944	910998	911051	911104	53
815	911158	911211	911264	911317	911371	911424	911477	911530	911584	911637	53
816	911690	911743	911797	911850	911903	911956	912009	912063	912116	912169	53
817	912222	912275	912328	912381	912435	912488	912541	912594	912647	912700	53
818	912753	912806	912859	912913	912966	913019	913072	913125	913178	913231	54
819	913284	913337	913390	913443	913496	913549	913602	913655	913708	913761	53
820	913814	913867	913920	913973	914026	914079	914132	914184	914237	914290	53
821	914343	914396	914449	914502	914555	914608	914660	914713	914766	914819	53
822	914872	914925	914977	915030	915083	915136	915189	915241	915294	915347	53
823	915400	915453	915505	915558	915611	915664	915716	915769	915822	915875	53
824	915927	915980	916033	916085	916138	916191	916243	916296	916349	916401	53
825	916454	916507	916559	916612	916664	916717	916770	916822	916875	916927	53
826	916980	917033	917085	917138	917190	917243	917295	917348	917400	917453	53
827	917506	917558	917611	917663	917716	917768	917820	917873	917925	917978	52

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
828	918030	918083	918135	918188	918240	918293	918345	918397	918450	918502	52
829	918555	918607	918659	918712	918764	918816	918869	918921	918973	919026	52
830	919078	919130	919183	919235	919287	919340	919392	919444	919496	919549	52
831	919601	919653	919706	919758	919810	919862	919914	919967	920019	920071	52
832	920123	920176	920228	920280	920332	920384	920436	920489	920541	920593	52
833	920645	920697	920749	920801	920853	920906	920958	921010	921062	921114	52
834	921166	921218	921270	921322	921374	921426	921478	921530	921582	921634	52
835	921686	921738	921790	921842	921894	921946	921998	922050	922102	922154	52
836	922206	922258	922310	922362	922414	922466	922518	922570	922622	922674	52
837	922725	922777	922829	922881	922933	922985	923037	923089	923140	923192	52
838	923244	923296	923348	923399	923451	923503	923555	923607	923658	923710	52
839	923762	923814	923865	923917	923969	924021	924072	924124	924176	924228	52
840	924279	924331	924383	924434	924486	924538	924589	924641	924693	924744	52
841	924796	924848	924899	924951	925003	925054	925106	925157	925209	925261	52
842	925312	925364	925415	925467	925518	925570	925621	925673	925725	925776	52
843	925828	925879	925931	925982	926034	926085	926137	926188	926240	926291	51
844	926342	926394	926445	926497	926548	926600	926651	926702	926754	926805	51
845	926857	926908	926959	927011	927062	927114	927165	927216	927268	927319	51
846	927370	927422	927473	927524	927576	927627	927678	927730	927781	927832	51
847	927883	927935	927986	928037	928088	928140	928191	928242	928293	928345	51
848	928396	928447	928498	928549	928601	928652	928703	928754	928805	928857	51
849	928908	928959	929010	929061	929112	929163	929215	929266	929317	929368	51
850	929419	929470	929521	929572	929623	929674	929725	929776	929827	929879	51
851	929930	929981	930032	930083	930134	930185	930236	930287	930338	930389	51
852	930440	930491	930542	930592	930643	930694	930745	930796	930847	930898	51
853	930949	931000	931051	931102	931153	931204	931254	931305	931356	931407	51
854	931458	931509	931560	931610	931661	931712	931763	931814	931865	931915	51
855	931966	932017	932068	932118	932169	932220	932271	932322	932372	932423	51
856	932474	932524	932575	932626	932677	932727	932778	932822	932879	932930	51
857	932981	933031	933082	933133	933183	933234	933285	933335	933386	933437	51
858	933487	933538	933589	933639	933699	933740	933791	933841	933892	933943	51
859	933993	934044	934094	934145	934195	934246	934296	934347	934397	934448	51
860	934498	934549	934599	934650	934700	934751	934801	934852	934902	934953	50
861	935003	935054	935104	935154	935205	935255	935306	935356	935406	935457	50
862	935507	935558	935608	935658	935709	935759	935809	935860	935910	935960	50
863	936011	936061	936111	936162	936212	936262	936313	936363	936413	936463	50
864	936514	936564	936614	936665	936715	936765	936815	936865	936916	936966	50
865	937016	937066	937117	937167	937217	937267	937317	937367	937418	937468	50
866	937518	937568	937618	937668	937718	937769	937819	937869	937919	937969	50
867	938019	938069	938119	938169	938219	938269	938320	938370	938420	938470	50
868	938520	938570	938620	938670	938720	938770	938820	938870	938920	938970	50
869	939020	939070	939120	939170	939220	939270	939320	939369	939419	939469	50
870	939519	939569	939619	939669	939719	939769	939819	939869	939918	939968	50
871	940018	940068	940118	940168	940218	940267	940317	940367	940417	940467	50
872	940516	940566	940616	940666	940716	940765	940815	940865	940915	940964	50
873	941014	941064	941114	941163	941213	941263	941313	941362	941412	941462	50
874	941511	941561	941611	941660	941710	941760	941809	941859	941909	941958	50
875	942008	942058	942107	942157	942207	942256	942306	942355	942405	942455	50
876	942504	942554	942603	942653	942702	942752	942801	942851	942901	942950	50
877	943000	943049	943099	943148	943198	943247	943297	943346	943396	943445	49
878	943495	943544	943593	943643	943692	943742	943791	943841	943890	943939	49
879	943989	944038	944088	944137	944186	944236	944285	944335	944384	944433	49
880	944483	944532	944581	944631	944680	944729	944779	944828	944877	944927	49
881	944976	945025	945074	945124	945173	945222	945272	945321	945370	945419	49
882	945469	945518	945567	945616	945665	945715	945764	945813	945862	945912	49
883	945961	946010	946059	946108	946157	946207	946256	946305	946354	946403	49
884	946452	946501	946551	946600	946649	946698	946747	946796	946845	946894	49
885	946943	946992	947041	947090	947140	947189	947238	947287	947336	947385	49
886	947434	947483	947532	947581	947630	947679	947728	947777	947826	947875	49
887	947924	947973	948022	948070	948119	948168	948217	948266	948315	948364	49

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
888	948413	948462	948511	948560	948609	948657	948706	948755	948804	948853	49
889	948902	948951	948999	949048	949097	949146	949195	949244	949292	949341	49
890	949390	949439	949488	949536	949585	949634	949683	949731	949780	949829	49
891	949878	949926	949975	950024	950073	950121	950170	950219	950267	950316	49
892	950365	950414	950462	950511	950560	950608	950657	950706	950754	950803	49
893	950851	950900	950949	950997	951046	951095	951143	951192	951240	951289	49
894	951338	951386	951435	951483	951532	951580	951629	951677	951726	951775	49
895	951823	951872	951920	951969	952017	952066	952114	952163	952211	952260	48
896	952308	952356	952405	952453	952502	952550	952599	952647	952696	952744	48
897	952792	952841	952889	952938	952986	953034	953083	953131	953180	953228	48
898	953276	953325	953373	953421	953470	953518	953566	953615	953663	953711	48
899	953760	953808	953856	953905	953953	954001	954049	954098	954146	954194	48
900	954243	954291	954339	954387	954435	954484	954532	954580	954628	954677	48
901	954725	954773	954821	954869	954918	954966	955014	955062	955110	955158	48
902	955207	955255	955303	955351	955399	955447	955495	955543	955592	955640	48
903	955688	955736	955784	955832	955880	955928	955976	956024	956072	956120	48
904	956168	956216	956265	956313	956361	956409	956457	956505	956553	956601	48
905	956649	956697	956745	956793	956840	956888	956936	956984	957032	957080	48
906	957128	957176	957224	957272	957320	957368	957416	957464	957512	957559	48
907	957607	957655	957703	957751	957799	957847	957894	957942	957990	958038	48
908	958086	958134	958181	958229	958277	958325	958373	958421	958468	958516	48
909	958564	958612	958659	958707	958755	958803	958850	958898	958946	958994	48
910	959041	959089	959137	959185	959232	959280	959328	959375	959423	959471	48
911	959518	959566	959614	959661	959709	959757	959804	959852	959900	959947	48
912	959995	960042	960090	960138	960185	960233	960281	960328	960376	960423	48
913	960471	960518	960566	960613	960661	930709	960756	960804	960851	960894	48
914	960946	960994	961041	961089	961136	961184	961231	961279	961326	961374	47
915	961421	961469	961516	961563	961611	961658	961706	961753	961801	961848	47
916	961895	961943	961990	962038	962085	962132	962180	962227	962275	962325	47
917	962369	962417	962464	962511	962559	962606	962653	962701	962748	962795	47
918	962843	962890	962937	962985	963032	963079	963126	963174	963221	963268	47
919	963316	963363	963410	963457	963504	963552	963599	963646	963693	963741	47
920	963788	963835	963882	963929	963977	964024	964071	964118	964165	964212	47
921	964260	964307	964354	964401	964448	964495	964542	964590	964637	964684	47
922	964731	964778	964825	964872	964919	964966	965013	965061	965108	965155	47
923	965202	965249	965296	965343	965390	965437	965484	965531	965578	965625	47
924	965672	965719	965766	965813	965860	965907	965954	966001	966048	966095	47
925	966142	966189	966236	966283	966329	966376	966423	966470	966517	966564	47
926	966611	966658	966705	966752	966799	966845	966892	966939	966986	967033	47
927	967080	967127	967173	967220	967267	967314	967361	967408	967454	967501	47
928	967548	967595	967642	967688	967735	967782	967829	967875	967922	967969	47
929	968016	968062	968109	968156	968203	968249	968296	968343	968390	968436	47
930	968483	968530	968576	968623	968670	968716	968763	968810	968856	968903	47
931	968950	968996	969043	969090	969136	969183	969229	969276	969323	969369	47
932	969416	969463	969509	969556	969602	969649	969695	969742	969789	969835	47
933	969882	969928	969975	970021	970068	970114	970161	970207	970254	970300	47
934	970347	970393	970440	970486	970533	970579	970626	970672	970719	970765	46
935	970812	970858	970904	970951	970997	971044	971090	971137	971183	971229	46
936	971276	971322	971369	971415	971461	971508	971554	971601	971647	971693	46
937	971740	971786	971832	971879	971925	971971	972018	972064	972110	972157	46
938	972203	972249	972295	972342	972388	972434	972481	972527	972573	972619	46
939	972666	972712	972758	972804	972851	972897	972943	972989	973035	793082	46
940	973128	973174	973220	973266	973313	973359	973405	973451	973497	973543	46
941	973590	973636	973682	973728	973774	973820	973866	973913	973959	974005	46
942	974051	974097	974143	974189	974235	974281	974327	974374	974420	974466	46
943	974512	974558	974604	974650	974696	974742	974798	974834	974880	974926	46
944	974972	975018	975064	975110	975156	975202	975248	975294	975340	975386	46
945	975432	975478	975524	975570	975616	975662	975707	975753	975799	975845	46
946	975891	975937	975983	976029	976075	976121	976167	976212	976258	976304	46
947	976350	976396	976442	976488	976533	976579	976625	976671	976717	976763	46

COMMON LOGARITHMS OF NUMBERS (*continued*).

No.	0	1	2	3	4	5	6	7	8	9	D.
948	976808	976854	976900	976946	976992	977037	977083	977129	977175	977220	46
949	977266	977312	977358	977403	977449	977495	977541	977586	977632	977678	46
950	977724	977769	977815	977861	977906	977952	977998	978043	978089	978135	46
951	978181	978226	978272	978317	978363	978409	978454	978500	978546	978591	46
952	978637	978683	978728	978774	978819	978865	978911	978956	979002	979047	46
953	979093	979138	979184	979230	979275	979321	979366	979412	979457	979503	46
954	979548	979594	979639	979685	979730	979776	979821	979867	979912	979958	46
955	980003	980049	980094	980140	980185	980231	980276	980322	980367	980412	45
956	980458	980503	980549	980594	980640	980685	980730	980776	980821	980867	45
957	980912	980957	981003	981048	981093	981139	981184	981229	981275	981320	45
958	981366	981411	981456	981501	981547	981592	981637	981683	981728	981773	45
959	981819	981864	981909	981954	982000	982045	982090	982135	982181	982226	45
960	982271	982316	982362	982407	982452	982497	982543	982588	982633	982678	45
961	982723	982769	982814	982859	982904	982949	982994	983040	983085	983130	45
962	983175	983220	983265	983310	983356	983401	983446	983491	983536	983581	45
963	983626	983671	983716	983762	983807	983852	983897	983942	983987	984032	45
964	984077	984122	984167	984212	984257	984302	984347	984392	984437	984482	45
965	984527	984572	984617	984662	984707	984752	984797	984842	984887	984932	45
966	984977	985022	985067	985112	985157	985202	985247	985292	985337	985382	45
967	985426	985471	985516	985561	985606	985651	985696	985741	985786	985830	45
968	985875	985920	985965	986010	986055	986100	986144	986189	986234	986279	45
969	986324	986369	986413	986458	986503	986548	986593	986637	986682	986727	45
970	986772	986817	986861	986906	986951	986996	987040	987085	987130	987175	45
971	987219	987264	987309	987353	987398	987443	987488	987532	987577	987622	45
972	987666	987711	987756	987800	987845	987890	987934	987979	988024	988068	45
973	988113	988157	988202	988247	988291	988336	988381	988425	988470	988514	45
974	988559	988604	988648	988693	988737	988782	988826	988871	988916	988960	45
975	989005	989049	989094	989138	989183	989227	989272	989316	989361	989405	45
976	989450	989494	989539	989583	989628	989672	989717	989761	989806	989850	44
977	989895	989939	989983	990028	990072	990117	990161	990206	990250	990294	44
978	990339	990383	990428	990472	990516	990561	990605	990650	990694	990738	44
979	990783	990827	990871	990916	990960	991004	991049	991093	991137	991182	44
980	991226	991270	991315	991359	991403	991448	991492	991536	991580	991625	44
981	991669	991713	991758	991802	991846	991890	991935	991979	992023	992067	44
982	992111	992156	992200	992244	992288	992333	992377	992421	992465	992509	44
983	992554	992598	992642	992686	992730	992774	992819	992863	992907	992951	44
984	992995	993039	993083	993127	993172	993216	993260	993304	993348	993392	44
985	993436	993480	993524	993568	993613	993657	993701	993745	993789	993833	44
986	993877	993921	993965	994009	994053	994097	994141	994185	994229	994273	44
987	994317	994361	994405	994449	994493	994537	994581	994625	994669	994713	44
988	994757	994801	994845	994889	994933	994977	995021	995065	995108	995152	44
989	995196	995240	995284	995328	995372	995416	995460	995504	995547	995591	44
990	995635	995679	995723	995767	995811	995854	995898	995942	995986	996030	44
991	996074	996117	996161	996205	996249	996293	996337	996380	996424	996468	44
992	996512	996555	996599	996643	996687	996731	996774	996818	996862	996906	44
993	996949	996993	997037	997080	997124	997168	997212	997255	997299	997343	44
994	997386	997430	997474	997517	997561	997605	997648	997692	997736	997779	44
995	997823	997867	997910	997954	997998	998041	998085	998129	998172	998216	44
996	998259	998303	998347	998390	998434	998477	998521	998564	998608	998652	44
997	998695	998739	998782	998826	998869	998913	998956	999000	999043	999087	44
998	999131	999174	999218	999261	999305	999348	999392	999435	999479	999522	44
999	999565	999609	999652	999696	999739	999783	999826	999870	999913	999957	43

Characteristic of log. of number containing one or more integral figs. is one *less* than the number of integral figs., and is positive.

Characteristic of log. of a number wholly decimal is one *more* than number of noughts at commencement of decimal, and is negative.

To multiply by logs., add logs., and find corresponding numbers.

To divide by logs., subtract logs., and find corresponding numbers.

To extract the root, divide log. by index, and find corresponding numbers.

To obtain any power, multiply log. by index, and find corresponding numbers.

Use of Differences.

Ex. 1.—Find the log. of 32685.

Difference (D)	log. 32680 = 4·514282†
for 326 = 133	133 × 5 = 665*
	4·5143485

Ex. 2.—Find number corresponding to log. 3·774743

Given log.	3·774743
Nearest log. in table	3·774736 = log. 5953
	Divide by Difference (D) 73)7 01
	Required number = 59537

In all cases last fig. of * must be set one beyond last fig. of †.

Hyperbolic or Natural Logarithms.

Hyp. log. = Common log. × 2·30258509. Common log. = Hyp. log. × ·43429448

No.	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
0	−∞	$\bar{3}$·69742	$\bar{2}$·39056	$\bar{2}$·79602	$\bar{1}$·08371	$\bar{1}$·30685	$\bar{1}$·48918	$\bar{1}$·64332	$\bar{1}$·77685	$\bar{1}$·89463
1	0·00000	0·09530	0·18213	0·26234	0·33646	0·40546	0·46998	0·53063	0·58776	0·64181
2	0·69315	0·74190	0·78843	0·83287	0·87544	0·91629	0·95548	0·99323	1·02962	1·06473
3	1·09861	1·13140	1·16314	1·19594	1·22373	1·25276	1·28090	1·30834	1·33406	1·36099
4	1·38629	1·41096	1·43505	1·45859	1·48161	1·50408	1·52603	1·54753	1·56859	1·58922
5	1·60944	1·62922	1·64865	1·66770	1·68633	1·70475	1·72276	1·74046	1·75785	1·77495
6	1·79175	1·80827	1·82545	1·84055	1·85629	1·87180	1·88658	1·90218	1·91689	1·93149
7	1·94591	1·96006	1·97406	1·98787	2·00149	2·01490	2·02816	2·04115	2·05415	2·06690
8	2·07944	2·09190	2·10418	2·11632	2·12830	2·14007	2·15082	2·16338	2·17482	2·18615
9	2·19722	2·20837	2·21932	2·23014	2·24085	2·25129	2·26191	2·27228	2·28255	2·29171

No.	0	1	2	3	4	5	6	7	8	9
10	2·30258	2·39789	2·48491	2·56494	2·63906	2·70805	2·77259	2·83321	2·89037	2·94444
20	·99573	3·04452	3·09104	3·13549	3·17805	3·21888	3·25810	3·29584	3·33220	3·36730
30	3·40120	·43399	·46574	·49651	·52636	·55535	·58352	·61092	·63759	·66356
40	·68888	·71357	·73767	·76120	·78419	·80666	·82864	·85015	·87120	·89182
50	·91202	·93183	·95124	·97029	·98898	4·00733	4·02535	4·04305	4·06044	4·07754
60	4·09434	4·11087	4·12713	4·14313	4·15888	·17439	·18965	·20469	·21951	·23411
70	·24849	·26268	·27667	·29046	·30406	·31749	·33073	·34380	·35671	·36945
80	·38203	·39445	·40672	·41884	·43082	·44265	·45435	·46591	·47734	·48864
90	·49981	·51086	·52179	·53260	·54329	·55388	·56435	·57471	·58497	·59512
100	4·60517	4·61512	4·62497	4·63473	4·64439	4·65396	4·66343	4·67283	4·68213	4·69135
110	·70048	·70953	·71849	·72739	·73619	·74493	·75359	·76217	·77068	·77912
120	·78749	·79579	·80402	·81218	·82028	·82831	·83628	·84418	·85203	·85981
130	·86753	·87519	·88280	·89035	·89784	·90527	·91265	·91998	·92725	·93447
140	·94164	·94876	·95583	·96284	·96981	·97673	·98360	·99043	·99721	5·00394
150	5·01063	5·01728	5·02388	5·03044	5·03695	5·04342	5·04985	5·05624	5·06259	5·06890
160	·07517	·08140	·08760	·09375	·09986	·10594	·11199	·11799	·12396	·12990
170	·13580	·14166	·14749	·15329	·15905	·16478	·17048	·17615	·18178	·18738
180	·19295	·19850	·20400	·20948	·21493	·22035	·22574	·23111	·23644	·24175
190	·24702	·25227	·25750	·26269	·26786	·27300	·27811	·28320	·28826	·29330
200	5·29832	5·30330	5·30826	5·31320	5·31812	5·32301	5·32787	5·33272	5·33754	5·34233
210	·34711	·35186	·35658	·36129	·36597	·37064	·37528	·37989	·38450	·38907
220	·39363	·39816	·40268	·40717	·41164	·41610	·42053	·42495	·42934	·43372
230	·43808	·44242	·44674	·45104	·45532	·45958	·46383	·46806	·47227	·47646
240	·48064	·48479	·48893	·49306	·49716	·50126	·50533	·50939	·51343	·51745
250	5·52146	5·52545	5·52943	5·53339	5·53733	5·54126	5·54517	5·54907	5·55296	5·55683
260	·56068	·56452	·56834	·57215	·57595	·57973	·58349	·58725	·59098	·59471
270	·59842	·60212	·60580	·60947	·61313	·61677	·62040	·62402	·62762	·63121
280	·63479	·63835	·64191	·64544	·64897	·65249	·65599	·65948	·66296	·66642
290	·66988	·67332	·67675	·68017	·68358	·68697	·69036	·69373	·69709	·70044
300	5·70378	5·70711	5·71043	5·71373	5·71703	5·72031	5·72358	5·72685	5·73010	5·73334
310	·73657	·73979	·74300	·74620	·74939	·75257	·75574	·75890	·76205	·76519
320	·76832	·77144	·77455	·77765	·78074	·78382	·78690	·78996	·79301	·79606
330	·79909	·80212	·80513	·80814	·81114	·81413	·81711	·82008	·82304	·82600
340	·82894	·83188	·83481	·83773	·84064	·84354	·84644	·84932	·85220	·85507
350	5·85793	5·86078	5·86363	5·86647	5·86929	5·87212	5·87493	5·87773	5·88053	5·88332

HYPERBOLIC FUNCTIONS.

(G. A. Burls.)

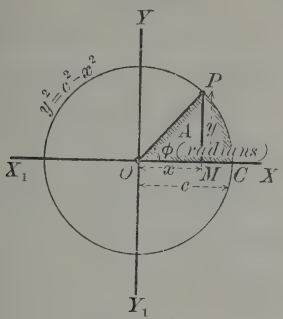

FIG. 107.

In the circle (fig. 107) $y^2=c^2-x^2$ if A denotes the area of the sector OCP and if ϕ be the angle COP, *in radians*, then :—

$$\phi = \frac{2}{c^2}.A \qquad (1)$$

and, by definition, we have also :—

$$\left.\begin{aligned} \frac{y}{c} &= \frac{PM}{OC} = \sin\phi \\ \frac{x}{c} &= \frac{OM}{OC} = \cos\phi \\ \frac{y}{x} &= \frac{PM}{OM} = \tan\phi \end{aligned}\right\} \qquad (2)$$

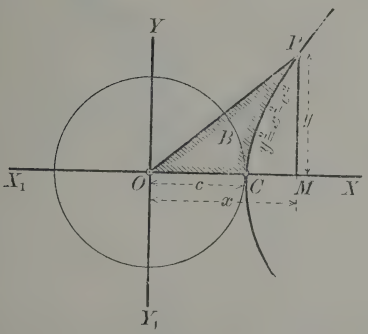

FIG. 108.

Similarly, in the rectangular hyperbola (fig. 108) $y^2=x^2-c^2$ it is found convenient to define corresponding ratios thus :—

$$\left.\begin{aligned} \frac{y}{c} &= \frac{PM}{OC} = \sinh.\theta \\ \frac{x}{c} &= \frac{OM}{OC} = \cosh.\theta \\ \frac{y}{x} &= \frac{PM}{OM} = \tanh.\theta \end{aligned}\right\} \qquad (3)$$

Where θ is a quantity such that if B be the area of the hyperbolic sector OCP :—

$$\theta = \frac{2}{c^2}.B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In ordinary notation, $\phi = \sin^{-1}\frac{y}{c}$; similarly it may be shown that $\theta = \text{Log}_e\left(\frac{x+y}{c}\right)$.

Just as in the ordinary trigonometrical or 'circular' functions we have the fundamenta identities :—

$$\left.\begin{aligned}\cos^2\phi + \sin^2\phi &= 1\\ \sec^2\phi &= 1 + \tan^2\phi\\ \text{cosec}^2\phi &= 1 + \cot^2\phi\end{aligned}\right\} \text{etc.,}$$

so also in the hyperbolic functions we have :—

$$\left.\begin{aligned}\cosh^2\theta - \sinh^2\theta &= 1\\ \text{sech}^2\theta &= 1 - \tanh^2\theta\\ \text{cosech}^2\theta &= \coth^2\theta - 1\end{aligned}\right\} \text{etc.}$$

Moreover, the exponential values of the functions show corresponding similarities ; thus w have, ι denoting $\sqrt{-1}$:—

$$\sin\phi = \frac{1}{2\iota}\left\{e^{\iota\phi} - e^{-\iota\phi}\right\} = \phi - \frac{\phi^3}{3} + \frac{\phi^5}{5} - \frac{\phi^7}{7} + \cdots$$

while :

$$\sinh\theta = \frac{1}{2}\left\{e^{\theta} - e^{-\theta}\right\} = \theta + \frac{\theta^3}{3} + \frac{\theta^5}{5} + \frac{\theta^7}{7} + \cdots$$

And again :

$$\cos\phi = \frac{1}{2}\left\{e^{\iota\phi} + e^{-\iota\phi}\right\} = 1 - \frac{\phi^2}{2} + \frac{\phi^4}{4} - \frac{\phi^6}{6} + \cdots$$

while :

$$\cosh\theta = \frac{1}{2}\left\{e^{\theta} + e^{-\theta}\right\} = 1 + \frac{\theta^2}{2} + \frac{\theta^4}{4} + \frac{\theta^6}{6} + \cdots$$

Relation between the *quantity* θ and the *radian-angle* ϕ :—

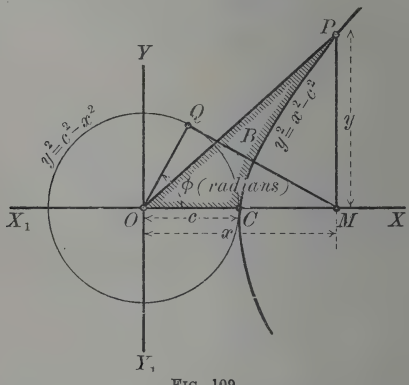

FIG. 109.

From M (fig. 109) draw MQ touching the circle, and join QO. Then $MQ^2 = OM^2 - OQ^2$ $x^2 - c^2 = y^2 = PM^2$; hence :

$$MQ = MP$$

Consequently :

$$\left.\begin{aligned}\sinh\theta &= \frac{MP}{OC} = \frac{MQ}{QO} = \tan\phi\\ \cosh\theta &= \frac{OM}{OC} = \frac{OM}{OQ} = \sec\phi\\ \tanh\theta &= \frac{PM}{MO} = \frac{QM}{MO} = \sin\phi\end{aligned}\right\}$$

Discussion of many problems is much facilitated by use of hyperbolic functions ; see, f example, 'The Catenary,' p. 43.

TABLE OF EXPONENTIAL AND HYPERBOLIC FUNCTIONS

θ	e^{θ}	$e^{-\theta}$	cosh θ*	sinh θ†	θ	e^{θ}	$e^{-\theta}$	cosh θ*	sinh θ†
·00	1·00000	1·00000	1·00000	·00000	·60	1·82212	·54881	1·18547	·63665
·01	1·01005	·99005	1·00005	·01000	·61	1·84043	·54335	1·19189	·64854
·02	1·02021	·98020	1·00020	·02000	·62	1·85893	·53794	1·19844	·66049
·03	1·03045	·97045	1·00045	·03000	·63	1·87761	·53259	1·20510	·67251
·04	1·04081	·96080	1·00080	·04001	·64	1·89648	·52729	1·21189	·68459
·05	1·05127	·95123	1·00125	·05002	·65	1·91554	·52205	1·21879	·69675
·06	1·06184	·94177	1·00180	·06004	·66	1·93479	·51685	1·22582	·70897
·07	1·07251	·93239	1·00245	·07006	·67	1·95424	·51171	1·23297	·72126
·08	1·08329	·92312	1·00320	·08009	·68	1·97388	·50662	1·24025	·73363
·09	1·09417	·91393	1·00405	·09012	·69	1·99372	·50158	1·24765	·74607
·10	1·10517	·90484	1·00500	·10017	·70	2·01375	·49659	1·25517	·75858
·11	1·11628	·89583	1·00606	·11022	·71	2·03399	·49164	1·26282	·77117
·12	1·12750	·88692	1·00721	·12029	·72	2·05443	·48675	1·27059	·78384
·13	1·13883	·87810	1·00846	·13037	·73	2·07508	·48191	1·27850	·79659
·14	1·15027	·86936	1·00982	·14046	·74	2·09594	·47711	1·28652	·80941
·15	1·16183	·86071	1·01127	·15056	·75	2·11700	·47237	1·29468	·82232
·16	1·17351	·85214	1·01283	·16068	·76	2·13828	·46767	1·30297	·83530
·17	1·18530	·84366	1·01448	·17082	·77	2·15977	·46301	1·31139	·84838
·18	1·19722	·83527	1·01624	·18097	·78	2·18147	·45841	1·31994	·86153
·19	1·20925	·82696	1·01810	·19115	·79	2·20340	·45384	1·32862	·87478
·20	1·22140	·81873	1·02007	·20134	·80	2·22554	·44933	1·33743	·88811
·21	1·23368	·81058	1·02213	·21155	·81	2·24791	·44486	1·34638	·90152
·22	1·24608	·80252	1·02430	·22178	·82	2·27050	·44043	1·35547	·91503
·23	1·25860	·79453	1·02657	·23203	·83	2·29332	·43605	1·36468	·92863
·24	1·27125	·78663	1·02894	·24231	·84	2·31637	·43171	1·37404	·94233
·25	1·28403	·77880	1·03141	·25261	·85	2·33965	·42741	1·38353	·95612
·26	1·29693	·77105	1·03399	·26294	·86	2·36316	·42316	1·39316	·97000
·27	1·30996	·76338	1·03667	·27329	·87	2·38691	·41895	1·40293	·98398
·28	1·32313	·75578	1·03946	·28367	·88	2·41090	·41478	1·41284	·99806
·29	1·33643	·74826	1·04235	·29408	·89	2·43513	·41066	1·42289	1·01224
·30	1·34986	·74082	1·04534	·30452	·90	2·45960	·40657	1·43309	1·02652
·31	1·36343	·73345	1·04844	·31499	·91	2·48432	·40252	1·44342	1·04090
·32	1·37713	·72615	1·05164	·32549	·92	2·50929	·39852	1·45390	1·05539
·33	1·39097	·71892	1·05495	·33602	·93	2·53451	·39455	1·46453	1·06998
·34	1·40495	·71177	1·05836	·34659	·94	2·55998	·39063	1·47530	1·08468
·35	1·41907	·70469	1·06188	·35719	·95	2·58571	·38674	1·48623	1·09948
·36	1·43333	·69768	1·06550	·36783	·96	2·61170	·38289	1·49729	1·11440
·37	1·44773	·69073	1·06923	·37850	·97	2·63794	·37908	1·50851	1·12943
·38	1·46228	·68386	1·07307	·38921	·98	2·66446	·37531	1·51988	1·14457
·39	1·47698	·67706	1·07702	·39996	·99	2·69123	·37158	1·53141	1·15983
·40	1·49182	·67032	1·08107	·41075	1·00	2·71828	·36788	1·54308	1·17520
·41	1·50682	·66365	1·08523	·42158	1·01	2·74560	·36422	1·55491	1·19069
·42	1·52196	·65705	1·08950	·43246	1·02	2·77319	·36059	1·56689	1·20630
·43	1·53726	·65051	1·09388	·44337	1·03	2·80107	·35701	1·57904	1·22203
·44	1·55271	·64404	1·09837	·45434	1·04	2·82922	·35345	1·59134	1·23788
·45	1·56831	·63763	1·10297	·46534	1·05	2·85765	·34994	1·60379	1·25386
·46	1·58407	·63128	1·10768	·47640	1·06	2·88637	·34646	1·61641	1·26996
·47	1·59999	·62500	1·11250	·48750	1·07	2·91538	·34301	1·62919	1·28619
·48	1·61607	·61878	1·11743	·49865	1·08	2·94468	·33960	1·64214	1·30254
·49	1·63232	·61263	1·12247	·50985	1·09	2·97427	·33622	1·65525	1·31903
·50	1·64872	·60653	1·12763	·52110	1·10	3·00417	·33287	1·66852	1·33565
·51	1·66529	·60050	1·13289	·53240	1·11	3·03436	·32956	1·68196	1·35240
·52	1·68203	·59452	1·13827	·54375	1·12	3·06485	·32628	1·69557	1·36929
·53	1·69893	·58860	1·14377	·55516	1·13	3·09566	·32303	1·70934	1·38631
·54	1·71601	·58275	1·14938	·56663	1·14	3·12677	·31982	1·72329	1·40347
·55	1·73325	·57695	1·15510	·57815	1·15	3·15819	·31664	1·73741	1·42078
·56	1·75067	·57121	1·16094	·58973	1·16	3·18993	·31349	1·75171	1·43822
·57	1·76827	·56553	1·16690	·60137	1·17	3·22199	·31037	1·76618	1·45581
·58	1·78604	·55990	1·17297	·61307	1·18	3·25437	·30728	1·78083	1·47355
·59	1·80399	·55433	1·17916	·62483	1·19	3·28708	·30422	1·79565	1·49143

* $\cosh\theta = \frac{e^{\theta}+e^{-\theta}}{2}$. † $\sinh\theta = \frac{e^{\theta}-e^{-\theta}}{2}$

EXPONENTIAL AND HYPERBOLIC FUNCTIONS—*continued.*

θ	e^{θ}	$e^{-\theta}$	cosh θ*	sinh θ†	θ	e^{θ}	$e^{-\theta}$	cosh θ*	sinh θ†
1·20	3·32012	·30119	1·81066	1·50946	1·81	6·11045	·16365	3·13705	2·97340
1·21	3·35348	·29820	1·82584	1·52764	1·82	6·17186	·16203	3·16694	3·00492
1·22	3·38719	·29523	1·84121	1·54598	1·83	6·23389	·16041	3·19715	3·03674
1·23	3·42123	·29229	1·85676	1·56447	1·84	6·29654	·15882	3·22768	3·06886
1·24	3·45561	·28938	1·87250	1·58311	1·85	6·35982	·15724	3·25853	3·10129
1·25	3·49034	·28650	1·88842	1·60192	1·86	6·42374	·15567	3·28970	3·13403
1·26	3·52542	·28365	1·90454	1·62088	1 87	6·48830	·15412	3·32121	3·16709
1·27	3·56085	·28083	1·92084	1·64001	1·88	6·55350	·15259	3·35305	3·20046
1·28	3·59664	·27804	1·93734	1·65930	1·89	6·61937	·15107	3·38522	3·23415
1·29	3·63279	·27527	1·95403	1·67876	1·90	6·68589	·14957	3·41773	3·26816
1·30	3·66930	·27253	1·97091	1·69838	1·91	6·75309	·14808	3·45058	3·30250
1·31	3·70617	·26982	1·98800	1·71818	1·92	6·82096	·14661	3·48378	3·33718
1·32	3·74342	·26714	2·00528	1·73814	1·93	6·88951	·14515	3·51733	3·37218
1·33	3·78104	·26448	2·02276	1·75828	1·94	6·95875	·14370	3·55123	3·40755
1·34	3·81904	·26185	2·04044	1·77860	1·95	7·02869	·14227	3·58548	3·44327
1·35	3·85743	·25924	2·05833	1·79909	1·96	7·09933	·14086	3 62009	3·47932
1·36	3·89619	·25666	2·07643	1·81977	1·97	7·17068	·13946	3·65507	3·51567
1·37	3·93535	·25411	2·09473	1·84062	1·98	7·24274	·13807	3·69041	3·55234
1·38	3·97490	·25158	2·11324	1·86166	1·99	7·31553	·13670	3·72611	3·58942
1·39	4·01485	·24908	2·13196	1·88289	2·0	7·38906	·13534	3·76220	3·62686
1·40	4·05520	·24660	2·15090	1·90430	2·1	8·16617	·12246	4·14431	4·02181
1·41	4·09596	·24414	2·17005	1·92591	2·2	9·02501	·11080	4·56791	4·45717
1·42	4·13712	·24171	2·18942	1·94770	2·3	9·97418	·10026	5·03722	4·93690
1·43	4·17870	·23931	2·20900	1·96970	2·4	11·0232	·09072	5·55695	5·46623
1·44	4·22070	·23693	2·22881	1·99188	2·5	12·1825	·08208	6·13229	6·05026
1·45	4·26311	·23457	2·24884	2·01428	2·6	13·4637	·07427	6·76900	6·69473
1·46	4·30596	·23224	2·26910	2·03686	2·7	14·8797	·06721	7·47347	7·40626
1·47	4·34924	·22993	2·28958	2·05965	2·8	16·4446	·06081	8·25273	8·19193
1·48	4·39295	·22764	2·31029	2·08265	2·9	18·1741	·05502	9·11458	9·05959
1·49	4·43710	·22537	2·33123	2·10586	3·0	20·0855	·04979	10·0677	10·0179
1·50	4·48169	·22313	2·35241	2·12928	3·1	22·1980	·04505	11·1215	11·0763
1·51	4·52673	·22091	2·37382	2·15291	3·2	24·5325	·04076	12·2866	12·245
1·52	4·57223	·21871	2·39547	2·17676	3·3	27·1126	·03688	13·5747	13·537
1·53	4·61818	·21654	2·41736	2·20082	3·4	29·9641	·03337	14·9987	14·965
1·54	4·66459	·21438	2·43949	2·22510	3·5	33·1155	·03020	16·5728	16·542
1·55	4·71147	·21225	2·46186	2·24961	3·6	36·5982	·02732	18·3128	18·285
1·56	4·75882	·21014	2·48448	2·27434	3·7	40 4473	·02472	20·2360	20·211
1·57	4·80665	·20805	2·50735	2·29930	3·8	44·7012	·02237	22·3618	22·339
1·58	4·85496	·20598	2·53047	2·32449	3·9	49·4024	·02024	24·7113	24·691
1·59	4·90375	·20393	2·55384	2·34991	4·0	54·5982	·01832	27·3082	27·289
1·60	4·95303	·20190	2·57746	2·37557	4·1	60·3403	·01657	30·1784	30·161
1·61	5·00281	·19989	2·60135	2·40146	4·2	66·6863	·01500	33·3507	33·335
1·62	5·05309	·19790	2·62549	2·42760	4·3	73·6998	·01357	36·8567	36·843
1·63	5·10387	·19593	2·64990	2·45397	4·4	81·4509	·01228	40·7316	40·719
1·64	5·15517	·19398	2·67457	2·48059	4·5	90·0171	·01111	45·0141	45·003
1·65	5·20698	·19205	2·69951	2·50746	4·6	99·4843	·01005	49·7472	49·737
1·66	5·25931	·19014	2·72472	2·53459	4·7	109·947	·00910	54·9781	54·969
1·67	5·31217	·18825	2·75021	2·56196	4·8	121·510	·00823	60·7593	60·751
1·68	5·36556	·18637	2·77596	2·58959	4·9	134·290	·00745	67·1486	67·141
1·69	5·41948	·18452	2·80200	2·61748	5·0	148·413	·00674	74·2099	74·203
1·70	5·47395	·18268	2·82832	2·64563	5·1	164·022	·00610	82·0140	82·007
1·71	5·52896	·18087	2·85491	2·67405	5·2	181·272	·00552	90·6388	90·633
1·72	5·58453	·17907	2·88180	2·70273	5·3	200·337	·00499	100·171	100·16
1·73	5·64065	·17728	2·90897	2·73168	5·4	221·406	·00452	110·705	110·70
1·74	5·69734	·17552	2·93643	2·76091	5·5	244·692	·00409	122·348	122·34
1·75	5·75460	·17377	2·96419	2·79041	5·6	270·426	·00370	135·215	135·21
1·76	5·81244	·17204	2·99224	2 82020	5 7	298·867	·00335	149·435	149·43
1·77	5·87085	·17033	3·02059	2·85026	5·8	330·300	·00303	165·151	165·14
1·78	5·92986	·16864	3·04925	2 88061	5·9	365·037	·00274	182·520	182·51
1·79	5·98945	·16696	3·07821	2·91125	6·0	403·429	·00248	201·716	201·71
1·80	6·04965	·16530	3·10747	2·94217					

* $\cosh\theta = \frac{e^{\theta}+e^{-\theta}}{2}$ † $\sinh\theta = \frac{e^{\theta}-e^{-\theta}}{2}$

DECIMAL EQUIVALENTS OF FRACTIONS.

Sixty-fourths, Thirty-seconds, Sixteenths, Eighths, and Quarters.

Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.
$\frac{1}{64}$	·015625	$\frac{17}{64}$	·265625	$\frac{33}{64}$	·515625	$\frac{49}{64}$	·765625
$\frac{2}{64}$ or $\frac{1}{32}$	·031250	$\frac{18}{64}$ or $\frac{9}{32}$	·281250	$\frac{34}{64}$ or $\frac{17}{32}$	·531250	$\frac{50}{64}$ or $\frac{25}{32}$	·781250
$\frac{3}{64}$	·046875	$\frac{19}{64}$	·296875	$\frac{35}{64}$	·546875	$\frac{51}{64}$	·796875
$\frac{4}{64}$ or $\frac{1}{16}$	·062500	$\frac{20}{64}$ or $\frac{5}{16}$	·312500	$\frac{36}{64}$ or $\frac{9}{16}$	·562500	$\frac{52}{64}$ or $\frac{13}{16}$	·812500
$\frac{5}{64}$	·078125	$\frac{21}{64}$	·328125	$\frac{37}{64}$	·578125	$\frac{53}{64}$	·828125
$\frac{6}{64}$ or $\frac{3}{32}$	·093750	$\frac{22}{64}$ or $\frac{11}{32}$	·343750	$\frac{38}{64}$ or $\frac{19}{32}$	·593750	$\frac{54}{64}$ or $\frac{27}{32}$	·843750
$\frac{7}{64}$	·109375	$\frac{23}{64}$	·359375	$\frac{39}{64}$	·609375	$\frac{55}{64}$	·859375
$\frac{8}{64}$ or $\frac{1}{8}$	·125000	$\frac{24}{64}$ or $\frac{3}{8}$	·375000	$\frac{40}{64}$ or $\frac{5}{8}$	·625000	$\frac{56}{64}$ or $\frac{7}{8}$	·875000
$\frac{9}{64}$	·140625	$\frac{25}{64}$	·390625	$\frac{41}{64}$	·640625	$\frac{57}{64}$	·890625
$\frac{10}{64}$ or $\frac{5}{32}$	·156250	$\frac{26}{64}$ or $\frac{13}{32}$	·406250	$\frac{42}{64}$ or $\frac{21}{32}$	·656250	$\frac{58}{64}$ or $\frac{29}{32}$	·906250
$\frac{11}{64}$	·171875	$\frac{27}{64}$	·421875	$\frac{43}{64}$	·671875	$\frac{59}{64}$	·921875
$\frac{12}{64}$ or $\frac{3}{16}$	·187500	$\frac{28}{64}$ or $\frac{7}{16}$	·437500	$\frac{44}{64}$ or $\frac{22}{32}$	·687500	$\frac{60}{64}$ or $\frac{15}{16}$	·937500
$\frac{13}{64}$	·203125	$\frac{29}{64}$	·453125	$\frac{45}{64}$	·703125	$\frac{61}{64}$	·953125
$\frac{14}{64}$ or $\frac{7}{32}$	·218750	$\frac{30}{64}$ or $\frac{15}{32}$	·468750	$\frac{46}{64}$ or $\frac{23}{32}$	·718750	$\frac{62}{64}$ or $\frac{31}{32}$	·968750
$\frac{15}{64}$	·234375	$\frac{31}{64}$	·484375	$\frac{47}{64}$	·734375	$\frac{63}{64}$	·984375
$\frac{16}{64}$ or $\frac{1}{4}$	·250000	$\frac{32}{64}$ or $\frac{1}{2}$	·500000	$\frac{48}{64}$ or $\frac{3}{4}$	·750000	1	1·000000

Twelfths, Sixths, and Thirds.

Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.
$\frac{1}{12}$	·083333	$\frac{4}{12}$ or $\frac{1}{3}$	·333333	$\frac{7}{12}$	·583333	$\frac{10}{12}$ or $\frac{5}{6}$	·833333
$\frac{2}{12}$ or $\frac{1}{6}$	·166667	$\frac{5}{12}$	·416667	$\frac{8}{12}$ or $\frac{2}{3}$	·666667	$\frac{11}{12}$	·916667
$\frac{3}{12}$ or $\frac{1}{4}$	·250000	$\frac{6}{12}$ or $\frac{1}{2}$	·500000	$\frac{9}{12}$ or $\frac{3}{4}$	·750000	1	1·000000

Fifths.

Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.
$\frac{1}{5}$	·200000	$\frac{2}{5}$	·400000	$\frac{3}{5}$	·600000	$\frac{4}{5}$	·800000

Sevenths.

Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.
$\frac{1}{7}$	·142857	$\frac{3}{7}$	·428571	$\frac{5}{7}$	·714285	—	—
$\frac{2}{7}$	·285714	$\frac{4}{7}$	·571428	$\frac{6}{7}$	·857142	—	—

Ninths.

Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.	Fraction.	Decimal.
$\frac{1}{9}$	·111111	$\frac{3}{9}$ or $\frac{1}{3}$	·333333	$\frac{5}{9}$	·555556	$\frac{7}{9}$	·777778
$\frac{2}{9}$	·222222	$\frac{4}{9}$	·444444	$\frac{6}{9}$ or $\frac{2}{3}$	·666667	$\frac{8}{9}$	·888889

THE SLIDE-RULE.

On the face of the ordinary (*e.g.* 10 in.) slide-rule, four scales, usually referred to as the A, B, C nd D scales are marked. A and D are on the rule, top and bottom, whilst B and C are marked oon the slide, and when the latter has not been moved either to the right or left, the divisions 1 A and B and also on C and D coincide. The graduation of the divisions of each of the ales is logarithmic, that is to say, the distance from the initial point of a scale to any number ereon represents the logarithm of that number.

The A and B scales are divided into primary graduations representing the logs of the numbers om unity to 100, and these divisions are each subdivided into ten secondary divisions. These, owards the left-hand side of the scales, are further subdivided, but as, in the progression towards ie right-hand side, the primary divisions approach one another rapidly, it is not possible to arry the extreme subdivision throughout the scale. Inspection of any rule will show the extent which such subdivision is practicable.

The C and D scales are divided similarly to the A and B scales, but here there are only ten primary divisions spread over the same length of scale as the 100 in the A and B scales. This admits of a greatly extended subdivision, affording a somewhat greater facility for accuracy in calculation. It may be observed here that the ratio between the two sets of scales involves the fact that the figures on the A and B scales are the squares of those on the C and D scales; conversely the figures on the C and D scales are of course the square roots of those on the A and B scales.

Most rules are also provided with a sliding runner, referred to as the 'Cursor,' which is enabled to slide along the length of the rule parallel to the scales. The cursor usually consists of a small frame carrying a glass window upon which a transverse hair line is marked, or else it is provided with four indices arranged in a transverse straight line. The cursor enables the figure or graduations of the slide to be set readily against those on the fixed scales, and also enables any reading to be marked temporarily during the manipulations of the rule.

It may be added that the extreme left- and right-hand graduations of the scales are referred to as the left- and right-hand indices respectively.

Multiplication.

$$a \times b \times c \ldots n = x)$$

It is obvious that although the figures on the scales start with unity, any multiple or sub-multiple of the value of 10 may be assigned to the indices provided that such value is adhered to throughout each complete operation. This holds good whatever be the nature of the calculation involved.

To multiply, the left-hand index of the slide is set to the multiplic and on the rule, and against the multiplier on the slide will be read the product on the rule. In this operation the length equivalent to the log of the first number is added to the length corresponding to the log of the second. Should there be more than two factors, the result of the first setting as above is not read, but the cursor is set thereto and the slide index brought up to the cursor setting, when the product is read as before, and so on to any number of factors. As continuous progression of the slide from left to right would bring the ultimate reading beyond the scale, it should be noted that the right-hand index may be used to set to the cursor; this will bring the product within the scale.

The number of digits, *i.e.* the position of the decimal point, may be evident from the factors. If such be not clear, however, it may be taken that the *sum* of the digits in the factors *less* the number of times the slide has been projected to the right will give the number of digits in the product. On some rules the cursor is provided with a movable index for registering the number of times the slide has been projected to the right.

Division.

$$\left(\frac{a}{b} = x\right)$$

This involves the *subtraction* of the logs of the numbers, therefore the process is exactly the reverse of multiplication, *i.e.* the divisor on the slide is set to the dividend on the rules, and against the index of the slide will be the quotient on the rule. The number of digits is found by *adding* the number of times the slide is projected to the right, to the *difference* between the divisor and dividend.

Proportion—Direct and Inverse.

Direct $\left(a : b :: c : x, \text{ or, } c \times \frac{b}{a} = x\right)$

Bring the first term on the slide to the second on the rule, move the cursor to the third on the slide, and read the fourth on the rule.

Mean proportional $\left(\frac{a}{x} = \frac{x}{c}\right)$

Set index on B to a on A, bring cursor to C on B; read under cursor x on D.

The procedure for inverse proportion is the same, save that the slide is *inverted*, so as to bring the A and C scales into juxtaposition.

Squares and Square Roots.

Squares and square roots are found by setting the cursor and reading from D to A or *vice versâ*.

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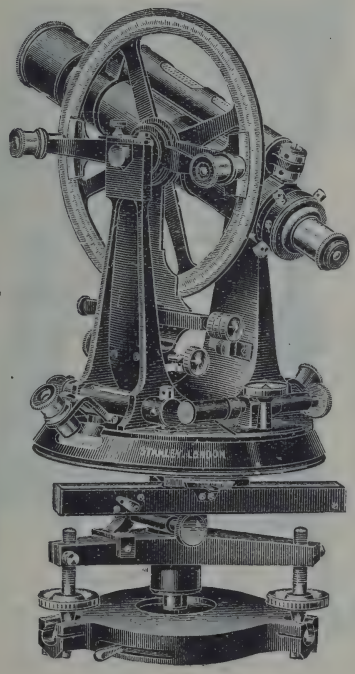

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Cubes and Cube Roots.

Cubes and cube roots as well as all higher powers and roots are best found by the use of logs, which may be read on the back of the slide of most rules if the C index be set to the number whose log is required on D. The log is then multiplied or divided by the power involved. On certain rules the D scale is replaced by a log of a log scale designed by Professor Perry; this facilitates the finding of high powers and roots; thus

$a^n = x$; set the index on C to a on D; against or on C, read x on D.

$\sqrt[n]{a} = x$, or, $a^{\frac{1}{n}} = x$. Set n on C to a on D; against index on C, read x on D.

Sines and Tangents.

These may be found by setting the slide as in the case of the log of a number, the values being marked on the back of the slide with the log values.

On the back of most rules will be found a number of 'gauge points' useful for various special calculations.

For other and more extended applications of the slide-rule one of the many manuals specially devoted to the subject should be consulted, notably those by Blaine or Pickworth.

THE FULLER SLIDE-RULE.

(W. F. Stanley & Co. Ltd.)

For accurate calculations this is one of the best slide-rules invented. It is equal to an ordinary straight slide-rule 83 ft. 4 ins. in length, and its value can hardly be over-estimated. Those who have once become familiar with the instrument will never dispense with its use.

The rule (fig. 110) consists of a cylinder (*d*) that can be moved up and down upon, and turned round, an axis (*f*), which is held by a handle (*e*). Upon this cylinder is wound in a spiral a single logarithmic scale. Fixed to the handle is an index (*b*). Two other indices (*c* and *a*), whose distance apart is the axial length of the complete spiral, are fixed to the cylinder *q*. This cylinder slides in *f* like a telescope tube, and thus enables the operator to place these indices in any required position relative to *d*; *n* and *m* are two scales, the one on the piece carrying the movable indices, the other on the cylinder *d*.

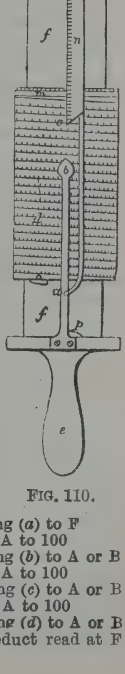

FIG. 110.

This rule possesses advantages over the flat edge-to-edge form besides that of increased length of scale. The setting and reading are performed by indices, and not by scale against scale, and this is very much less troublesome. Also, multiplications and divisions containing a series of factors can be worked with the greatest facility, and as the logarithms of numbers by the use of scales *m* and *n* are easily read, the powers and roots of numbers are within the capacity of the instrument.

An additional improvement has now been effected in these rules, by adapting the case to support them when in use, thus overcoming the objection of being always obliged to hold them in the hand.

Rules for Instruments with one Fixed and two Movable Indices.

The fixed index will be denoted by F.
The top movable index will be denoted by A.
The lower „ „ „ B.
When the indices are to be moved the term Set is used.
When the cylinder has to be moved the term Bring is used.

Multiplication.

$(a \times b)$
- Bring A to F
- Set A to 100
- Bring (*b*) to A or B
- Product read at F

$(a \times b \times c)$
- Bring (*a*) to F
- Set A to 100
- Bring (*b*) to A or B
- Set A to 100
- Bring (*c*) to A or B
- Product read at F

$(a \times b \times c \times d)$
- Bring (*a*) to F
- Set A to 100
- Bring (*b*) to A or B
- Set A to 100
- Bring (*c*) to A or B
- Set A to 100
- Bring (*d*) to A or B
- Product read at F

It will be seen that a similar sequence of operations applies to finding the product of any number of factors.

General Rule for the Number of Figures in the Product.

The *maximum* number of figures in the product is the algebraic sum of the number of figures in the factors, and this maximum results when all the factors (except the first) have to be brought to B. For each time a factor is brought to A, ONE is to be deducted from that sum.

So that if, during the operation, the number of times a factor has to be brought to A is noted, then the number of figures in the product is the sum of the number of figures in the factors (which is at once evident on inspection), less the number noted.

Thus, in the case of multiplying two factors together, the number of figures in the product is the sum or sum -1, according as the second factor is brought to B or A.

Division.

$\frac{a}{m}$
- Bring (a) to F
- Set A or B to (m)
- Bring 100 to A
- Quotient read at F

$\frac{a \times b}{m}$
- Bring (a) to F
- Set A or B to (m)
- Bring (b) to A or B
- Quotient read at F

$\frac{a \times b \times c}{m}$
- Bring (a) to F
- Set A or B to (m)
- Bring (b) to A or B
- Set A to 100
- Bring (c) to A or B
- Quotient read at F

$\frac{a}{m \times n}$
- Bring (a) to F
- Set A or B to (m)
- Bring 100 to A
- Set A or B to (n)
- Bring 100 to A
- Quotient read at F

$\frac{a \times b}{m \times n}$
- Bring (a) to F
- Set A or B to (m)
- Bring (b) to A or B
- Set A or B to (n)
- Bring (100) to A
- Quotient read at I

$\frac{a \times b \times c}{m \times n}$
- Bring (a) to F
- Set A or B to (m)
- Bring (b) to A or B
- Set A or B to (n)
- Bring (c) to A or B
- Quotient read at F

It will be seen that a similar sequence of operations applies to the division of the product of any number of factors by the product of any number of other factors.

General Rule for the Number of Figures in the Quotient.

The *maximum* number of figures in the quotient is the algebraic difference between the sum of the number of figures in the factors of the numerator and those of the denominator + (ONE) *for each factor of the denominator*, and this maximum results when A has to be set to *all* the factors of the denominator and all the factors of the numerator (except the first) brought to B.

One is to be deducted from the maximum number of figures each time B is set to a factor of the denominator or a factor of the numerator is brought to A.

So that if the number of times during the operation B is set to a factor of the denominator and a factor of the numerator is brought to A is noted, then the number of figures in the quotient is the maximum number of figures as found above (which is at once evident on inspection), less the number noted.

Thus, in the case of dividing one factor by another, the number of figures in the quotient is the difference or difference + 1, according as B or A is set to the divisor.

It should be remarked that the sequence of operations in *every case* is the same both for multiplication and division. The sequence of operations is :—First factor of numerator—First factor of denominator—Second factor of numerator—Second factor of denominator; and so on, commencing with the first factor of numerator at F, and ending by reading the quotient at F. If the above be written thus, this is at once evident.

$$a \times b = \frac{a \times b}{1}. \qquad a \times b \times c = \frac{a \times b \times c}{1 \times 1}. \qquad \frac{a}{m} = \frac{a \times 1}{m}.$$

$$\frac{a \times b \times c}{m} = \frac{a \times b \times c}{m \times 1}. \qquad \frac{a}{m \times n} = \frac{a \times 1 \times 1}{m \times n}. \qquad \frac{a \times b}{m \times n} = \frac{a \times b \times 1}{m \times n}.$$

This is important, as it is easy to remember. Also it will be seen, and should be remembered, that all factors of the numerator (except the first) are *Brought* to the movable index, and the movable index is *Set* to all factors of the denominator. Upon the upper movable index is marked - MUL., and on the lower one, - DIV. These are to remind the operator that when a factor of the numerator is *brought* to the upper index, and when the lower index is *set* to a factor of the denominator, 1 is to be deducted from the maximum number of figures that can occur in the result.

To Reduce Shillings to Decimals of a Pound.

Divide the number of shillings by 2 and point off one place. Thus 17 shillings $\div 2 = 8{\cdot}5 = £0{\cdot}85$.

To reduce pence to decimals of a pound multiply the pence by 4 for rough approximation and point off three places thus, 4 pence $\times 4 = 16 = £0{\cdot}016$. For accuracy multiply this last number by 4 and add the result with two figures overlapping to the right thus, $0{\cdot}016 \times 4 = 0{\cdot}064$. Then

0·016
064
0·01664

Any degree of accuracy can be reached by multiplying the last product by 4 and adding to the previous sum as before with two overlapping figures to the right, thus

$$\cdot 01664 + (064 \times 4) = \cdot 01664$$
$$256$$
$$\cdot 0166656$$

The absolute value of 4 pence is of course ·016. For purposes of the slide rule it is only needful at most, to go to the second multiplication, and this can be done mentally. Thus 5 pence is easily set down as £0·0208.

Conversions by the Slide-Rule—Gauge Points.

The application of the rule for problems involving proportion enables the implement readily to be used for conversions from values in one term to equivalent values in another. The following table, compiled from various sources, enables such conversions to be performed with accuracy. For instance, the circumference of any circle whose diameter is given may be read on the rule against the diameter on the slide if the value 226 on the slide is set to the value 710 on the rule, and so on.

The following table is based on the assumption that the C and D scales of the rule are used. Certain values, however, cannot be read owing to the projection of the slide off the rule. If these

Table of Gauge Points for Ordinary Slide-Rule.

Known Value on Slide.	Required Value on Rule.	Set to.	
		On Slide.	On Rule.
Circle, diameter	Circle, circumference	226	710
Circle, diameter	Circle, side of inscribed square	99	70
Circle, diameter	Circle, side of equal square	79	70
Circle, diameter	Circle, side of equal equilateral triangle	72	97
Circle, circumference	Circle, side of inscribed square	40	9
Circle, circumference	Circle, side of equal square	39	11
Circle, area	Inscribed square area	300	191
Square, side	Square, diagonal	70	99
Inches	Centimetres	50	127
Inches, eighths	Millimetres	40	127
Feet	Metres	292	89
Yards	Metres	35	32
Miles	Kilometres	87	140
Square inches	Square centimetres	31	200
Square feet	Square metres	140	13
Square yards	Square metres	161	51
Square miles	Square kilometres	112	290
Acres	Hectares	42	17
Cubic inches	Cubic centimetres	36	590
Cubic feet	Cubic metres	106	3
Cubic feet	Litres	3	85
Cubic yards	Cubic metres	51	39
Gallons	U.S. gallons	5	6
Bushels	Cubic metres	110	4
Ounces (avoirdupois)	Grammes	67	1900
Ounces (avoirdupois)	Kilogrammes	670	19
Pounds (avoirdupois)	Kilogrammes	280	127
Hundredweights	Kilogrammes	5	254
Tons	Tonnes	62	63
Feet per second	Metres per minute	7	128
Feet per second	Miles per hour	22	15
Feet per minute	Miles per hour	264	3
Yards per minute	Miles per hour	88	3
Miles per hour	Metres per minute	12	322
Knots (nauts) per hour	Metres per hour	33	38
Pounds per square inch	Kilogrammes per sq. centimetre	128	9
Pounds per square inch	Atmospheres	485	33

TABLE OF GAUGE POINTS FOR ORDINARY SLIDE-RULE—*(continued)*.

Known Value on Slide.	Required Value on Rule.	Set to. On Slide.	Set to. On Rule.
Pounds per square inch	Water head, feet	13	30
Pounds per square inch	Water head, metres	33	25
Pounds per square inch	Inches, mercury gauge	25	51
Inches, water gauge	Pounds per square inch	360	13
Inches, water gauge	Inches, mercury gauge	14	1
Inches, mercury gauge	Atmospheres	30	1
Atmospheres	Kilos per square cm.	89	92
Pounds per square foot	Kilos per square metre	87	425
Pounds per lineal foot	Kilos per lineal metre.	41	61
Pounds per lineal mile	Kilos per kilometre	71	20
Pounds per cubic foot	Kilos per cubic metre	39	625
Cubic feet of water	Weight in pounds	17	1060
Cubic feet of water	Gallons (imperial)	17	106
Gallons of water	Weight, kilos	108	490
Pounds of water (fresh)	Pounds of water (sea).	38	39
British thermal unit	Calories	250	63
British thermal unit per pound	Calories per kilogramme	9	5
Foot pounds	Kilogrammetres	340	47
Horse-power	Force de cheval	72	73
Pounds per H.P.	Kilos per cheval	300	134
Horse-power per hour	Kilowatte (B.T.U.)	134	100
Watts	Horse-power.	5	·0067

be required, the cursor should be set to whichever index on C falls on the rule, and then the other index moved to coincide with the cursor line. If in this operation the slide be moved from left to right, the results must be multiplied by 10. If the slide be moved in the opposite direction the results should be divided by 10.

The A and B scales can be used conveniently if less accuracy is admissible. In this case the gauge points should be chosen on the left-hand side of the rule and the results read on the right and multiplied by 10. The arithmetical relation is:

$$\text{Required value} = (\text{known value}) \times \frac{\text{number in 'on rule' col.}}{\text{number in 'on slide' col.}}$$

SLIDE RULE CONSTANTS FOR BAR WEIGHTS.

If W = weight in lbs.; D = diam. in ins. of round bars; S = side in ins. of square bars A and B = sides in ins. of rectangular bars; L = length in ins.; C = weight of 1 cub. in. of the material, then for

round bars, $W = \left(\frac{D}{e_1}\right)^2 L$; square bars, $W = \left(\frac{S}{e_2}\right) L$; rectangular bars, $W = \frac{AB}{e_3} L$;

in which e_1, e_2, and e_3 have the following values:—

Material.	Round Bars. e_1 (ins.).	Round Bars. e_1 (ft.).	Square Bars. e_2 (ins.).	Square Bars. e_2 (ft.).	Rectangular Bars. e_3 (ins.).	Rectangular Bars. e_3 (ft.).
Aluminium	3·71	1·071	3·29	0·950	10·82	0·903
Brass 80/20	2·023	0·584	1·795	0·518	3·221	0·268
„ 70/30	2·047	0·591	1·816	0·524	3·298	0·275
„ 60/40	2·052	0·593	1·951	0·525	3·314	0·276
Naval brass	2·035	0·588	1·805	0·521	3·258	0·271
Gunmetal	2·01	0·580	1·781	0·514	3·175	0·265
Muntz metal	2·072	0·598	1·838	0·531	3·378	0·281
Copper	2·0	0·577	1·773	0·512	3·145	0·262
Cast iron	2·212	0·638	1·961	0·566	3·846	0·321
Wrought iron	2·123	0·613	1·883	0·544	3·546	0·296
Steel	2·115	0·611	1·876	0·542	3·522	0·294

(C.A.P., in 'Machinery.')

Averaging Experimental Results.*

Arrange the results *in order of magnitude* and plot them at equal intervals along a base line, as in fig. 111, which represents the values of breaking tests of Portland cement made after 28 days in each case, the height of the base line being, for convenience, taken as 600 lbs. per

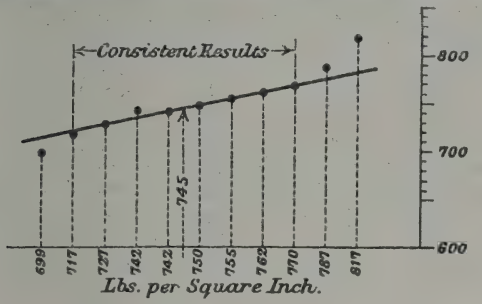

FIG. 111.

sq. in. It is now easy to draw a *straight* line through a large proportion of the dots with certainty as to its position, and to discard the discrepant values. The line will not usually be horizontal, though it would be so with experiments giving identical results. The centre of the line through the consistent results will give the mean height required, which in this case is 745 lbs. (or strictly 745·6 lbs.) per sq. in., instead of the arithmetical mean, which is 751·6.

Nomographic or Alignment Charts.

(Contributed by T. B. Morley, D.Sc., M.I.Mech.E.)

The ordinary ' curve ' plotted with rectangular co-ordinates serves conveniently to show the relation between two varying quantities. If the relationships between three quantities are to be represented on a flat sheet, a series of curves may be drawn, one of the variables having a constant value for each curve. If a wide range of values is to be covered, and if it is desired to avoid errors in interpolation, the curves must be numerous and close. This, again, introduces liability of error in the use of the diagram, as it requires great care to follow with certainty a particular curve lying among a number of closely packed similar curves.

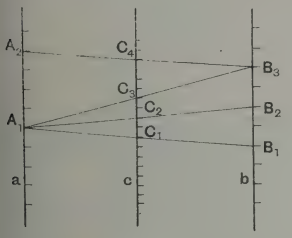

FIG. 112.

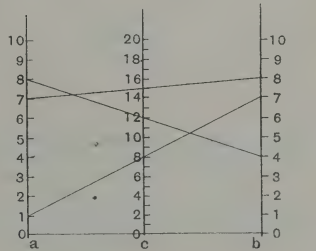

FIG. 113.

By the use of nomographic charts—or alignment charts—quantities having certain mathematical relationships can be correlated in a very simple manner, and the chart avoids a multiplicity of curves altogether. Moreover, it can, with little extra complication, be drawn out for calculations involving more than three variables.

The construction and use of the simpler and more commonly used forms of these charts can be readily explained by examples.

Suppose $a + b = c$, where a, b, c, are variables.

* C. H. Wingfield, *Engineering*. August 13, 1917.

Draw three parallel equidistant axes, fig. 112, and mark off equal scales to represent a and b on the outer ones, and on the middle axis a scale such that if 1 inch represents n units of a or b, it represents $2n$ units of c. If a straight line, $A_1C_1B_1$, be drawn, cutting the axes at A_1, C_1, B_1, and if it be pivoted about A_1 and swung into positions $A_1C_2B_2$, $A_1C_3B_3$, etc., it is obvious that for any

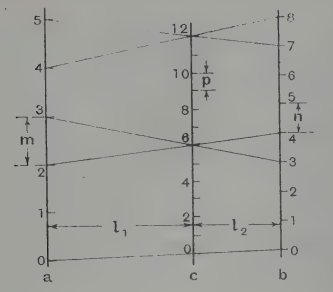

FIG. 114.

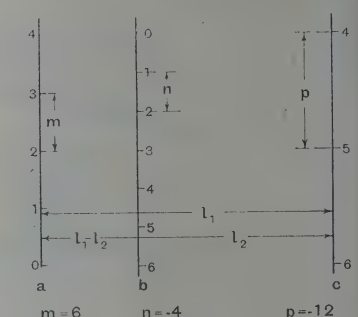

FIG. 115.

increments on the b scale represented by B_1B_2, etc., C_1C_2, C_2C_3, etc., on the middle scale will represent the same increments of the value of C. *Eg.*, if B_1B_2 represents 2 units of b, then C_1C_2, which is half B_1B_2, represents 2 units of C.

Similarly, if B is fixed and A moves, C advances on its scale exactly the same amount as that represented by the advance of A.

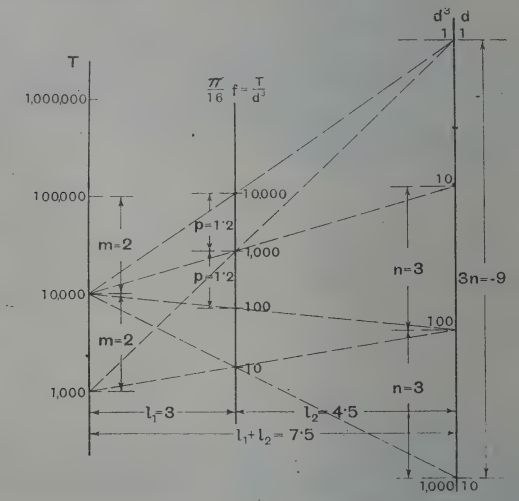

FIG. 116.

The scale of c can therefore be so placed on the middle axis that for any line crossing the three axes, the reading at the intersection of the c scale is the sum of the readings at the a and b scales. All three scales run in the same direction. Fig.113, in which the numbers all increase in the upward direction, makes the principle clear, and illustrates the simple nomogram for $a + b = c$. The same

nomogram serves also for subtraction, for the same relationship can be expressed by $c - a = b$ or $c - b = a$.

The scales of a and b need not necessarily be equal, nor need they both run in the same direction. Two may be chosen at will; there will then, however, be only one correct scale and one correct position for the third.

If the a and b scales both run in the same direction, and if m inches represents one unit of a, and n inches one unit of b, then p, the number of inches representing one unit of c, will be given by $p = \frac{m \times n}{m + n}$. Also the c axis will lie between the a and b axes, and will divide the distance between them in the ratio of m to n.

For example, in fig. 114, $m = 1{\cdot}5n$, hence $p = \frac{1{\cdot}5n \times n}{1{\cdot}5n + n} = {\cdot}6n$, and $\frac{l_1}{l_2} = \frac{m}{n} = \frac{3}{2}$. Note also that $\frac{l_1}{l_1 + l_2} = \frac{m}{m + n}$.

Furthermore, the scales may run in opposite directions. In fig. 115, representing $a + b = c$, the scales of a and b are opposite. In this case $p = \frac{m \times n}{m - n}$ and the axis of c is not between those of a and b, though $l_1 \div l_2$ is still equal to $m \div n$.

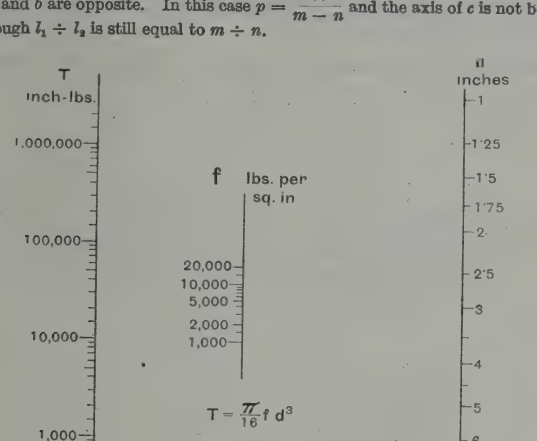

FIG. 117.

The quantities whose relationships are required may not themselves be suitable for direct nomographic treatment, but it may be possible to choose instead convenient functions of the quantities and construct the nomogram for them, graduating the axes, however, to read the original quantities.

By the proper choice and location of scales and position of axes, nomographic charts of the type described can be devised to correlate a, b, and c, if their relationship is of the type $ra \pm sb \pm lc = 0$. Additional scales can be added to permit of the addition or subtraction of further terms.

Consider now a formula of the type $x \cdot \times y \cdot = z$. From this, $m \log x + n \log y = \log z$, which is of the form of the previous equation, if $\log x$ replaces a, and so on.

Scales of $\log x$, $\log y$, $\log z$ are plotted, but are *marked* with the values of x, y, z, giving what are called logarithmic scales (like those of the slide-rule). The nomogram with logarithmic scales then serves for multiplication or division, and by proper choice of scales any powers of the quantities can be dealt with.

The most common nomograms are of this type.

As an example, suppose a nomographic chart is to be designed for the twisting moment formula, $T = \frac{\pi}{16} f d^3$, and that d is to range from 1 to 10 ins., and f from 2000 to 10,000 lbs. per sq. in. T will therefore range from 393 to 3,930,000 in. lbs.

For the T scale, we may represent log 10 (*i.e.* the distance from T = 1,000 to T = 10,000, or from T = 10,000 to T = 100,000, and so on) by, say, 2 ins. ($m = 2$), the overall length of the scale being (log 3,930,000 − log 393) × 2 ins. or 8 ins.

For the scale of d, we may represent log 10 by, say, 9 ins., *i.e.* the length from $d = 1$ to $d = 10$ is 9 ins. Then for d^3, log 10 will be represented by 3 ins. ($n = 3$). Draw the T and d axes, say 7·5 ins. apart, and let T increase upwards while d increases in a downward direction (see fig. 116); the axis of f will then be $7{\cdot}5 \times \frac{n}{m+n} = 7{\cdot}5 \times \frac{2}{3+2} = 3$ ins. from that of T.

The scale of f will be such that log 10 is represented by

$$\frac{mn}{m+n} = \frac{3 \times 2}{3+2} = 1{\cdot}2 \text{ ins.}$$

The proper location of the f scale can be found by calculating f for particular values of T and d, and setting the f scale so that the value of f found by the calculation lies on the line joining the T and d values.

In practice the above calculations for the position and scale of f need not be made. It is usually more convenient to join a number of points on the T and d scales and determine points on the f scale by the appropriate intersections as shown in fig. 116. Fig. 117 (p. 129) shows the completed nomogram. (*Continued on p.* 132.)

NOMOGRAM FOR SAFE LOADS AND DEFLECTION OF SMALL SPIRAL SPRINGS.

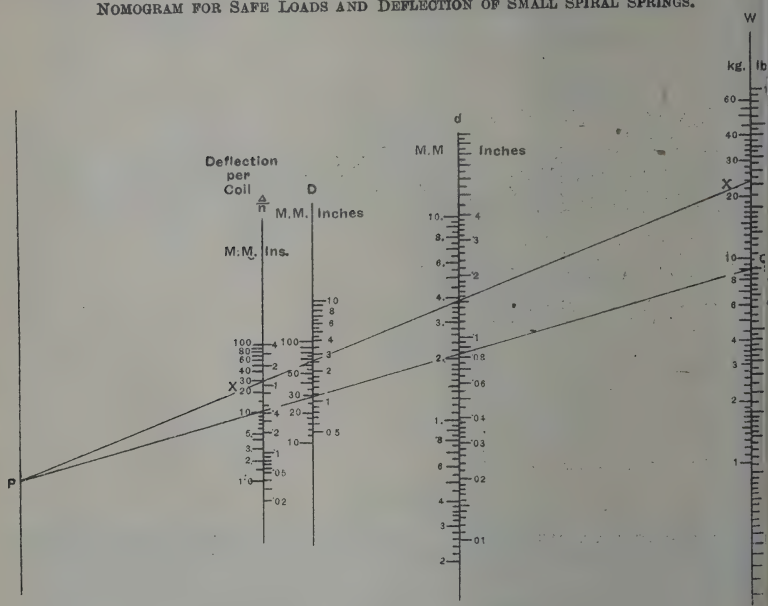

FIG. 118.

$$W = \cdot 395\frac{fd^3}{D} \qquad f = 100{,}000 \text{ lbs./D}'' = 7{,}040 \text{ kg./cms}^2.$$

$$\frac{\Delta}{n} = \frac{8WD^3}{cd^4} \qquad C = 12{,}000{,}000 \text{ lbs./D}'' = 846{,}000 \text{ kg./cms}^2.$$

For different stresses, alter W proportionately.

Line X X gives corresponding values of D, d, maximum W, and $\frac{\Delta}{n}$ for maximum W.

For deflection at other loads, produce X X to cut reference line at P.

Join P to required load at Q and read where PQ cuts scale of $\frac{\Delta}{n}$.

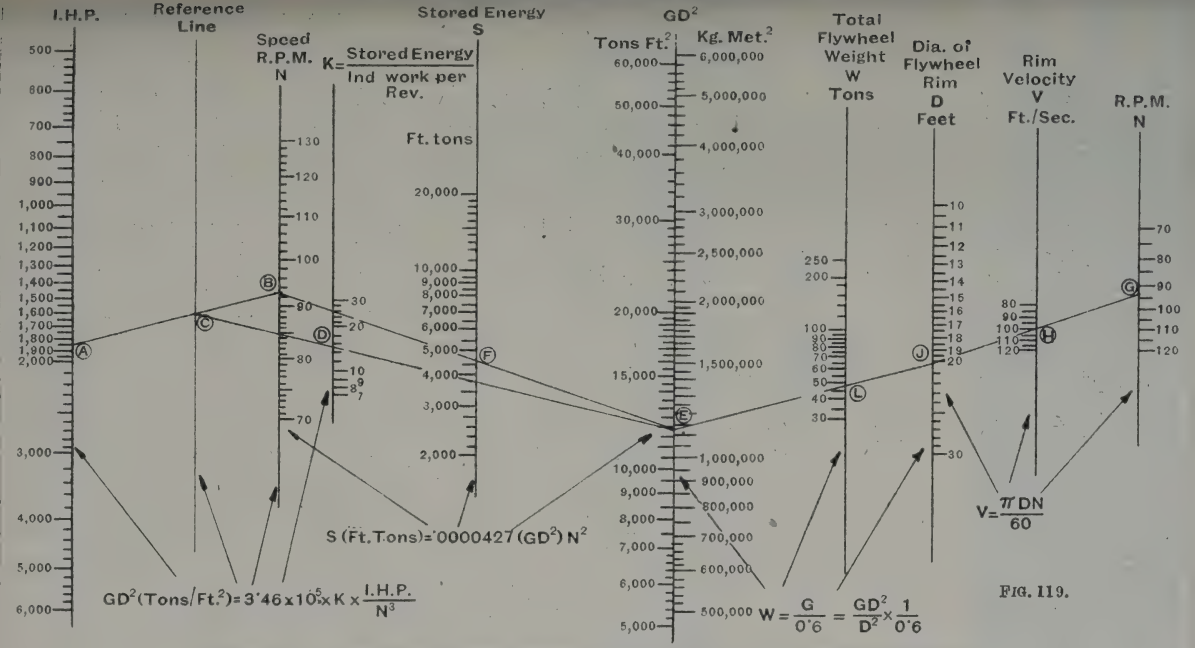

FIG. 119.

Join the given I.H.P. and given N values, points (A) and (B) and where (A) (B) cuts reference line at (C).
Join (C) to given value of K at (D) and produce to "GD²" scale, and at (E) read "GD²."
To find stored energy S, join (E) to (B) and read where (E) (B) cuts scale of S at (F).
Line (G) (H) (J) shows corresponding values of speed N, flywheel diameter D, and rim velocity Y.
Join (J) to (E), and read flywheel weight W at (L).

Though the chart, fig. 117 (p. 129), can be drawn without knowledge of the relationships between l_1, l_2, m, n, and p, it is useful to know these relationships, as it helps in choosing convenient scales which shall not be too fine for accurate reading or too long to be conveniently accommodated. It is usually advisable to try a few combinations of scales and locations of axes before the final choice for the nomogram is made and the axes fully graduated.

For four variables, five axes are required, one of which need not be graduated. It serves merely as an intermediate reference line, giving, for example, a point representing the product of two of the known variables a and b; then by joining this point to the third known variable, the intersection with the axis of the fourth variable, the unknown, gives the result sought for.

Examples of this kind of chart are shown by figs. 118 and 119 (pp. 130 and 131).

There are other forms of nomographic charts in which the axes are inclined or curved. For these, the treatises on nomography should be consulted. Charts of these types are illustrated in p. 1614, as applied to questions of heat transmission in boiler tubes.

See also p. 1746 for a nomographic chart for the flow of steam in pipes.

SECTION II

POWERS

STATICS—CENTRE OF GRAVITY—LEVERS—PULLEYS—PARALLELOGRAM OF FORCES—INCLINED PLANE—DYNAMICS—MOVING BODIES—ACCELERATION—WORK—PENDULUM—OSCILLATION AND PERCUSSION—GYRATION—INERTIA—BALLISTIC PENDULUM—POWER BRAKES—ANIMAL POWER

SECTION II

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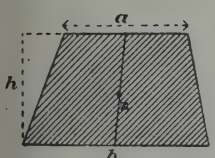
STATICS.

CENTRE OF GRAVITY.

Plane Figures.



Quadrangle.
a and b parallel.

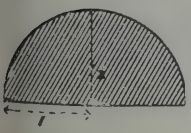
$$z = \frac{h}{2} \cdot \frac{h}{6}\left(\frac{b-a}{b+a}\right).$$

Fig. 172.

Triangle.

$$z = \frac{h}{3}.$$

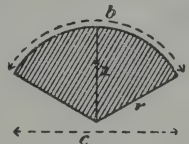
Fig. 173.



Half a Circle Plane or Elliptic Plane.

$$z = 0{\cdot}424r.$$

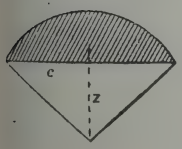
Fig. 174.



Circle Sector.

$$z = \frac{2cr}{3b}.$$

Fig. 175.

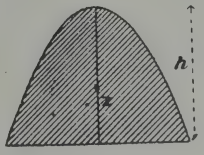


Circle Segment.

$$z = \frac{c^3}{12a}.$$

a = area.

Fig. 176.



Parabola.

$$z = \frac{2h}{5}.$$

Fig. 177.

Shell or Convex Surface, and Solid Figures.

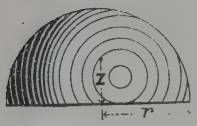


Fig. 178.

Half Sphere.

Convex surface, $z = \frac{1}{2}r$.
Solid, $z = \frac{3}{8}r$.

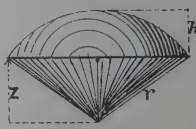


Fig. 179.

Spherical Sector.

Solid, $z = \frac{1}{4}\left(r - \frac{h}{2}\right)$

Fig. 180.

Spherical Segment.

Convex surface, $z = \frac{h}{2}$.

Solid, $z = \frac{h}{2} \cdot \left[\frac{2r^2 + h^2}{3r^2 + h^2}\right]$.

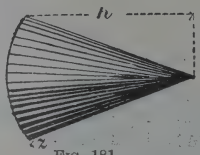


Fig. 181.

Cone.

Shell, $z = \frac{h}{3}$.

Solid, $z = \frac{h}{4}$.

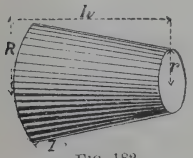


Fig. 182.

Conic Frustum.

Convex surface, $z = \frac{h}{2} - \frac{h}{6}\left[\frac{R - r}{R + r}\right]$. Solid, $z = \frac{h}{4} \cdot \left[\frac{R^2 + r(2R + 3r)}{R^2 + r(R + r)}\right]$

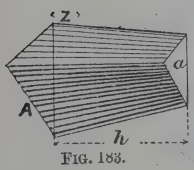


Fig. 183.

Pyramidal Frustum.

Solid, $z = \frac{h}{4}\left[\frac{A + 3a + 2\sqrt{Aa}}{A + a + \sqrt{Aa}}\right]$.

A and a = areas of the two bases.

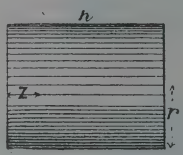


Fig. 184.

Cylindri Surface with a Bottom i one End

$z = \frac{h}{r+2}$

Circumferential Figures.

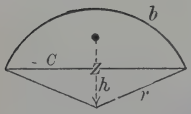


Fig. 185.

Circle Arc or Elliptic Arc.

$z = \frac{cr}{b} = \frac{c\sqrt{4h^2 + c^2}}{4b}$.

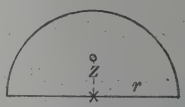


Fig. 186.

Half a circumference o a Circle or Ellipse.

$z = 0{\cdot}6367r$.

LEVERS.

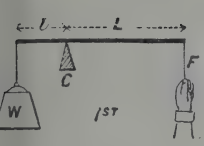


FIG. 187.

$F : W = l : L,$

$FL = Wl.$

$F = \frac{Wl}{L},$

$W = \frac{FL}{l}.$

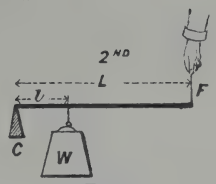


FIG. 188.

$F : W = l : L,$

$FL = Wl.$

$F = \frac{Wl}{L},$

$W = \frac{FL}{l}.$

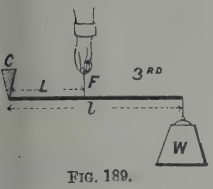


FIG. 189.

$F : W = l : L,$

$FL = Wl.$

$F = \frac{Wl}{L},$

$W = \frac{FL}{l}.$

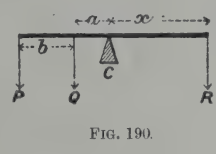


FIG. 190.

To find the fulcrum, C, when three forces act on one lever.

$Rx = Qa + P(b+a),$

$x = \frac{Qa + P(b+a)}{R}.$

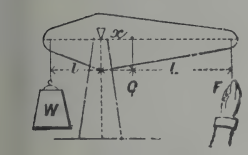


FIG. 191.

Q = weight of the lever.
x = distance from the centre of gravity of the lever to the fulcrum.

$F = \frac{Wl - Qx}{L},$

$W = \frac{FL + Qx}{l}.$

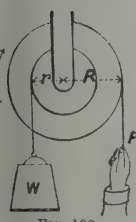


FIG. 192.

$F : W = r : R,$

$FR = Wr.$

$F = \frac{Wr}{R},$ $R = \frac{Wr}{F},$

$W = \frac{RF}{r},$ $r = \frac{RF}{W}.$

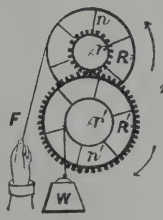


FIG. 193.

$F = \frac{Wrr'}{RR'},$ $W = \frac{FRR'}{rr'}.$

n, n' = numbers of revolutions of the wheels.

$n : n' = R' : r,$ $v : v' = RR' : rr'.$

v = velocity of F,

v' = velocity of W.

PULLEYS.

$\frac{v'}{v}$ = ratio of distances moved by W and F.

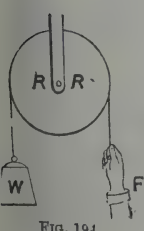


FIG. 194.

A single fixed Pulley.

$F : W = R : R,$

or $F = W.$

$\frac{v'}{v} = 1.$

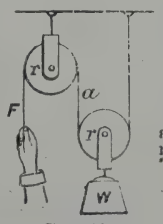


FIG. 195.

A single movable Pulley.

$F : W = r : 2r,$

or $F = \frac{1}{2}W.$

If the force F be applied at a and act upwards, the result will be the same.

$\frac{v'}{v} = 2.$

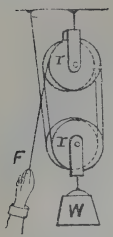


FIG. 196.

A double movable Pulley.

$F : W = r : 4r$,

or $F = \frac{1}{4}W$.

$\frac{v'}{v} = 4$.

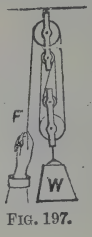


FIG. 197.

A double movable Pulley.

$F = \frac{1}{4}W$.

$\frac{v'}{v} = 4$.

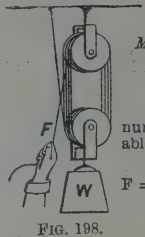


FIG. 198.

Multiple movable Pulley.

Let n = any number of movable pulleys, then

$F = \frac{W}{2n}$, $\frac{v'}{v} = 2n$

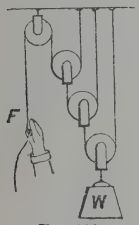


FIG. 199.

Compound Pulleys.

n = number of movable pulleys.

$F = \frac{W}{2^n}$, $W = 2^n F$,

$\frac{v'}{v} = 2^n$.

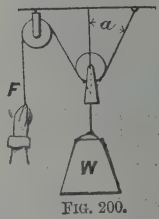


FIG. 200.

An oblique fixed Pulley.

$F : W = \sec a : 2$.

$W = \frac{2F}{\sec a}$, $F = \frac{W \sec a}{2}$

PARALLELOGRAM OF FORCES.

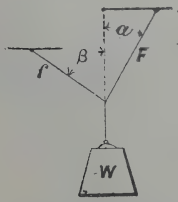


FIG. 201.

$W : F = \sin(\alpha+\beta) : \sin\beta$,

$W : f = \sin(\alpha+\beta) : \sin\alpha$.

$F = \frac{W \sin\beta}{\sin(\alpha+\beta)}$,

$f = \frac{W \sin\alpha}{\sin(\alpha+\beta)}$,

$W^2 = F^2 + f^2 + 2Ff\cos(\alpha+\beta)$.

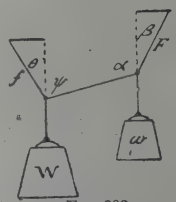


FIG. 202.

$F = \frac{w \sin\alpha}{\sin(\alpha+\beta)}$,

$f = \frac{W \sin\psi}{\sin(\psi+\theta)}$.

INCLINED PLANE.

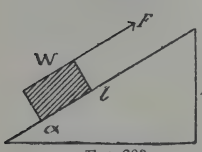


FIG. 203.

No Friction.

$F = \frac{Wh}{l} = W\sin\alpha$,

$W = \frac{Fl}{h} = \frac{F}{\sin\alpha}$.

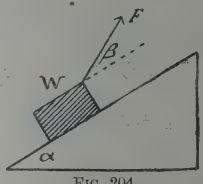


FIG. 204.

No Friction.

$F = W\frac{\sin\alpha}{\cos\beta}$,

$W = F\frac{\cos\beta}{\sin\alpha}$.

Friction.

$$F = W\frac{\mu\cos\alpha + \sin\alpha}{\mu\sin\beta + \cos\beta},$$

where μ = coefficient of friction.

$$F = W\frac{\sin(\phi+\alpha)}{\cos(\beta-\phi)},$$

where ϕ = limiting angle of resistance.

$\mu = \tan\phi$.

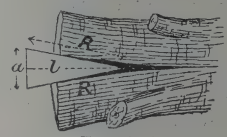


FIG. 205.

Wedge.

$F = \frac{Ra}{l}$,

$R = \frac{Fl}{a}$.

F = force requ to drive e wedge.

Force Acting at an Angle.

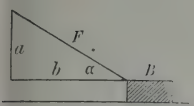


Fig. 206.

Let the line F represent the magnitude and direction of a force acting at an angle a to move the body B on the line CD; then the line a represents a part of F which presses the body B against CD, and the line b represents the magnitude of the force which actually moves the body B.

$$b = \sqrt{F^2 - a^2}, \quad b = F \cos a.$$

Force by a Screw.

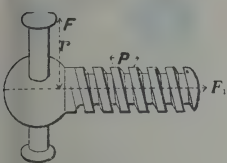


Fig. 207.

P = pitch of the screw.
r = radius on which the force F acts.
$\pi = 3{\cdot}1416$.

$$F_1 : W :: P : 2\pi r.$$

$$F_1 = \frac{WP}{2\pi r} \qquad W = \frac{F_1 2\pi r}{P}.$$

DYNAMICS.

Uniform Motion.

s = space passed through in time t. v = velocity.

$$s = vt.$$

If s is in ft. and t in secs., then v = ft. per sec.

FALLING BODIES.

Body Falling Freely.

s = space passed through in time t. v = velocity at end of time t.
g = coefficient of terrestrial acceleration = 32·2 (where s is in ft. and t in secs.).

$$s = \tfrac{1}{2}gt^2. \qquad v = gt. \qquad v^2 = 2gs.$$

Body Thrown Downward.

If body is *thrown downward* with a velocity V,

$$v = V + gt. \qquad s = Vt + \tfrac{1}{2}gt^2. \qquad v^2 = V^2 + 2gs.$$

Body Thrown Upward.

If body is *thrown upward* with a velocity V,

$$v = V - gt. \qquad s = Vt - \tfrac{1}{2}gt^2. \qquad v^2 = V^2 - 2gs$$

IMPACT OF BODIES.

The Bodies inelastic.

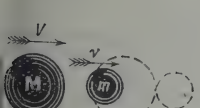


Fig. 208.

The Bodies move in the same direction.

$$v'(M+m) = MV + mv,$$

$$v' = \frac{MV + mv}{M+m}.$$

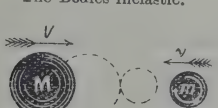


Fig. 209.

The Bodies move in opposite directions.

$$v'(M+m) = MV - mv,$$

$$v' = \frac{MV - mv}{M+m}$$

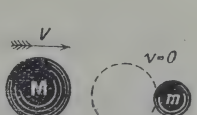


Fig. 210.

Only one Body in motion.

$$v'(M+m) = MV,$$

$$v' = \frac{MV}{M+m}.$$

where M and m are either mass or weight.

IMPACT OF BODIES.

The Bodies elastic.

$\left\{\begin{matrix} K = \text{coefficient of elasticity of } M \\ k = \quad\quad\quad\

TABLE OF COEFFICIENTS OF FRICTION—*continued.*

Sliding Surface.	Coefficient (μ)
Metal on Wood—	
Wrought Iron on Elm, fibres parallel to motion	·25
" " " Oak, " " "	·62
Cast Iron on Elm, " " "	·20
" " " Oak, " " "	·49
Copper " " " " "	·62
Brass " Pine, " " "	·19
" " Mahogany " " "	·24
Steel " Pine, " " "	·16
" " Mahogany, " " "	·18
Metal on Metal:—	
Wrought Iron on Wrought Iron, fibres parallel to motion	·14
" " " Cast " " " "	·19
" " " Brass, " " "	·17
Cast " " Cast Iron	·15
" " " Brass	·15
Steel on Steel (*Trautwine*)	·14
" " Cast Iron	·20
" " Brass	·15
Copper on Cast Iron	·19
Metal on Metal (average), dry	·17
" " " " wet and clean	·36
" " " " damp and slimy	·14
Leather on Metal:—	
Leather on Metal, dry	·56
" " " wet	·36
" " " greasy	·23
" " " oily	·15
Wood on Stone:—	
Oak, across the grain, on hard or soft Limestone	·38
Metal on Stone:—	
Wrought Iron on soft Limestone, well dressed	·49
" " " hard " " "	·24
" " " " " " " wet	·30
" " " " Marble, sawn (*Trautwine*)	·17
Stone on Stone, or Brickwork:—	
Polished Marble on polished Marble (*Trautwine*)	·16
" " " common Brick	·44
Soft Limestone, well dressed, on soft Limestone, well dressed	·64
Hard " " " " hard " "	·38
" " " " " soft " "	·67
Common Brick on soft Limestone, well dressed	·65
" " " hard " "	·60
" " " common Brick	·64
Masonry on dry Clay	·51
" " wet "	·33
Miscellaneous:—	
Leather on Oak	·27 to ·38
Hemp " " dry	·53
" " " wet	·33
Perodo fibre on Metal	·4 to ·8
" bonded asbestos on Metal	·3
Smooth surface continually greased	·05

WORK.

ACCUMULATED WORK.

W = weight of body. V = velocity.

$$\text{Work accumulated} = \frac{WV^2}{2g};$$

Where g = coefficient of terrestrial acceleration = 32·2.

body changes its velocity from V to V_1,

$$\text{Work gained or lost} = \pm \frac{W(V^2 - V_1^2)}{2g}.$$

Accumulated Work.

(Continued.)

If a shot of weight w is fired into a mass of weight W lbs. with a velocity of V ft. per sec., then

$$\text{Work accumulated in shot} = \frac{1}{2} \cdot \frac{W}{g} \cdot V^2.$$

$$\text{Work lost} = \frac{1}{2} \cdot \frac{W}{g} \cdot \frac{W}{W + w} \cdot V^2. \qquad \text{Work remaining} = \frac{1}{2} \cdot \frac{W}{g} \cdot \frac{W}{W + w} \cdot V^2.$$

$$g = 32{\cdot}2.$$

Gravity.

g = acceleration in centimetres per second due to gravity. l = length of seconds pendulum in centimetres.

Values of g and l in various localities.

Place.	Latitude.	g.	l.
Equator	°	978·1	99·103
Greenwich	51·29	981·17*	99·413†
Paris	48·50	980·94	99·39
Berlin	52·30	981·25	99·422
Dublin	53·21	981·32	99·429
Glasgow	55° 52′ 42″·8	981·44	99·442
Edinburgh	55·57	981·54	99·451
N. Pole	90°	983·11	99·61

* Equals 32·1902, in ft. per sec.
† Equals 3·2615 ft.

THE PENDULUM.

Simple Pendulum.

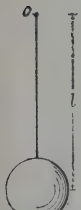


Fig. 215.

l=length of pendulum in inches. t=time in secs. of one oscillation (the time of moving from the highest point on one side to the highest point on the other). g=coefficient of terrestrial acceleration at equator=32·097 ft. per sec.=385·163 ins. per sec. π=3·1416.

$$t = \pi \sqrt{\frac{l}{g}} = 3{\cdot}1416 \sqrt{\frac{l}{385{\cdot}163}} = \frac{\sqrt{l}}{6{\cdot}247}.$$

Length of seconds pendulum at equator=39·0265 ins.

If L=latitude,

$$l = 39{\cdot}0265 + {\cdot}1608 \sin^2 \text{L}, \text{ for a 1-second pendulum.}$$

Compound Pendulum.

Fig. 216.

o = centre of suspension. l = equivalent length of simple pendulum to give the same time of oscillation. W = weight of lower bob. w = weight of upper bob.

Fig. 216, $l = \dfrac{a^2\text{W} + b^2 w}{a\text{W} - bw}$; Fig. 216A, $l = \dfrac{a^2\text{W} + b^2 w}{a\text{W} + bw}$.

The length is actually the distance of the *centre of suspension* from the *centre of oscillation* (this is the same as the *centre of percussion*), the *centre of oscillation* being that point at which, if all the matter were collected, the time of oscillation would remain unaltered.

In case fig. 216A, if w = W, then rate of oscillation will be greatest if w is put in such a position that $b = (\sqrt{2} - 1)a$, in which case $l = 2(\sqrt{2} - 1)a$.—*H.R.K.*

Fig. 216A.

Conical Pendulum.

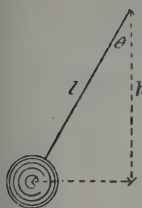


Fig. 217.

t = time of one revolution in secs., g = coefficient of terrestrial acceleration = 32·2, π = 3·1416.

$$t = 2\pi\sqrt{\frac{h}{g}}. \qquad (A)$$

This formula is correct irrespective of the length, l, of the rod (fig. 217).

Governor of Steam Engine.

Hence from (A), if

θ = angle (fig. 217) corresponding to a given period of rotation, t, g = coefficient of terrestrial acceleration = 32·2, π = 3·1416.

$$l = \frac{t^2 g}{4\pi^2 \cos\theta}.$$

CENTRE OF OSCILLATION OR PERCUSSION.

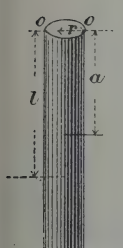


Fig. 218.

The *Centre of Oscillation* is that point in a vibrating body where, if all the matter were collected, the time of vibration would be unchanged.

The *Centre of Percussion* is that point in a revolving body at which, upon the point striking against an immovable obstacle, the whole of the motion of the body is destroyed. The centres of oscillation and percussion are the same.

o = centre of suspension. r = radius of cylinder. a = half length.

$$l = \frac{16a^2 + 3r^2}{12a} = \frac{4a}{3} + \frac{r^2}{4a}.$$

If r is small,

$$l = \frac{4a}{3}$$

i.e. in a bar the centre of oscillation or percussion is at a point distant from the centre of suspension two-thirds of the *total* length of the bar.

CENTRIFUGAL FORCE.

F = ***Centrifugal Force***, **in lbs.**
W = ***Weight*** **of revolving body in lbs.**
v = ***Velocity*** **of revolving body, in ft. per sec.**
R = ***Radius*** **of circle in which body revolves, in ft.**
n = ***Revolutions*** **per min.**
= Coefficient of terrestrial acceleration = 32·2. π = 3·1416.

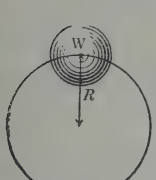


Fig. 219.

$$F = \frac{Wv^2}{gR} = \frac{Wv^2}{32\cdot16R}. \qquad F = \frac{4WR\pi^2n^2}{60^2g} = \frac{WRn^2}{2933}.$$

$$W = \frac{FgR}{v^2} = \frac{2933F}{Rn^2}. \qquad R = \frac{Wv^2}{Fg} = \frac{2933F}{Wn^2}.$$

$$n = \sqrt{\frac{2933F}{WR}}. \qquad v = \sqrt{\frac{FRg}{W}}.$$

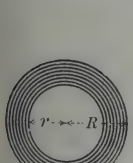


Fig. 220.

Centrifugal force of a ring.

$$F = \frac{Wn^2\sqrt{R^2 + r^2}}{4150}.$$

Fig. 221.

Centrifugal force of a grindstone, circle-plane, cylinder, rotating round its centre.

$$F = \frac{WRn^2}{4150}.$$

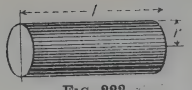


FIG. 222.

Centrifugal force of a cylinder rotating round the diameter of its base.

$$F = \frac{Wn^2\sqrt{4l^2 + 3r}}{10260}.$$

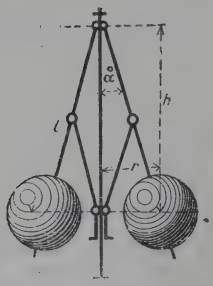


FIG. 223.

Governor.

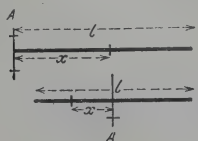
$$n = \frac{60}{2\pi}\sqrt{\frac{g}{h}} = \frac{54{\cdot}16}{\sqrt{h}} = \frac{54{\cdot}16}{\sqrt{l\cos\alpha}},$$

$$h = \frac{2933}{n^2}, \quad l = \frac{2933}{n^2\cos\alpha} = \frac{h}{\cos\alpha},$$

$$\cos\alpha = \frac{2933}{n^2 l} = \frac{h}{l}, \qquad r = \sqrt{l^2 - h^2}$$

RADIUS OF GYRATION.

The *Centre of Gyration* is that point at which, if all the revolving matter were collected, it would obtain equal angular velocity from, and sustain equal resistance to, the force that gives the rotary motion. The *Radius of Gyration* (x) is the distance of the centre of gyration from the axis, A.

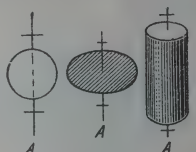


A Line or Bar.

$x = 0{\cdot}5775l,$

$x = 0{\cdot}2887l.$

FIG. 224.



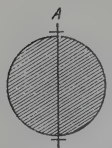
A Circumference round its Diameter.

A Circle-plane round its Centre.

A Cylinder round its Axis.

$x = 0{\cdot}7071r.$

FIG. 225.



A Circle-plane round its Diameter.

$x = 0{\cdot}5r.$

FIG. 226.

A Sphere round its Diameter.

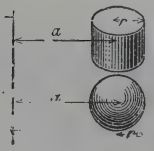
Convex surface.
$x = 0{\cdot}8165r.$

Solid.
$x = 0{\cdot}6324r.$

r = radius.

FIG. 227.

FIG. 229.



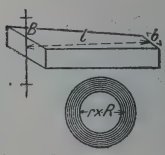
Cylinder.

$x = \sqrt{a^2 + \frac{1}{2}r^2},$

Sphere.

$x = \sqrt{a^2 + \frac{2}{5}r^2}.$

FIG. 228.



Wedge.

$x = 0{\cdot}204\sqrt{12l^2 + B^2 + b^2}.$

Ring.

$x = \sqrt{\frac{R^2 + r^2}{2}}.$

FIG. 230.

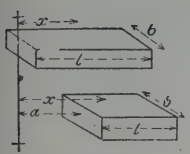


FIG. 231.

Parallelopiped.

$$x = \sqrt{\frac{4l^2 + b^2}{12}}.$$

$$x = \sqrt{\frac{4l^2 + b^2}{12} + a^2 + al}.$$

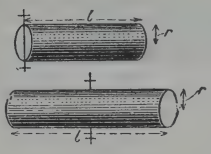


FIG. 232.

Cylinder.

$$x = \sqrt{\frac{4l^2 + 3r^2}{12}}.$$

$$x = \sqrt{\frac{l^2 + 3r^2}{12}}.$$

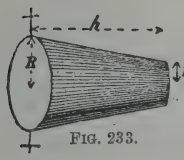


FIG. 233.

Conic Frustum.

$$x = \sqrt{\frac{h}{10}\left(\frac{R^2 + 3Rr + Rr^2}{R^2 + Rr + r^2}\right) + \frac{3}{20}\left(\frac{R^5 - r^5}{R - r^3}\right)}.$$

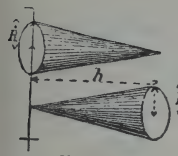


FIG. 234.

Cone.

$$x = \sqrt{\frac{2h^2 + 3R^2}{20}},$$

$$x = \sqrt{\frac{12h^2 + 3R^2}{20}}.$$

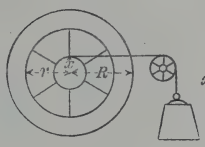


FIG. 235.

Flywheel.

$$x = \sqrt{\frac{R^2 + r^2}{2}},$$

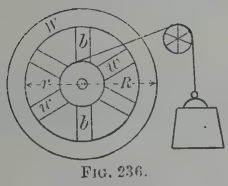


FIG. 236.

Flywheel with Arms.

$$x^2(W + w) = W\frac{R^2 + r^2}{2} + w\frac{4r^2 + b^2}{12},$$

$$= \sqrt{\frac{6W(R^2 + r^2) + w(4r^2 + b^2)}{12(W + w)}}.$$

MOMENTS OF INERTIA.

If each element of the mass of any solid body be supposed to be multiplied by the square of its perpendicular distance from a given line or axis, the sum of all these products is called the moment of inertia of the body with respect to that axis. The following Table gives the most useful cases :

M = mass of the body. I = moment of inertia.

Uniform thin rod, axis at end, length = l . . . . . $I = M\frac{l^2}{3}$.

" " " through middle, length = l . . . . . $I = M\frac{l^2}{12}$.

Rectangular lamina, axis through centre and parallel to one of sides, a and b lengths of sides, a the side bisected . . . . . $I = M\frac{a^2}{12}$.

Rectangular lamina, axis through centre and parallel to one of sides, a and b lengths of sides, b the side bisected . . . . . $I = M\frac{b^2}{12}$.

Rectangular lamina, axis through centre and perpendicular to the plane, a and b lengths of sides	$I = M\frac{a^2 + b^2}{12}$
Rectangular parallelopiped, axis through centre and perpendicular to a side, a, b, and c lengths of sides:	
1. Axis perpendicular to side contained by a and b	$I = M\frac{a^2 + b^2}{12}$.
2. " " " a " c	$I = M\frac{a^2 + c}{12}$.
3. " " " b " c	$I = M\frac{b^2 + c^2}{12}$.
Circular plate, axis through centre perpendicular to the plate, radius $= r$	$I = M\frac{r^2}{2}$.
Circular plate, axis any diameter, radius $= r$	$I = M\frac{r^2}{4}$.
Circular ring of round material, axis through centre perpendicular to plane of ring, outer radius $= R$, inner radius $= r$	$I = M\frac{7R^2 + 2Rr + 7r^2}{16}$
Circular ring of round material, axis any diameter	$I = M\frac{9R^2 - 2Rr + 9r^2}{32}$
Circular ring of flat material (washer), axis through centre perpendicular to plate of ring, outer radius $= R$, inner radius $= r$	$I = M\frac{R^2 + r^2}{2}$.
Right cylinder, axis the axis of figure, $r =$ radius of section	$I = M\frac{r^2}{2}$.
Right cylinder, axis through centre perpendicular to axis of cylinder of length, l	$I = M\left(\frac{l^2}{12} + \frac{r^2}{4}\right)$.
Hollow cylinder, axis the axis of figure, outer radius $= R$, inner radius $= r$	$I = M\frac{R^2 + r^2}{2}$
Right cone, axis the axis of figure, $r =$ radius of base	$I = \frac{3}{10}Mr^2$.
Sphere, axis any diameter, $r =$ radius	$I = \frac{2}{5}Mr^2$.

ENERGY OF A ROTATING BODY.

The energy of a rotating body $= \frac{1}{2}\omega^2 I$, ω being the angular velocity, and I the moment of inertia.

BALLISTIC PENDULUM.

W = weight of pendulum. P = weight of a shot fired into W. V = velocity of shot. θ = angle through which pendulum moves. n = number of vibrations per minute pendulum makes. a = distance from centre of suspension of point at which shot enters block. h = distance of centre of gravity of pendulum weight with shot in it from centre of suspension. g = coefficient of terrestrial acceleration = 32·2. $\pi = 3{\cdot}1416$.

$$V = \frac{W + P}{P} \cdot \frac{120g \sin \frac{\theta^\circ}{2}}{\pi n} \cdot \frac{h}{a}$$

BRAKES FOR POWER MEASUREMENT.

Hirn's Rope Brake.

A convenient form of brake for power measurement is one consisting of a band of rope enveloping the fly-wheel of the engine being measured.

Fig. 237 (p. 147) represents the rope brake as arranged by Mr. B. H. Thwaite for the purpose. It consists of a band of rope carrying five wood blocks, with side flanges to hold the brake on the wheel. Each end of the rope is attached to a spring balance.

The net pull upon the wheel rim is the difference of the two spring balance readings, and the power developed by the engine is

$$(W - w) \times D\ \pi \times N \div 33{,}000 = \text{B.H.P.},$$

where,

W = reading of the large balance or the pull in lbs.; w = reading of the small balance or the pull in lbs.; D = diameter in ft. of the rim on which the brake lies; N = revolutions per minute; B.H.P. = brake horse-power; $\pi = 3{\cdot}1416$.

The results of the formula are slightly below the actual power, owing to the brake belt not being absolutely flexible. French engineers measure D at the centre of the rope thickness, an error perhaps slightly in the other direction.

For the large spring balance a weight may be substituted.

A rope brake never sticks, nor does it ever suddenly lose its grip.

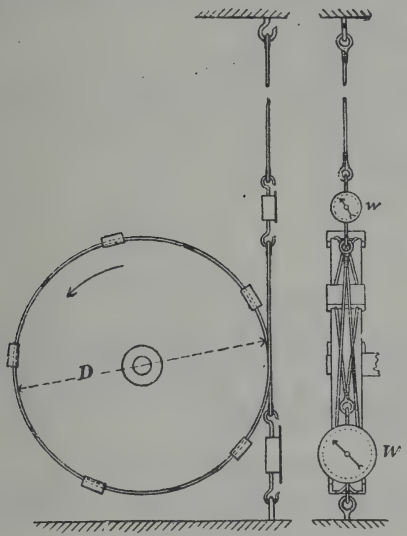


FIG. 237

The Prony Brake.

This form of brake is useful for small power measurements. In its simple form, fig. 238, it consists of a couple of wooden blocks clipped upon the pulley or shaft transmitting the power

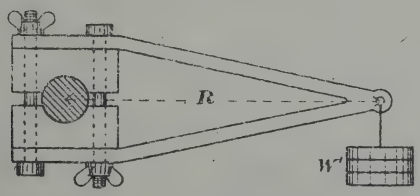


FIG. 238

to be indicated. Attached to the blocks is a lever, to which is hung a scale pan or a spring balance. The diameter D in the formula for Thwaite's brake is, in the case of the Prony brake, double the radius R measured to the point of suspension of the pan, and $W - w$ is the weight W'.

The difficulty with the Prony Brake is the constant vibration of the weighted arm. The difficulty has been reduced at Purdue University by the addition of a pendulum lever weight, B, fig. 239 (p. 148), the quadrant of which may be divided by actual weight determination.

Fig. 239A shows a form of stabiliser * which, it is stated, will damp down the vibrations to a very marked extent. Between the balance and the brake arm are placed in series a heavy weight A and a resilient coil spring B. The pointer of the balance is then set back to offset the

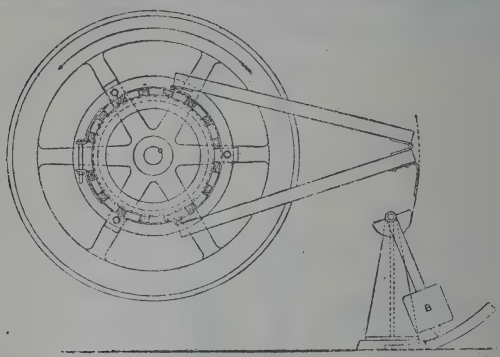


FIG. 239.

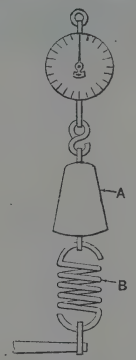


FIG. 239A.

nitial force, or tare, exerted by the weight. When the motor being tested is in motion, the average torque is transmitted through the spring and suspended weight, and is accurately indicated on the dial of the balance. The momentary vibrations, however, are not of sufficient duration to move the weight, and their motion is dissipated by the auxiliary spring. By employing this type of stabiliser, an oil dashpot may be dispensed with entirely, and readings of a high degree of accuracy may be obtained.

Ringelmann's Brake.

In the brake of M. Ringelmann (fig. 240) the brake band is a strap of iron, on which, by a hook, *C*, is suspended a weight, *Q*. If the wheel runs faster and lifts the weight, the hook travels

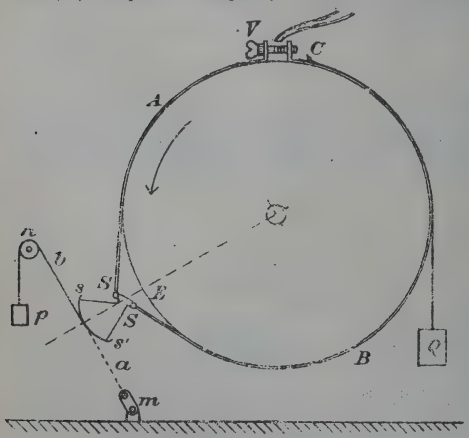


FIG. 240.

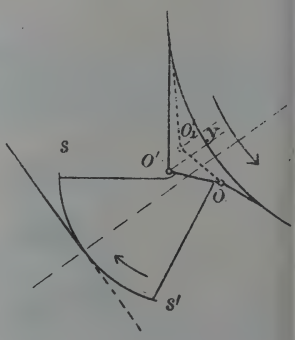


FIG. 241.

in the direction of the arrow, and *vice versa*. The brake is in two halves, *A* and *B*, joined by a tightening screw at *V*, and by a peculiar joint at *E*, shown enlarged in fig. 241. The sector, *S S*, which carries the ends of the brake straps, is held by a pair of cords, *mas* and

* J. W. R., *Machinery*, June 7, 1923.

s bnp, the first fixed to a regulating roller *m*, attached to the floor; the second to a small weight, *p*, over a pulley, *n*. The mean position of the sector is as shown, the cords *b* and *a* being in one straight line. If in the course of a test the brake is pulled round the point *O* (fig. 241) is lowered, the sector rolls on the cord, and the point *O'* comes to O'_1, lengthening the brake strap by the amount *y*. Soap and water is kept flowing on at the point *V*. The tension of the brake is thus maintained to a constant power, and the lubrication is also constant, so that the motor is compelled to exercise a constant power. This brake was used for the testing of small motors at Meaux by M. Ringelmann in 1894.

Water-pipe Absorption Dynamometer.

In place of ropes the encircling band may be made of flexible water-pipes, the rim being of wood. Water is circulated through the pipes to keep them cool. Each band of $\frac{3}{8}$ in. iron pipe on

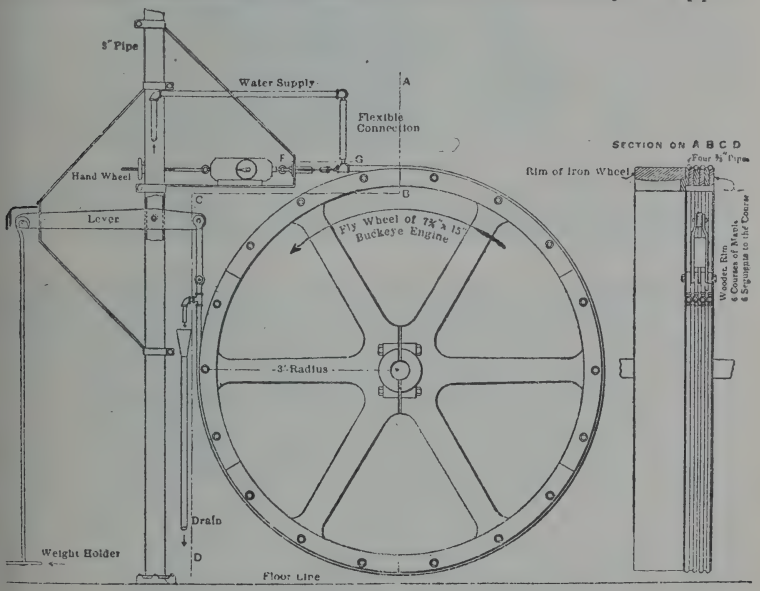


FIG. 242

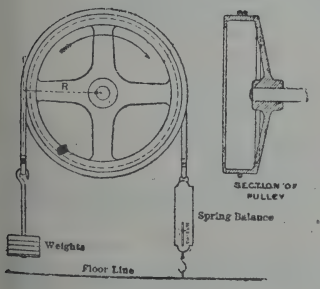


FIG. 243.

a 6 ft. wooden rim will absorb 10 horse-power at 150 revolutions. Fig. 242, as used at Purdue University, shows a brake of this description.

Cooling Brake Rims.

In many cases the inside of a brake rim is of trough form (fig. 243), which will hold water when revolving, by virtue of the centrifugal action. The trough being filled with water is kept to (at most) 212° F. by the evaporation of the water, which is kept constantly running into the rim in a small stream.

Another means of cooling is to encircle a sheet-steel brake band with iron wire netting, which holds by capilliary action water poured on it; this evaporates and cools the strap. Surplus water runs off at the bottom of the band.

The Alden Brake.

This brake consists, for 200 horse-power, of a 56-inch disc of cast iron revolving between two plates of copper, containing cylinder oil, which is circulated from the circumference towards the centre. Outside the copper plates water circulates at about 15 lbs. pressure, and serves both to cool the plates and maintain contact pressure on the moving disc. By circulating more water the brake resistance may be sensibly increased through the diminished viscosity of the oil, and *vice versâ*. This brake is said to run for hours at great constancy, and to be nearly perfect in its action.

The Brotherhood Fluid Friction Dynamometer.

This arrangement (*Peter Brotherhood, Ltd., Peterborough*) is specially suitable for high and moderate speed testing. All power given to the machine is recorded accurately: no losses in shaft bearings, etc., have to be allowed for, as the friction of bearings is measured by the dynamometer and included in the readings; no calibration is required. Calculations involve simple multiplication only from the direct readings of a spring balance or weighing machine; no clutch is required. Motors under test may be started up with the brake set for full loads, the torque at the lowest speeds being extremely small and rising rapidly as the normal speed is reached. The resistance rises very rapidly with increase of speed and also diminishes rapidly with decrease in speed, so that the brake is self-governing, and any sudden increase in friction is impossible. The machine is extremely accurate, the only power not recorded being the infinitesimal friction between the casing and its supporting roller bearings. The casing rests freely on the rollers, and motion at the supports only occurs when the load is changing, and is then very small, so that no measurable energy is absorbed. The constants may be verified by use of a rule and standard weights only, the only factors being the distance from the shaft centre to the point of application of the spring balance, and the readings of the spring balance which may be directly tested by deadweights. This feature enables the user to check the readings immediately before and after each test if desired.

The principle employed is that of the frictional resistance between fluids and rotating plates. Several perforated annular plates are secured to the casing of the brake, and between each pair a disc rotates with the shaft. The rotating discs run near the fixed plates, but do not touch them. On the introduction of water or other fluid into the casing, friction is set up between the fluid and the plates. The moment of the frictional resistance between the fluid and the fixed plates is measured by means of a spring balance acting at a convenient radius, the casing being free to rotate within limits on trunnions and anti-friction rollers. A platform weighing machine may be substituted for the spring balance if preferred. The energy delivered to the dynamometer is transformed by fluid friction into heat which is absorbed by the fluid; as no solid friction occurs, unequal heating and seizing of surface cannot arise. The quantity of water flowing through the dynamometer need be only sufficient to absorb the power and keep the temperature down to the desired limits. For example, when absorbing 100 b.h.p., assuming that the temperature of the water supply is 60° F., and that the water is raised to 160° F. before leaving the casing, about 5 gallons per minute would be sufficient. This water enters and leaves the casing quietly—no water is splashed about. The load on the motor at any desired speed can be quickly and smoothly adjusted by varying the amount in the casing; any desired quantity of water may be retained, and therefore any load may be steadily maintained, although water is flowing through continuously. For short tests sufficient water may be placed in the casing, and no continuous flow provided. This feature is of great use in comparing and calibrating motors, engines, etc. With these dynamometers a constant and definite torque resistance will always be obtained at any given speed and with a definite quantity of water in the casing. It is thus easy to adjust the machine to give a predetermined load curve. This feature has been found of great value in testing engines for marine propulsion, the dynamometer resistance varying with speed proportionally in precisely the same way as the speed and power of a marine propeller varies.

The Froude Water Dynamometer.

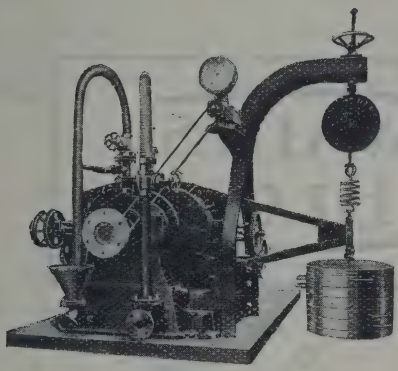
This dynamometer (*Heenan & Froude, Ltd., Worcester*), is made in the following types, viz.:

1. *Type D.P.X.*, in small and medium sizes for dealing with high-speed prime movers, including internal combustion engines for motor cars and aeroplanes.

2. *Types S. and F.*, in medium and large sizes, for dealing with slow-speed prime movers, such as land and marine Diesel, oil, gas, and steam engines, also with medium and slow-speed and hydraulic turbines.

Fig. 244 shows a cross-sectional drawing through the D.P.X. type 'Froude' dynamometer.

The engine is directly coupled to the main shaft, transmitting the power to a rotor revolving inside a casing, through which water is circulated to provide the hydraulic resistance and simultaneously to carry away the heat developed by destruction of power.



Three Dynamometers

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HEENAN-FELL *Patent*
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Works: BARNET.

In each face of the rotor are formed pockets of semi-elliptical cross-section divided one from another by means of oblique vanes. The internal faces of the casing are also pocketed in the same way.

When in action, the rotor discharges water at high speed from its periphery into the casing pockets, by which it is then returned at diminished speed into the rotor pockets at a point near the shaft. Thus, the pockets in rotor and casing together form elliptical receptacles round which the water courses at high speed, creating vortices which destroy the power of the engine as quickly as it is developed.

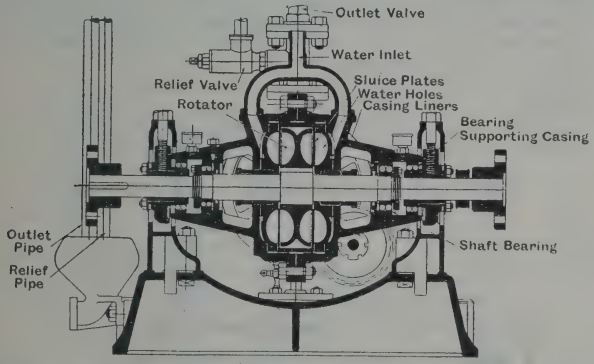
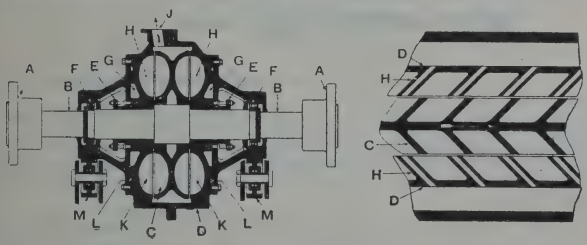


FIG. 244.

Between the faces of the rotor and the casing are interposed thin metal plates or sluices capable of sliding radially towards or away from the shaft. By rotating an external handwheel these sluices can be caused to mask or uncover more or less of the power-absorbing cups, and in this way to regulate the load exerted by the dynamometer.

In this type of dynamometer under running conditions the pockets should remain always full of water, which enters through holes in the casing to a point near the centre of each vortex where



A...Couplings
B...Shaft
C...Rotor
D...Casing
E...Gland
F...Bearing
G...Water Inlet Channel
H...Water Holes
J...Water Outlet
K...Air Holes
L...Air Channel
M...Casing Trunnions

IG. 245.—Sectional Elevation through Casing of Single Rotor Non-Reversible Dynamometer showing Section through Vanes.

e pressure is low. After being heated by the destruction of power, the water passes to waste rough an outlet valve, which in practice is regulated to give to the water a temperature of about 10° F.

All 'Froude' dynamometers have casings supported upon anti-friction trunnions and free to vivel about the axis of the shaft. The shaft is mounted upon bearings fitted into the casing and ot in independent supports. The piping conveying water to and away from the casing is flexible, nd precautions are taken to prevent external forces from resisting the free swivelling motion of he casing. When a turning moment is applied to the shaft, any resistance created by the dyna-ometer, whether by hydraulic or solid friction, must of necessity react upon the casing, which nds to swivel upon its supports. In the 'Froude' dynamometer this tendency is resisted solely

by a weighing machine, which correctly indicates the magnitude of the torque. *This arrangement ensures scientific accuracy.*

The form of weighing apparatus varies somewhat. In the D.P.X. type dynamometer it consists of an arm directly attached to the casing, and connected through pin joints to a spring balance upon which dead weights are suspended so as to put the springs of the balance into tension. When the dynamometer is at rest, uncoupled from the engine, and the arm is in a horizontal position, the pointer indicates zero. The dial is graduated so as to give a direct reading of the lifting force exerted by the end of the lever arm when at work.

Fig. 245 shows a cross-sectional drawing through the 'Froude' dynamometer types S. and F. The power-absorbing pockets and vanes are generally similar in shape to those incorporated in the D.P.X. type, but the vanes in the casing are drilled with air holes in addition to water

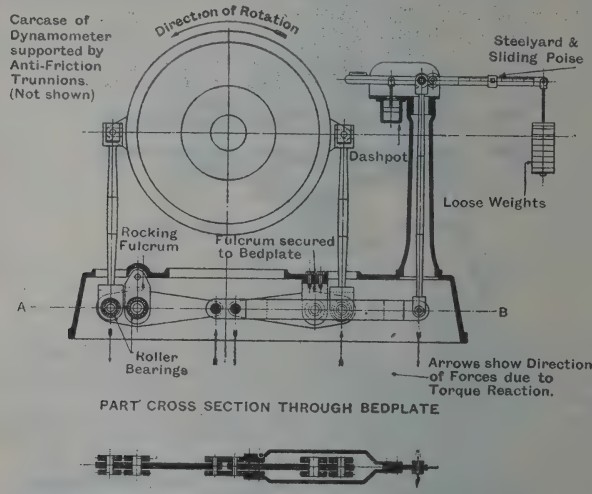


FIG. 246.—Arrangement of Torque Meter for Froude Dynamometer.

holes. No sluice plates are interposed between rotor and casing, but the load is regulated by varying the volume of water contained by the power-absorbing pockets.

The shape of the pockets is such as to create the formation of eddies in exactly the same manner as previously described, but in the case of the S. and F. type dynamometers the pockets do not always remain full of water, and the vortices which they contain are free to cavitate under the action of centrifugal forces.

When working full of water they exert maximum resistance to rotation; when nearly empty, each pocket contains a vortex, consisting merely of a thin film of water coursing around the periphery of the pocket, and resistance to rotation is small. The partial closing of the outlet valve fixed upon the casing increases both the volume of water in the pockets and the load, and *vice versâ*.

The dynamometer carcase carries a special centrifugal pump (not shown in the above figure) positively driven from dynamometer shaft, controlling the rate of flow of water to the power absorbing cups. This gives the dynamometer automatic self-governing properties, such that should the speed of the dynamometer (and therefore of the pump) become slightly higher, the dynamometer load will increase in a higher proportion, owing to the augmented rate of water supply which increases the volume of water in the cups. The contrary effect takes place upon a decrease in speed, and this patented feature is of great assistance in keeping steady the speed of the engine upon test and minimising 'hunting,' often caused previously by the usual slight fluctuations of engine output.

The pump is fitted with a fine-adjustment valve which is used in conjunction with the outlet valve for control of load and speed. The whole of the power absorbed by pump and drive is correctly indicated by the weighing apparatus, so that no errors in B.H.P. readings result on this account.

In the new 'S' type of dynamometer, the reaction is balanced by coupling up the measuring apparatus to two diametrically opposed points on the periphery of the casing, as seen in fig. 246. This shows a diagrammatic arrangement of Heenan & Froude's new Torque Meter. The casing is coupled up at the two points through stout rods having articulated joints, to a system of levers

ixed in the underlying baseplate. When the direction of rotation is counter-clockwise, as shown. he right-hand connecting rod transmits a vertically upward force upon the short arm of main ever B; the left-hand connecting rod pushes downwardly upon main lever A; and he long arms of this pair of levers are connected together by the short arm of a third lever, the ong end of which pulls down upon a steelyard type of weighing machine. The direction of the orces due to torque is shown by the arrows. This system of levers is equivalent to a lever arm ixed on the dynamometer casing, and having an effective length 600 times as great as the radius rom axis of dynamometer to one of the points where the connecting rods are attached to the asing. The torque can thus be measured by a number of very small weights and a steelyard, nstead of by enormously heavier weights.

The Fan Dynamometer.

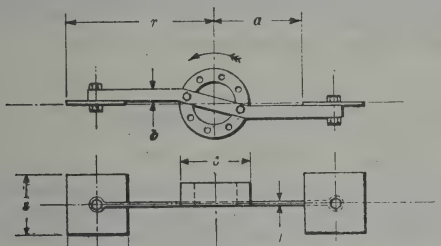


FIG. 247.

If

w = torque driving the fan in inch-lbs.;

wb = resisting torque due to the blades alone;

wa = ,, ,, ,, arms ,,

N = revs. per min. of the fan;

s = length of side of square blades or diameter of round blades in inches; r, a, b, t, and c are other dimensions in inches;

W = density of the fluid in which the fan rotates, in lbs. per cubic foot,

$$= 62{\cdot}33 \text{ for water at } 50^\circ \text{ F.} = \frac{1{\cdot}317 \times \text{barometric pressure in in., for air}}{(460 + \text{temp. in } ^\circ \text{F.})};$$

H.P. = horse-power absorbed by fan;

K = a coefficient depending upon the value of r/s and upon the shape of the blade; see values tabulated below for square and circular blades having square edges.

Values of r/s . . .	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5	9·0	12·0
$K \times 10^{-8}$ for circular blades	1·69	1·69	1·66	1·63	1·60	1·59	1·58	1·575	1·575	1·575	1·575
$K \times 10^{-8}$ for square blades	2·25	2·28	2·24	2·18	2·16	2·12	2·10	2·08	2·04	2·04	2·04

σ = a coefficient depending upon the ratio b/t.

Values of b/t . .	2	3	6
Values of σ . . .	1·3	0·94	0·62

then,

$$wa = 0{\cdot}35 \times 10^{-8} \sigma N^2 a^4 t W; \quad wb = KN^2 r^3 s^2 W; \quad w = wa + wb^*; \quad \text{H.P.} = wN/63{,}000.$$

* For this relation to hold, t must be less than $\frac{s}{7}$.

Notes on the Fan Dynamometer.

Care should be taken that the arms and fastenings are amply strong enough to withstand the centrifugal stresses. For reasonably accurate work, with fans rotating in air, one side of the fan should be completely free from obstruction for a distance of at least '3 *r*' inches from the plane of rotation, and on the other side 'C' should not exceed '*a*.' Also the floor should be distant at least '*r*' inches. The linear velocity of the centre of the blades must not exceed, say, 350 ft. per second. In order to compute W with accuracy, the barometric pressure, and the temperature of the air at the periphery of the fan should be taken. Fans rotating in water must have at least as much clearance around them as is specified above, and must not be rotated at such a speed as to produce cavitation. To facilitate work in the test-shop the 'H.P., Rev.' curves for each blade used should be plotted on logarithmic paper for some standard value of W. Since the H.P. varies approximately as N^3, N should be observed with great accuracy—a speedometer is usually not sufficiently accurate.

See also Hodgson, *Proc. Inst. Automobile Engineers*, March 1916.

(*J. L. Hodgson.*)

The Torsion Meter.

(*Hopkinson-Thring Patent.*)

The Hopkinson-Thring Torsion Meter has been designed for determining the power transmitted by turbine and other shafts. It requires only a very short length of shaft, is extremely compact and strong, and it gives a direct reading of the torsion on the shaft. The zero point of the apparatus can readily be ascertained by barring the shaft. The instrument offers also a simple means of determining the friction of the shafts themselves.

The principle of the apparatus consists in the observation of the twist between two adjacent points on the shaft by means of two beams of light projected on to a scale from a fixed and a movable mirror.

A diagrammatic arrangement of the complete apparatus is shown in end elevation and plan in fig. 248. A collar R, clamped to the shaft of which the torque has to be measured, is provided with a flange projecting at right angles to the shaft and an extension. A sleeve T, provided with a similar flange and extension at one end, is clamped at its further end on to the shaft in such a manner that its flange is close to that on the collar R, whilst its extension overlaps that of the collar R, on which it is supported to keep it concentric. Both the collar and sleeve are quite rigid, so that when the shaft is twisted by the transmission of power the flange on the sleeve T will move relatively to that on the collar R, the movement being equal to that between the two parts of the shaft on which these fittings are clamped. This movement is made visible by one or more systems of torque mirrors mounted between the two flanges, which reflect a beam of light, projected from a lamp, on to a scale divided in a suitable manner on ground glass.

Each system of torque mirrors consists of a mounting, pivoted top and bottom on one or other of the flanges, in which two mirrors are arranged back to back. This mounting is provided with an arm, the end of which is connected by a flat spring to an adjustable stop on the other flange. Any relative movement of the two flanges will turn the torque mirror and thereby cause the beam of light to move on the scale, the deflection produced being directly proportional to the torque applied to the shaft. Hence, if the rigidity of the material and the number of revolutions per minute are known, the h.p. transmitted can be arrived at immediately.

With the arrangement described, a reflection will be received from each mirror at every half revolution of the shaft; but where the torque varies during a revolution (as with reciprocating engines), a second system of mirrors may be arranged at right angles to the first system, so that four readings can be taken during one revolution; or, if two scales are used, eight readings can be taken.

Fig. 249 shows how the beam of light reflected by the mirror when in its highest position passes through the upper part of the scale; while the second reflection will occur when the mirror is in the position occupied by the zero mirror, the beam of light passing through the lower part of the scale. The position of the torque mirror in fig. 249 is such that if the reflected beam strikes the scale to the right of the zero line, when the shaft has made a further half revolution, the reflected beam from the other mirror will strike the scale to the left of the zero line.

The fixed mirror is attached to one of the flanges (in fig. 248 to the flange of the sleeve T). This must be adjusted so that the beam of light reflected from it is received at the same point on the scale as those from the movable mirrors when there is no torque on the shaft. To facilitate the erection and adjustment of the apparatus, the box containing the scale and carrying the lamp is fitted with trunnions, so that it can be inclined as required.

HOPKINSON-THRING TORSION METER.

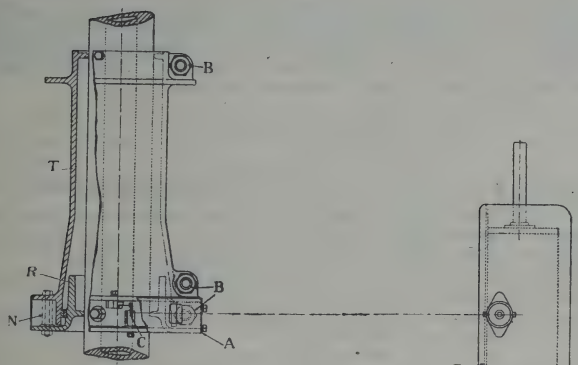


FIG. 248.

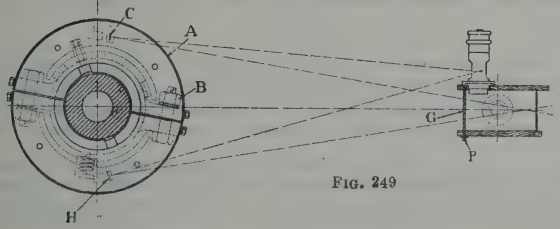
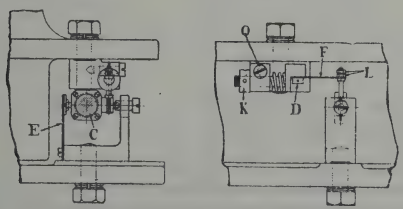


FIG. 249



If the position of the apparatus on the shaft becomes altered relatively to the scale, owing to the warming up of the shaft or from other causes, this is indicated immediately to the observer by an alteration in the position of the zero as reflected by the fixed mirror. Hence the scale zero may be adjusted, if desired, by moving the scale so that its zero coincides with the reflection from the fixed mirror, but this is not necessary to obtain a correct result, since the mean of the two readings will be the same. It will readily be understood that, as a movement of the torque mirrors can only occur through a relative movement of the two flanges, the vibration of the shaft or of the ship will not influence the readings in any way.

The apparatus is made in seven standard sizes, to fit shafts from 1 up to 21 inches in diameter, the overall length of the meters being 13½ to 58½ inches. All sizes have been in practical operation for a considerable time, with entirely satisfactory results, in warships and other turbine-driven steamers, running at speeds up to 1,500 revolutions per minute. The smaller sizes of the instrument are designed to run up to 3,000 revolutions per minute.

ANIMAL POWER.

MEN.

The mean effect of the power of a man, unaided by a machine, working to the best practicable advantage, is the raising of 70 lbs., 1 foot in a second, for 10 hours in a day.

Two men, working at a windlass with the handles at right angles to each other, can raise 70 lbs. more easily than one man can 30 lbs.

A man of ordinary strength exerts a force of 30 lbs., for 10 hours in a day, with a velocity of 2½ feet per second = 4,500 lbs. raised 1 foot in a minute = ·2 of the work of a horse.

A man can travel, without a load, on level ground, during 8½ hours a day, at the rate of 3·7 miles an hour, or 31½ miles a day. He can carry 111 lbs. 11 miles in a day.

A porter going short distances, and returning unloaded, can carry 135 lbs. 7 miles a day. He can transport, in a wheelbarrow, 150 lbs. 10 miles in a day.

Weight of Crowds.

Experiments carried out by Professor L. J. Johnson, of Harvard University, show that it is possible for this to reach the high figure of 181·3 lbs. per square foot of floor surface. If the crowd jumps, the apparent load may be 50 per cent. more than the steady load, and running four abreast will show a similar result. A weight of 140 lbs. per square foot is quite possible where there are throngs of people; while a load of 80 lbs. per square foot is quite common in buildings and private houses where social gatherings are frequent, and a maximum of 40 lbs. or 45 lbs. is far short of what actually does prevail.

Some experiments carried out in America show that a crowd of men pushing against a balustrade may exert a horizontal pressure of 168 lbs. per foot run when they are three deep.

HORSES.

A horse can travel 400 yards, at a walk, in 4½ minutes; at a trot, in 2 minutes; and at a gallop, in 1 minute. A draught horse can draw 1,600 lbs. 23 miles a day, weight of carriage included. The ordinary work of a horse may be stated at 22,500 lbs., raised 1 foot in a minute, for 8 hours a day. In a horse-mill a horse moves at the rate of 3 feet in a second; the diameter of the track should not be less than 25 feet. The strength of a horse is equivalent to that of 5 men.

Table of the amount of Labour a Horse of Average Strength is capable of Performing, at different Velocities, on Canals, Railroads, and Roads.

Velocity per Hour.	Duration of Work.	Useful Effect for 1 Day, drawn 1 Mile.			Velocity per Hour.	Duration of Work.	Useful Effect for 1 Day, drawn 1 Mile.		
		On a Canal.	On a Railroad.	On a Road.			On a Canal.	On a Railroad.	On a Road.
Miles.	Hours.	Tons.	Tons.	Tons.	Miles.	Hours.	Tons.	Tons.	Tons.
2½	11·5	520	115	14·0	6	2·000	30·0	48·0	6·0
3	8·0	243	92	12·0	7	1·500	19·0	41·0	5·1
4	4·5	102	72	9·0	8	1·125	12·8	36·0	4·5
5	2·9	52	57	7·2	10	0·750	6·6	28·8	3·6

A horse in a mill can produce an effect of 106 lbs., at a velocity of 3 feet in a second, for 8 hours in a day. A mule can produce, under a like velocity and time, an effect of 71 lbs.; and an ass, 37 lbs.

An ox, walking at a velocity of 2 feet in a second (1·34 miles per hour), will exert a pull of 154 lbs. for 8 hours in a day.

The draught of man and animals by traces is as follows:

Man, 150 lbs. | Horse, 600 lbs. | Mule, 500 lbs. | Ass, 360 lbs.

A man rowing a boat 1 mile in 7 minutes performs the labour, while rowing, of 6 fully-worked labourers at ordinary occupations of 10 hours.

The force of traction on a railroad or road is constant, but the mechanical power necessary to move the carriage increases as the velocity.

Labour upon Embankments.

Single Horse and Cart.—A horse with a loaded dirt-cart, employed in excavation and embankment, will make 100 lineal feet of trip, or 200 feet in distance per minute, while moving. The time lost in loading, dumping, awaiting, etc. = 4 minutes per load.

A medium labourer will load with a cart in 10 hours, the following earths, measured in the bank:

Gravelly Earth, 10; *Loam*, 12; *Sandy Earth*, 14 cubic yards.

Carts are loaded as follows: *Descending Hauling*, ¼ of a cubic yard in bank; *Level Hauling*, ⅓ of a cubic yard in bank; *Ascending Hauling*, ¼ of a cubic yard in bank.

Loosening, etc.—In *Loam*, a three-horse plough will loosen from 250 to 800 cubic yards per day of 10 hours.

WORK DONE BY MEN AND ANIMALS.

Nature of Labour.	Daily Duration of Work in Hours.	No. of Units of Work per Day.	No. of Units of Work per Min.	Weight raised or Mean Pressure.	Velocity.	
					Feet per Min.	Miles per Hour.
(1) *Raising weights vertically.*						
A man mounting a gentle incline or ladder without burden, i.e. raising his own weight	8·0	2,032,000	4,230	145	29	0·33
Labourer raising weights with rope and pulley, the rope returning without load	6·0	563,000	1,560	40	39	0·44
Labourer lifting weights by hand	6·0	531,000	1,480	44	34	0·38
Labourer carrying weights on his back up a gentle incline or up a ladder and returning unladen	6·0	406,000	1,130	145	8	0·09
Labourer wheeling materials in a barrow up an incline of 1 in 12 and returning with the empty barrow	10·0	313,000	520	130	4	0·045
Labourer lifting earth with a spade to a mean height of 5½ ft.	10·0	281,000	470	6	78	0·9
(2) *Action on Machines.*						
Labourer walking and pushing or pulling horizontally	8·0	1,500,000	3,130	27	116	1·32
Labourer turning a winch	8·0	1,250,000	2,600	18	144	1·64
Labourer pulling and pushing alternately in a vertical direction	8·0	1,146,000	2,390	11	216	2·70
Horse yoked to a cart and walking	10·0	15,688,000	26,150	150	175	2·00
Do. to a whim gin	8·0	8,440,000	17,600	100	175	2·00
Do. do. trotting	4·5	7,036,000	26,060	66⅔	391	4·44
Ox yoked to a whim gin and walking	8·0	8,127,000	16,930	145	117	1·33
Mule do. do.	8·0	5,627,000	11,720	66⅔	176	2·00
Ass do. do.	8·0	2,417,000	5,030	30	168	1·95

The following table gives the useful effect of men and animals employed in the horizontal transport of burdens. The second and third columns give the useful effect, viz. the product of the weight in lbs. and the distance in feet. This must not be mistaken for the units of work done by the agent, the agent being employed *not* in raising the weight, but in overcoming the passive resistances, friction, etc., which depend on the weight indeed, but are only a fraction of it.

USEFUL EFFECT OF AGENTS EMPLOYED IN THE HORIZONTAL TRANSPORT OF BURDENS.

Agent.	Daily Duration of Work in Hours.	Useful Effect Daily.	Useful Effect per Minute.	Weight transported.*	Velocity.	
					Feet per Min.	Miles per Hr.
Man walking on a horizontal road without burden, i.e. transporting his own weight . .	10·0	25,398,000	42,330	145	292	3·32
Labourer transporting materials in a truck on two wheels, returning with it empty for a new load	10·0	13,025,000	21,710	220	99	1·12
Do. in a wheelbarrow . .	10·0	7,815,000	13,030	130	160	1·14
Labourer walking with a weight on his back	7·0	5,470,000	13,030	90	145	1·64
Labourer transporting materials on his back and returning unburdened for a new load .	6·0	5,087,000	14,110	145	97	1·10
Do. on a handbarrow . .	10·0	4,298,000	7,160	110	65	0·74
Horse transporting materials in a cart, walking, always laden .	10·0	200,582,000	334,300	1,500	223	2·53
Do. trotting	4·5	90,262,000	334,300	750	44	5·06
Do. transporting materials in a cart returning with the cart empty for a new load . .	10·0	109,408,000	182,350	1,500	121	1·38
Horse walking with a weight on his back	10·0	34,385,000	57,310	270	212	2·41
Do. trotting	7·0	32,092,000	76,410	180	424	4·82

* Exclusive of the weight of the barrow, truck, cart, etc.

In advocating the employment of mechanical tractors on the farm, *Modern Farming* sta that the horse eats annually the product of five acres. According to Edison, the efficiency the horse is about 2 per cent.

NOTES ON MAN POWER.

(*R. T. Hancock.*)

The amount of foot-lbs. of energy which a man engaged on heavy labour can exert duri a working day is entirely bound up with fatigue and opportunity for recovery from fatig and is a question of physiology rather than of dynamics. The number of hours constituti a working day and the opportunities given during the working day for at least part replacement of the waste of the muscle tissues are the governing factors. All forms of hum energy, physical or mental, are similarly conditioned. All unnecessary motions or distracti produce fatigue just as much as if they formed part of the useful work done, and correspo ingly reduce the useful work possible. The basis of the subject is fully treated by Taylor i his 'Principles of Scientific Management.' Instances are given of the great increase in wo possible by careful attention to length of working day, provision of short periods for r fixing the actual percentage of the working day during which the labourer can remain un load, the optimum load, and the planning of the work to enable it to be done with the minim of motions. The performance of labourers loading pig-iron from the ground into railro

cars an average distance of 36 ft. away was raised from 12½ to 47½ tons per man per day; of labourers shovelling iron-ore from cars, from 16 to 59 tons per day; and the number of bricks laid by a bricklayer, from 120 to 350 per hour.

The average labourer is not only incapable of planning his work so as to effect it with the least waste of energy, but many of the conditions affecting its amount are not under his control, but that of the management. The intelligence of the labourer of course plays no small part, but it is the function of scientific management, according to Taylor, to train each individual to follow the routine which the management has evolved as tending to maximum production for a given expenditure of energy. The expenditure of energy by the labourer, or the amount of fatigue involved, being much the same as where no system is followed, the increased production benefits chiefly the employer who has made this state of things possible, and the extra pay which the labourer may receive bears only a small proportion to the extra useful work he accomplishes. Even in highly skilled and specialised trades the improvement in output following on the adoption of scientific systems of work-planning is very great, but its principal field would appear to lie in the improvement of the performance of the lowest and most unintelligent class of labour. As instancing the differences which already exist due solely to the class of labour employed, Hoover ('Principles of Mining') considers that in the simplest forms of mining work, such as shovelling or tramming, one white labourer equals two to three members of the coloured races, and in the more highly skilled branches such as mechanics, the proportion rises to 1 to 7, or even 1 to 11. As under the principles laid down by Taylor the labourer eventually ceases to use any initiative of his own but becomes practically an automaton, it would appear possible to train the lowest type of labour so that they could eventually replace on an equal footing men whose higher attributes fit them for a better class of work.

COSTS AND CAPACITIES OF VARIOUS METHODS OF TRANSPORT.

ansport Unit.	Load.	Total Daily Mileage Capacity.	Total Daily Mileage Laden.	Capacity in Ton-Miles a Day.	Charges per Ton-Mile.	Gross Daily Takings.
ters . .	60 lb.	15	Assumed always laden	0·4	5*s.* to 1*s.* 6*d.*	2*s.* to 7*d.*
k animals .	200 to 400 lb.	24	12 to 18	1 to 3	5*s* to 2*s.*	5*s.* to 6*s.*
mal-drawn ehicles	1 to 5 tons	16	8 to 12	8 to 60	1*s.* 6*d.* to 9*d.*	12*s.* to 2*l.* 5*s.*
hanical pneu-atic-tyred heeled vehicles	½ to 1 ton	80	40 to 60	20 to 60	2*s.* 6*d.* to 1*s.* 6*d.*	2*l.* 10*s.* to 4*l* 10*s.*
adless vehicles	1 to 2 tons	70	35 to 50	35 to 100	1*s.* 6*d.* to 1*s.*	2*l.* 12*s.* 6*d.* to 5*l.*
adless vehicles	2 to 5 tons	60	30 to 45	60 to 225	1*s.* to 8*d.*	3*l.* to 7*l.* 10*s.*
adless vehicles	5 to 20 tons	60 to 40	30	150 to 600	8*d.* to 4*d.*	5*l.* to 10*l.*
adless vehicles	20 to 200 tons	40 to 32	20 to 24	400 to 4,800	4*d.* to 2*d.*	6*l.* 13*s.* 4*d.* to 40*l.*
erial railway oods trains	200 to 500 tons	150 to 300	75 to 225	15,000 to 112,500	2*d.* to 1*d.*	125*l.* to 468*l.* 15*s.*

NOTE.—The column of total daily mileage is based on no-return loads as a minimum up to half-return loads as a maximum.

Philip Johnson; paper read at a Joint Meeting of Section G (Engineering) and Section F (Economics) at the Southampton Meeting of the British Association, August 31, 1925.

SECTION III

PART I

SURVEYING—SURVEYING INSTRUMENTS—ASTRONOMY—ASTRONOMY IN FIELDWORK (pp. 163–196)

(With contributions by R. T. Hancock, Assoc.Inst.M.M., Reginald Ryves, A.M.I.C.E., Fred. Simpson, A.M.I.C.E., and others.)

PART II

DRAWING (pp. 197–206)

(H. A. Miles)

SECTION III

PART I

SURVEYING.

Chaining.

Chains.—The surveying chain is 22 yards = 66 feet long. It consists of 100 links, and each link = 7·92 inches. This chain is known as 'Gunter's' chain.

Another chain is known as the '100-foot' chain, and consists of 100 links, each 1 foot long. It is used almost exclusively for work done abroad.

A third form is the 'Decimetre' chain; this is divided into 100 links, each of which measures a decimetre = ·328 foot.

Chain Measurement.—The most careful measurement that can be made with the common surveying chain is liable to an error of $\frac{1}{3000}$ of the distance measured, and an ordinary measurement across fields, &c., to an error of $\frac{1}{100}$.

Chain measurement alone will not suffice for a greater extent than a square mile on a scale of 6 inches to a mile; or than $\frac{1}{6}$ square mile on a scale of 20 inches to a mile.

Arrows.—With each chain 10 arrows or pins of strong wire about $1\frac{1}{2}$ feet long, and preferably having a piece of red cloth tied to the ring of each, are carried.

Ranging.

Poles and Ranging Rods.—The former are poles of red pine about 15 feet high, 2 inches thick at the bottom and $\frac{3}{4}$ inch at the top; each should be shod with an iron shoe. The ranging rods are about 6 feet high, and have a white and red flag about 9 inches square at the top.

Offset Staff.—A narrow slip of deal about $1\frac{1}{2}$ inches wide, 1 inch thick, and 10 links long, divided into links. It is used for the purpose of measuring small distances from the line to hedges, &c.

The statute acre in England consists of 10 square chains, that is, of 10 square blocks of land whose length and breadth are 1 chain each; or, taking 10 blocks as one whole block, then an acre is equal to the area of a rectangle whose base is 10 chains and perpendicular 1 chain; or to any other rectangle, the product of whose base and perpendicular also equals 10 chains: thus, 4 chains base with $2\frac{1}{2}$ chains perpendicular, and 2 chains base with 5 chains perpendicular, are each equal to 1 acre.

With any quantity less than 1 chain, to bring feet into links add $\frac{1}{2}$ more; to bring links into feet take $\frac{1}{2}$ less.

MENSURATION.

To find the Area of a Triangle when the Base and Perpendicular Height are given.—Multiply the base by half the height, or *vice versâ*.

To find the Area of a Triangle when the Three Sides are given.—Take half the sum of the sides, subtract each side severally from this sum, then multiply this and the three remainders together, and take the square root for the area.

To find the Area of a Rectangular Figure.—Multiply the length by the breadth; the product will be the area.

To find the Area of a Trapezoid.—Multiply half the sum of the two parallel sides by the distance between them.

To find the Area of a Parallelogram whose Angles are not Right Angles.—Multiply the length of any one of the sides by the perpendicular let fall on it from the angle opposite that side.

To find the Area of a Trapezium.—Divide the trapezium into two triangles, and find the areas of the latter by the first rule.

To find the Area of an Irregular Polygon.—Divide the polygon into trapeziums and triangles, and find the sum of the areas of each.

To find the Area of an Irregular Figure.—Draw the figure on fine cardboard or thin sheet-metal, cut the same carefully out, and weigh it with an accurate balance. Then this weight, compared with the weight of a piece of the cardboard or metal of a definite size—say 1 inch square—gives at once the area required.

Calculation of Areas from Co-Ordinates.

If necessary adjust the traverse so that the co-ordinates correctly close the figure.

Consider each line round the figure, not the stations.

Take the total, or reduced, departures of the stations at each end of one line, add them algebraically, and divide by two. This gives the 'middle departure' of that line.

Repeat for all the lines of the figure.

It makes no difference from what initial point the departures are reckoned, whether from one of the stations on the figure, or from another point either inside or outside the figure.

Taking each line round the figure in order—it makes no difference which way round—take the difference between the reduced latitudes of the stations at each end of the line. The result is the same as the actual amount of Northing or Southing made by that particular line.

Multiply these results for each line by the middle departure of the same line, paying attention to the algebraic sign of each factor, and add all the results together algebraically.

The result is that the area of the figure in squares of the units employed in measuring the length of the sides.

If these are feet, then

divide by 27,878,400 (Log 7·445 2678) for sq. miles: divide by 43,560 (Log 4·639 0878) for acres.

In the logarithmic computation of middle departures by latitudes, it is convenient to use the arithmetical complements of the logs given in preceding paragraph, adding all three logs, and thus avoidlng taking out differences.

The terms latitude and departure are mutally interchangeable throughout the above.

TRIANGULATION.

For large surveys a base line is accurately measured and triangles built upon it, the sides being for 6 inches scale from $\frac{3}{4}$ to $1\frac{1}{2}$ mile. Each point should, if possible, be fixed by three distances.

EXAMPLE.—AB (fig. 106) is the base line; C, D, E, F are convenient points to be fixed by triangulation.

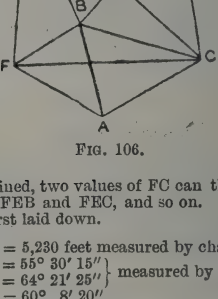


FIG. 106.

AC, AF, BF and BC being obtained, two values of FC can then be found from FBC and FAC, and then two values of FE from FEB and FEC, and so on. In plotting the triangulation the long lines EF, FC, EC should be first laid down.

AB = 5,230 feet measured by chain.
BAC = 55° 30′ 15″
CBA = 64° 21′ 25″ } measured by instrument.
BCA = 60° 8′ 20″

$$BC = \frac{AB \sin BAC}{\sin BCA}.$$

Log AB =	3·7185017
Log sin BAC =	9·9130154
	13·6345171
Log sin BCA =	9·9381368
Log BC =	3·6963803
BC =	4970

The triangles are then broken up into smaller ones and measured by the chain.

Simson's Rule for Area Computation.

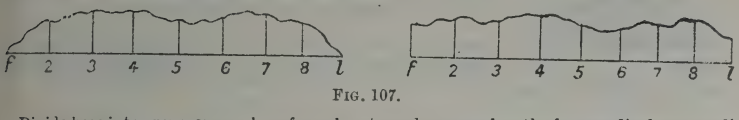


FIG. 107.

Divide base into any even number of equal parts, and measure length of perpendiculars or ordinates through each division.

If S = sum of lengths of first (f) and last (l) ordinates; E = sum of lengths of intermediate even ordinates: N = sum of lengths of intermediate odd ordinates; d = common distance between ordinates; then

$$\text{Area} = \frac{S + 4E + 2N}{3} \times d.$$

See also Weddle's Rule, p. 30.

Rate of Surveying.

The average daily progress of a good surveyor in England, surveying with one chainman, for the 6-inch-to-a-mile scale, is, according to Frome—

Close large village	about 5 acres.
Villages and surrounding fields, etc.	„ 14 acres.
Close country, gentlemen's houses, etc.	„ 20 acres.
Medium country, ordinary fields, and scattered farms	„ 30 to 32 acres.
Open moorland, with roads, streams, boundaries, cart tracks, etc. (no fields)	„ 55 acres.

A survey of a piece of country of about 6 square miles, on a scale of 6 inches to a mile (which would comprise measuring and levelling base line, triangulating, finding variation of the compass, traversing the principal roads, filling in detail by prismatic compass, contouring to every 25 feet, and completing fair plan), would take a good surveyor thirty working days.

A greater area takes less time in proportion, for the base is the same, as also variation of compass and part of the triangulation.

TO ASCERTAIN THE DISTANCE OF AN INACCESSIBLE OBJECT.

To measure a Base Line across a River.

Let DA (fig. 108) be the direction of the line which has been measured up to the river. It is required to ascertain the distance BA at once upon the ground, so as to continue the measurement of the line.

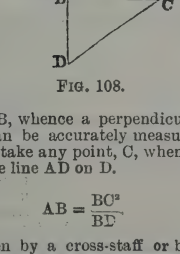


FIG. 108.

On the line DA take any point, B, whence a perpendicular, BC, can be taken, which wil be free from obstruction, so that BC can be accurately measured; carry the range on across the river, and at A set up a flag; on BC take any point, C, whence A can be seen; and at C erect a perpendicular to AC, intersecting the line AD on D.

Measure DB; then

$$AB = \frac{BC^2}{BD}$$

These angles can either be taken by a cross-staff or by the chain, with the distances of 30 links, 40 links, and 50 links; 50 being the hypotenuse of a right-angled triangle when the base and perpendicular are respectively 30 and 40.

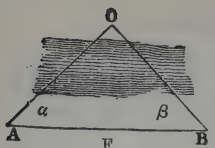


FIG. 109.

To measure the Width of a River with the Base Line alongside of it.

Take at the ends of the base line, AB (fig. 109), with a theodolite, the angles α and β, made between the base line and a flag, O, placed at the edge, on the other side of the river; then width OF is

$$OF = AB \frac{\tan \alpha \tan \beta}{\tan \alpha + \tan \beta}.$$

To find the Distance of one Object from another, where a River divides them, without using the Theodolite.

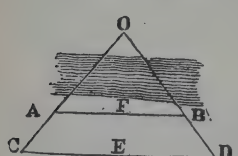


FIG. 110.

Let O and A (fig. 110) be the given objects, and AO the distance required. From A draw AB at *any* angle to AO, and produce OA to C, measuring AC about one-third length of AB; from C measure CD, parallel to AB, OBD being in one straight line. To make CD parallel to AB, at A and B erect equal perpendiculars, which can be done either by a cross-staff or by means of the unit proportion of the sides of a right-angled triangle, viz. 3, 4, and 5, or any multiples of them whatever. Then

$$AO = \frac{AB \cdot CA}{CD - AB}.$$

If the perpendicular distance OF be required, then this can be obtained by the formula—

$$OF = FE \frac{OA}{AC}.$$

Or we can so select the point A as to have OAC at right angles to the river, and make AB and CD at right angles to OAC, when AO, given by the foregoing formula, gives, of course, the required perpendicular distance.

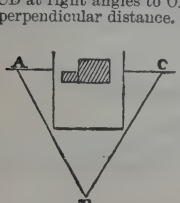


FIG. 111.

To continue the Measurement and Direction of a given Line when any Obstacle stands in the way, which cannot be crossed but can be avoided by going to the right or left.

At any point, A (fig. 111), on the given line, AC, take an angle with the given line, of 120° if you would turn to the left, or 240° if to the right, as in the present case, and proceed measuring to B till an angle of 60° made with this line towards the first line, AC, will carry you clear of the obstacle. Take this angle, ABC, 60°, and measure BC the same distance as AB; the point C will then be on the given line, and AC will be equal to AB or BC. By taking an angle of 240° with the line BC, the range of the line can be continued.

General Remarks.

1. Avoid taking bearings and distances along a circuitous boundary line like *abc* (fig. 112), but run the straight line *ac*, and at right angles to it measure offsets to the crooked line. 2. If it is desired to survey a straight line from *a* to *c*, but the instrument cannot be directed precisely towards *c*, on account of intervening obstacles, first run a trial line, *am*, as nearly in the proper direction as can be guessed. Measure *mc*, and calculate a distance, *y*, say, so that *am* is to *mc* as is 100 ft. to *y*. Lay off *ao* equal to 100 ft., and *os* equal to *y*, and run the final line *asc*. Or, if *mc* is quite small, calculate offsets like *os* for every 100 ft. along *am*. 3. When *c* is visible from *a*, but the intervening ground difficult to measure along on account of marshes, &c., extend the side *ya* to good ground at *t*; then, making the angle *ytd* equal to *yac*, run the line *tn* to that point, *d*, at which the angle *ndc* is found by trial to be equal to the angle *atd*. It will rarely be necessary to make more than one trial for this point *d*;

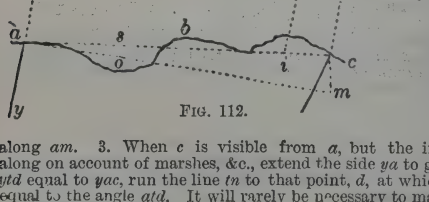


FIG. 112.

for, suppose it to be made at x, see where it strikes ac at i; measure ic, and continue from x, making $xd = ic$. 4. In the case of a very irregular piece of land, or a lake (fig. 113), surround it by straight lines. Survey these, and at right angles to them measure offsets to the crooked boundary. 5. When between two objects, m and n (fig. 114), and it is wished to place oneself in range with them, lay a straight rod, cb, on the ground, and point it to one of the objects, m; then go to the end c, and see if it points to the other object; if it does not, then, by successive trials, find the position, ed, in which the rod points to both objects, and consequently is in range with them. If no rod is at hand, two stones will answer, or two chain-pins. A plumb-line (a pebble tied to a piece of thread) will add to the accuracy of ranging the rod, or stones, &c.

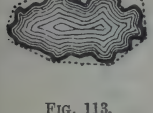


FIG. 113.

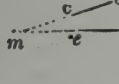


FIG. 114.

TO MEASURE THE HEIGHT OF AN OBJECT.

(1) When the Base is Accessible.

Measure any distance from the base of the object as nearly equal as possible to the height, and take the angle of elevation by the theodolite.

Let BA (fig. 115) be the object; measure BC, and take the angle a; then

$$BA = BC \tan a.$$

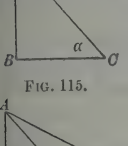


FIG. 115.

(2) When the Object is Inaccessible.

If the object be inaccessible, so that DB *cannot be measured*, range DB (fig. 116) on to C, and taking BC nearly equal to DB, measure BC, and at B and C take the angles of elevation, a and a_1; then

$$AD = BC \tan a_1 \left(\frac{\tan a}{\tan a - \tan a_1} \right).$$

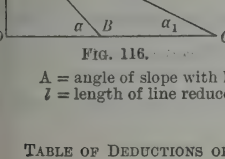


FIG. 116.

Chaining on Slopes.

A = angle of slope with horizon. L = length of line chained on slope.

l = length of line reduced to the horizontal.

$$l = L \cos A.$$

TABLE OF DEDUCTIONS OR ADDITIONS TO BE MADE PER 100 FEET IN CHAINING OVER SLOPING GROUND

In order to reduce the inclined measurements to horizontal ones.

Slope in Deg.	Deduct Feet.	Rise in 100 ft. Hor.	Slope in Deg.	Deduct Feet.	Rise in 100 ft. Hor.	Slope in Deg.	Deduct Feet.	Rise in 100 ft. Hor.	Slope in Deg.	Deduct Feet.	Rise in 100 ft. Hor.
¼	·001	·436	5¼	·420	9·189	10¼	1·596	18·08	15¼	3·521	27·26
½	·004	·873	½	·460	9·629	½	1·675	18·53	½	3·637	27·73
¾	·009	1·309	¾	·503	10·07	¾	1·755	18·99	¾	3·754	28·20
1	·015	1·746	6	·548	10·51	11	1·837	19·44	16	3·874	28·67
¼	·024	2·182	¼	·594	10·95	¼	1·921	19·89	¼	3·995	29·15
½	·034	2·619	½	·643	11·39	½	2·008	20·35	½	4·118	29·62
¾	·047	3·055	¾	·693	11·84	¾	2·095	20·80	¾	4·243	30·10
2	·061	3·492	7	·745	12·28	12	2·185	21·26	17	4·370	30·57
¼	·077	3·929	¼	·800	12·72	¼	2·277	21·71	¼	4·498	31·05
½	·095	4·366	½	·856	13·17	½	2·370	22·17	½	4·628	31·53
¾	·115	4·803	¾	·913	13·61	¾	2·466	22·63	¾	4·760	32·01
3	·137	5·241	8	·973	14·05	13	2·563	23·09	18	4·894	32·49
¼	·161	5·678	¼	1·035	14·50	¼	2·662	23·55	¼	5·030	32·98
½	·187	6·116	½	1·098	14·95	½	2·763	24·01	½	5·168	33·46
¾	·214	6·554	¾	1·164	15·39	¾	2·866	24·47	¾	5·307	33·95
4	·244	6·993	9	1·231	15·84	14	2·970	24·93	19	5·448	34·43
¼	·275	7·431	¼	1·300	16·29	¼	3·077	25·40	¼	5·591	34·92
½	·308	7·870	½	1·371	16·73	½	3·185	25·86	½	5·736	35·41
¾	·343	8·309	¾	1·444	17·18	¾	3·295	26·33	¾	5·882	35·90
5	·381	8·749	10	1·519	17·63	15	3·407	26·79	20	6·031	36·40.

The foregoing table gives deductions or additions to be made every 100 ft. as actually chained along sloping ground in order to reduce the sloping measurements to horizontal ones. Even when it is so nearly level that the eye cannot detect the slope, an over-measurement of an inch or two in 100 ft. may readily occur. It is plain that if we measure all the undulations of the ground we shall get greater totals than if we measure horizontally, as is *supposed* always to be done; but since few surveyors pretend to measure horizontally until the slope becomes apparent to the eye, their lines are usually too long by from 1 to 2 inches in 100 ft. To counteract this to some extent chains are frequently made from 1 to 2 inches longer than 100 ft.; and for ordinary purposes the precaution is a good one. When greater accuracy is required the chainmen should be attended by a third person, with a rod and slope-level, for taking the inclinations of the ground. These deductions being made, the remainder will be the actual horizontal distance.

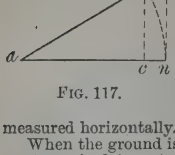


FIG. 117.

For example, in fig. 117 each 100 ft. *ao* measured up or down the slope *ae* plainly corresponds to the shorter horizontal distance, *ac*, the difference or deduction being *cn*. Taking *ao* as radius, then *ac* is the cosine, and *cn* the versed sine of the angle *ean* of the slope. Therefore *ao* multiplied by the nat. cosine of the angle *ean* gives the reduced horizontal distance, *ac*, which, taken from *ao*, gives the deduction *cn* of our table.

But if, while chaining along the slope *ae*, we wish to drive stakes that shall correspond with horizontal distances, *an*, of 100 ft., it is evident that we must add *cn* to each 100 ft. *ao*, as shown at *xe*, and the stake must be driven at *e* instead of at *o*. Observe that $xe = cn$ must be measured horizontally.

When the ground is very sloping all this calculation may be avoided, where great accuracy is most required, by actually holding the chain horizontal, as nearly as can be judged by eye, and finding, by means of a plumb-line, where its raised end would strike the ground. A whole chain at a time cannot be measured in this way, but shorter distances must be taken, as the ground requires—at times, on very steep ground, not more than 5 or 10 ft.

The following short rules may be used for finding the approximate correction to be made :—

(1.)

Square the number of degrees in the slope, multiply by $1\frac{1}{2}$, and obtain correction in hundredths of a foot.

Example.—10° slope. $10^2 \times 1\frac{1}{2} = 150$, or 1·50 ft. correction.

(2.)

Square the rise in feet per 100 ft. horizontal, and divide by 2; this gives correction in hundredths of a foot.

Example.—10 ft. rise in 100. $10^2 \div 2 = 50$, or 0·50 ft. correction.

SCALES FOR SURVEYS.

Ordnance Survey Scales.

VARIOUS SCALES OF MAPS OF GREAT BRITAIN AND IRELAND.

Natural Scales.	Inches to one Statute Mile.	Statute Miles to one Inch.	Chains to one Inch.	REMARKS.
$\frac{1}{500}$	126·720	0·0079	$0·63\dot{3}\dot{1}$	Town maps.
$\frac{1}{528}$	120·000	$0·008\dot{3}$	$0·6\dot{6}$	
$\frac{1}{1056}$	60·000	$0·01\dot{6}$	$1·\dot{3}$	
$\frac{1}{1000}$	25·344	0·0395	$3·15\dot{6}$	Cadastral, or parish, maps of the United Kingdom.
$\frac{1}{2640}$	24·000	$0·041\dot{6}$	$3·\dot{3}$	Map of Alnwick.
$\frac{1}{2500}$	12·000	$0·08\dot{3}$	$6·\dot{6}$	Special maps of districts around London and Plymouth.
$\frac{1}{10560}$	6·000	$0·1\dot{6}$	$13·\dot{3}$	County maps of United Kingdom, and special maps.
$\frac{1}{15840}$	4·000	0·25	20·0	Special index.
$\frac{1}{63360}$	1·000	1·0	80·0	General map of United Kingdom, and special maps.

Small-Scale Maps of Great Britain and Ireland.

Fifteen miles to one inch: British Isles.

Ten miles to one inch: Great Britain: (*a*) in outline, with water coloured blue; (*b*) hills shaded, water blue, roads sienna. Ireland: (*a*) outline engraved; (*b*) hills shaded, water blue, roads sienna.

Four miles to one inch: England: (*a*) engraved in outline; (*b*) conspicuously coloured. Also county maps with main roads coloured. Ireland and Scotland: (*a*) outline, water blue; (*b*) coloured. County maps of Scotland.

Two miles to one inch: England and Scotland; coloured.

One mile to one inch: England: (*a*) in outline with *contours*; (*b*) hills shaded in brown; (*c*) hills shaded in black; (*d*) coloured, with *contours* in red. Ireland: (*a*) in outline; latest editions with *Contours*; (*b*) hills shaded in black (unrevised); (*c*) coloured; (*d*) in outline, with *boundaries* of counties and urban and rural districts in red. Scotland: (*a*) in outline, with contours; (*b*) hills shaded in brown, zincographed; (*c*) hills shaded in black (unrevised); (*d*) coloured.

Maps of the India Survey Department.

One mile to one inch: Topographical maps; about one-eighth of the total number has been published (1914).

Four miles to one inch: Prepared in sheets of one degree by one degree. Publication only recently begun.

Thirty-two miles to one inch: The outline engraving of this new map of India and adjacent countries is completed. The hills are shown in the 'layer' system. (*a*) A new edition of the railway, canal, and road map of India. (*b*) A new map of India and adjacent countries, hills shown on the 'layer' system. (*c*) A new edition of the map showing railway stations.

Dip of Horizon.

d = dip of horizon, in seconds. h = height of observer's eye, in feet.

s = distance of horizon, in statute miles. n = distance of horizon, in nautical miles.

$d = 57{\cdot}4\sqrt{h}$; approximate, varying with temperature. $h = {\cdot}666s^2 = {\cdot}86n^2$.

Table of Dip and Distance of Horizon at Various Heights.

h.	s.	n.	d.	h.	s.	n.	d.
Feet.	Miles.	Miles.	′ ″	Feet.	Miles.	Miles.	′ ″
5	2·739	2·411	2 8·35	80	10·959	9·644	8 33·4
10	3·874	3·409	3 1·51	90	11·624	10·229	9 4·54
15	4·745	4·176	3 42·31	100	12·253	10·783	9 34
20	5·480	4·822	4 16·7	150	15·007	13·206	11 43
25	6·126	5·391	4 47	200	17·329	15·249	13 31·76
30	6·711	5·906	5 14·39	300	21·223	18·676	16 34·2
35	7·249	6·379	5 39·58	400	24·507	21·566	19 8
40	7·749	6·819	6 3·03	500	27·399	24·111	21 23·5
45	8·219	7·233	6 25·05	1,000	38·749	34·099	30 15·1
50	8·664	7·624	6 45·88	2,000	54·799	48·223	42 47
60	9·491	8·352	7 24·62	3,000	67·115	59·061	51 23·9
70	10·252	9·021	8 0·24	4,000	77·498	68·198	60 30·3

To reduce a Measured Base to the Level of the Sea.

Let r represent the radius of the earth corresponding to the base b at the level of the sea, and $r + a$ the radius referred to the level of the measured base, B; then

$$r + a : r :: B : b, \quad \text{or,} \quad b = B \times \frac{r}{r+a}, \quad \text{and,} \quad B - b = B - B\frac{r}{r+a} = B\left(1 - \frac{r}{r+a}\right)$$

$$= B\left(\frac{a}{r+a}\right) = B\left\{\frac{\frac{a}{r}}{1+\frac{a}{r}}\right\} = \frac{Ba}{r}\left(\frac{1}{1+\frac{a}{r}}\right) = \frac{Ba}{r}\left(1 - \frac{a}{r} + \frac{a^2}{r^2} - \&c.\right) = B\left(\frac{a}{r} - \frac{a^2}{r^2} + \frac{a^3}{b^3} - \&c.\right).$$

But the radius of the earth being very great in comparison with the difference of level, a, we have the correction, $B - b$, or d, say, sufficiently accurate by retaining only the first term. Hence

$$d = \frac{Ba}{r} \text{ is the value to be deducted from the measured base.}$$

Spherical Excess.

$$\text{E, in seconds} = \frac{S}{r^2 \sin 1''} = \frac{ab \sin C}{2r^2 \sin 1''},$$

S = the area of the triangle. r = the radius of the earth.

$$S = \frac{ab \sin C}{2} = \sqrt{s(s-a)(s-b)(s-c)}, \quad s \text{ being} = \frac{a+b+c}{2}.$$

Between latitudes 45° and 25° the spherical excess amounts to about 1′ for an area of 75·5 square miles.

Hence, if the area in square miles be known, a close approximation to the spherical excess will be had by dividing the area by 75·5. Log mean radius of the earth in yards = 6·8427917. If the three angles of a triangle are assumed to have been equally well determined, the previous determination of the spherical excess is not necessary for the calculation of the sides, though it will be required for estimating the relative value of the observations. For the sides of a spherical triangle may be computed as if they were rectilineal if one-third the excess of the sum of the three angles above 180° is deducted from each of the three observed angles, in which case

$$\text{side } b = \text{side } a \sin (B - \tfrac{1}{3}E) \div \sin (A - \tfrac{1}{3}E).$$

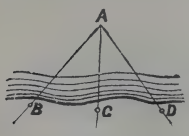


FIG. 118.

Surveying Soundings

To determine the position of any sounding, A (fig. 118), when afloat, take simultaneously the bearings of three known objects on shore, B, C, D, plot the angles on tracing-paper, and move them on plan until the lines cut the points B, C, D.

Another method.—B, C, and D being known points on shore, and the angles BAC, CAD having been measured—

Double the angle BAC, and deduct this doubled angle from 180°. Halve the remainder, and set off from B and C angles, each equal to the half remainder—that is, BCE, CBE; then BE = EC. With E as a centre and radius EC, describe the circle BCA. Then the point A will be in the circumference of this circle.

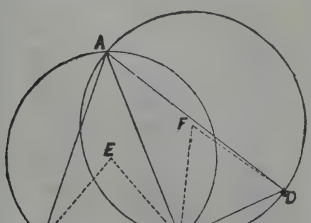


FIG. 119.

In like manner, double the angle CAD and proceed as before; the point A will be in the circumference of the circle CAD. Being in the circumference of the two circles, the point A will therefore be at the intersection of the two.

Suppose the angle BAC to have been 40°, CAD 30°, the double of BAC is 80°; then 180° − 80° = 100°, which divided by 2 gives 50°. Set off from B and C angles equal to 50°. In like manner, 2CAD = 60°, and 180° − 60° = 120°; half 120° = 60°; from C and D set off 60°. With E and F as centres (fig. 119), and radii EB, FC, describe the two circles, whose intersection determines the position, A, of the observer.

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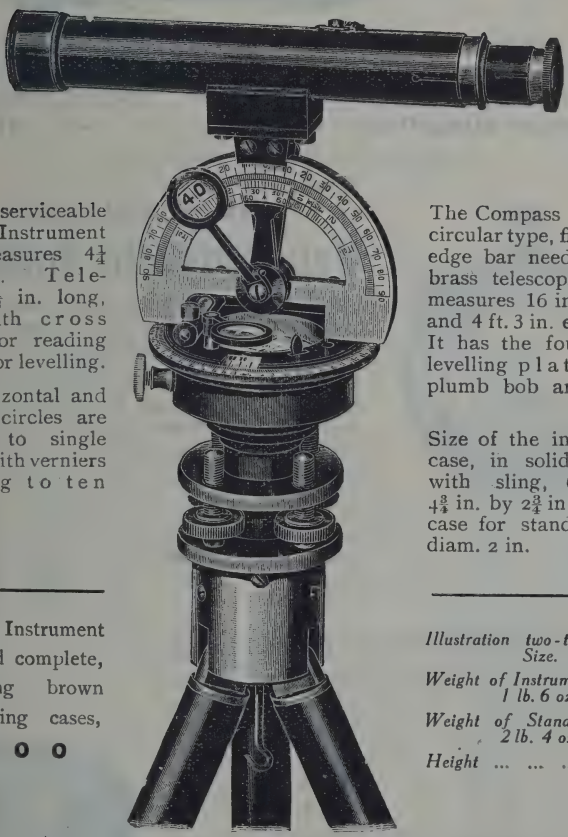
Improved Pocket Theodolite.

A MOST USEFUL AND COMPACT INSTRUMENT FOR ENGINEERS, ARCHITECTS AND SURVEYORS.



This serviceable little Instrument only measures 4¼ in. high. Telescope 5½ in. long, fitted with cross webbs for reading off staff, or levelling.

The horizontal and vertical circles are divided to single degrees with verniers reading to ten minutes.

The Compass is of the circular type, fitted with edge bar needle. The brass telescopic stand measures 16 in. closed, and 4 ft. 3 in. extended. It has the four screw levelling plates, also plumb bob and hook.

Size of the instrument case, in solid leather with sling, 6 in. by 4¾ in. by 2¾ in. Size of case for stand 16 in., diam. 2 in.

Price of Instrument and Stand complete, in strong brown eather sling cases,

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Illustration two-thirds Full Size.

Weight of Instrument in case, 1 lb. 6 oz.

Weight of Stand in case, 2 lb. 4 oz.

Height ... ... 4 ft. 3 in.

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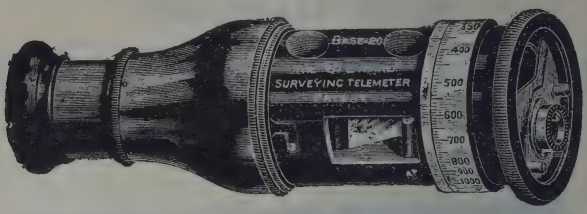
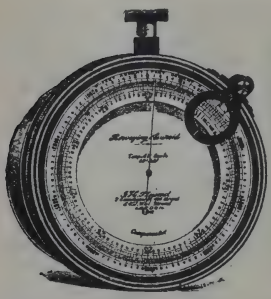


THE 'STEWARD' POCKET SURVEYING TELEMETER
with sighting telescope, will rapidly determine and mechanically compute the distance of any object within the range of vision. Size 4½ by 1½ inches.

In Leather Sling Case and instructions - - **£11 11 0**

See Editorial on Surveying Instruments.



THE 'STEWARD'
Hypsometric Aneroid.

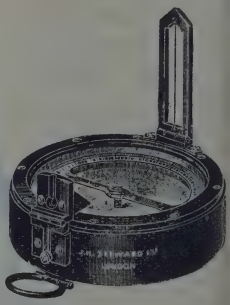
Constructed to eliminate many common sources of error. Reads to 5 feet or 2 metres without a vernier. No calculation necessary. No parallactic error. Altitude scale automatically locks. Movement compensated for temperature. Diameter of dial 3½ inches. Aneroid fixed to leather sling case, cannot drop to ground. Swing thermometer for ascertaining air temperature.

Range of Altitude Scale	6,000 feet, or 2,000 metres	..	**£12 10 0**
Ditto ditto	10,000 feet, or 3,000 metres	..	**12 15 0**
Ditto ditto	16,000 feet, or 5,000 metres	..	**13 10 0**
Ditto ditto	20,000 feet, or 6,000 metres	..	**14 10 0**

LIQUID PRISMATIC COMPASS

Graduated Aluminium Ring floating in non-freezable liquid, giving greater steadiness and settling very quickly. Compensation for expansion. With leather sling case.

2⅛" Ring - £7 10 0
3½" Ring - £9 15 0



Illustrated Catalogue of Surveying, Mathematical and Nautical Instruments, Section S.M. Post free.

J. H. STEWARD, Ltd., 406 & 457 Strand, LONDON.

To reduce a Sounding to Low Water.

h = vertical rise of tide, in feet. h' = height of tide above low water, in feet, at the time t.
t = time between high and low water. t' = time from time of sounding to low water, in hours.

$$\frac{h}{2}\left(1 \mp \cos\frac{180t'}{t}\right) = h' ; \; - \cos \text{ when } \frac{180t'}{t} < 90°, \text{ and } + \cos \text{ when } > 90°.$$

EXAMPLE.—Low water occurring at 3.45, and high water at 10.15 P.M., a sounding taken at 5.30 P.M. was 18·25 feet; what was the depth at low water, the vertical rise being 10 feet?

$$h = 10 \textit{ feet}; \; t = 5h.\ 30m. - 3h.\ 45m. = 1h.\ 45m. = 1{\cdot}75 \textit{ hours}.$$
$$t = 10h.\ 15m. - 3h.\ 45m. = 6h.\ 30m. = 6{\cdot}5 \textit{ hours}.$$

Then

$$\frac{10}{2}\left(1 \mp \cos\frac{180 \times 1{\cdot}75}{6{\cdot}5}\right) = 5(1 - 48° 27') = 5 \times (1 - {\cdot}662) = 1{\cdot}69 \textit{ feet}.$$

Sounding	18·25 *feet*.
Reduction	1·69 ,,
	16·56 ,,

SURVEYING INSTRUMENTS.

(W. F. Stanley.)

The Plain Theodolite.

In this instrument (fig. 119A) there is a horizontal circle reading to minutes by two verniers, and a vertical half circle reading also to minutes by a single vernier—both readings being provided with clamps to fix the telescope nearly to the reading required, and tangent screws to make the final adjustment. Below the horizontal divided limb of this theodolite a separate axis is formed, so that every reading may be set to start from zero. The telescope has two turned collars which rest in a cradle formed of Y-form supports. This form of cradle permits the telescope to be revolved upon its axis to set it in collimation with the object glass, by adjustment of the spider webs in front of the eye-piece until the revolution of the telescope does not appear to displace any small object observed. A magnetic needle of about three inches in length is placed in a compass box over the axis of the instrument. In old instruments this is very difficult to read, from interference of vision by the standards of the telescope. In modern instruments (fig. 119A) an aluminium ring compass is provided, which is read from one side by a microscope. This theodolite is set up upon a tripod stand and adjusted to level, before commencing a survey, by four adjusting screws (parallel plate screws) which are used oppositely to tip the instrument one way or the other until the bubbles of the level tubes on the limb are brought to the centre of their run. As the pressure of these parallel plate screws must be more or less according to the force used, the axis is slightly distorted by them; dull bubble tubes have therefore to be used. Where greater exactness is required, the support, as of every scientific instrument, is placed upon three points only, an arrangement which is termed the tribrach system, and which admits of quick adjustment.

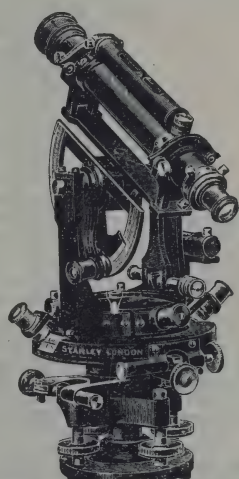


FIG. 119A.

To set up a Tribrach.—Place the level linable with either pair of screws B.C. (fig. 119B, p. 172), and bring the bubble to the centre of its run. Then place the level at right angles to this, so that the screw A comes opposite the centre of the telescope. Bring the bubble to the centre of its run. Now return to first position to see that this is right. If not exact, repeat the operation.

With tribrach support a modern well-ground bubble will read sensibly to five seconds of arc, or, if required in high-class work, even to a single second or less.

Adjustment of the Theodolite.

(R. T. Hancock.)

The first and most important adjustment consists in correctly levelling the instrument with its vertical axis pointing truly to the zenith, every time it is set up. Other errors in adjustment can be corrected or compensated by special methods of observation, but correct results are impossible if the theodolite is out of level. This adjustment must precede all others.

Set the instrument up firmly with its legs well spread and bring it approximately level by means of the base adjusting screws, with the aid of the bubble tubes on the vernier plate. Place the telescope as nearly horizontal as possible, with the vertical arc clamped to zero if desired, and bring it over one pair of the base levelling screws, or parallel to a pair in the case of a tribrach base, and observe the position of one end of the bubble of the telescope level in relation to the gradations on the tube. Select and use one end throughout, say, the end of the bubble nearest the eyepiece. Revolve the upper part of the theodolite through 180°, bring the bubble back half way, if it has moved, by means of the base levelling screws. Check by turning the instrument back to its original position. If the bubble remains in its mean position, turn the upper part of the instrument through 90°, so that telescope lies over the other pair of levelling screws, or the remaining one of the tribrach, and bring the bubble to the same position by these. Finally check by turning the instrument slowly through 360°, and see that the bubble remains unmoved. If not, repeat adjustment from the beginning. The bubble may not finally occupy the centre of its tube : this is unimportant. What is important is that it should not move when the instrument is revolved about its vertical axis. If the bubbles of the levels on the vernier plate are not well centered when the instrument is thus levelled, it will be convenient to make them so now by means of the turret screws at the ends of the cases, so that a close approximation to true levels may be obtained when setting up on future occasions. It should make no difference in levelling up whether the two plates revolve together or whether the lower is clamped and the upper free. If it does, it shows that the cones require regrinding.

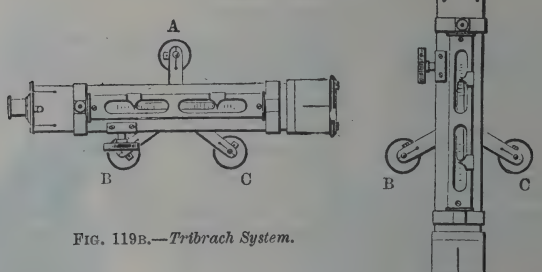


FIG. 119B.—*Tribrach System.*

Adjustment for parallax consists in moving the eyepiece in or out, altering the focus of the object glass to correspond, until the crosshairs of the diaphragm do not appear to move relative to the point viewed when the eye is moved slightly from side to side of the lens opening. Care should be taken not to revolve the eyepiece tube in its casing, as this affects the optical centering of the system of lenses. For this reason the lens cell and its casing are usually provided with corresponding marks by the maker.

The transit axis upon which the telescope swings should be accurately at right angles with the vertical axis of the instrument. The adjustment of this is effected by sliding bearings at the top of the standards, but in cheaper instruments no provision for adjustment in this respect is made, the makers supposedly securing it once and for all by correctly proportioning the height of the standards. Direct the telescope to some high object, such as the finial of a spire. Depress the telescope and mark on the ground the point where the intersection of the hairs falls. Transit the telescope, sight up again, and mark where the intersection falls on the ground the second time. Raise or lower one bearing so that the intersection falls one-quarter of the distance between the marks from the second mark. Check, and repeat if necessary.

The collimation line may be defined as a line joining the optical centre of the object glass and the intersection of the crosshairs. To make it at right angles to the axis on which the telescope swings, set up, level, and sight to a well-defined mark about 100 feet away ; transit the telescope, and mark where the intersection falls in the opposite direction, at about the same distance away and on the same level as near as may be. Revolve the plates through 180° about, and sight to the original mark. Again transit, and mark the new point of intersection, if altered, near the former one. Measure a point one-fourth of the distance between the two from the latter, and move the diaphragm carrying the crosshairs by means of the adjusting screws holding it in the telescope until the intersection covers the measured mark. It will be necessary to loosen all four screws to do this, but care should be taken not to move the diaphragm up or down more than can be helped, and to keep the crosshairs vertical and horizontal. Check by transiting back again to the original mark, which will now not fall under the crosshairs ; bring it under the intersection by the slow motion tangent screw, and transit back again. The intersection should now fall half way between the two original marks.

Having performed the foregoing adjustments we now have the vertical axis of the instrument pointing truly to the zenith, the horizontal axis on which the telescope swings truly at right angles

to the vertical axis, and the line of collimation truly at right angles to the horizontal axis. The collimation line then lies wholly in a vertical plane cutting the horizontal axis at right angles, but does not necessarily lie parallel to the axis of the level on the telescope in that plane. It can be made to do so by altering the lie of one or the other, and in order to avoid disturbing the adjustment just completed, it is better to bring the axis of the telescope-level parallel to the collimation line as it now lies. This is why it was recommended not to disturb the up and-down position of the collimation line more than can be helped, so as to avoid the necessity for much alteration in the telescope level. This adjustment is not really required for the theodolite, unless it is intended to use it occasionally as a level, and the surveyor who desires to effect it can proceed as described below for the level, except that after setting up beyond the levelled pegs, the telescope is lowered or raised by the slow-motion tangent screw of the vertical arc till the crosshairs read the same on both pegs; the bubble of the telescope level is then brought to the centre of its run by altering the capstan-headed screws at each end of its casing.

Everest's Theodolite.

This instrument was much used in the survey of India, and is a modification of the plain theodolite, in which the cradle fitting, somewhat liable to derangement from its light loose parts, is replaced by a telescope fixed in a solid collar. The segments of arc of this theodolite are used upon each side of the axis, so that double vernier reading may be employed to vertical angles. It was the first English-made theodolite in which the tribrach system of adjustment was employed, and is still considered to be an excellent instrument for survey upon fairly level country.

Lister's Inclinometer.

The construction (fig. 119c) is similar to that of a plain theodolite, but with the addition of an extra vertical axis to the telescope, carried through the horizontal axis at right angles. By this means the telescope can be moved upon this supplementary vertical axis in a plane of any inclination desired, so that if the horizontal axis is set to the slope of a railway cutting a large number of pegs may be set out continuously with the same setting by direct observation through

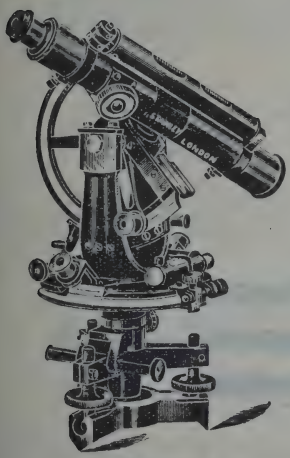


Fig. 119c.

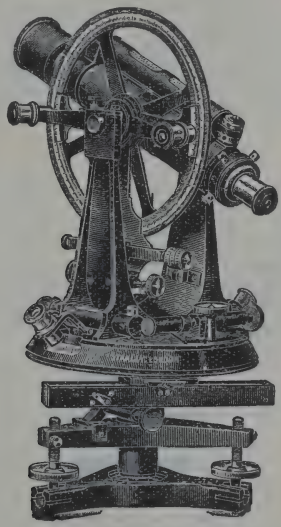


Fig. 119d.

the telescope across any irregularity or inclination of the land surface. The slopes for curves also are readily pegged by means of the special horizontal angle repeater with which the instrument is fitted, so that one angle only need be set and that can be repeated round a curve until complete, when the angle repeater is simply released to return to a straight line.

The instrument is readily made into an ordinary surveying theodolite by fixing the telescope by means of a catch, which places it firmly true to the reading of the arc and limb.

Transit Theodolite.

In modern practice this instrument (fig. 119D), in some form, is generally used. Its great merit is that the telescope being placed high enough above the limb to revolve over half a revolution on its axis, a direct fore-and-back sight can be taken in line with its centre, and, as this may also be done by moving the reading through 180°, it is a good test for the division and the true centering of the instrument. Except for the transitting telescope the general principle of structure of this theodolite is the same as that of the plain theodolite above described. The height necessary for the telescope is generally somewhat reduced by replacing the circular magnetic compass by a magnetic needle placed in a trough under the limb. The needle can move only 20° of arc, but, as it can be brought co-incident with the magnetic north by the lower adjustment of the axis of the theodolite, this arc is quite sufficient. It possesses the advantage of having a longer needle placed in clear daylight for observation. With the bad object-glasses formerly used the cradle adjustment in Y's was necessary for true collimation. In modern instruments the object glasses are truly centered so that the webs or other indices may be placed exactly in the axis of the telescope. On this point, in the old pieced-up instruments every severe shake or journey threw the instrument out of adjustment, and it was necessary that the experienced surveyor should have every facility for restoring this. In modern good work with refined apparatus for adjustment, a permanent index, or diaphragm, as it is termed, may be fixed to position by the maker, which will remain in perfect adjustment with careful usage the whole life of the surveyor. As this index matter is a subject not too well known, it will be discussed further on.

Notes on Diaphragms.

Spider's Webs (fig. 119E)—the oldest form of telescope index—are clear and good, but very delicate, sagging with damp and breaking by tension if they remain so long in the instrument as to become very dry. Unless the user is specially skilled, the re-webbing and re-adjustment must be done by an optician.

Lines on Glass (fig. 119F).—These are accurate and permanent. The presence of the glass diaphragm obstructs a little light at all times, but the great defect of this diaphragm is that it becomes bedewed by changes of temperature and requires cleaning. Where glass is fitted it should be easily removable with means of returning it exactly to its former adjustment.

Point Diaphragms (fig. 119G) should be formed of very sharp fine needle points made of platinum-iridium alloy, which is as hard as finely-tempered steel and is non-corrosive.

This index gives the most exact reading and is permanent, so that an instrument with points will remain in adjustment for many years. In case of dust on the points this can be removed gently with a camel hair brush. The only objection made to this diaphragm is that it requires great care in bringing an object exact to reading, but certainly not greater care than is always desirable. Its precision may be demonstrated most simply. Upon first impression the

Fig. 119E.

Fig. 119F.

Fig. 119G.

point may not appear so fine as a web. Practically it is more exact, as it does not cover the reading, as will be seen by the magnified appearance of the readings (fig. 119H).

Both these readings are of ·4 upwards of the black band, but this quantity is less clear with the web **W W** than with the point P. This principle is most important with subtense measuring as will be shown presently.

Fig. 119H.

Some objections have been made by railway engineers to the large size of the transit theodolite, as they do not require the vertical circle except occasionally in mountainous districts. To meet this difficulty Messrs. W. F. Stanley & Co. Ltd. have made a transit theodolite (fig. 119I) as low and as portable as the plain theodolite. This transits over the eye end only, which is loaded by a heavy casting to balance the object end, which is made in aluminium for lightness.

Tunnelling Transit Theodolite.

This is a most useful form (fig. 119K) for all underground work. It is built very low and the telescope transits. The vertical axis is made hollow, so that any angle to about 10° may be read

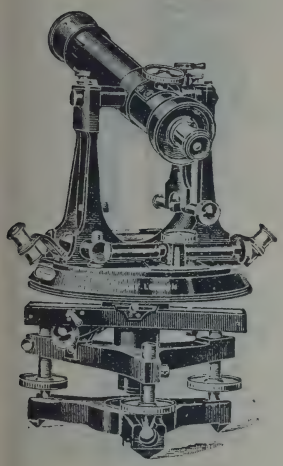


FIG. 119I.

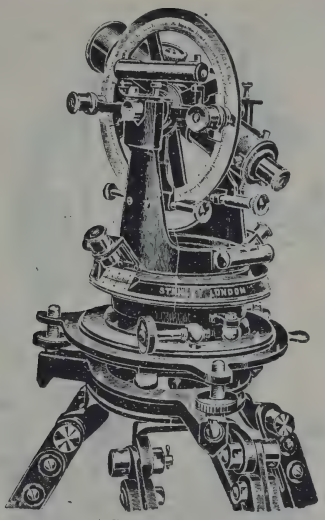


FIG. 119K.

directly below the vertical. This will be found very useful in transferring lines underground from the surface, by sighting down a shaft, and also for plumbing. The hollow centre is supported upon a sliding fitting so that it may be displaced 1½ in. about the centre of the tripod and clamped to its position. It is a form of theodolite most convenient for the mining engineer, in which a long diagonal eye-piece permits a surface line to be observed from the bottom of a deep shaft.

DUNBAR SCOTT'S AUXILIARY TOP AND SIDE TELESCOPE.

Is fitted to theodolites for reading steeper horizontal angles than can be read with the ordinary telescope, also precipitous vertical angles. The zenith-nadir telescope is placed on top of telescope for the former and upon the outside of the standards to project beyond the limb for the latter. This telescope can also be removed so that the instrument then becomes an ordinary transit theodolite.

MICROMETRIC THEODOLITES.

In modern practice for superior triangulation, a vernier reading does not give the necessary accuracy, so the more exact system of reading by a microscope provided with a fine scale in the focus of the eye-piece is employed; over this scale an adjustable web is moved by a fine screw with divided head. With this appliance (fig. 119L, page 176) much finer divisions may be made upon the instrument, and the micrometer scale will subdivide these divisions to read to any exactness desired. Micrometers were formerly employed upon large theodolites only. In modern practice they are used for as small as five-inch circles. The precision of the micrometric system may be shown in that a vernier on a six-inch theodolite can only be made to read satisfactorily 20 seconds of arc. The micrometer on the same instrument will read clearly five seconds. As a rule six-inch instruments are made to read to five seconds; five-inch, to ten seconds; eight-inch, to two seconds; ten-inch, to single seconds. It is necessary with micrometric instruments, even five-inch, that they should be figured at every degree; large instruments to half degrees. The micrometric theodolite is made the same in general structure as the ordinary transit, except for the micrometer.

THE OMNIMETER.

The omnimeter (fig. 120, page 176) is an instrument in which the tangent to a radius reads direct from the axis of the telescope to a rule or stadia of constant length, so that the subtense angle varies with the distance. The instrument consists of a theodolite to which the subtense tangential system is added. In the construction of the instrument there are two sights, one, a telescope to sight the object, and the other, a powerful compound microscope to read divisions upon a tangential scale. The telescope and microscope are united together at 90° to each other with their axes exactly crossing the transverse axis of the theodolite, so as to move together through the

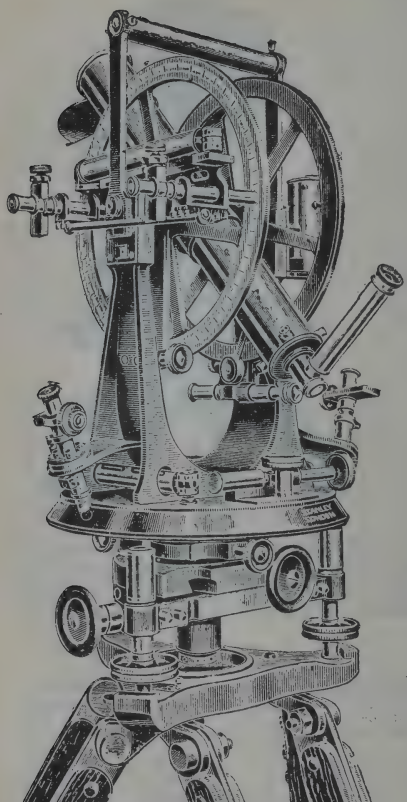


FIG. 119L.

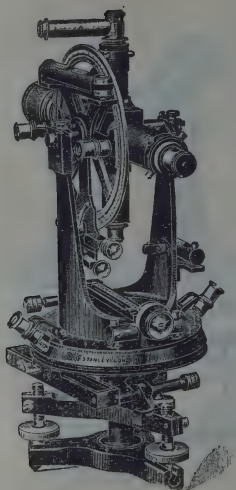


FIG. 120

same amount of angle by the motion of the telescope in traversing the azimuth. A delicate level is placed upon the telescope, and when the bubble is in the centre of its run the scale is at right angles to the axis of the microscope. The scale, which lies flat on the limb at a central distance of six inches, is four inches long, placed in a sliding fitting to adjust longitudinally to its central position by means of a micrometer screw. It is generally divided into 100 parts for numerical calculation. The divisions are subdivided by shorter lines making the total division 200. The micrometer screw has fifty threads to the inch, and moves over one of the divisions of the scale only. The micrometer head is divided into 100, numbered at the tens ; a vernier placed against the head subdivides each of these divisions into five making the total micrometer 500 for one complete revolution. The total division of the four-inch scale therefore becomes : 200 (divisions of scale) × 500 (micrometer) = 100,000 in four inches. The scale is placed centrally to the instrument, so that when the telescope is level the microscope is vertical, and reads 50,000 when in perfect adjustment.

The mathematical theory of the instrument is very simple :

In fig. 121, O is the centre point of the axis of rotation, directly over the divided scale, AB ; O*b*, the base line of the instrument, which may be found by experiment or by calculation ; *mn*, a staff of known length, say 10 feet ; *b*, the departure-point of the scale when the telescope is parallel to AB ; in this position, from the nature of the construction, the microscope points in the direction of the line O*b*, which is perpendicular to AB.

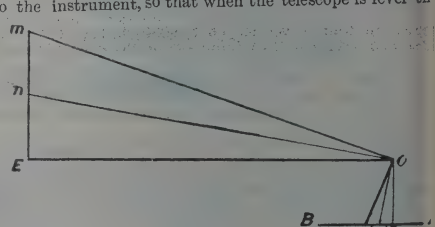


FIG. 121.

Then if the telescope be pointed to *m*, the microscope will be directed to *m'*, the line O*m'* being

perpendicular to the line Om. Again, if the telescope be directed to the point n, the microscope will be in the direction of On' and perpendicular to On. Omn and $Om'n'$ being similar triangles, we have $m'n' : Ob :: mn : OE$; the perpendicular distance from the line mnE passing through the staff mn, $\therefore OE = \frac{mn \times Ob}{m'n'}$; $m'n' : bn' :: mn : nE$, consequently the altitude $nE = \frac{mn \times bn'}{m'n'}$, or $= \frac{bn' \times OE}{Ob}$.

The perpendicular Ob, which is termed the base line of the instrument, when the temperature is not very variable, may be found very accurately by taking OE about 100 feet, and placing the 10-foot staff, mn, as shown in fig. 121; for we have $Ob = \frac{m'n' \times OE}{mn}$.

Let $m'n'$ be $= 47{,}735 - 46{,}015 = 1{,}720$, as in the example we have taken; and suppose the staff $mn = 10$ feet between the upper and lower marks, $Ob = 6$ inches (by construction), therefore $Ob = 150{,}000$ equal parts, when 4 inches contain 100,000 such parts.

$$\therefore OE = \frac{mn \times Ob}{m'n'} = \frac{10 \times 150{,}000}{1{,}720} = 872{\cdot}09 \text{ feet.}$$

Hence, for calculating distances we have the following easy rule: Multiply the length of the staff in feet by the length of the base of the instrument in micrometric equal parts, and divide the product by the difference of the two micrometer readings (of the staff); the quotient will be the required distance.

Subtense Measurements. Tacheometers.

It is quite common at present to place a pair of webs—or much better, a pair of points—in the diaphragm of a theodolite or level, these being at such a distance from each other that they will by vision correspond to a measurement (upon a distant levelling staff), which is proportional to the base of the subtense angle, so as to show thereby, in the space between the lines or points, the true distance of the instrument from the staff. Fig. 121A shows the form these points appear in focus of the eye piece. By the employment of this system chain measurements are entirely dispensed with, and the system has the merit of a simple sight measurement, as upon a rule, without any calculation. Theoretically it is scarcely as exact as the work of the Omnimeter, as there is great difficulty of exact adjustment of the points without the use of complicated optical means, but practically, as testified in some recent work by the Surveyor-General of Lagos and Nigeria, a good instrument in correct adjustment may be read within less than ·001

FIG. 121A.

FIG. 121B.

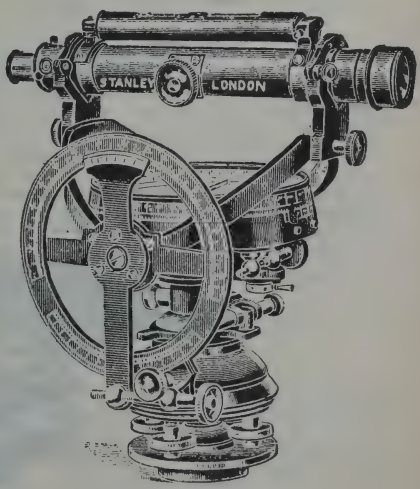


FIG. 121C.

of total distance, which is nearer than is possible by chaining over uneven ground. One merit over the Omnimeter is that the instrument is not touched by the hand during the observation of the points, cut by vision upon the staff, which give the distance.

Mining Surveying Instruments.

Where the mining theodolite cannot be conveniently used, in consequence of the absence of height of gallery, constant short turns or otherwise, as also for economy, some form of mining dial is used. One of the most general is Hedley's (fig. 121B, page 177). This being sighted only, it permits the eye to take observation from nearly the top of a gallery or cutting. The sights rock on an axis to any desired inclination, which may be read off on a small divided arc on the side. The compass reads by an edge bar needle. Dials of various patterns are made into instruments nearly resembling theodolites, the important points being observed that the instrument must be low and light, and read as nearly as possible at its highest part. The tripod of a dial is made with the legs to separate about the centre so that the instrument may be brought low, or what is better with sliding legs to adjust to any height required.

Stanley's Cranked Gimbal Dial.

This instrument (fig. 121c, page 177) is fitted with sliding stand with solid head, and an improved form of ball head to give the necessary amount of tip to the instrument, when the tripod is upon sloping ground, to bring it level. It has clamp and tangent movement to the lower axis, also to the limb, which is outside reading by two verniers to single minutes. The gimbal is cranked so that the telescope will read 90° both ways, thus enabling a bearing to be taken of any object upon the surface from the top of the shaft, and a line being sighted at the bottom of the shaft in the same vertical plane with it, without changing the horizontal adjustment of the instrument. It is also useful for taking vertical sights up a shaft. The vertical arc has a clamp and tangent, and is divided to read single minutes. The telescope is fitted with stadia points for reading distances *without the use of a chain*. It is also fitted with folding sights for use without the telescope and a needle pin to lock compass at zero. The entire instrument is constructed as low as possible for use in shallow workings.

The Dumpy Level.

This is a perfect knock-about instrument. If stations are taken at equal distances apart, say one chain, this form of level will act correctly although out of adjustment. Thus with the level

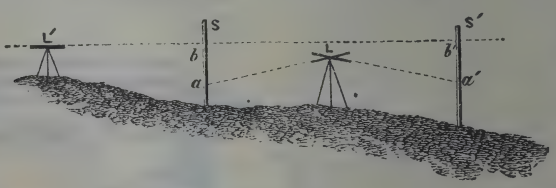


Fig. 121D.

at L (fig. 121D), place a staff vertically at one chain distance from the instrument at S. The inaccurate instrument will read the staff at *a*. Now place the staff vertically at S′. It will read at *a′*. The distances and verticality being equal, *a* and *a′* will be level. If we now place

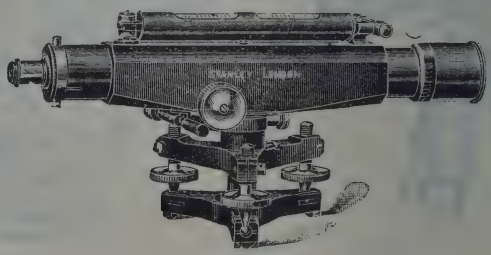


Fig. 121E.

the level at some distant position nearly in line L′ and adjust the level by the bubble screw to read equal distances above *a* and *a′* as *b* and *b′*, the level must be true.

The stability of the level, without increase of weight, has always been a very desirable consideration with all engineers. This is best attained by shaping the level as nearly as possible out of solid castings. Fig. 121E (page 178) shows a level made in this way, and it is the strongest and most compact level made.

Adjustment of the Level.

(R. T. Hancock.)

Select a fairly level piece of ground, set up the instrument, carefully levelled up as described for the theodolite (p. 171), and drive a peg at a distance of 100 feet or so away. Hold the levelling staff on the peg and note the exact reading. On the opposite side of the instrument, and exactly the same distance away, set another peg, driving it down till the staff held on it reads exactly the same as on the first peg. The tops of the pegs are then on the same level, independent of instrument error. Set up on the prolongation of the line beyond one of the pegs, level up carefully, and make the crosshairs read the same on both pegs by raising or lowering the diaphragm cell by means of the screws holding it in the telescope tube. The collimation line is now horizontal.

It is not necessary to level the pegs if the difference in level is noted, and the crosshairs are altered to read the same difference. To facilitate the adjustment in this case, set up beyond the pegs at a distance which bears some simple relation to the distance between the pegs, make a sketch of the position of instrument and staffs, insert readings and distances, and calculate the amount it is necessary to alter the reading on either staff (by moving the crosshairs), on the principle of similar triangles.

The telescope bubble may not finally occupy the centre of its tube when the collimation has been put horizontal as described. This is unimportant, as the instrument can always be correctly levelled up if the procedure as described for the theodolite is followed, in fact the central position of the bubble should never be relied on as a test for levelling up, even if it has once been secured by adjustment. It may be brought to the centre of its run by adjusting the screws holding the level to the telescope, care being necessary not to disturb the instrument.

The Gradiometer.

This instrument (fig. 121F) (*Stanley's patent*) is designed for taking vertical inclines at fixed small angles for railways, irrigation, drainage works, &c., &c., by means of an open extended scale, which may be conveniently and distinctly read without the use of a vernier.

It is also the most rapid levelling instrument yet made, as the telescope can be put level instantly at any sight by moving the drum, without any setting up whatever by the levelling screws. When the drum is at zero it forms an ordinary level of the most approved form. The gradiometric arrangement is effected by the telescope being mounted in trunnions, one being adjustable vertically; the amount of elevation or depression being indicated by a drum graduated to read rise or fall from 1 in 12 to 1 in 1,200.

The additional parts do not increase the size, and add little to the weight.

By its use a great saving of work is effected; for instance, a town drainage in which it is desired to work out an inclination which the levels indicate to have a fall of, say, 10 feet between the extreme points. If the line which the drainage is intended to take is measured, then however angular or zigzag it may be, the length of that line will be that into which the 10 feet is to be divided: thus if the line of streets measure 5,000 feet, this gives 1 foot in 500. Therefore if the drum is set to that proportion, then all the pipes may be laid directly without further setting.

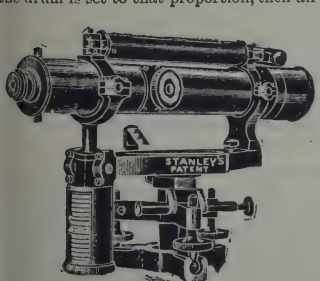


Fig. 121F.

For levelling on steep inclines the instrument also saves a great number of settings up, as instead of levelling for say every 14 feet rise or fall, the gradient of the total distance can be taken, and also the distance, by stadia reading, and by reference to a gradient table the difference of level can at once be seen. Telemetrical readings at great distance may also be taken with accuracy by this instrument.

This gradiometer has been adopted by the Government for producing contour maps.

Box Sextant.

This is the most convenient instrument for filling in details of work performed by the theodolite, or for small surveys. It is constructed upon the principle of the nautical sextant, but the arrangement is made very portable by being placed in a circular box. The radius arm reads to single minutes. It is provided with dark glasses for adjustment upon the sun.

The adjustment is best performed by setting the sextant so that the sun appears a perfectly cir-

cular disc in the telescope with the index at zero. In defect of the sun some distant object may be taken, such as one edge of a chimney, house, or flagstaff, this object being looked at through the eye-hole and horizon glass. Turn the index arm, by means of the large mill-headed screw, until the reflected image of the selected object coincides in the horizon glass with the object seen direct. Having effected this, the vernier should then be examined, to note whether the zero-point of the vernier coincides with the zero-point of the arc. If this coincidence occurs, and the observed object be distant *fully half a mile*, then the instrument is in horizontal adjustment, but if the two zero-points do not agree, the index arm is moved until they do, and the key placed in the key-holes by the side of the sextant to move the horizon glass by which the reflected image of the distant object is made to coincide with the object seen direct through the lower part of the horizon glass. The key is inserted in the keyhole on the *top* of the instrument when it is required to move the image up or down for vertical adjustment. In all cases it is better to see that a perfect disc of the sun appears in the telescope when the index is at zero.

The Plane Table.

This instrument is now generally used in new countries and in our colonies, for filling in details of work with the theodolite. It has the great merit that an intelligent native without technical education can be instructed to do valuable detail work with it. In its simplest form

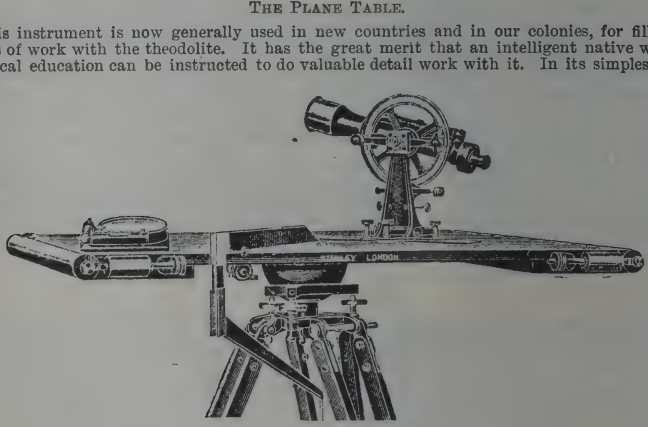


Fig. 122.

it consists of a sighted rule placed on a small board supported by a light tripod, the work being performed on the surface of paper. Many civil engineers find its work extremely convenient, because this work being made most definite by sketches upon the paper used, from these sketches they have a certainty of position in making maps from the same; so that they employ plane tables with all the refinement of means of observation possessed by the theodolite. One of these instruments is shown by fig. 122.

Prismatic Compass.

Details of small surveys or filling-in work are made by this compass, which is sighted for observation of direction, so that the eye may also see the compass ring by reflection through a prism at the instant of sighting. A reflector is commonly fixed to the forward sight so that distant objects may be seen up or down hill. The instrument is generally held in the hand for work, but where greater refinement is desired it is supported on a tripod stand. 2½ in. or 3 in. instruments are used by hand; 3½ in., 4 in., and 4½ in. are each set on a stand.

The Abney Reflecting Level.

A small level to hold in the hand. For flying work and approximate measurements from bench marks on an ordnance map the instrument is very useful. It may be used to level uphill from or to a bench mark by setting to zero and taking successive horizontal sights to points on the ground such as a stone or a daisy. The observer walks to the daisy and takes another forward sight, and so on up to the point whose level is required. Then the difference of level is the height of the observer's eye × number of sights taken. Or if the site is visible from the bench mark it can be sighted at once, the bubble being brought to the line of sight and the angle of the vernier arm read. The distance horizontally can be measured on the map, and the difference of elevation is this length multiplied by the tangent of the angle.

(See also 'Surveying and Levelling Instruments,' Stanley: published by E. and F. N. Spon.)

THE STEWARD SURVEYING TELEMETER.

(J. H. Steward, Ltd.)

This Pocket Telemeter (fig. 122A) is especially useful when the survey of a tract of country, a preliminary survey for a railway, or some topographical reconnaissance, has to be made in a short space of time, and when the transport of cumbersome instruments is inconvenient. The size of the telemeter is $4\frac{1}{2} \times 1\frac{1}{2}$ in., and its weight 10 oz.

FIG. 122A.

The arrangement consists of two plane mirrors mounted upon pivots and serving as index and horizon mirrors. The mirrors are mounted upon a base enclosed in a metal tube, to one end of which is attached a small sighting telescope. To the other end is adapted a movable collar, connected to the index mirror by means of a metal arm. By rotating this collar the index mirror is moved in azimuth, and the angular displacement is measured by reference to a graduated scale upon the exterior of the collar. When the scale is set to zero the mirrors form an optical square and reflect a right angle. A small toothed wheel attached to a screw acts on the horizon mirror so that the angle of double reflection can be varied about 5 degrees out of the right angle, in order to facilitate the determination of the direction of the base.

The scale of distances is divided upon the German silver rotating collar, each division representing 10 units of distance. Any unit of measurement may be employed with the Telemeter, the graduations showing the range in terms of units of the base.

The principle of the Telemeter is to measure the two angles at the extremities of the base, forming a triangle with the object of which the distance is required. The distance or range of the object is read directly from a scale graduated on the instrument, and is expressed in terms of units of the base, so that any scale of measurement (yards, feet, metres, etc.) may be employed. The scale of distances is computed for a base of 20 units, and as the unit of measurement employed may be of any length, it follows that distances of any length can be determined, the limit of distance being governed by the length of base that can be employed and the visibility of the object. The instrument is also adapted for use with a base which is of constant ratio to the distance of the object.

The accuracy of the indications is assured by empirically graduating the scale. The results obtained with the Telemeter have been most satisfactory, the mean error working out at less than 1 per cent.

THE STEWARD HYPSOMETRIC ANEROID, WITH SWING THERMOMETER.

(J. H. Steward, Ltd.)

This aneroid (fig. 122B) is constructed so as to eliminate the many sources of error present in aneroids of ordinary construction and to facilitate operations by doing away with the necessity of calculations.

The altitude scale is regularly divided, to the left for 'ascents' and to the right for 'descents,' and forms a complete circle of equal divisions closed at the two extremities. The zero of the altitude scale can be displaced relatively to the barometric scale and set opposite the index hand at any point of the barometric scale without introducing an error; consequently it is only necessary to set the zero to the index hand by means of the rack and pinion at one station, and the index hand will indicate the difference in altitude at the next station. The divisions are so arranged that with an altitude scale extending up to 10,000 feet, differences as small as five

FIG. 122B.
The Steward Hypsometric Aneroid.

feet or less can be read without the application of a vernier; and by a special arrangement of the reading lens there is no error of parallax. The movement being compensated, changes of temperature do not affect the readings. The aneroid is read and set without removing it from its case, and the altitude scale is automatically locked so that it cannot shift during transit. The diameter of the dial is 3¼ in. A small swing thermometer, for ascertaining the air temperature, to make the correction for difference in the weight and volume of the atmosphere is carried in a pocket at the back of the case.

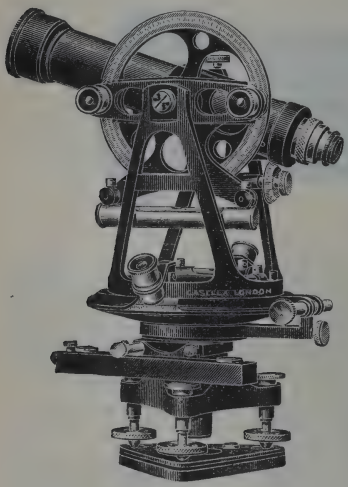


FIG. 122C.

THE CASELLA THEODOLITE.

(*C. F. Casella & Co. Ltd.*)

In recent years, the tendency of many British makers of surveying instruments has been to design lighter and more compact models than those previously in use. Strength has not been sacrificed to lightness in weight, nor convenience to a compact design, for these newer models are often both stronger and more convenient.

The theodolite shown by fig. 122C has several special features. It has internal focusing for the telescope, an improved trough compass (watertight and easily taken to pieces), a screw-focusing eyepiece, and a simple but effective centering head. The clamps operate on the axes of circles, and not on the peripheries, and are therefore less liable to strain the instrument. The horizontal circle is 5 in. in diameter and the vernier gives readings to 20 or 30 seconds. The vertical circle is 4 in. in diameter, with readings to 30 or 60 seconds. The instrument packs into a case measuring only 14 × 8 × 7 in., and the weight of the instrument and its case is only 16 lb.

THE CASELLA DUMPY LEVEL

(*C. F. Casella & Co. Ltd.*)

The Dumpy Level, fig 122D, is very much smaller in build than the pre-war pattern, although the telescope itself is larger and has specially good optical properties. The centre of gravity

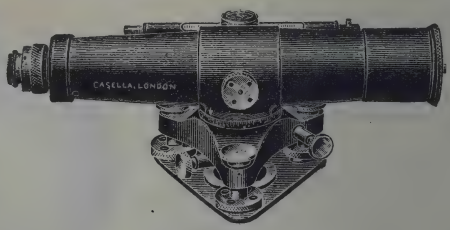


FIG. 122D.

of the instrument is low, and the danger of a fall injuring it is very much reduced. It is sometimes fitted with a divided horizontal ring, reading to 1° or 0·5°, which is used for contour work or for setting out angles of buildings, etc.

The tripod stands of both these instruments are light though rigid.

To Find the Variation of the Compass.

1. By the Pole Star (Polaris).

The pole star is on the meridian, either above or below the pole, when a vertical plane passes through it, and the bright star at the root of the tail of the Great Bear ϵ Ursæ Majoris (Alioth). Thus, during the twenty-four hours, two opportunities will be presented of finding the pole star on the meridian. Set up a fine plumb-line in a convenient place, free from currents of air, and the observer, placing himself behind the thread, waits until the moment when the two stars are hidden by the thread. If the bearing of the pole star be then read, it will show the variation of the compass. But as it is not very easy to read a compass at night, it is best to fix a stick with a light on it in the line of the pole star, and as far off as possible, the line joining the observer's position, and the light is the meridian line, and its bearing may be read in the morning.

2. By a Single Altitude of the Sun.

1. Compare watch with chronometer to get correct mean time.

2. Note readings of barometer and thermometer.

3. Adjust theodolite and note index error.

4. Set up instrument at . . . . . Δ station; make the temporary adjustments, and set instrument at 360° on . . . . . Δ station.

5. About three hours from 12 o'clock, morning or afternoon, unclamp upper horizontal plate and vertical arc. See that the dark eye-piece is down, and move upper part of instrument till the sun is in the field of object glass. Clamp upper horizontal plate and vertical arc, and with the two tangent screws follow (morning observation) the sun's movement till the sun's upper limb just touches the intersection of the cross-hairs. Note the time by watch, and read on horizontal arc the azimuth, and on vertical arc the altitude of ⊙, sun's upper limb.

6. Unclamp horizontal plate, and either with a slight motion, or, if plate be clamped, wholly with tangent screw, follow the sun's motion in azimuth till the sun's lower limb (⊙) becomes tangent to the intersection of cross-hairs, the vertical arc being untouched. Note the time and the reading on the horizontal arc.

7. The mean of the times and the mean of the azimuths will give the time and azimuth at which the vertical reading of the arc denotes the apparent altitude of the sun's centre ⊙.

8. Correct apparent altitude, ⊙.

Correction 1. For index error of instrument. Correction 2. For refraction, modified by barometric and thermometric readings: corrections to be found in tables in Frome's 'Surveying,' Drayson, or Chambers. Correction 3. For parallax. To be found in tables in 'Nautical Almanac,' and modified to noted altitude by formula:—Sin par. in alt. = sin hor. par. × cos. alt.

9. Apparent altitude thus corrected gives true alt. ⊙.

10. The true alt. ⊙ subtracted from 90° gives the zenith distance ZS.

11. As the altitude of the elevated pole is equal to the latitude of the place, 90° minus latitude = zenith distance of the pole, viz. PZ.

12. The declination of the sun is given in the 'Nautical Almanac,' page 1, of each month, for each day at apparent noon. The variation or declination for each hour is also given, and the direction of declination, N. or S. Hence the declination at the time of observation is obtained. If the time of observation be 9 A.M., and declination increasing, the correction for three hours' variation must be subtracted from the declination at apparent noon, *vice versâ* if the declination be decreasing.

13. Then we have the three sides of the astronomical triangle to ascertain the angle Z, which is the measure of the angular deviation of the sun from the true meridian.

14. Compute the angle Z by the formula

$$\cos \frac{Z}{2} = \sqrt{\frac{\sin S \sin (S - PS)}{\sin PZ \sin ZS}}$$

where $S = \frac{1}{2}$ sum of the three sides of the triangle.

15. The magnetic bearing of the Δ station from which the sun's azimuth was taken should be noted two or three times with great care. If possible a stand to be used for the compass.

16. Then, knowing the sun's azimuth from a station and the direction of that station as regards the magnetic north, we get the deviation of the sun from the magnetic north. The computed angle, Z, is the deviation of the sun from the true north, and the difference of the two deviations is the variation of the compass.

17. Note that for afternoon observations the computed angle, Z, is to be subtracted from 360° before comparison with sun's magnetic bearing.

Annual Compass Variation.

The mean declination at the observing station (in connection with the Royal Observatory, Greenwich) on the northern slope of Leith Hill, Surrey, was, for 1926, 13° 10·4′ W. The value of the declination at Greenwich may be inferred by subtracting the station difference, viz. 12·8′.

Horizontal and Vertical Force of Earth's Magnetism.

At Leith Hill the horizontal force was 0·18581, and the vertical force 0·42947, c.g.s. units.

Magnetic Dip.

The mean magnetic dip for 1926 at Leith Hill was 66° 36·3′.

To Determine the South by Means of a Watch.

Point the hour hand of the watch at the sun, then half-way round (clockwise) between the hour hand and 'XII' on the dial points 'south.' Thus, suppose it to be 8 P.M., point the hour hand at the sun, then the 'IIII' of the dial points to south. In southern latitudes, to find 'north,' point 'XII' at the sun, then half-way round between 'XII' and the hour is due 'north.'

To Determine a True East and West.

Set up a *vertical* rod (any size) on a flat floor. Describe a circle round the base about twice (this varies with the latitude) the height of the rod. Some time in the forenoon mark the point where the shadow of the rod just touches the circle, and repeat this in the afternoon on the other side of the circle; mark this point also. A line through these points will be true east and west.

As a guide to the true north, the following notes as to the whereabouts of the pole star at convenient hours in the evening or night will be useful, and correct enough for the purpose for the next hundred years.

The times given (Greenwich mean time) are for the first day of each month, and become about 4 minutes (3 mins. 59·34 secs.) *less* every day.

Month.	1° W.	True N.	1° E.	Month.	1° W.	True N.	1° E.
January	9·45	6·30	..	July	..	..	9·45
February	7·45	..	..	August	..	..	7·45
March	11·15	..	..	September	..	..	11·15
April	9·15	12·30	..	October	..	12·30	9·15
May	7·15	10·30	..	November	..	10·30	7·15
June	..	8·30	11·45	December	..	8·30	5·15

Equation of Time.

TABLE SHOWING TIME TO BE ADDED TO OR SUBTRACTED FROM SUNDIAL TIME IN ORDER TO OBTAIN TRUE OR CLOCK TIME.

Date.	Minutes (approximate).	Date.	Minutes (approximate).	Date.	Minutes (approximate).	Date.	Minutes (approximate).
Jan. 1	+ 4	Mar. 28	+ 5	Aug. 9	+ 5	Oct. 27	−16
„ 3	+ 5	April 1	+ 4	„ 15	+ 4	Nov. 15	−15
„ 5	+ 6	„ 4	+ 3	„ 20	+ 3	„ 20	−14
„ 7	+ 7	„ 7	+ 2	„ 24	+ 2	„ 24	−13
„ 9	+ 8	„ 11	+ 1	„ 28	+ 1	„ 27	−12
„ 12	+ 9	„ 15	0	„ 31	0	„ 30	−11
„ 15	+10	„ 19	− 1	Sept. 3	− 1	Dec. 2	−10
„ 18	+11	„ 24	− 2	„ 6	− 2	„ 5	− 9
„ 21	+12	„ 30	− 3	„ 9	− 3	„ 7	− 8
„ 25	+13	May 13	− 4	„ 12	− 4	„ 9	− 7
„ 31	+14	„ 29	− 3	„ 15	− 5	„ 11	− 6
Feb. 10	+15	June 5	− 2	„ 18	− 6	„ 13	− 5
„ 21	+14	„ 10	− 1	„ 21	− 7	„ 16	− 4
„ 27	+13	„ 15	0	„ 24	− 8	„ 18	− 3
Mar. 4	+12	„ 20	+ 1	„ 27	− 9	„ 20	− 2
„ 8	+11	„ 25	+ 2	„ 30	−10	„ 22	− 1
„ 12	+10	„ 29	+ 3	Oct. 3	−11	„ 24	0
„ 15	+ 9	July 5	+ 4	„ 6	−12	„ 26	+ 1
„ 19	+ 8	„ 11	+ 5	„ 10	−13	„ 28	+ 2
„ 22	+ 7	„ 28	+ 6	„ 14	−14	„ 30	+ 3
„ 25	+ 6			„ 19	−15		

LENGTH OF A DEGREE OF LONGITUDE AND LATITUDE.

Lat.	Degree of Longitude.		Degree of Latitude.		Lat.	Degree of Longitude.		Degree of Latitude.	
$\phi°$	Stat. Miles.	Naut. Miles.	Stat. Miles.	Naut. Miles.	$\phi°$	Stat. Miles.	Naut. Miles.	Stat. Miles.	Naut. Miles.
0	69·174	60·000	68·711	59·598	45	49·002	42·503	69·053	59·895
1	69·162	59·991	68·711	59·598	46	48·136	41·752	69·077	59·916
2	69·132	59·964	68·712	59·599	47	47·261	40·993	69·089	59·926
3	69·080	59·918	68·713	59·600	48	46·372	40·222	69·101	59·937
4	69·006	59·854	68·715	59·602	49	45·469	39·439	69·113	59·947
5	68·911	59·774	68·718	59·604	50	44·552	38·643	69·125	59·958
6	68·798	59·674	68·720	59·606	51	43·621	37·836	69·137	59·968
7	68·661	59·557	68·723	59·609	52	42·677	37·017	69·149	59·978
8	68·505	59·420	68·725	59·611	53	41·719	36·186	69·160	59·988
9	68·327	59·265	68·730	59·615	54	40·749	35·345	69·172	59·998
10	68·130	59·094	68·734	59·618	55	39·766	34·492	69·183	60·008
11	67·912	58·905	68·739	59·622	56	38·771	33·629	69·195	60·018
12	67·673	58·698	68·744	59·627	57	37·765	32·777	69·206	60·028
13	67·413	58·473	68·749	59·631	58	36·746	31·896	69·216	60·037
14	67·133	58·230	68·755	59·637	59	35·716	30·979	69·227	60·046
15	66·832	57·969	68·761	59·642	60	34·675	30·076	69·238	60·056
16	66·511	57·690	68·767	59·647	61	33·623	29·163	69·248	60·064
17	66·172	57·396	68·774	59·653	62	32·561	28·242	69·258	60·073
18	65·810	57·080	68·780	59·658	63	31·488	27·312	69·268	60·082
19	65·428	56·751	68·789	59·666	64	30·406	26·374	69·277	60·089
20	65·028	56·404	68·796	59·672	65	29·315	25·427	69·287	60·098
21	64·608	56·040	68·804	59·679	66	28·215	24·479	69·296	60·106
22	64·167	55·654	68·813	59·687	67	27·106	23·511	69·303	60·112
23	63·709	55·260	68·822	59·695	68	25·988	22·594	69·313	60·121
24	63·228	54·843	68·830	59·702	69	24·862	21·565	69·321	60·128
25	62·731	54·411	68·840	59·710	70	23·729	20·582	69·329	60·135
26	62·212	53·961	68·849	59·718	71	22·589	19·598	69·336	60·140
27	61·676	53·496	68·859	59·727	72	21·441	18·597	69·343	60·147
28	61·119	53·013	68·869	59·736	73	20·287	17·596	69·350	60·153
29	60·550	52·520	68·879	59·744	74	19·126	16·590	69·357	60·158
30	59·957	52·005	68·890	59·754	75	17·960	15·562	69·363	60·164
31	59·347	51·476	68·901	59·763	76	16·788	14·561	69·368	60·168
32	58·718	50·933	68·911	59·772	77	15·611	13·540	69·374	60·174
33	58·071	50·372	68·923	59·782	78	14·429	12·515	69·379	60·177
34	57·409	49·795	68·935	59·792	79	13·242	11·486	69·383	60·181
35	56·726	49·203	68·946	59·802	80	12·051	10·453	69·387	60·185
36	56·027	48·597	68·957	59·812	81	10·857	9·417	69·391	60·188
37	55·312	47·976	68·968	59·822	82	9·659	8·378	69·394	60·191
38	54·579	47·232	68·980	59·832	83	8·458	7·336	69·397	60·193
39	53·829	46·583	68·992	59·842	84	7·254	6·292	69·400	60·196
40	53·064	46·027	69·004	59·853	85	6·049	5·247	69·402	60·198
41	52·282	45·348	69·016	59·863	86	4·842	4·199	69·404	60·200
42	51·483	44·655	69·028	59·874	87	3·632	3·151	69·405	60·200
43	50·670	43·950	69·041	59·885	88	2·422	2·102	69·406	60·201
44	49·840	43·230	69·053	59·895	89	1·211	1·051	69·406	60·201
45	48·996	42·503			90	0·000	0·000		

Length of a degree of longitude at $\phi°$ latitude = cos $\phi_1°$ × 69·174 statute miles; where tan $\phi_1° = b \div a$ tan $\phi°$; a = equatorial radius (3963·36 miles), and b = polar radius (3950·06 miles); $b \div a = 3950{\cdot}04 \div 3963{\cdot}36 = 0{\cdot}99664$.

Example: What is the length of a degree of longitude at 50° latitude?

tan 50° = 1·1917536, therefore,

tan $\phi_1°$ = ·99664 × 1·1917536 = 1·1877493 = tan 49° 54′ 18″; cos 49° 54′ 18″ = ·6440569, therefore length of degree = ·6440569 × 69·174 = 44·552 statute miles.

Length of a degree of latitude at $\phi°$ latitude ($\phi°$ being at the middle of the arc) = 69·174 × (·99330 + ·01005 sin² $\phi°$) = 68·711 + ·6952 sin² $\phi°$ statute miles.

Example: What is the length of a degree of latitude between 30° and 31°?

$\phi°$ = 30° 30′, sin 30° 30′ = ·5075384, therefore length of degree = 68·711 + (·6952 × ·5075384 × ·5075384) = 68·711 + ·179 = 68·890 statute miles. (*H. R. Kempe.*)

APPROXIMATE DISTANCE OF OBJECTS WHEN FIRST SEEN AT SEA, THE OBSERVER'S EYE BEING SUPPOSED AT SEA LEVEL.

Height. Feet.	Distance. Naut. Miles.	Height. Feet.	Distance. Naut. Miles.	Height. Feet.	Distance. Naut. Miles.	Height. Feet.	Distance. Naut. Miles.	Height. Feet.	Distance. Naut. Miles.	Height. Feet.	Distance. Naut. Miles.
1	1·1	22	5·4	43	7·5	120	12·6	300	19·9	520	26·2
2	1·6	23	5·5	44	7·6	125	12·9	310	20·2	540	26·7
3	2·0	24	5·6	45	7·7	130	13·1	320	20·6	560	27·2
4	2·3	25	5·7	46	7·8	135	13·4	330	20·9	580	27·7
5	2·6	26	5·9	47	7·9	140	13·6	340	21·2	600	28·1
6	2·8	27	6·0	48	8·0	145	13·8	350	21·5	620	28·6
7	3·0	28	6·1	49	8·1	150	14·1	360	21·8	640	29·1
8	3·2	29	6·2	50	8·2	160	14·5	370	22·1	660	29·5
9	3·4	30	6·3	55	8·5	170	15·0	380	22·4	680	29·9
10	3·6	31	6·4	60	8·9	180	15·4	390	22·7	700	30·4
11	3·8	32	6·5	65	9·3	190	15·8	400	23·0	720	30·8
12	4·0	33	6·6	70	9·6	200	16·3	410	23·2	740	31·2
13	4·1	34	6·7	75	9·9	210	16·7	420	23·6	760	31·7
14	4·3	35	6·8	80	10·3	220	17·0	430	23·8	780	32·1
15	4·4	36	6·9	85	10·6	230	17·4	440	24·1	800	32·5
16	4·6	37	7·0	90	10·9	240	17·8	450	24·4	820	32·9
17	4·7	38	7·1	95	11·2	250	18·1	460	24·7	840	33·3
18	4·9	39	7·2	100	11·5	260	18·5	470	24·9	860	33·7
19	5·0	40	7·3	105	11·8	270	18·9	480	25·2	880	34·1
20	5·1	41	7·4	110	12·1	280	19·2	490	25·5	900	34·5
21	5·3	42	7·5	115	12·3	290	19·6	500	25·7	920	34·9

Example : From what distance will a hill 300 feet high be visible to an observer 20 feet abov the sea ?

To an observer on the summit of the hill the horizon would be 19·9 miles distant, and to th observer in the example it would be 5·1 miles distant, hence two such observers facing on another would just see each other at a distance of 19·9 + 5·1 = 25 miles, which is therefore th distance the hill will be visible.

ASTRONOMY.

The Earth and Sun.

Equatorial radius of the earth = 6,378,200 metres (3963·30 miles) (*Helmert*) = 6,378,3 metres (3963·42 miles) (*Hayford*) ; mean value, 6,378,294 metres (3963·36 miles). Polar radiu of the earth = 6,356,818 metres (3950·01 miles) (*Helmert*) = 6,356,909 metres (3950·06 mile (*Hayford*) ; mean value, 6,356,864 metres (3950·04 miles).

Equatorial horizontal parallax of sun (angle under which the equatorial radius of th earth would appear at the sun's centre) = 8″·80. Mean distance of sun from earth = $\frac{3963{\cdot}23}{\sin 8''{\cdot}8}$

= $\frac{3963{\cdot}23}{{\cdot}000042664}$ = 92,890,000 miles. Maximum distance (1st July) = 93,950,000 miles. Min mum distance (1st Jan.) = 90,950,000 miles.

Angle under which the radius of the sun would appear at the earth's centre, at the earth mean distance from the sun = 16′ 1″·18 (*Auwers*).

Radius of sun = $3963{\cdot}23 \frac{\sin 16'1''{\cdot}18}{\sin 8''{\cdot}8} = 3963{\cdot}23 \frac{{\cdot}0045699}{{\cdot}000042664}$ = 424,500 miles.

None of the foregoing numerical values can be accepted as absolute, as authorities are n agreed on the subject.

Identification of Stars.

In stellar observations for time, latitude, or azimuth, the star selected for observation m be conveniently found from the following notes, which describe the relative positions of t larger stars in the constellations. The angular distance between two stars can be closely estimat by comparison with half the distance between the observer's zenith and the horizon—i.e. 45°.

(*a*) In the constellation *Ursa Major* the two well-known stars α and β (THE POINTERS) poi directly to POLARIS, the Pole star. The latter also forms the end or tail of *Ursa Minor*.

(*b*) If the curve of the tail of *Ursa Major* be continued, about 30° along it will be fou ARCTURUS (α *Boötes*).

(*c*) A line from POLARIS at right angles to the line from THE POINTERS gives 50° from the former, CAPELLA (*α Aurigæ*).

(*d*) A line from POLARIS through the last star but one of the tail of *Ursa Major* passes through SPICA, 30° beyond ARCTURUS.

(*e*) The POINTERS' line continued through POLARIS for 60° indicates THE GREAT SQUARE OF PEGASUS. The star in the corner opposite to the Pole is MARKAB.

(*f*) Midway between the SQUARE and POLARIS is the constellation *Cassiopeia* (five stars grouped like W).

(*g*) A diagonal through the SQUARE S.E. to N.W. produced 40° gives DENEB (*α Cygni*).

(*h*) 25° further and 10° to the right the same line gives VEGA (*α Lyræ*), a large white star.

(*j*) 35° south of DENEB and VEGA is ALTAIR (*α Aquilæ*). This star is between two companions, and forms the apex of an isosceles triangle with DENEB and VEGA.

(*k*) A line from POLARIS through CAPELLA will touch RIGEL, 65° from CAPELLA. This line passes between ALDEBARAN (*α Tauri*), 10° west and 30° from CAPELLA, and BETELGEUSE, 10° east and 40° from CAPELLA. RIGEL and BETELGEUSE are diagonal stars in *Orion*.

(*l*) A line from ALDEBARAN through *Orion's Belt* passes near SIRIUS (*α Canis Majoris*) at an equal distance from ALDEBARAN. This is the brightest star in the heavens.

(*m*) 50° east of BETELGEUSE, forming nearly an equilateral triangle with BETELGEUSE and SIRIUS, is PROCYON.

(*n*) 30° north of PROCYON is CASTOR, and 5° S.E. of CASTOR is POLLUX.

(*o*) The apex of an isosceles triangle with CASTOR and PROCYON, 45° east, is REGULUS (*α Leonis*).

(*p*) Eastward from PROCYON to REGULUS 30° is DENEBOLA. DENEBOLA forms an equilatera triangle with ARCTURUS and SPICA.

ASTRONOMY IN FIELD WORK.

(*Fred. Simpson, A.M.I.C.E.*)

Choice of Instrument.

Choice of Instrument.—The most suitable instrument is the Transit Theodolite provided with a delicate level attached to the vernier arms of the vertical circle, and a sensitive striding level for use on the pivots of the horizontal axis. See figs. 119K, 119L, pp. 175, 176. The adjustments must be made as perfectly as possible, and the residual index error carefully ascertained. The value of a division of each of the sensitive levels should be determined, and the position of the bubbles should be noted at the time of observing, and an allowance made for any variation in their readings. The most suitable form of diaphragm for astronomical work is that with simple vertical and horizontal cross hairs. For night work on stars it is necessary to illuminate the cross hairs, if the instrument is not provided with an illuminated axis; a lamp held a little distance in front of, and a little on one side of the object glass, may be used for this purpose.

With the ordinary eyepiece, altitudes exceeding 60° cannot be conveniently taken; for greater altitudes some form of diagonal attachment to the eyepiece is required. A makeshift arrangement can be improvised with a small piece of mirror held in the hand, or provisionally attached in front of the eyepiece at an angle of 45° to the axis of the telescope.

In observing the sun, a very convenient method, less trying to the eyes, is to cast the image of the sun and cross hairs on to a piece of white paper or card (to act as a screen) held about

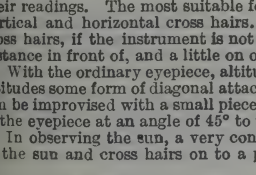


FIG. 123.

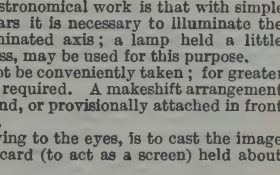


FIG. 124.

three or four inches from the eyepiece; the telescope must be focused for long-distance vision, with the cross hairs in focus; the telescope is then directed to the sun, and the eyepiece drawn out until perfect images of the sun and cross hairs are projected on the screen, the diameter of the image of the sun being smaller as the eyepiece is withdrawn. If the telescope inverts with direct vision, the image on the screen will be erect.

The limbs of the sun are observed when tangential to the respective cross hairs; the image of the sun should be allowed to leave one cross hair clamped a little in advance and followed with the other cross hair, using the tangent motion, so that the moving hair is brought tangential to the other limb as the first limb is just leaving the fixed hair; in this way only one hand is

occupied with the tangent motion. The correction for semi-diameter must be applied to the readings in altitude and azimuth. In the case of the altitudes, the correction for semi-diameter is applied as taken from the Almanac; in that of the azimuths, the correction to be applied to the horizontal circle reading is approximately the semi-diameter, taken from the Almanac, multiplied by the secant of the angle of altitude. These corrections apply to observations taken on any one limb of the sun to reduce the reading to the centre of the sun; but by taking the means of pairs of observations, on the upper and lower limbs for altitude, and on the right and left limbs for azimuth, the necessity for correction for semi-diameter is eliminated.

In a double observation on upper and lower and right and left limbs, a pair of observations are made, one in which the horizontal hair is fixed in advance, the vertical hair being moved by the tangent motion of the horizontal circle; the other observation is then made with the vertical hair fixed in advance, the tangent motion of the vertical circle being then used to follow the lower or upper limb with the horizontal cross hair, up to the time of the vertical hair, with the right or left limb which is being observed.

The cross hair which is being moved should always be kept slightly on the disc of the sun, up to the time of contact with the other hair, as it becomes indistinct when off the disc.

The means of the circle readings of the altitudes and azimuths taken in this way will be thus reduced to the centre, and will correspond to the mean of the times of observations, and no correction for semi-diameter is required.

Altitudes require correction for index error (+ or −), for refraction corresponding to altitude (always −), parallax (in case of sun or planets) corresponding to altitude (always +); semi-diameter in case of sun or planets, + if lower limb is observed, − if the upper; this correction is eliminated if observations on upper and lower limbs are combined.

Refraction.—The mean refraction values are near enough for ordinary purposes when the altitude observed is over 20°, but for lower altitudes a correction may be necessary, corresponding to the altitude, temperature, and barometric pressure; refraction decreasing with higher temperature and increasing with higher barometric pressure.

Parallax.—The horizontal parallax of the sun is approximately 9″, and for any given altitude = 9 × cosine of altitude, in seconds.

Declination as taken from the Almanacs must be corrected to correspond to the time of observation referred to time at the principal meridian adopted in the Almanac; generally it is sufficient to know his time to within ten minutes in spring or autumn, or within thirty minutes in summer or winter.

To Find Latitude.

Latitude may be deduced from a single altitude of a star, or the upper or lower limb of the sun, when crossing the meridian. This altitude is corrected for index error and refraction in the case of a star; in that of the sun a further correction is required for parallax and semi-diameter to reduce the altitude to the sun's centre. The declination is corrected to the time of observation.

In the case of the sun, and of stars with declination less than the latitude if of the same name:—
Latitude = 90° − (altitude + declination), if declination is of the opposite name to latitude
Latitude = 90° − (altitude − declination), if declination is of the same name as latitude.
In case of stars with declination of the same name, but greater than latitude:—
Latitude = (altitude + declination) − 90° at the upper transit.
Latitude = altitude + (90° − declination) at lower transit of circumpolar stars.

More exact determination of the meridian altitude can be obtained from a series of ex-meridian altitudes taken about the time of the star or sun's meridian passage, provided three altitudes are taken at equal intervals of time, or equal intervals of azimuth (it is immaterial what interval are taken, but they must be equal and not extend more than about twenty minutes on either side of the meridian passage).

The corrected altitude at the meridian may be obtained by the following reduction:—

Subtract the lowest altitude from the other two and let these differences, reduced to seconds, be denoted by d_1 and d_2; then the meridian altitude will be = lowest altitude + $\frac{(4d_1 - d_2)^2}{8(2d_1 - d_2)}$ seconds.

EXAMPLE.—Three altitudes of the upper limb of the sun were taken at intervals of 6 minutes as follows:

	° ′ ″	° ′ ″	° ′ ″
	38 10 35	38 12 40	38 12 30
+ correction	2 17	− 38 10 35	× 38 10 35
= altitude on meridian, upper limb	38 12 52	2 05 = 125′	1 55 = 115′

$$\frac{(4 \times 125 - 115)^2}{8(2 \times 125 - 115)} = 137'' = 2' 17''.$$

To Find Time and Azimuth.

Time and Azimuth from sun or star altitudes.

Let a = altitude observed (corrected for under error and refraction in case of star, as well as for parallax and semi-diameter in case of sun);

l = latitude

p = polar distance = 90° − declination, if latitude and declination are of the same name, = 90° + declination, if latitude and declination are of different names.

$$s = \frac{a + l + p}{2};$$

then,

$$\log \sin \tfrac{1}{2} \text{ Hour Angle} = \frac{\log \sec l + \log \operatorname{cosec} p + \log \cos s + \log \sin (s - a)}{2}$$

$$\log \cos \tfrac{1}{2} \text{ Azimuth} = \frac{\log \sec a + \log \sec l + \log \cos s + \log \cos (p - s)}{2}$$

The Hour Angle in arc is reduced to time; if from a P.M. observation of the sun this will be Apparent Time P.M., but if from an A.M. observation this Hour Angle in time should be deducted from 12, the result being Apparent Time A.M. To arrive at Mean Time, the Equation of Time must be added or subtracted as directed in the Almanac, this Equation of Time being first corrected to correspond to the approximate time of the observation at the principal meridian to which the Almanac refers.

In star observations for time, the Hour Angle found and reduced to time is deducted from or added to the Right Ascension of the star (deducted from if before the meridian transit, but added to if after), this gives the Sidereal Time of observation. Take the Right Ascension of the Mean Sun for the previous noon from the Almanac, and correct this to the meridian of the place of observation; this deducted from the Sidereal Time of observation, and the difference reduced to Solar Time, will give the Mean Time of the observation.

	h. m. s.	h. m. s.
E.g., suppose Hour Angle found after transit of meridian		4 30 24
Right Ascension of star		8 10 43
Sidereal Time at observation		12 41 07
R.A. Mean Sun	1 35 28	
Correction for longitude 3 h. 54 m. West	+ 38	
		1 36 06
Interval in Sidereal Time from Mean Noon		11 05 01
Correction of interval, Sidereal to Mean Time		− 1 49
Mean Time of observation		11 03 12

The horizontal circle reading of the azimuth found as above should be corrected for the inclination of the horizontal axis of the vertical circle as denoted by the reading of the cross striding level; the difference of level in seconds of arc multiplied by the tangent of the altitude taken will give the correction to the horizontal circle reading this being added if the left-hand pivot is highest, and subtracted if the right-hand pivot is highest. The circle reading of some distant well-defined object should be used as a Reference Point to which the azimuth observed will then be connected.

In a series of observations where the sun has been utilised in the daytime, and it is desired to connect up a series of observations on stars, the adjustment of the instrument should be carefully gone over after sundown, and when the instrument has attained an even temperature, the Reference Point being utilised to check the results of the day observations with those of the night.

The degree of accuracy of the results will depend upon the care taken to eliminate slight errors in the data assumed or instrumental defects. In the case of observations for time, the taking of the mean of a combination of A.M. and P.M. observations will to a great extent eliminate the slight errors that may be due to instrumental defects, incorrect latitude assumed, or almanac corrections to date. The same remarks apply also to Azimuth except that the cross level error can only be eliminated by observations taken with reversed positions of vertical axis. In observations for latitude the errors of the instrument can be to a great extent corrected by taking the mean of meridian observations on stars to the north and to the south of the zenith.

EXAMPLE (in time and azimuth; P.M. observation). Data: latitude (l) 53° 29′ 05″ N.; corrected declination, 0° 35′ 13″ S.; corrected altitude of the sun's centre (a) 20° 37′ 18″; polar distance (p) 90° + 0° 35′ 13″ = 90° 35′ 13″.

Time.			*Azimuth.*		
	h. m. s.			° ′ ″	
a =	20 37 18		a =	20 37 18	log sec 0·02876
l =	53 29 05	log sec 0·22546	l =	53 29 05	log sec 0·22546
p =	90 35 13	log cosec 0·00002	p =	90 35 13	
	2)164 41 36			2)164 41 36	
s =	82 20 48	log cos 9·12444		82 20 48	log cos 9·12444
$s-a$ =	61 43 30	log sin 9·94482	$(p-s)$ =	8 14 25	log cos 9·99549
		2)19·29474			2)19·37415
½-hour angle	26 21 30	log sin 9·64787		60 53 30	log cos 9·68707
	2			2	
hour angle	52 43 00	in arc	Azimuth N. 121 47 00 W.		
	4				
hour angle	3 30 52	in time			

To Find Azimuth from Greatest Elongation of Circumpolar Stars.

At instant of greatest elongation:—

$$\sin \text{Azimuth} = \cos d \sec l;$$
$$\cos \text{Hour Angle} = \tan l \cot d;$$
$$\sin \text{Altitude} = \sin d \operatorname{cosec} l.$$

The Hour Angle, reduced to time, is added to the Right Ascension of the star if the Greatest Elongation is to the west of the meridian, or subtracted if to the east; this will give the Sidereal time of the Greatest Elongation. The sidereal time of the mean sun's passage of meridian for the succeeding noon subtracted from this will give the sidereal interval of time from noon, which, reduced to mean time, will give the Mean Time of Greatest Elongation. The altitude at Greatest Elongation is useful in setting the instrument for the observation.

Without knowledge of the latitude the Azimuth may be obtained from two observations on stars, one to the east, the other to the west of the meridian, and from the horizontal angle between them, which will be the sum of their Azimuths. Let this angle be denoted by ($A + A_1$), and let d and d' be the respective declinations of the stars used, then,

$$\tan\left(\frac{A - A_1}{2}\right) = \tan\frac{d + d_1}{2} \times \tan\frac{d - d_1}{2} \times \tan\left(\frac{A + A_1}{2}\right),$$

giving the half difference of Azimuths, which added to and subtracted from the half sum of Azimuths will give A and A_1 respectively. The latitude can then be computed from one of the Azimuths and found by formula

$$\cos l = \cos d \operatorname{cosec} A.$$

EXAMPLE.—Taking stars β Crucis (d_1 = 59° 06′ 30″ S.); γ Hydri (d = 74° 33′ 59″ S.); angle between their Greatest Elongations 57° 33′ 33″ (= $A + A_1$).

$\frac{d + d_1}{2}$ =	66° 50′ 14½″	l tan	0·36874
$\frac{d - d_1}{2}$ =	7 43 44½	l tan	9·13264
$\frac{A + A_1}{2}$ =	28 46 46½	l tan	9·73980
$\frac{A - A_1}{2}$ =	9 53 05	l tan	9·24118
	± 28 46 46½		

Greatest Elongation γ Hydri 18 53 41½
" " β Crucis 38 39 51

The latitude may then be calculated as follows, from γ Hydri :—

Azimuth	18° 53′ 41½″	l cosec 0·48968
d	74 33 59	l cos 9·42508
		l cos 9·91476

latitude = 34 43 55 S.

To reduce Mean Solar Time intervals to Sidereal Time intervals (approximate).

Reduce interval into hours and decimals of an hour, multiply by 10 and diminish product by $\frac{1}{10}$; the result will be correction in seconds to be *added* to Mean Time interval.

	h. m. s.	
EXAMPLE.	16 30 18 M.T.	16·505 × 10 = 165·05
Correction	+ 2 42·7	− $\frac{1}{10}$ 2·36
	16 33 00·7 Sidereal T.	162·69 sec.
		= 2 m. 42·69 sec.

To reduce Sidereal to Mean Time intervals.

Reduce intervals into hours and decimals of an hour, multiply by 10 and diminish product by $\frac{1}{10}$; the result will be correction to be *subtracted* from Sidereal Time interval.

	h. m. s.	
EXAMPLE.	16 33 00·7 Sid. T.	16·5502 × 10 = 165·50
Correction	− 2 42·7	− $\frac{1}{10}$ 2·76
	16 30 18 M.T.	162·74 sec.
		= 2 m. 42·74 sec.

The error in using these approximations will be less than $\frac{1}{10}$ second in a 24-hour interval.

To Find Longitude by Moon Culminating Stars.

This is the most convenient method for determining the longitude when the Mean Time at Greenwich is not accurately known, the only requirements being a well-adjusted transit theodolite, a watch whose rate can be depended upon for a short interval of time but whose actual error need not be known, and a Nautical Almanac.

The moon varies comparatively rapidly in Right Ascension (R.A.), but its R.A. at the instant of its transit across the plane of the meridian can be accurately determined by comparing its time of transit with that of a star or stars which pass the meridian about the same time.

The theodolite is adjusted with its line of collimation in the plane of the meridian by the aid of one of the methods before described for obtaining azimuths ; the time of transit, over the centre thread, of the selected stars of reference and the moon's bright limb are carefully noted.

The intervals (reduced to Sidereal Time) between the times of transit of the respective stars and the time of transit of the moon's bright limb, added to the R.A. of the respective stars (in the case of stars which transit before the moon), or subtracted from the R.A. of any stars which transit after the moon, will give the R.A. of the moon's bright limb at the instant of its transit over the meridian.

We have, under the heading of 'Moon Culminating Stars,' the R.A. of the moon's bright limb at its transit at Greenwich, and also the variation of the moon's R.A. in one hour of longitude expressed in seconds ; the difference between the R.A. of the moon's bright limb when passing the meridian of Greenwich and the R.A. as found when passing the meridian at the place of observation gives the change of R.A., and this difference (reduced to seconds), being divided by the variation corresponding to one hour difference of longitude, will give the difference of longitude between Greenwich and the place of observation expressed in hours and fractions of an hour.

Under the same heading of 'Moon Culminating Stars' will be found convenient pairs of stars which transit within half an hour or so of the time of transit of the moon, and which have a declination nearly that of the moon, so that a slight movement of the telescope of the instrument

inaltitude will bring them within its field. As these stars are generally of small magnitude and not easily distinguishable it is advisable to (approximately) calculate the altitude at which they cross the meridian ; the instrument may then be set in advance so that the star will cross approximately in the centre of the field. Any of the stars catalogued in the Nautical Almanac of greater magnitude, and easily distinguishable, may be used, but their declination and R.A. should not differ much from those of the moon.

When the longitude of the place of observation differs considerably from that of Greenwich the ' variation for one hour ' given in the tables should be corrected by interpolation to correspond to the approximate middle interval of time between the transit at Greenwich and that of the observed transit.

Let

t_1 t_2 be the observed times of transit of the star and the moon's bright limb ;

RA_1, RA_2 be the Right Ascensions of the star and the moon's bright limb taken from the catalogue ;

c the hourly variation (corrected, if necessary, to the middle time) ;

then the longitude in time $= \dfrac{(t_1 - t_2) - (RA_1 - RA_2)}{c}$,

the interval $(t_1 - t_2)$ if in Mean Time must be reduced to Sidereal Time,

$(RA_1 - RA_2)$ must be expressed in seconds,

the longitude will be expressed in hours and fractions of an hour, and to the west if positive and to the east if negative.

Timing Observations.

When working with an assistant the time may be noted at the instant a signal is given by the observer, but when observing alone it is difficult to note the exact time of contact or transit on watch or chronometer when the hands are employed in manipulating the instrument and the eye engaged in taking the sight.

In this case a convenient method is to use a watch whose time of beat is known (in modern watches usually $\frac{1}{5}$ second) ; this watch should be in such a position that the beats are distinctly heard, for example, suspended over the ear from the cap, in a small bag or watch pocket. The beats are then counted from the instant of contact or transit and continued until the second finger of the standard timepiece can be noted on some convenient second ; this time noted less the number of beats of the auxiliary watch, reduced to seconds and fractions, will be the actual time of the observation.

As probably some little time may elapse after the observation before the standard timepiece can be read, especially at night where a lamp has to be used, this extended counting of beats of say $\frac{1}{5}$ second becomes difficult when arriving at the double syllable numbers ; but by adding a ' dummy ' syllable to the first twelve counted and then continuing with ' thir-teen,' ' four-teen ' and so on, giving one syllable to each beat, the counting of $\frac{1}{5}$ seconds becomes quite easy, even if carried to 100 beats and over, e.g. taking the dummy syllable as ' and,' and starting the instant of observation with ' nought,' the counting would continue :—' nought-and,' ' one-and,' ' two-and,' ' three-and,' . . . ' leven-and,' ' twelve-and,' ' thir-teen,' ' four-teen,' . . . ' twen-ty ' twent'-one,' and so on. Then taking the first syllable as units and the second syllable as half the counted beats multiplied by 4 and divided by 10 will give the required intervals in seconds and tenths, in the case of the auxiliary watch beating fifths of seconds.

Taking examples, say the beats counted between the instant of observation and the time noted on the timepiece was on the first syllable to thirty-seven, the time at that beat being 3 hrs. 47 mins. 15 secs. ; then the interval to be deducted would be $\dfrac{37 \times 4}{10} = 14{\cdot}8$ seconds and the corrected time of the observation would then be 3 hrs. 47 mins. 15 secs. $- 14{\cdot}8$ secs $= 3$ hrs. 47 mins. $0{\cdot}2$ secs. In another case, say the second syllable of ' nine-and ' corresponds to 6 hrs. 22 mins. 55 secs. on the timepiece, the correction would then be $\dfrac{9\frac{1}{2} \times 4}{10} = 3{\cdot}8$ seconds and the corrected time of observation 6 hrs. 23 mins. 55 secs $- 3{\cdot}8$ secs. $= 6$ hrs. 23 mins. $51{\cdot}2$ secs.

This method of measuring short intervals of time is useful in other instances ; for example in estimating distances by the velocity of sound, etc.

TABLE OF MEAN REFRACTIONS.

Corresponding to altitudes, A; at 50° F. and Barometer 29½ ins.

A	0′	5′	10′	15′	20′	25′	30′	35′	40′	45′	50′	55′
°	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″
0	34 54	33 51	32 49	31 50	30 52	29 57	29 3	28 12	27 23	26 35	25 50	25 6
1	24 25	23 45	23 7	22 30	21 56	21 23	20 51	20 21	19 52	19 24	18 58	18 33
2	18 7	17 45	17 23	17 1	16 41	16 20	16 1	15 42	15 23	15 5	14 48	14 31
3	14 15	13 59	13 44	13 29	13 15	13 1	12 48	12 36	12 24	12 12	12 1	11 50
4	11 39	11 28	11 18	11 8	10 59	10 49	10 40	10 30	10 21	10 12	10 3	9 55
5	9 47	9 39	9 31	9 23	9 16	9 9	9 2	8 55	8 48	8 54	8 36	8 29
6	8 23	8 17	8 12	8 6	8 0	7 55	7 49	7 44	7 39	7 34	7 29	7 24
7	7 20	7 15	7 11	7 6	7 2	6 57	6 53	6 49	6 45	6 42	6 37	6 33
8	6 30	6 26	6 22	6 18	6 15	6 12	6 8	6 5	6 2	5 59	5 55	5 52
9	5 49	5 46	5 43	5 40	5 38	5 35	5 32	5 29	5 26	5 24	5 21	5 19
10	5 16	5 14	5 11	5 9	5 6	5 4	5 2	4 59	4 57	4 55	4 53	4 51
11	4 49	4 46	4 44	4 42	4 40	4 38	4 36	4 34	4 32	4 30	4 29	4 27
12	4 25	4 23	4 21	4 20	4 18	4 16	4 15	4 13	4 11	4 10	4 8	4 7
13	4 5	4 3	4 2	4 0	3 59	3 57	3 56	3 54	3 53	3 52	3 50	3 49
14	3 47	3 46	3 45	3 43	3 42	3 41	3 39	3 38	3 37	3 36	3 35	3 33
15	3 32	3 31	3 30	3 29	3 27	3 26	3 25	3 24	3 23	3 22	3 21	3 20
16	3 19	3 18	3 16	3 15	3 14	3 13	3 12	3 11	3 10	3 9	3 8	3 7
17	3 7	3 6	3 5	3 4	3 3	3 2	3 1	3 0	2 59	2 58	2 57	2 57
18	2 56	2 55	2 54	2 53	2 52	2 52	2 51	2 50	2 49	2 48	2 48	2 47
19	2 46	2 45	2 45	2 44	2 43	2 42	2 42	2 41	2 40	2 39	2 39	2 38
20	2 37	2 37	2 36	2 35	2 35	2 34	2 33	2 33	2 32	2 31	2 31	2 30
21	2 29	2 29	2 28	2 27	2 27	2 26	2 26	2 25	2 24	2 24	2 23	2 22
22	2 22	2 21	2 21	2 20	2 20	2 19	2 18	2 18	2 17	2 17	2 16	2 16
23	2 15	2 15	2 14	2 14	2 13	2 13	2 12	2 11	2 11	2 10	2 10	2 9
24	2 9	2 8	2 8	2 7	2 7	2 7	2 6	2 6	2 5	2 5	2 4	2 4

A	0′	10′	20′	30′	40′	50′	A	0′	10′	20′	30′	40′	50′
°	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″	°	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″
25	2 3	2 2	2 1	2 0	2 0	1 59	40	1 9	1 8	1 8	1 8	1 7	1 7
26	1 58	1 57	1 56	1 55	1 54	1 54	41	1 6	1 6	1 6	1 5	1 5	1 4
27	1 53	1 52	1 51	1 50	1 50	1 49	42	1 4	1 4	1 3	1 3	1 3	1 2
28	1 48	1 47	1 47	1 46	1 45	1 45	43	1 2	1 1	1 1	1 1	1 0	1 0
29	1 44	1 43	1 42	1 42	1 41	1 40	44	1 0	59	59	59	58	58
30	1 40	1 39	1 38	1 38	1 37	1 36	45	58	57	57	57	56	56
31	1 36	1 35	1 35	1 34	1 33	1 33	46	56	55	55	55	54	54
32	1 32	1 32	1 31	1 30	1 30	1 29	47	54	54	54	53	53	52
33	1 29	1 28	1 27	1 27	1 26	1 26	48	52	52	51	51	51	50
34	1 25	1 25	1 24	1 24	1 23	1 23	49	50	50	50	49	49	49
35	1 22	1 22	1 21	1 21	1 20	1 20	50	48	48	48	48	47	47
36	1 19	1 19	1 18	1 18	1 17	1 17	51	47	46	46	46	46	45
37	1 16	1 16	1 16	1 15	1 15	1 14	52	45	45	45	44	44	44
38	1 14	1 13	1 13	1 12	1 12	1 12	53	43	43	43	43	42	42
39	1 11	1 11	1 10	1 10	1 10	1 9	54	42	42	41	41	41	41

A	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
°	″	″	″	″	″	″	″	″	″	″
50	48	47	45	43	42	40	39	37	36	35
60	33	32	31	29	28	27	26	25	23	22
70	21	20	19	18	17	15	14	13	12	11
80	10	9	8	7	6	5	4	3	2	1

SUN'S PARALLAX IN ALTITUDE.

A	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Parallax	9″	9″	8″	8″	7″	6″	5″	3″	2″	0″

Graphic Method of finding Time and Azimuth from Altitude of Sun or Star.

Describe a circle, fig. 125, of any convenient radius; through the centre O draw diameter MOM_1. From O draw PO making angle POM equal to the latitude; draw OQ at right angles to PO. Through O draw OA, making AOM equal to the corrected altitude, and OD, making DOQ equal to the corrected declination, and on the side of OQ towards P if the declination and latitude are of the same name, or on the opposite side if of different names.

Through A draw AA_1 parallel to MM_1 and through D draw DD_1 parallel to QO, intersecting AA_1 in s.

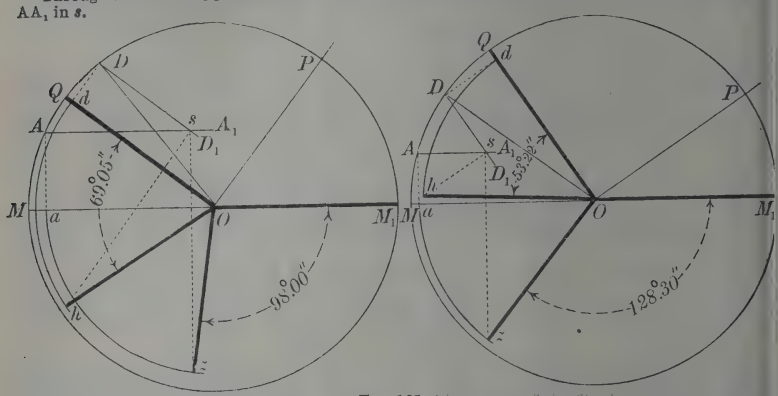


FIG. 125.

Data.	Result.	Data.	Result.
Lat. 53° 30′ N.	Azimuth N. 98° 00′ W.	Lat. 34° 30′ S.	Azimuth S. 128° 30′ W.
Dec. 14° 50′ N.	Hour Angle 69° 05′	Dec. 19° 50′ N.	Hour Angle 53° 22′
Alt. 24° 20′ P.M.		Alt. 15° 40′ P.M.	

To find the Azimuth.

Drop a perpendicular from A to OM, intersecting this latter in a; from centre O and radius Oa draw arc az, and from s draw sz perpendicular to MOM_1, intersecting arc az in z; through z draw Oz. Then the angle M_1Oz will represent the azimuth from the elevated pole east or west of the meridian according as the time (A.M. or P.M.) at which the observation was made.

To find the Hour Angle.

Draw Dd at right angles to QO, and with centre O and radius Od draw arc dh; from s draw line sh perpendicular to QO, intersecting arc dh in h; draw line Oh. Then QOh will be the hour angle at the time of observation before or after apparent noon.

This diagrammatic method may be utilised for approximate determination of other problems, such as azimuth and time of sun or stars at instant of rising or setting; altitude and azimuth at a given time; or for altitude and time of passing prime vertical.

Geodetic Formulæ.

From measurements made of various meridians and parallels it has been found that the earth has the form of an ellipsoid of revolution with its greatest diameter at the equator and its least between the poles; and that the radius of curvature of the meridian varies with the latitude, being least at the equator and greatest at the poles, so that the length of a degree of latitude is more at the poles than at the equator. The length of a degree of longitude varies also with the latitude, being greatest at the equator and zero at the poles.

In treating with measurements of an extensive character over the surface of the earth, it is necessary to take into account its ellipsoidal shape, and it is convenient to employ certain approximations, so that spherical trigonometry may be used in the solution of the problems involved. The following formulæ enable the radius of a spherical surface to be found that approximates most nearly to the ellipsoidal surface embracing the area under consideration.

In these formulæ
a = the equatorial radius of the earth; e = the eccentricity; ϕ = the mean latitude; A = the azimuth.

$$\text{Radius of curvature of meridian} = Q = \frac{a(1-e^2)}{\sqrt{(1-e^2\sin^2\phi)^3}}.$$

$$\text{Radius of curvature of normal section perpendicular to meridian} = N = \frac{a}{\sqrt{(1-e^2\sin^2\phi.)}}$$

Radius of curvature of a normal section which cuts meridian at an angle A

$$= \frac{QN}{Q \sin^2 A + N \cos^2 A}.$$

Radius of curvature of an area of the earth's surface, or mean curvature $= \sqrt{QN}$.

Radius of a parallel of latitude $= N \cos \phi = \frac{a \cos \phi}{\sqrt{1 - e^2 \sin^2 \phi}}$

The logarithms of the most probable values of the constants used above are as follows (taking a in statute miles):—

$$\log. a = 3{\cdot}59806. \qquad \log. e^2 = 7{\cdot}83047. \qquad \log. (1 - e^2) = 9{\cdot}99853.$$

Adopting the radius which most nearly corresponds to the surface considered at the mean latitude ϕ, any measured length l on this surface may be reduced to arc by one of the following formulæ, ρ being the radius adopted reduced to the same unit as l:—

$\frac{l \times 57{\cdot}2958}{\rho}$ in degrees of arc; $\frac{l \times 3437{\cdot}747}{\rho}$ in minutes of arc; $\frac{l \times 206265}{\rho}$ in seconds of arc.

The table on page 185, 'Length of a Degree of Longitude and Latitude,' is calculated from the accepted dimensions of the earth. Values for intermediate latitudes may be obtained from this table, by interpolating, with sufficient exactitude for most purposes. The length of a degree on a great circle at right angles to the meridian at a given latitude may be obtained by multiplying the length of a degree of longitude (as taken from the table) by the secant of the latitude.

Convergence of Meridians.

In traverses and route surveys, a survey line is referred to a meridian at a certain point crossing the meridian with an azimuth A, this line, if continued in the same direction, having increased or diminished azimuths. The differences of azimuth can be approximately determined by calculating the convergence of the meridian corresponding to a given unit departure at the mean of the latitudes, and multiplying this by the departure as calculated from the traverse. To obtain the azimuth on crossing the second meridian, the convergence obtained in the manner just explained is added to or subtracted from the azimuth crossing the first meridian, being added where the longitude is increased and subtracted where the longitude is diminished.

The convergence, corresponding to various unit lengths of departure, may be calculated by the following formulæ, with sufficient approximation for use in ordinary traverse surveying. The length of a degree of longitude corresponding to the mean latitude is taken in miles from table, page 193, interpolating if necessary; then:—

Log. of convergence in seconds per mile of departure
$= \log. \sin \phi + 3{\cdot}55630 - \log.$ miles per 1° longitude.

Log. of convergence in seconds per 1,000 feet of departure
$= \log. \sin \phi + 2{\cdot}83367 - \log.$ miles per 1° longitude.

Log. of convergence in seconds per 1,000 metres of departure
$= \log. \sin \phi + 3{\cdot}34966 - \log.$ miles per 1° longitude.

To range a parallel of latitude by setting out chords of a given length:—

The chords are ranged making an angle to the meridian of 90° — half the angle of convergence corresponding to the length of the chord at the proposed latitude. The succeeding chords will have an angle of deflection from the preceding chord produced, equal to the convergence corresponding to the length of chord used.

To range a parallel of latitude by means of offsets:—

A line is run, perpendicular to the meridian, then the lengths of offsets are equal to the distances along this perpendicular line multiplied by the sine of half the angle of convergence corresponding to the lengths.

If the offsets are equidistant the length of the second offset will be four times the length of the first; the third, nine times the first, and so on; the nth offset will be n^2 times the length of the first.

Horizontal Sun Dial.

On a line NS, fig. 126, mark off a convenient length NO; from O set off a line towards L, making an angle NOL equal to the latitude of the position (taken in diagram 53° 30′), and from N draw a perpendicular to OL, cutting the latter in point L. From N and with length NL mark off a point C in the line NS, and with C as centre and the same length NL as radius describe the quadrant NQ and join NQ with a straight line.

Divide the quadrant NQ into six equal parts (each corresponding to one hour) and from these divisions on the arc draw lines towards the centre C and mark the points at which these radial lines cross the line NQ.

From O draw a line perpendicular to NS and mark off OE equal to CQ and join NE.

From each division on line NQ draw a line parallel to NS, marking where this line crosses the line NE in each case.

Then lines drawn from O through each of these points, marked off in NE, will be the dial lines corresponding to the hour divisions on the quadrant from which they were found respectively.

Having completed the divisions of one quadrant, these angles may be transferred to the other quadrants but in reverse order (VI–VII equals VI–V, VI–VIII equals VI–IIII, and so on).

An allowance must be made for the thickness of the style between the AM and PM portions of the dial, the AM dial being exactly similar to the PM dial but drawn with the XII lines the thickness of the style apart.

The style is constructed with the angle of inclination of the inclined face equal to the latitude of the site, its lower point at O and its upper towards the elevated pole, so that its

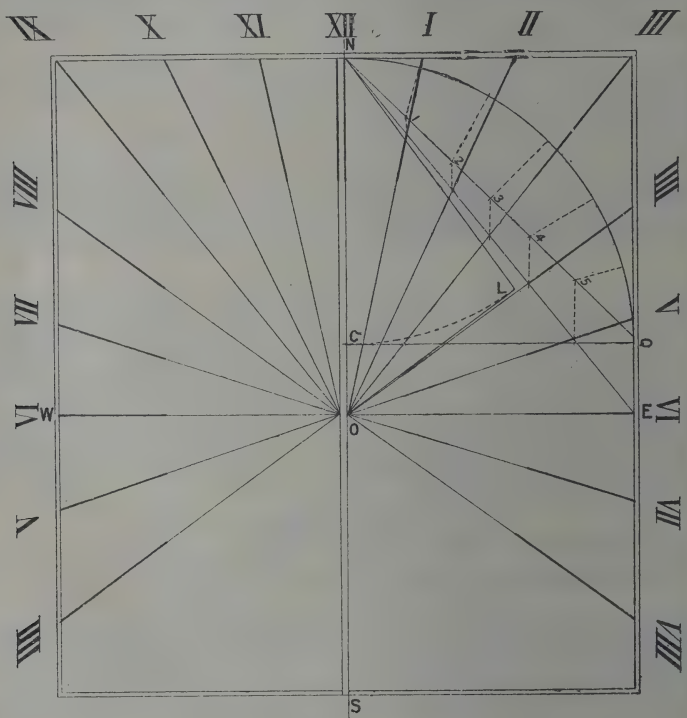


FIG. 126.

plane is in that of the meridian, the XII (noon) lines pointing towards the north in northern latitudes or towards the south in southern latitudes, and the VI–VI lines pointing east and west, so that the upper face of the style will be parallel to the Polar axis. The plane of the dial should be perfectly level.

(Methods of fixing the direction of the true north and south line will be found on page 184.)

The time indicated by the dial is sun time, and to get mean time the table of Equation of Time, page 184, should be applied as there directed. To arrive at standard time a constant correction must be applied according to the difference of longitude between the dial and the standard meridian (Greenwich in Great Britain) adopted in the country (subtracted if to the east or added if to the west).

The dial angles may be calculated if preferred by formula :

$$\tan t = \sin l \tan h ;$$

where

t = angle at O from NO to the hour line on dial corresponding to h ; l = latitude of position : h = hour angle.

SECTION III.

PART II.

DRAWING.

(Contributed by H. A. Miles.)

Engineering drawings are usually required for one of two purposes, viz. as illustrations or for workshop use. The former, which are not necessarily to scale, or dimensioned, may be either 'line' or 'wash' drawings—the first for preference—or prepared from photographs in the following manner. A bromide print is outlined and worked up with waterproof ink, after which the photographic image is bleached out. This is useful in complicated perspective views, or where the skill of the draughtsman is not equal to elaborate freehand work.

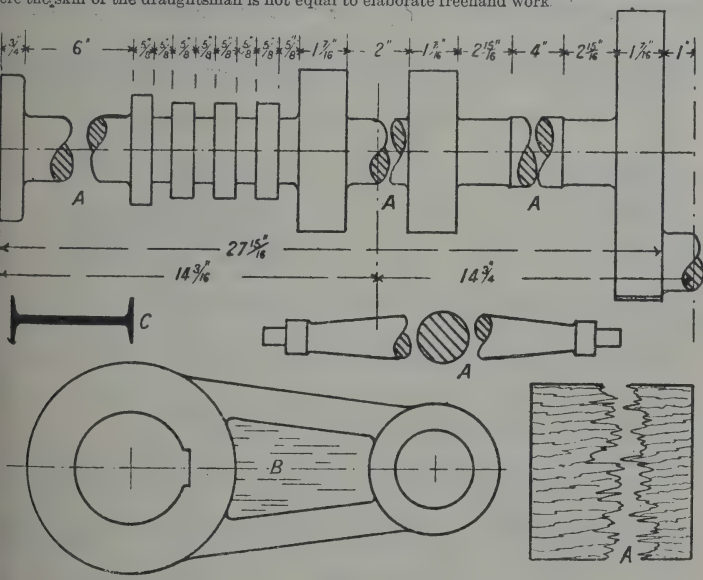


FIG. 1.

For reproduction purposes, drawings should always be prepared to an enlarged scale—twice full size is usual. If a scale is necessary it should be *drawn* (not denoted in words), so as to be reduced proportionately with the illustration to which it refers. Bold and striking effects should be aimed at, simplicity rather than elaboration being most effective. Shade lines and dotted hidden details are both useful, and surface lining, B, fig. 1, is sometimes necessary, but care must be taken to avoid overcrowding. A good rule is never to introduce a superfluous line or to omit one which is necessary.

The best material is 'Turkey Mill' paper or 'Bristol Board,' but it is sometimes advantageous to use tracing cloth, and (provided it is not yellow) good results will be secured with this. The blackest of black ink should be employed. All artists' colourmen now stock the liquid carbon or waterproof ink, and process black, either of which will be found suitable.

For workshop purposes a drawing should be looked upon as a book explaining the designer's views—it should be easily 'read' by the mechanic, and must contain all information necessary for the construction of the item represented. To this end there are certain conventions generally employed, and in the same shop these always mean the same thing, but unfortunately, owing to the absence of a recognised standard, each firm is at liberty to please itself, and consequently there is no uniformity.

The conventions which follow are those most frequently employed :—

Construction and visible boundaries . . . .

Ditto hidden from view .

Centre or pitch lines . .

Projection lines . . .

Dimension lines . . . 1'. 3"

One view of an article is seldom sufficient for a proper understanding of its construction, and plans, elevations and sections are usually given, minor details being generally drawn separately and frequently to an enlarged scale.

All such drawings should be fully dimensioned. Where a number of small dimensions combine to make up a total, the overall should be given, not only to save time, but to act as a check upon the others.

Where coloured drawings are desired to indicate sections, the following will meet requirements :—

Cast iron	Neutral tint or Payne's grey.
Wrought iron	Prussian blue.
Steel	Violet carmine.
Copper	Crimson lake, little gamboge.
Brass	Gamboge, little burnt umber.
Lead	Indian ink and Prussian blue.
Brickwork	Light red, little crimson lake.
Wood	Yellow ochre and burnt sienna.

In each case the section is coloured a considerably deeper shade of the same tint than the other parts of the drawing.

In building plans (otherwise uncoloured) prepared to show alterations or additions to existing premises, it is a common practice to colour new work red.

Different methods of lining are sometimes employed to represent different materials, but if followed to any extent this is likely to lead to mistakes unless supplemented by a key or written explanation, in which case it can scarcely be considered necessary.

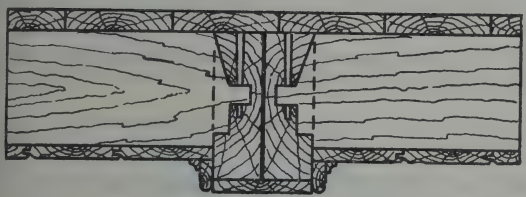
A very general practice is to adopt C (fig. 2) for all metals; to line up woodwork in imitation of the grain A (fig. 2); and to use as few others as possible—the material being specified in words thus :—'Brass'—'Copper 75 mils'—'Spring Steel 22 S.W.G.'—etc.

It is obviously impossible to fix any definite spacing between the lines. Small details must necessarily be treated differently from larger surfaces, and very large areas need only be sectioned around their boundaries.

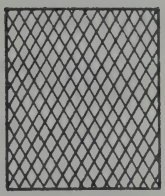
Typical specimens of various section conventions are shown in fig. 2. Where two pieces of material butt against each other, the section lining should run in opposite directions : if three meet, the lines running in the same direction should break joint. (D, fig. 2.)

Small or thin sections such as boiler plates, engine beds, girders, joists, etc., may be blacked in solid. (C, fig. 1.)

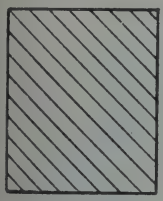
Long details such as columns, shafting, pipes, etc., need not necessarily be shown full length and in such cases break lines, A, fig. 1, are employed. Should the diameter vary, one or more sections may be shown, as in the firebar example.



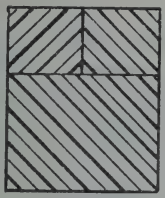
A. Wood, with and across grain.



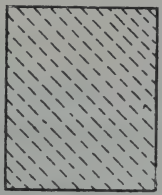
B. Lead



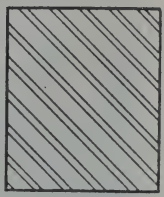
C. Cast Iron.



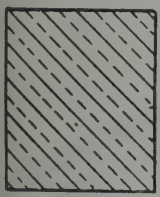
D Wrought Iron.



E. Steel or Stone.



F. Cast Steel.



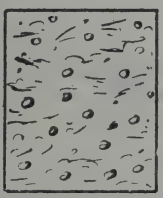
G. Brass or Brick.

H. Brickwork.

I. Stonework.

K. Insulators.

L. Earth.



M. Concrete.

N. Water.

O. Glass.

FIG. 2.

Patent Specification Drawings.

All necessary information will be found in a pamphlet entitled 'Instructions to Applicants for Patents,' published by and obtainable free on application at the Patent Office, 25 Southampton Buildings, Chancery Lane, London, W.C., or it will be sent free on receipt of 1*d.* for postage.

One point to remember in this class of work is that the 13-inch side of each sheet is bound up with the specification, and should be looked upon as the left-hand side. All lettering, etc., should therefore be upright, viz., not facing different ways.

For whatever purpose drawings are prepared, they will inevitably indicate to the expert eye the character of the draughtsman. One man scarcely varies the thickness of his lines, muddles his lettering, and does not space his work out to advantage. Another has the knack of 'displaying' his work, as a printer would say: his construction lines are bold and the others thin, his lettering varies according to whether it is of major or minor importance—heavy block, small capitals, or small italics being used as considered advisable; all his details are nicely spaced, and the whole effect is one of neatness, clearness, and completeness.

Drawing Appliances.

The Harling Pantagraph.

(*W. H. Harling*, 117, *Moorgate, London, E.C.* 2.)

This Pantagraph (fig. 3), which has been recently designed, is used for copying plans or parts of plans to a reduced scale.

The instrument is made of boxwood with brass fittings, and has a heavy iron weight, or fulcrum, which is further secured to the board at option, by two loose-fitting brass pins. When opened for use the pantagraph forms a square the sides of which measure 17 ins.

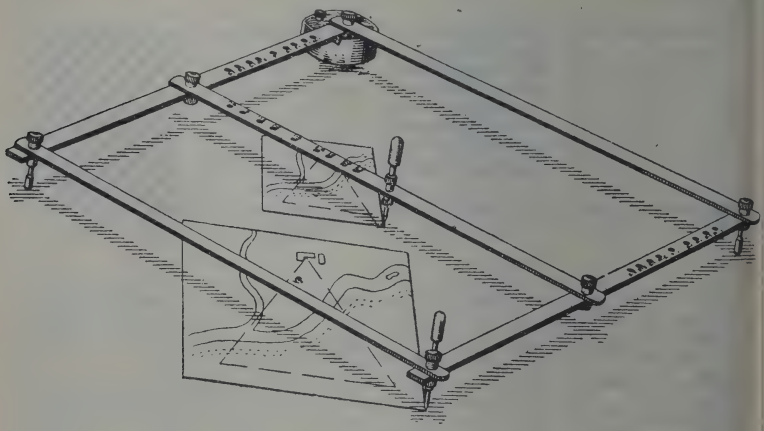


Fig. 3.

There are sixteen different ratios at which the instrument may be used.

The instrument will work quite smoothly and accurately, there being no perceptible friction or shake.

The price, complete with lead holder and tracing point, and fitted in strong cardboard box, is 25*s.*

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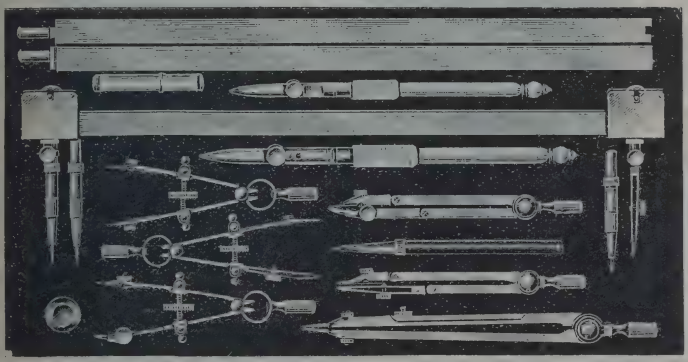

Our No. B.E. 114 Case illustrated above is a most useful set, comprising a set of portable Beam compasses, with Duralumin beam lath, made in three ten-inch lengths (29 inches long when joined), No. B.E. 98; Hair Spring divider B.E.40; Bow pen compass B.E.50; Bow pencil B.E.51; Set of three Spring bows with centre screw adjustment B.E. 83/85; Quick set Drawing pen B.E. 5; Spring nib Drawing pen B.E.12; Pricker B.E. 90; Case of leads, Spare needles, Key, Horn centre, fitted in Wallet Pocket case, Price **£5 10 0**

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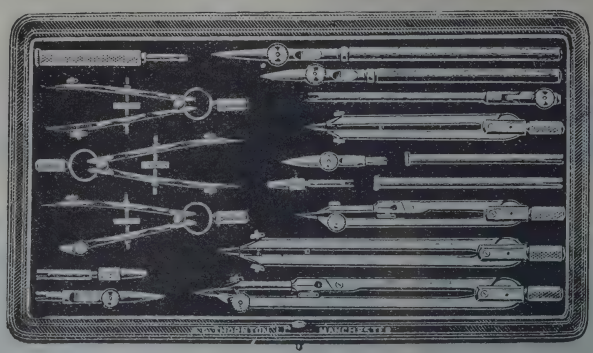
DRAWING INSTRUMENTS

(BRITISH MADE)



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ENGINEERS' PHOTO PAPERS & CLOTHS

DRAWING OFFICE STATIONERY.

Stanley's Patent Drawing Pen.

(W. F. Stanley & Co., Ld., Great Turnstile, Holborn, London, W.C. 1.)

This pen (fig. 4) is made with one nib to swivel round, so that it can be opened out for

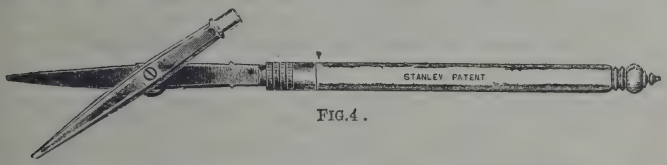


FIG. 4.

clearing, the arrangement being such that it locks back again in exact position, and the adjustment for the thickness of line is not interfered with.

A Compass Pencil-Leg Kink for Draughtsmen.

Draughtsmen who find that the jaws of the lead-holding clamp of a compass pencil-leg have become so smooth that it is difficult to tighten them sufficiently to hold the lead, can easily overcome this difficulty in the following way. First remove the clamping screw and insert a tap in place of the lead; then press the jaws together gently with the fingers and run the tap backwards and forwards five or six times; this will roughen the jaws so that they will grip the lead firmly.

(O. T. R., 'Machinery.')

A Steel Drawing-Board Edge.

One of the difficulties a draughtsman quite frequently bumps up against is that of trying to draw long lines parallel to each other. When drawn, he often finds that, instead of being parallel throughout, they are from $\frac{1}{16}$ to $\frac{1}{4}$ in. farther apart at one end than the other. This condition is almost surely to be found in steam-heated offices, where the cross-grained end of the board is depended upon to make a straight edge upon which the head of the T-square is expected to slide.

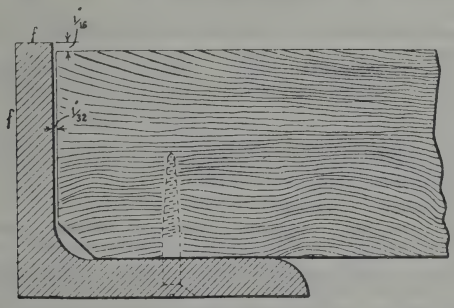


FIG. 5.

Fig. 5 shows an arrangement fitted to a board to overcome this difficulty, and found to answer the purpose admirably. The straight edge is made from a piece of angle iron 2 by 2 by $\frac{1}{4}$-in. ground or otherwise finished on the top and outside edges to ensure its being perfectly straight. The top edges project about $\frac{1}{32}$ in. above the surface of the drawing-board to give the T-square clearance above the drawing-pins when sliding up and down, and small particles of dirt are thus prevented from being ground into the paper. The angle iron is fastened to the drawing-board by two wood screws about $1\frac{1}{2}$ in. long, screwed in about 5 ins. from each end of the angle iron. The screw hole in one end should be slightly slotted to take care of swelling and shrinking of the wood.

(W. F., 'Machinery.')

SIZES OF DRAWING-PAPER.

	Ins. Ins.		Ins. Ins.		Ins. Ins.
Antiquarian	52 × 31	Columbia	34 × 23	Super royal	27 × 19
,, extra	56 × 40	Elephant	27½ × 22½	Royal	24 × 19
Double elephant	40 × 26	Double crown	42 × 22	Medium	22 × 17
Atlas	33 × 26	Imperial	30 × 21	Demy	20 × 15

To Trisect an Angle by Means of a Set-Square.

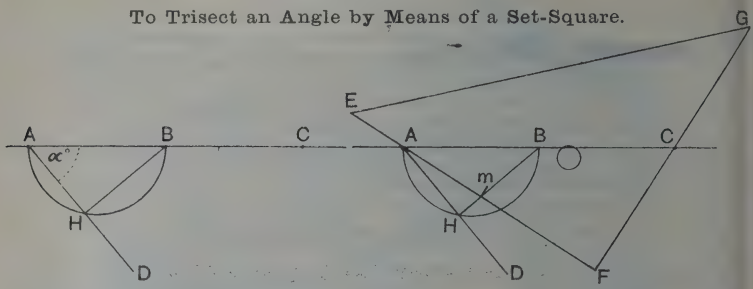


FIG. 7

On the line AC, fig. 6, AB is a semicircle, the diameter AB being equal to BC. At A and C are inserted pins of as small a gauge as possible (fine needles are best).

Let DAB be the angle ($a°$) to be trisected. Join B and H.

Drop the set-square between the pins A and C and move it about until the mark (which is in such a position on the edge EF of the square that $Fm = AB$) comes on the line HB, then the edge EF of the set-square trisects the angle.

See also p. 26. (*H. R. Kempe.*)

BRITISH STANDARD ENGINEERING DRAWING OFFICE PRACTICE.*

(No. 308—1927.) (*Abstract.*)

(*Recommendations.*)

1. The following to be the standard overall sheet sizes for drawings and tracings:

72 in. × * 40 in.		40 in. × 15 in.	
60 in. × * 40 in.	* The width of rolls from which these sizes are cut.	30 in. × 20 in.	These sizes are subdivisions of the 40 × 30 in. sheets.
53 in. × * 30 in.		20 in. × 15 in.	
* 40 in. × * 30 in.		15 in. × 10 in.	
* 40 in. × 27 in.		10 in. × 7½ in.	

2. The drawing number, date, and firm's name to be placed in the right-hand bottom corner of the drawing and repeated, the same way up, in the top left-hand corner to meet the requirements of both horizontal and vertical filing.

3. The scale or scales of all drawings to be clearly indicated.

4. The standard method of projection to be first angle projection—namely, that in which each view is so placed that it represents the side of the object remote from it in the adjacent view.

6. The use of colours should be avoided as far as possible. When colours are used, centre lines to be brown, and dimension lines blue with black arrowheads and figures.

Note.—To facilitate reproduction by photo-printing brown should be used instead of red, and a mixture of Prussian blue and Chinese white should be used for the blue.

COPYING PROCESSES.

GLYCERINE-JELLY PROCESS.

(1.)

8 ozs. glycerine, 2 ozs. best glue; to the glue add 8 ozs. of water, and when dissolved stir in glycerine. Pour the mixture into a zinc dish, and as soon as it sets it is ready for use. Use aniline ink.

* By permission of the British Engineering Standards Association.

(2.)

16 ozs. glycerine, 8 ozs. golden syrup, 3 ozs. flake gelatine, 16 ozs. water. Soak gelatine in water for 10 hours; heat gently in water bath; add glycerine and golden syrup. Pour into dish. Use aniline ink.

(3.)

Gelatine, 1 lb.; water, 2 lbs.; glycerine, 5 lbs. Melt together and pour in shell dish. For the ink: aniline violet, 1 oz.; water, 5 ozs.; methylated spirit, 1 oz.

(4.)

Whiting to fill dish; glycerine in sufficient quantity to mix the whiting to the consistency of glaziers' putty. Press into dish and smooth with knife, and finally with small indiarubber squeegee. For ink use violet aniline, ½ oz.; sugar, ½ drachm; boiling water, 2 ozs.; when cold add 1 drachm each of alcohol and glycerine and 2 drops carbolic acid.

Write or draw original on dry smooth paper with a pen well filled with the aniline ink. Directly it is quite dry place it face down for 1 to 5 minutes, according to number of copies required, on composition, the surface of which must previously be moistened with water and dried with paper (newspaper will do); gently smooth down with hand to remove air bubbles. On peeling it off a negative is left on the composition. To take copies, apply to the negative sheet after sheet of any paper, smoothing them down with slight pressure, and removing them at first as quickly as possible; but as the copies become faint the paper may be left down longer on the negative, or it may be damped before putting down. The copies having been taken, sponge off the negative immediately with cold water, or tepid water if it does not come off readily. When the surface is worn and uneven, re-melt composition; a little glycerine may have to be added at each re-melting.

(5.)

The following formula for making hectograph pads is given by Mr. H. E. Smith in the 'American Engineer and Railroad Journal': Clear hide glue, 1 lb.; water, 1½ pint; glycerine, 2½ pints. The glue should be of a good quality, and the kind that comes in transparent, light-brown sheets, as the white or brown opaque glue does not give as good results. Break the glue into small pieces and soak it in the water over-night in a covered vessel. Then melt it in a water-bath, and add the glycerine, which should previously be heated to the same temperature as the melted glue. Stir only as much as is necessary to mix the glue and the glycerine, as too much stirring introduces air bubbles, which are difficult to remove. Pour the hot mixture through a cheese-cloth bag into the pans. When the pans are filled and the jelly is still quite fluid, sweep off air bubbles or impurities from the surface with the edge of a card. Let the pans stand 48 hours before using. This formula calls for much less water than usually required by other formulas, since it is preferred to secure the requisite softness by means of the glycerine, which does not evaporate and allow the pads to dry out and harden, as does the water.

In writing the original copy always use hard, glazed paper, and write with hectograph ink. In making the negative moisten the surface of the pad with a cold, wet sponge, wiping off the excess of moisture. Dry off with a newspaper, and let it stand for two minutes. Place the original face down on the pad for from one to three minutes, rubbing down to a perfect contact, and then carefully remove. In printing apply a clean sheet of any kind of paper so that it touches the hectograph at all points, rubbing as little as possible. Never use hot water for removing the negative; as soon as the copies are all made, wash off with a sponge and cold water and dry off well with a newspaper. Never let the pad stand with ink in it after the copies are made, and always keep it closed when not in use.

Blakeley Process.

The following process, devised by Mr. R. W. Blakeley, of Pendleton, Manchester, is a modification of the glycerine-jelly process, but dispenses with the glycerine-jelly.

Take a pad of 10 to 12 sheets of tissue paper, damp well and screw up for a minute between damping sheets in the ordinary letter-copying press to distribute the moisture evenly. The pad should be thoroughly damp—if too dry it will not take up the ink from the original and if too wet the ink will run.

The original is drawn on any hard-surfaced paper with aniline ink, such as violet blue copying ink, and then placed face down on the damp tissue paper pad and screwed up in the press for five minutes; this gives the negative on the damp pad, from which copies are taken by screwing up blank sheets with the negative in the press. For the first copy 20 seconds in the press is enough. For the fifth or sixth, 45 or 50 seconds is required.

As the negative pad loses moisture to every copy this damping cloth under the negative is redamped every half-dozen copies or so.

AUTOCOPYIST.

Tough paper is coated by means of a sponge, at a temperature of 120° F., with a gelatine (flake 5 ozs.; glycerine, 5 drachms ; water 20 ozs. ; and then allowed to dry.

The best paper to use is either prepared vegetable tracing-paper, or else vegetable-parchment paper.

The prepared paper is stretched tightly over a felted wooden block or board. The original is written or drawn on smooth paper with an ink composed of a saturated solution of alum tinged with aniline black, and then applied to the prepared paper as in the glycerine process. An inked roller (lithographic ink) is then passed over the surface, a sheet of paper laid on the latter, and a felted roller passed briskly over two or three times, and the paper taken off. One hundred to two hundred sharp, clear copies can thus be obtained. The prepared paper cannot be cleaned and used a second time.

CYCLOSTYLE.

A stencil is formed by writing or drawing on prepared paper with a pen fitted with a revolving perforator. Copies are taken by passing over the stencil an india-rubber scraper charged with lithographic ink thinned with lard-oil.

BLUE PHOTOGRAPHIC COPYING-PROCESS.

Draw design on thin paper. Brush paper over with a solution of (1), and dry in the dark.

(1.)

Double citrate of iron and ammonia, 44 grs. ; water, 1 oz.

Expose under plan, which is pressed out flat by a sheet of plate-glass, and develop with solution (2).

(2.)

Ferrocyanide of potassium, 50 grs. ; water, 1 oz.

Wash with water slightly acidulated with hydrochloric acid, and then in water alone, and dry.

This gives white lines on a blue ground, or a negative of the drawing.

The following gives blue lines on a white ground, or a positive print :—
Sensitising solution—

(1.)

Ferric chloride, 50 grs. ; oxalic acid, 25 grs. ; water, 1 oz.

Develop with

(2.)

Ferrocyanide of potassium, 80 grs. ; water, 1 oz.

All the steps being the same as in the other process.

BLACK PHOTOGRAPHIC COPYING-PROCESS.—TO COPY DRAWINGS IN BLACK LINES ON WHITE GROUND.

(1.)

The following process has been patented by A. Colas, of Neuilly, France. Paper is prepared with the following solution :—½ oz. each of sulphate of iron, sesquichloride of iron, gelatine, and tartaric acid, in 10½ ozs. of distilled water. The paper, kept flat, is stored in a dark closet. When exposed to the light beneath a transparent drawing, the parts influenced by the light lose their greenish-yellow colour. It is afterwards dipped into a bath made of 7 ozs. of gallic acid, ⅔ fluid oz. of alcohol, and 1 quart of water. The greenish-yellow lines turn black at once, and the sheet requires only to be rinsed in water.

(2.)

The following is known as the 'Polygraphic' method :—A solution of ½ oz. of aniline colour and 8 drops of glacial acetic acid in 3½ fluid ozs. of water is used as an ink in this process. Japanese paper, a copying press, and a smooth, polished zinc plate are used for producing copies. The paper, after the corners have been moistened, is spread out upon the zinc plate. On the top of the paper is placed a linen cloth, first soaked in water and then wrung out, and on the top of this a sheet of waterproof paper. A cushion formed of ordinary paper by folding it several times together is pressed upon the zinc plate thus prepared. The side of the sheet written on is placed upon the sheet fastened on the zinc plate, and on the top of this a sheet of paper of the same size. The sheets of paper which are to receive the copy must be damped. It is now pressed : in a few minutes the impression will be ready, which can be used at once for 20 to 25 copies. After the impression is drawn off the Japanese paper is removed and the zinc plate washed and cleansed. If 2 pages of a sheet have to be copied, the pages must be enveloped in sheets of paper, which will prevent the ink from one page depositing itself on the other.

The Ferrocyanide Process.

This process, by which it is possible to make direct positive prints, was the first step taken towards important improvements in the reproduction of drawings. The ferrocyanide paper is

prepared with a sensitising solution, the nature of which varies according to the class of work to be done. The following are two formulas:

	Grammes.		Grammes.
1. Perchloride of iron	80	2. Tartaric acid	90
Gum	120	Persulphate of iron	110
Citric acid	30	Perchloride of iron	120
Water	1,000	Gum solution	1,000

This paper when prepared is of a yellow colour; when exposed to light beneath the tracing important changes take place in the sensitised surface which is not protected by the lines of the drawing. The salts of iron are reduced, the exposed surface becomes white, and as soon as the drawing appears in yellow lines, which can be ascertained by raising the back of the frame, the paper is removed and put in a ferrocyanide or potassium bath, which immediately forms Prussian blue by combining with the iron salts that are not reduced—that is to say, in those parts of the sheet that have been protected from the light. In this way the drawing is developed in a bright blue tint. The sheet is afterwards washed, and then placed in a bleaching bath made up in the proportion of 40 grammes of sulphuric acid and 1,000 grammes of water; finally, the sheet is subjected to a liberal washing, and any spots which do not appear to have been completely bleached are treated with a soft brush.

Photo-Copying.

The simplest outfit for photo-copying consists of a flat frame, a developing bath and rubber squeegee, cutting and trimming table and knife, drying racks, and some metal tubes to hold the sensitised papers. The frame (of ash or oak) has a plate-glass front, a thick sheet of felt, back boards saw cut and battened, pressure bars and springs. In each frame there should be an equal number of boards and bars, and all bars and boards should be interchangeable.

The developing bath consists of an oblong shallow tray; the larger sizes are fitted with outfall socket and plug. These baths are usually stocked (in zinc) up to 56 ins. by 36 ins.; for larger sizes, wooden baths lead-lined, or simply made water-tight and provided with a glass or slate slab at the bottom, are generally used. The bath should be fixed with a fall of about ½ in. per ft., so that the water used in developing will flow off readily.

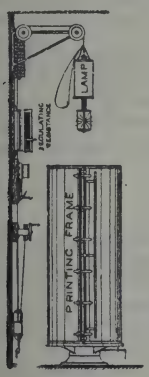


FIG. 7.

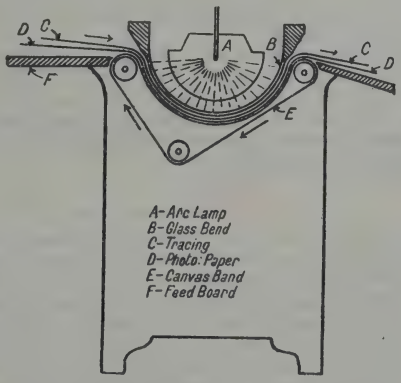


FIG. 8.

The cutting table is simply a board fitted with a strip of zinc about 6 ins. wide on the upper side, running the full length, and close to the edge. A piece of felt should be tacked to the opposite edge of the table sufficiently large to cover the whole table. This can be drawn over undeveloped prints or sensitised papers. Such a board may be very conveniently supported on trestles. It is often the practice to substitute for the trestles a cabinet of drawers, in which tracings and finished prints can be stored.

The metal tubes for holding the papers should be of tin or zinc, with sliding lids and at least twice the diameter of the roll of paper before unwrapping, otherwise, when unwrapped, it will expand and be difficult to remove. The simplest form of rack for natural drying consists of two brackets attached to a wall, about 3 ft. 6 ins. apart; clips are attached to the prints when in the bath, a rod is slipped through and the whole hung on the brackets.

A flat squeegee is frequently used for removing the superfluous moisture from the prints while lying in the bath. It consists of a thin strip of rubber about 10 ins. long secured in a wooden handle.

The outfit above described is suitable for offices having good daylight and no great pressure of copying work. For large and rapid outputs an electrical outfit is necessary.

Such a machine, capable of taking two tracings, is shown in fig. 7. It is made in several sizes varying from 40 ins. by 27 ins. to 60 ins. by 40 ins. The tracings are clamped closely around a glass cylinder, inside which an arc lamp is alternately raised and lowered until the prints have been fully exposed.

An improved type of copier for a considerably larger output is shown in fig. 9. It enables prints from tracings of any length up to that of a complete roll of paper (30 or 32 feet) to be produced in one piece. The paper A, fed with tracings B, travels slowly downwards between the

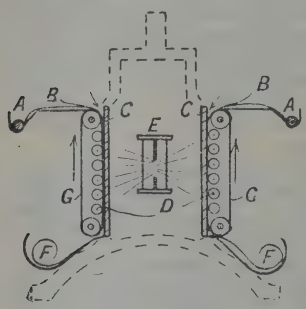


FIG. 9.

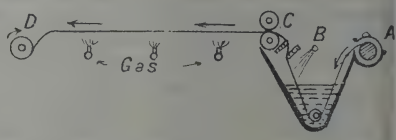


FIG. 10.

glass plate C and an endless blanket G pressed against it by the geared rollers D, passing several fixed arc lamps or one travelling one, E, after which it emerges and rolls up at F ready for trimming and washing.

Continuous printing machines, which are in two sizes, for paper either 30 or 40 ins. wide, are made single or double, the latter printing simultaneously two rolls of paper as in fig. 9. The speed can be varied from 4 feet per minute to 6 minutes per foot on either side so that fast and slow work can be done simultaneously. Fig. 10 shows a 'washing machine.' The roll of prints is placed in the trough A, passed through a running water-bath and spray B, between squeegees and rollers C, over a series of gas burners, and rolled up dry at D.

Trimming in quantities is usually effected with a guillotine for large work and a trimmer of the Merrett type for smaller sizes.

THE 'HALL-MARK' PHOTO-COPYER.

The 'Hall-Mark,' fig. 8, (p. 205), has a Hall-Thorkelin horizontal arc lamp specially designed to throw a richly actinic light downwards without causing a shadow. It is claimed for this lamp that it yields a higher percentage of actinic light per unit of current consumed than any arc lamp hitherto made, and also possesses the unique advantage that the carbons can be adjusted immediately after switching off and without waiting for the lamp to cool.

Beneath the lamp A, which travels automatically from side to side of the machine and across the width of the paper, is a curved glass plate, B, against the underside of which the tracing C and sensitised paper D, are pressed and caused to travel by an endless canvas belt, E.

The close proximity of the arc light to the glass bend reduces the loss of light to a minimum and enables the machine to be operated at a very high rate of speed. Suitable mechanism provides for a range of from 4 ins. up to 8 ft. per minute.

The frame of the machine is of aluminium and wood for lightness, and everything, including the motor, is self-contained.

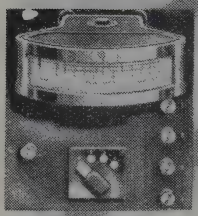
A machine taking continuous rolls of 42-in. (wide) paper occupies, including all projections a floor space of about 5 ft. 6 ins. by 3 ft. 9 ins.

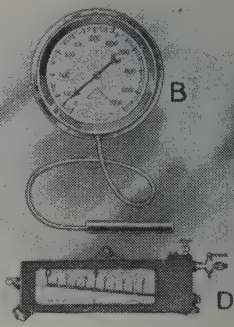
Tracing.

Place the sheet of paper over the drawing to be copied, and lightly rub it over with a ball of wool saturated with benzine; this renders the paper transparent temporarily, when the tracing can readily be made. The benzine by evaporation leaves the paper opaque as before. The benzine must be absolutely pure to secure good results.

SECTION IV

HEAT — SOUND — OPTICS.

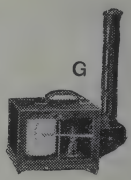




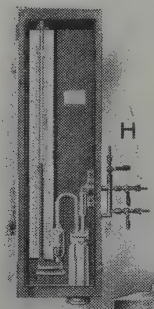
INSTRUMENTS

of every description for
Heat, Moisture, Ventilation, etc.

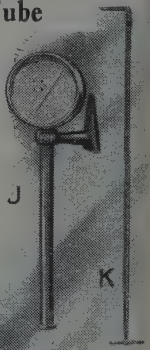
A. Electrical Pyrometer
B. Dial Thermometer
C. Temperature Recorder
D. Draught Gauge
E. Pipe Thermometer



F. U. Gauge
G. Humidity Recorder
H. Baro-Vacuum Gauge
J. Humidity Indicator
K. Pitot Tube

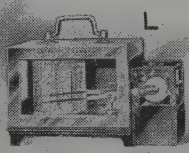


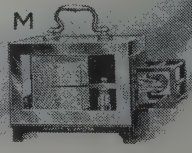
L. Humidity Recorder
M. Temperature Recorder



NEGRETTI & ZAMBRA

38, HOLBORN VIADUCT, E.C.1.
LONDON





SECTION IV

HEAT—SOUND—OPTICS.

HEAT.

Temperature Conversion Tables.

TABLE FOR THE CONVERSION OF DEGREES ON THE CENTIGRADE THERMOMETER INTO THOSE OF FAHRENHEIT'S SCALE.

Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.
−100	−148·0	− 55	− 67·0	−10	14·0	35	95·0	80	176·0	125	257·0
− 99	−146·2	− 54	− 65·2	− 9	15·8	36	96·8	81	177·8	126	258·8
− 98	−144·4	− 53	− 63·4	− 8	17·6	37	98·6	82	179·6	127	260·6
− 97	−142·6	− 52	− 61·6	− 7	19·4	38	100·4	83	181·4	128	262·4
− 96	−140·8	− 51	− 59·8	− 6	21·2	39	102·2	84	183·2	129	264·2
− 95	−139·0	− 50	− 58·0	− 5	23·0	40	104·0	85	185·0	130	266·0
− 94	−137·2	− 49	− 56·2	− 4	24·8	41	105·8	86	186·8	131	267·8
− 93	−135·4	− 48	− 54·4	− 3	26·6	42	107·6	87	188·6	132	269·6
− 92	−133·6	− 47	− 52·6	− 2	28·4	43	109·4	88	190·4	133	271·4
− 91	−131·8	− 46	− 50·8	− 1	30·2	44	111·2	89	192·2	134	273·2
− 90	−130·0	− 45	− 49·0	0	32·0	45	113·0	90	194·0	135	275·0
− 89	−128·2	− 44	− 47·2	+ 1	33·8	46	114·8	91	195·8	136	276·8
− 88	−126·4	− 43	− 45·4	2	35·6	47	116·6	92	197·6	137	278·6
− 87	−124·6	− 42	− 43·6	3	37·4	48	118·4	93	199·4	138	280·4
− 86	−122·8	− 41	− 41·8	4	39·2	49	120·2	94	201·2	139	282·2
− 85	−121·0	− 40	− 40·0	5	41·0	50	122·0	95	203·0	140	284·0
− 84	−119·2	− 39	− 38·2	6	42·8	51	123·8	96	204·8	141	285·8
− 83	−117·4	− 38	− 36·4	7	44·6	52	125·6	97	206·6	142	287·6
− 82	−115·6	− 37	− 34·6	8	46·4	53	127·4	98	208·4	143	289·4
− 81	−113·8	− 36	− 32·8	9	48·2	54	129·2	99	210·2	144	291·2
− 80	−112·0	− 35	− 31·0	10	50·0	55	131·0	100	212·0	145	293·0
− 79	−110·2	− 34	− 29·2	11	51·8	56	132·8	101	213·8	146	294·8
− 78	−108·4	− 33	− 27·4	12	53·6	57	134·6	102	215·6	147	296·6
− 77	−106·6	− 32	− 25·6	13	55·4	58	136·4	103	217·4	148	298·4
− 76	−104·8	− 31	− 23·8	14	57·2	59	138·2	104	219·2	149	300·2
− 75	−103·0	− 30	− 22·0	15	59·0	60	140·0	105	221·0	150	302·0
− 74	−101·2	− 29	− 20·2	16	60·8	61	141·8	106	222·8	151	303·8
− 73	− 99·4	− 28	− 18·4	17	62·6	62	143·6	107	224·6	152	305·6
− 72	− 97·6	− 27	− 16·6	18	64·4	63	145·4	108	226·4	153	307·4
− 71	− 95·8	− 26	− 14·8	19	66·2	64	147·2	109	228·2	154	309·2
− 70	− 94·0	− 25	− 13·0	20	68·0	65	149·0	110	230·0	155	311·0
− 69	− 92·2	− 24	− 11·2	21	69·8	66	150·8	111	231·8	156	312·8
− 68	− 90·4	− 23	− 9·4	22	71·6	67	152·6	112	233·6	157	314·6
− 67	− 88·6	− 22	− 7·6	23	73·4	68	154·4	113	235·4	158	316·4
− 66	− 86·8	− 21	− 5·8	24	75·2	69	156·2	114	237·2	159	318·2
− 65	− 85·0	− 20	− 4·0	25	77·0	70	158·0	115	239·0	160	320·0
− 64	− 83·2	− 19	− 2·2	26	78·8	71	159·8	116	240·8	161	321·8
− 63	− 81·4	− 18	− 0·4	27	80·6	72	161·6	117	242·6	162	323·6
− 62	− 79·6	− 17	+ 1·4	28	82·4	73	163·4	118	244·4	163	325·4
− 61	− 77·8	− 16	3·2	29	84·2	74	165·2	119	246·2	164	327·2
− 60	− 76·0	− 15	5·0	30	86·0	75	167·0	120	248·0	165	329·0
− 59	− 74·2	− 14	6·8	31	87·8	76	168·8	121	249·8	166	330·8
− 58	− 72·4	− 13	8·6	32	89·6	77	170·6	122	251·6	167	332·6
− 57	− 70·6	− 12	10·4	33	91·4	78	172·4	123	253·4	168	334·4
− 56	− 68·8	− 11	12·2	34	93·2	79	174·2	124	255·2	169	336·2

TABLE FOR THE CONVERSION OF DEGREES (*continued*).

°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.	°Cent.	° Fahr.
170	338·0	210	410·0	250	482·0	290	554·0	330	626·0	440	824
171	339·8	211	411·8	251	483·8	291	555·8	331	627·8	450	842
172	341·6	212	413·6	252	485·6	292	557·6	332	629·6	460	860
173	343·4	213	415·4	253	487·4	293	559·4	333	631·4	470	878
174	345·2	214	417·2	254	489·2	294	561·2	334	633·2	480	896
175	347·0	215	419·0	255	491·0	295	563·0	335	635·0	482	900
176	348·8	216	420·8	256	492·8	296	564·8	336	636·8	490	914
177	350·6	217	422·6	257	494·6	297	566·6	337	638·6	500	932
178	352·4	218	424·4	258	496·4	298	568·4	338	640·4	538	1000
179	354·2	219	426·2	259	498·2	299	570·2	339	642·2	593	1100
180	356·0	220	428·0	260	500·0	300	572·0	340	644·0	600	1112
181	357·8	221	429·8	261	501·8	301	573·8	341	645·8	649	1200
182	359·6	222	431·6	262	503·6	302	575·6	342	647·6	700	1292
183	361·4	223	433·4	263	505·4	303	577·4	343	649·4	704	1300
184	363·2	224	435·2	264	507·2	304	579·2	344	651·2	760	1400
185	365·0	225	437·0	265	509·0	305	581·0	345	653·0	800	1472
186	366·8	226	438·8	266	510·8	306	582·8	346	654·8	815	1500
187	368·6	227	440·6	267	512·6	307	584·6	347	656·6	871	1600
188	370·4	228	442·4	268	514·4	308	586·4	348	658·4	900	1652
189	372·2	229	444·2	269	516·2	309	588·2	349	660·2	926	1700
190	374·0	230	446·0	270	518·0	310	590·0	350	662·0	982	1800
191	375·8	231	447·8	271	519·8	311	591·8	351	663·8	1000	1832
192	377·6	232	449·6	272	521·6	312	593·6	352	665·6	1037	1900
193	379·4	233	451·4	273	523·4	313	595·4	353	667·4	1093	2000
194	381·2	234	453·2	274	525·2	314	597·2	354	669·2	1100	2012
195	383·0	235	455·0	275	527·0	315	599·0	355	671·0	1148	2100
196	384·8	236	456·8	276	528·8	316	600·8	356	672·8	1200	2192
197	386·6	237	458·6	277	530·6	317	602·6	357	674·6	1300	2372
198	388·4	238	460·4	278	532·4	318	604·4	358	676·4	1400	2552
199	390·2	239	462·2	279	534·2	319	606·2	359	678·2	1500	2732
200	392·0	240	464·0	280	536·0	320	608·0	360	680·0	1600	2912
201	393·8	241	465·8	281	537·8	321	609·8	370	698	1700	3092
202	395·6	242	467·6	282	539·6	322	611·6	371	700	1800	3272
203	397·4	243	469·4	283	541·4	323	613·4	380	716	1900	3452
204	399·2	244	471·2	284	543·2	324	615·2	390	734	2000	3632
205	401·0	245	473·0	285	545·0	325	617·0	400	752	2100	3812
206	402·8	246	474·8	286	546·8	326	618·8	410	770	2200	3992
207	404·6	247	476·6	287	548·6	327	620·6	420	788	2300	4172
208	406·4	248	478·4	288	550·4	328	622·4	426	800	2400	4352
209	408·2	249	480·2	289	552·2	329	624·2	430	806	2500	4532

TABLE FOR THE CONVERSION OF DEGREES ON THE FAHRENHEIT THERMOMETER INTO THOSE OF THE CENTIGRADE SCALE.

°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.
212	100·0	193	89·4	174	78·8	155	68·3	136	57·7	117	47·2
211	99·4	192	88·8	173	78·3	154	67·7	135	57·2	116	46·6
210	98·8	191	88·3	172	77·7	153	67·2	134	56 6	115	46·1
209	98·3	190	87·7	171	77·2	152	66·6	133	56·1	114	45·5
208	97·7	189	87·2	170	76·6	151	66·1	132	55·5	113	45·0
207	97·2	188	86·6	169	76·1	150	65·5	131	55·0	112	44·4
206	96·6	187	86·1	168	75·5	149	65·0	130	54·4	111	43·8
205	96·1	186	85·5	167	75·0	148	64·4	129	53·8	110	43·3
204	95·5	185	85·0	166	74·4	147	63·8	128	53·3	109	42·7
203	95·0	184	84·4	165	73·8	146	63·3	127	52·7	108	42·2
202	94·4	183	83·8	164	73·3	145	62·7	126	52·2	107	41·6
201	93·8	182	83·3	163	72·7	144	62·2	125	51·6	106	41·1
200	93·3	181	82·7	162	72·2	143	61·6	124	51·1	105	40·5
199	92·7	180	82·2	161	71·6	142	61·1	123	50·5	104	40·0
198	92·2	179	81·6	160	71·1	141	60·5	122	50·0	103	39·4
197	91·6	178	81·1	159	70·5	140	60·0	121	49·4	102	38·8
196	91·1	177	80·5	158	70·0	139	59·4	120	48·8	101	38·3
195	90·5	176	80·0	157	69·4	138	58·8	119	48·3	100	37·7
194	90·0	175	79·4	156	68·8	137	58·3	118	47·7	99	37·2

TABLE FOR THE CONVERSION OF DEGREES (*continued*).

°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.	°Fahr.	° Cent.
98	36·6	76	24·4	53	11·6	30	− 1·1	8	−13·3	−14	−25·5
97	36·1	75	23·8	52	11·1	29	− 1·6	7	−13·8	−15	−26·1
96	35·5	74	23·2	51	10·5	28	− 2·2	6	−14·4	−16	−26·6
95	35·0	73	22·7	50	10·0	27	− 2·7	5	−15·0	−17	−27·2
94	34·4	72	22·2	49	9·0	26	− 3·3	4	−15·5	−18	−27·7
93	33·8	71	21·6	48	8·8	25	− 3·8	3	−16·1	−19	−28·3
92	33·3	70	21·1	47	8·3	24	− 4·4	2	−16·6	−20	−28·8
91	32·7	69	20·5	46	7·7	23	− 5·0	1	−17·2	−21	−29·4
90	32·2	68	20·0	45	7·2	22	− 5·5	0	−17·7	−22	−30·0
89	31·6	67	19·4	44	6·6	21	− 6·1	− 1	−18·3	−23	−30·5
88	31·1	66	18·9	43	6·1	20	− 6·6	− 1	−18·8	−24	−31·1
87	30·5	65	18·3	42	5·5	19	− 7·2	− 3	−19·4	−25	−31·6
87	30·5	64	17·7	41	5·0	18	− 7·7	− 4	−20·0	−26	−32·2
86	30·0	63	17·2	40	4·4	17	− 8·3	− 5	−20·5	−27	−32·7
85	29·4	62	16·6	38	3·3	16	− 8.8	− 6	−21·1	−28	−33·3
84	28·8	61	16·1	37	2·7	15	− 9·5	− 7	−21·6	−29	−33·8
83	28·3	60	15·5	36	2·2	14	−10·0	− 8	−22·2	−30	−34·4
82	27·7	59	15·0	35	1·6	13	−10·5	− 9	−22·7	−31	−35·0
81	27·2	58	14·4	34	1·1	12	−11·1	−10	−23·3	−32	−35·5
80	26·6	57	13·8	33	0·5	11	−11·6	−11	−23·8	−33	−36·1
79	26·1	56	13·3	32	0·0	10	−12·2	−12	−24·4	−34	−36·6
78	25·5	55	12·7	31	−0·5	9	−12·7	−13	−25·0	−35	−37·2
77	25·0	54	12·2								

See also next page.

Miscellaneous Temperatures.

Description.	° F.	° C.	Description.	° F.	° C.
In the Bessemer furnace	4000	2204	A comfortable room	70	21·1
Puddling furnace	3500	1927	Mean temperature of ocean	62	16·6
Cupola	3000	1649	1 alcohol, 1 water freezes	− 7	−21·6
Heat of common fire	1100	593·3	Mean temperature of poles	− 13	−25·0
Red heat in daylight	1070	571·1	Interstellar space	Abs. 0	
Iron red in dark	752	400·0	Greatest natural cold	− 56	−48·5
Mean temp. of earth	50	10·0	Vinous fermentation	65	18·3
" " torrid zone	75	23·8	Acetous fermentation begins	78	25·5
" " temp. zone	50	10·0	Acetification ends	88	31·1
" " polar region	20	6·6	Phosphorus takes fire	112	44·4
Highest temp. of wind	117	47·2	Greatest artificial cold produced (*Kamerlingh Onnes*)	−457·9	−272·18
Temp. of human blood	98	36·6			

Ignition Temperatures.

Name of Substance.	° F.	° C.	Name of Substance.	° F.	° C.
Phosphorus, transparent	112	44·4	Rifle-powder	550	287·8
Bisulphide of carbon	300	143·3	Forced gunpowder	560	293·3
Fulminating powder	370	187·8	Picrate powder for torpedoes	570	299·0
Fulminate of mercury	390	198·9	Charcoal from willow wood	660	349·0
Gun-cotton	430	221·1	Picrate powder for cannon	720	382·2
Nitro-glycerine	490	254·4	Very dry pine wood	800	426·7
Phosphorus, amorphous	500	260·0	Dry oak wood	900	480·2

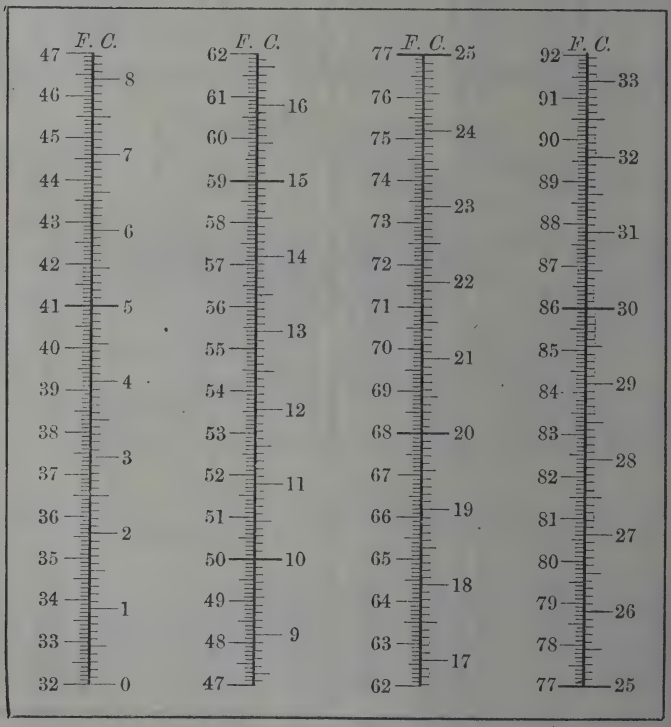
See also page 222, Flash Temperatures.

Values of Degrees.

°C. contain °F.			°F. contain °C.		
1 = 1·8	4 = 7·2	7 = 12·6	1 = 0·56	4 = 2·22	7 = 3·89
2 = 3·6	5 = 9·0	8 = 14·4	2 = 1·11	5 = 2·78	8 = 4·44
3 = 5·4	6 = 10·8	9 = 16·2	3 = 1·67	6 = 3·33	9 = 5·00

$$C° = \frac{5}{9}(F° - 32°) = \frac{F° - 32°}{1·8}. \qquad F° = \frac{9}{5}C° + 32° = 1·8\,C° + 32°.$$

Thermometer Scale Conversion Chart.



(R. E. Gould, American Bureau of Standards.)

Fig. 1.

Melting Points of Chemical Elements.

The following table gives the melting points of chemical elements and is reproduced from a ircular issued by the U.S. Bureau of Standards. The value of the melting points used y the Bureau as standard temperatures for the calibration of thermometers and pyrometers re indicated in italics. The other values have been assigned after a careful survey of all the vailable data.

Element.	°F.	°C.	Element.	°F.	°C.
Helium	<−456	<−271	Barium	1560	850
Hydrogen	−434	−259	Praseodymium	1725	940?
Neon	−423	−253?	Germanium	1756	958
Fluorine	−369	−223	*Silver*	1761	960·5
Oxygen	−360	−218	Glucinum	—	>Ag
Nitrogen	−346	−210	Radium	—	?
Argon	−306	−188	*Gold*	1945·5	1063·0
Krypton	−272	−169	*Copper*	1981·5	1083·0
Xenon	−220	−140	Manganese	2237	1225
Chlorine	−150·5	−101·5	Yttrium	—	?
Mercury	− 37·7	− 38·7	Samarium	2370–2550	1300–1400
Bromine	+ 18·9	− 7·3	Scandium	—	?
Cæsium	79	26	Silicon	2588	1420
Gallium	86	30	*Nickel*	2646	1452
Rubidium	100	38	Cobalt	2714	1490
Phosphorus	111·4	44	Chromium	2750	1510
Potassium	144	62·3	*Iron*	2768	1520
Sodium	207·5	97·5	*Palladium*	2820	1549
Iodine	236·5	113·5	Zirconium	3100	1700?
Sulphur	S_{I} 235·0 S_{II} 246·6 S_{III} 224·2	112·8 119·2 106·8	Thorium	>3090 <Pt	>1700 <Pt.
Indium	311	155	Vanadium	3150	1730?
Lithium	367	186	*Platinum*	3191	1755
Selenium	422–428	217–220	Beryllium	>3270	>1800?
Tin	449·4	231·9	Ytterbium	—	?
Bismuth	520	271	Titanium	3450	1900?
Thallium	576	302	Rhodium	3525	1940
Cadmium	609·6	320·9	Ruthenium	>3550	>1950
Lead	621·1	327·4	Columbium (Niobium)	4000	2200?
Zinc	786·9	419·4	Boron	4000–4500	2200–2500
Tellurium	846	452	Iridium	4170	2300?
Antimony	1166	630·0	Uranium	—	?
Cerium	1184	640	Molybdenum	4500	2500?
Magnesium	1204	651	Osmium	4900	2700?
Aluminium	1217·7	658·7	Tantalum	5160	2850
Calcium	1490	810	*Tungsten*	5430	3000
Lanthanum	1490	810?	Carbon	>6500 for p=1 At.	>3600 for p=1 At
Strontium	—	>Ca<Ba?			
Neodymium	1544	840?			
Arsenic	1560	850?			

? Volatilise, but do not melt.

Melting Points of Various Substances.

Solids.	°F.	°C.	Solids.	°F.	°C.
Litharge	1739°	954°	Ice of milk	30°	− 1·1°
Slag of copper	2462	1350	„ sea-water	28	− 2·2
„ tin	2402	1318	„ vinegar	28	− 2·2
Puddle slag	2606	1430	„ strong wine	20	− 6·6
Sodic nitrate	591	310·5	„ „ brandy	7	− 13·9
Potassium nitrate	642	339	Ice of oil of turpentine	14	− 1
Beeswax (white)	155	68	1 snow, 1 salt	0·00	− 17.8
„ (yellow)	142	61	1 alcohol, 1 water	− 7	− 21·6
Spermaceti	142	61	Cyanogen	− 30	− 34·4
Yellow wax	143·6	62	Oil of vitriol	− 30	− 35
Olive oil	92	33	Sulphuric ether	− 47	− 43·9
Tallow	36	2·2	Sulphurous acid	− 105	− 76
Ice of water	32	0·000	Nitrous oxide	− 150	−101

MELTING POINTS OF ALLOYS.

Bismuth.	Lead.	Tin.	Melting Point.		Bismuth.	Lead.	Tin.	Melting Point.	
			° F.	° C.				° F.	° C.
50	31·2	18·8	201	94	16·6	33·2	50·2	316	158
47	35·5	17·7	208	98	16	36	48	311	155
42·1	42·1	15·8	226	108	15·3	38·8	45·9	309	154
40	40	20	235	113	14·8	40·2	45	307	153
36·5	36·5	27	243	117	14	43	43	309	154
33·3	33·3	33·3	253	123	13·7	44·8	41·5	320	160
30·8	38·4	30·8	266	130	13·3	46·6	40·1	329	165
28·5	43	28·5	270	132	12·8	49	38·2	342	172
25	50	25	300	149	12·5	50	37·5	352	178
23·5	47	29·5	304	151	11·7	46·8	41·5	333	167
22·2	44·4	33·4	289	143	11·4	45·6	43	329	165
21	42	57	289	143	11·2	44·4	44·4	320	160
20	40	40	293	145	10·8	43·2	46	318	159
19	38	43	298	148	10·5	42	47·5	320	160
18·1	36·2	45·7	304	151	10·2	41	49·8	322	161
17·3	34·6	48·1	311	155	10	40	50	324	162

The addition of cadmium gives alloys of still lower melting point. The following table includes the best known of these :—

Alloy.	Cadmium.	Lead.	Tin.	Bismuth.	Melting Point.	
					° F.	° C.
Fusible alloy	12·5	25	12·5	50	149	65
Lipowitz's alloy	10	26·6	13·3	50·1	158	70
Woods' alloy	15·4	30·8	15·4	38·4	160	71
Fusible alloy	34·5	27·5	10	27·5	167	75
" "	6·2	34·5	9·3	50	171	77
" "	25	25	50	—	187	86
" "	16·6	—	33·3	50·1	203	95
" "	11·1	—	33·3	55·6	203	95
" "	25	—	25	50	203	95

(*Parkes and Martin.*)

The following are the melting points in C.° on the thermo-dynamic scale used by the Washington Bureau of Standards as standard temperatures in the standardisation of thermometers and pyrometers :—Mercury 38·9°, tin 231·9°, cadmium 320·9°, lead 327·4°, zinc 419·4°, antimony 630·0°, aluminium 658·7°, silver 960·5°, gold 1061·0°, copper 1083·0°, nickel 1452°, iron 1530°, palladium 1549°, platinum 1755°, tungsten 3000°. At temperatures of 1000° the uncertainty is of the order 0·1°, for platinum 5°, and for tungsten 100°. A further table of other standard temperatures is given in which the following are included :—Normal boiling point of oxygen 183·0°, sublimation of carbon dioxide in an inert liquid 78·5°, normal boiling points of water 100°, naphthalene 217·96°, benzo-phenone 305·9°, sulphur 444·6°, freezing point of sodium chloride 801°.

In the *Physical Review* the melting-point in C.° of rhodium is estimated to be at 1907° or 1968°, and that of iridium at 2292° or 2388°. That of silicon is placed at 1434° or 1452°, and that of palladium at 1548° or 1576°. The reason for two figures being given in each case is due to the fact that the calculations are based on different estimates of the melting-point of platinum, which has been placed at 1745° by some experimenters, and at 1789° by others.

MELTING POINTS OF REFRACTORY MATERIALS.*

The melting-points in C.° of various samples of fire-brick, as determined in an electric vacuum furnace, the temperature being measured with an optical pyrometer, were as follows :—Kaolin, 1740° ; pure alumina, 2010° ; pure silica, 1600° ; bauxite, 1820° ; bauxite clay, 1795° ; chromite, 2180° ; magnesite brick, 2165°. (*W. M. Barr, in 'Industrial Engineering.'*)

* See also 'Refractory Materials,' page 532.

Colour of Different Temperatures.

Colour.	F.°	C.°	Colour.	F.°	C.°	Colour.	F.°	C.°
Faint Red .	960	516	Bright Cherry Red	1830	999	Bright White Heat . .	2550	1399
Dull Red .	1290	699	Orange . .	2010	1099			
Brilliant Red	1470	743	Bright Orange .	2190	1199	Brilliant White Heat . .	2750	1510
Cherry Red .	1650	899	White Heat .	2370	1299			

(*Becquerel.*)

Freezing Mixtures.

Mixture.	Reduction in Temperature.	Mixture.	Reduction in Temperature
1 part nitre 1 part sal ammoniac 2 parts water . .	40° F.; 4·4° C.	5 parts hydrochloric acid 8 parts crystallised sulphate of soda . .	50° F.; 10° C.
Equal parts crystallised nitrate of ammonia and water	46° F.; 7·7° C.	2 parts powdered ice or fresh snow . . . . 1 part common salt .	a temperature of −4° F.; −20° C.
Equal parts crystallised nitrate of ammonia (powdered), crystallised carbonate of soda (powdered), and water	57° F.; 13·8° C.	3 parts crystallised chloride of calcium (cooled to 32°) . . . . 2 parts fresh snow . .	a temperature of −50° F.; −45·6° C.

Non-freezing Mixtures.

Common Salt (Sodium Chloride).				Commercial Calcium Chloride.			
Lbs. per Gal.	Freezing Point, F.°	Lbs. per Gal.	Freezing Point, F.°	Lbs. per Gal.	Freezing Point, F.°	Lbs. per Gal.	Freezing Point, F.°
½	24 above zero	2	6 above zero	½	29 above zero	3½	6 below zero
1	18 ,,	2½	3 ,,	1	27 ,,	4	17 ,,
1½	15 ,,	2½	1 ,,	1½	23 ,,	4½	27 ,,
1½	12 ,,	3	3 below zero	2	18 ,,	5	39 ,,
1½	9 ,,	3½	8 ,,	2½	4 ,,	5½	54 ,,

The salt should be thoroughly dissolved, or the results will not be satisfactory. Calcium loride is said to be superior to sodium chloride in that it does not corrode steel tanks and arrel hoops. Where calcium chloride is used, the wooden barrels should first be well coated iside with asphaltum, or a mixture of crude paraffin and resin, to prevent the shrinking of ie staves and subsequent leakage.

Glycerine is recommended for use in chemical fire extinguishers. It has no effect upon metals, ut has a tendency to disintegrate rubber. It has been stated, however, that the continued use glycerine in water renders it liable to a decomposition that would develop compounds having corrosive action on metals. The following proportions may be used :—

Glycerine, pounds per gallon . .	3½	5½	(One gall. of glycerine
Temp. solution will withstand . .	+ 10° F.	− 10° F.	weighs 10½ lbs.)

Denatured alcohol has advantages over both glycerine and calcium chloride, in water solu- ons, as it has no injurious effect on either metal or rubber. A solution of about 50 per cent. inflammable, but it would rarely be necessary to have a solution of over 30 per cent.

A 20 per cent. solution freezes at + 10° F. | A 40 per cent. solution freezes at − 20° F.
30 ,, ,, ,, − 5° F. | 50 ,, ,, ,, − 35° F.

Freezing Temperatures.

Sea water, −2·5° C., 27·5° F.; Mercury, −38·8° C., −37·8° F.; Acetone, −95° C., −139° F.
Pratt's petrol spirit, −128° C., −198° F.

Temperature of the Atmosphere.

diminishes according to the height above the earth's surface. In the Temperate Zone a diminution of 1° C. corresponds in the mean to an ascent of 180 yards. As the mean of a series o observations made during balloon ascents, a diminution of 1° C. corresponded to an increase i height of 232 yards.

According to Kropotkin, the temperature above the earth's surface decreases 3° to 5°F. for each 1,000 ft. The average temperature at an altitude of 20,000 ft. is 13° below 0° F.; at 25,000 ft. it is 35° below 0° F.; these low temperatures prevail all the year round. The ratio of decrease i temperature, which is 3° F. for each 1,000 ft. at the lower strata, is twice as great at the highes levels, but varies from summer to winter to the extent of about 20° F. (See also page 1245.)

The Mean Daily Temperature is that obtained by adding together twenty-four hourly observa tions and dividing by 24, the temperature being taken of the air, and not of the ground. The temperature of a month is the mean of those of thirty days, and the temperature of the year i the mean of those of twelve months. The mean temperature of London is 8·28° C., or 46·9° F. the mean in summer is 62° F., and in winter 40° F.

Temperature of Seas and Lakes.

The temperature of the sea under the Torrid Zone is always about 26° to 27° C. at the surface it diminishes as the depth increases, and in temperate as well as in tropical regions the tempera ture of the sea at great depths is between 2·5° and 3·5° C. The average winter temperature of th sea round the coast of England is higher than that of the land. The mean annual temperatur of the surface of the sea round England is 49° F.; the mean surface temperature of the India Ocean is 89° F., and of the Red Sea 94° F. The temperature of lakes at their surface may b 20° to 25° C. in summer; the temperature of the bottom, 4° C., which is that of the maximu density of water. The Great Geyser, in Iceland, at a depth of 66 feet, has a temperature of 124° C

Temperature of the Earth.

The average increase in temperature is 1° C. for every 27·4 metres of descent, which is at th rate of 100° F. per mile. Cordier says 1° C. for every 25 metres, or 1° F. in 45 feet.

Another statement is that the increase in temperature of the earth's strata shows a mea average for the entire earth surface of 1° F. for every 56 ft. of depth.

Specific Heat.

M = weight of body. T = temperature of body. C = specific heat of body
m = weight of cold water. t = temperature of cold water.
θ = temperature of water after body has been plunged into it.

$$C = \frac{m(\theta - t)}{M(T - \theta)}$$

Specific Heat of Substances at Ordinary Temperatures.

Element.	Specific Heat of Equal Weights.	Element.	Specific Heat of Equal Weights.	Element.	Specific Heat of Equal Weights
Diamond	·1468	Cast-iron (white)	·1298	Palladium	·0523
Graphite	·2018	„ (grey)	·1216	Rhodium	·0580
Wood charcoal	·2415	Cast-steel (hard)	·1185	Osmium	·0306
Coke	·2000	„ (soft)	·1166	Iridium	·0326
Average coal	·2412	Mild steel	·1158	Iodine	·0541
Clinkers	·1674	Wrought-iron	·1146	Bromine (solid)	·0843
Petrolcum	·4340	Nickel	·1086	„ (liquid)	·1060
Silicon (fused)	·1750	Cobalt	·1070	Potassium	·1696
„ (crystallised)	·1767	Manganese	·1217	Sodium	·2934
Boron (crystallised)	·2500	Tin	·0562	Lithium	·9408
Firebrick	·2000	Tungsten	·0334	Phosphorus	·1887
Sulphur (native)	·1776	Molybdenum	·0722	Arsenic	·0814
„ (purified)	·2026	Copper	·0965	Antimony	·0508
Selenium	·0837	Gunmetal	·0952	Bismuth	·0308
Tellurium	·0474	Brass	·0940	Thallium	·0326
Magnesium	·2499	Lead	·0314	Silver	·0570
Zinc	·0956	Mercury (solid)	·0319	Gold	·0324
Cadmium	·0567	„ (liquid)	·0333	Water	1·0000
Aluminium	·2143	Platinum	·0324	Ice	·5040

Specific Heat of Gases at High Temperatures.

$CO_2 = 0{\cdot}1477 + 0{\cdot}000176t.$ | $N = 0{\cdot}170 + 0{\cdot}0000872t.$
$H_2O = 0{\cdot}3211 + 0{\cdot}000219t.$ | $O = 0{\cdot}1488 + 0{\cdot}0000763t.$

Where t = Centigrade temperature

(*Mallard and Le Chatelier.*)

SPECIFIC HEAT OF GASES PER LB. AT HIGH TEMPERATURES.

(*Based on Mallard and Le Chatelier's results.*)

Temperature.		CO_2.	CO & N.	O.	H.
F.°	C.°				
200	932	·198	·241	·211	3·37
400	204	·210	·245	·214	3·41
600	316	·222	·247	·216	3·45
800	427	·235	·250	·218	3·49
1,000	538	·247	·252	·220	3·53
1,200	649	·260	·255	·223	3·57
1,400	760	·272	·257	·225	3·60
1,600	871	·285	·260	·227	3·64
1,800	981	·297	·261	·230	3·67
2,000	1,093	·310	·265	·231	3·70

(*G. H. Gill.*)

Latent Heat.

Equal weights of water, one quantity at 0° C., and the other at 100° C., when mixed have a temperature of 50° C.; but equal weights of ice and water, the former at 0° C., and the latter at 100° C., when mixed have a temperature of 10·6° C.

The conversion of a cube of ice 3-feet side into water at 0° would absorb the whole heat emitted by the combustion of a bushel of coal.

Absolute Zero of Temperature.

458° below Fahr. zero, or 272° below Cent. zero.

Heat Generated by the Combustion of Carbon.

HEAT GENERATED BY THE COMBUSTION OF ONE POUND OF CARBON.

State of Carbon.	Product of Combustion.	British Thermal Units per Pound.
Diamond	Carbon monoxide	3,915
„	„ dioxide	14,146
Graphite	„ „	14,222
Amorphous	„ monoxide	4,415
„	„ dioxide	14,647
Gaseous	„ monoxide	10,232
„	„ dioxide	20,463
2½ lb. Carbon monoxide	„ „	10,231

HEAT ABSORBED IN THE METAMORPHIC CONVERSIONS OF CARBON.

State of Carbon.	Product of Metamorphism.	British Thermal Units per Pound.
Diamond	Gas	6,316
Graphite	„	6,241
Amorphous	„	5,817
Diamond	Amorphous	499
„	Graphite	74·7
Graphite	Amorphous	424

Comparison of Hydrometer Scales.

(Compiled by Kestner Evaporator and Engineering Co. Ltd.)

Degrees Twaddell.	Sp. Gr.	Degrees Baume.	Approximate Degrees Brix at 15° C.	Degrees Twaddell.	Sp. Gr.	Degrees Baume.	Approximate Degrees Brix at 15° C.
1	1·005	0·7	1·3	52	1·260	29·7	55·2
2	1·010	1·4	2·5	54	1·270	30·6	56·6
3	1·015	2·1	3·7	56	1·280	31·5	58·5
4	1·020	2·7	4·9	58	1·290	32·4	60·2
5	1·025	3·4	5·9	60	1·300	33·3	62·0
6	1·030	4·1	7·2	62	1·310	34·2	63·8
7	1·035	4·7	8·3	64	1·320	35·0	65·4
8	1·040	5·4	9·5	66	1·330	35·8	66·8
9	1·045	6·0	10·6	68	1·340	36·6	68·6
10	1·050	6·7	12·0	70	1·350	37·4	70·0
11	1·055	7·4	13·4	72	1·360	38·2	71·8
12	1·060	8·0	14·5	74	1·370	39·0	73·5
13	1·065	8·7	15·8	76	1·380	39·8	75·0
14	1·070	9·4	17·0	78	1·390	40·5	76·4
15	1·075	10·0	18·2	80	1·400	41·2	77·8
16	1·080	10·6	19·3	82	1·410	42·0	79·5
17	1·085	11·2	20·4	84	1·420	42·7	81·0
18	1·090	11·9	21·6	86	1·430	43·4	82·5
19	1·095	12·4	22·5	88	1·440	44·1	83·8
20	1·100	13·0	23·6	90	1·450	44·8	85·4
21	1·105	13·6	24·6	92	1·460	45·4	86·6
22	1·110	14·2	25·6	94	1·470	46·1	88·0
23	1·115	14·9	26·8	96	1·480	46·8	89·5
24	1·120	15·4	27·6	98	1·490	47·4	90·8
25	1 125	16·0	28·6	100	1·500	48·1	92·2
26	1·130	16·5	29·5	102	1·510	48·7	93·8
27	1·135	17·1	30·5	104	1·520	49·4	95·2
28	1·140	17·7	31·5	106	1·530	50·0	96·8
29	1·145	18·3	32·5	108	1·540	50·6	—
30	1·150	18·8	33·4	110	1·550	51·2	—
31	1·155	19·3	34·4	112	1·560	51·8	—
32	1·160	19·8	35·4	114	1·570	52·4	—
33	1·165	20·3	36·2	116	1·580	53·0	—
34	1·170	20·9	37·4	118	1·590	53·6	—
35	1·175	21·4	38·4	120	1·600	54·1	—
36	1·180	22·0	39·4	122	1·610	54·7	—
37	1·185	22·5	40·4	124	1·620	55·2	—
38	1·190	23·0	41·4	126	1·630	55·1	—
39	1·195	23·5	42·2	128	1·640	56·3	—
40	1·200	24·0	43·2	130	1·650	56·9	—
41	1·205	24·5	44·2	132	1·660	57·4	—
42	1·210	25·0	45·2	134	1·670	57·9	—
43	1·215	25·5	46·2	136	1·680	58·4	—
44	1·220	26·0	47·0	138	1·690	58·9	—
45	1·225	26·4	47·8	140	1·700	59·5	—
46	1·230	26·9	48·8	142	1·710	60·0	—
47	1·235	27·4	49·8	144	1·720	60·4	—
48	1·240	27·9	50·6	146	1·730	60·9	—
49	1·245	28·4	52·0	148	1·740	61·4	—
50	1·250	28·8	53·4	150	1·750	61·8	—

(Compiled by Dr. F. L. Slocum, Pittsburgh.)

Name.	Molecular Symbol.	Atomic Weight.	Molecular Weight.	Products of Combustion.	Specific Gravity. Hydrogen = 2.	Specific Gravity. Air = 1.	Weight of 1 Litre in grams.	Weight of 1 cu. ft. in grains.	Weight of 1 cu. ft. in lbs.	Calories C–K.	Heat-Value. Carbon = 1.	Volume-Calorie. Hydrogen = 1.
Hydrogen	H_2	1	2	H_2O	2·000	0·06925	0·08955	39·1263	0·00559	34217·5	4·23	1·00
Marsh Gas	CH_4	—	15·97	H_2O–CO_2	15·974	0·55300	0·71506	312·4450	0·44640	13244·0	1·63	3·09
Carbon Monoxide	CO	—	27·93	CO_2	27·937	0·96715	1·25058	546·4397	0·07806	2441·7	0·302	1·00
Acetylene	C_2H_2	—	25·94	H_2O–CO_2	25·947	0·89829	1·16148	507·5338	0·07255	11923·0	1·48	4·53
Aethylene	C_2H_4	—	27·94	H_2O–CO_2	27·947	0·96749	1·25103	546·6318	0·07809	11884·0	1·47	4·86
Aethane	C_2H_6	—	29·94	H_2O–CO_2	29·947	1·03675	1·34058	585·7637	0·08368	12347·0	1·53	5·41
Propylene	C_3H_6	—	41·91	H_2O–CO_2	41·921	1·45124	1·87654	819·9506	0·11713	11731·0	1·45	7·21
Butylene	C_4H_8	—	55·89	H_2O–CO_2	55·894	1·93488	2·50190	1093·2072	0·15617	11619·0	1·44	9·51
Allylene	C_4H_4	—	39·92	H_2O–CO_2	39·921	1·38194	1·78692	780·7961	0·11154	11690·0	1·45	6·83
Benzole	C_6H_6	—	77·82	H_2O–CO_2	77·822	2·69463	3·48429	1522·4659	0·21749	10102·0	1·25	11·51
Napthalene	$C_{10}H_8$	—	127·70	H_2O–CO_2	127·722	4·39880	5·68783	2485·322	0·35505	9618·7	1·19	17·98
Sulphuretted Hydrogen	H_2S	—	33·98	SO_2–H_2O	33·981	1·17664	1·52147	664·802	0·09497	3488·0	0·43	1·73
Carbon Bi-Sulphide	CS_2	—	75·93	CO_2–SO_2	75·931	2·62580	3·39980	1483·577	0·21194	3404·0	0·421	3·79
Water Gas		* See analysis below.			15·562	0·53883	0·69678	304·438	0·04349	4839·7	0·5989	0·936
Coal Gas		* See analysis below.			11·332	0·39236	0·50739	186·620	0·02666	13817·0	1·710	1·924
Ammonia	NH_3	—	17·01	H_2O–N_2	17·010	0·58901	0·76163	332·790	0·47543	5332·0	0·659	1·33
Air	—	—	—	—	14·444	1·00000	1·29306	565·000	0·08071	—	—	—
Nitrogen	N_2	14·01	28·02	—	28·021	0·97026	1·25461	548·197	0·07831	—	—	—
Oxygen	O_2	15·96	31·92	—	31·920	1·10531	1·42923	624·500	0·08921	—	—	—
Carbon Dioxide	CO_2	—	43·89	—	43·892	1·51980	1·96519	858·687	0·12267	—	—	—
Carbon from Wood	C_2	11·97	23·94	CO_2	—	—	—	—	—	8080·0	1·000	—
Anthracite—Penna	—	—	—	CO_2–H_2O	—	—	—	—	—	7844·4	0·971	—
Bituminous Coal	—	—	—	CO_2–H_2O	—	—	—	—	—	8391·7	1·038	—
Cannel Coal	—	—	—	CO_2–H_2O	—	—	—	—	—	6365·5	0·788	—
Furnace Coke	—	—	—	CO_2–H_2O	—	—	—	—	—	7019·4	0·868	—
Gas House Coke	—	—	—	CO_2–H_2O	—	—	—	—	—	7000·0	0·866	—
Coal Tar	—	—	—	CO_2–H_2O	—	—	—	—	—	8667·0	1·073	—
Crude Petroleum	—	—	—	CO_2–H_2O	—	—	—	—	—	11094·1	1·373	—

* NOTE.

	Water Gas. (Uncarburetted.) Per cent.	Coal Gas. Per cent.
Hydrogen	49·2	50·28
Marsh gas	0·3	36·95
Illuminants	Trace.	6·34
Carbon monoxide	43·8	4·37
Carbon dioxide	2·7	None.
Nitrogen	4·0	Trace.

Properties of Gases, &c.

(*W. H. Booth.*)

In the tables pages 222 to 225 are given many figures relative to the gases chiefly, which are of interest in questions of heat combustion, and the gas engine. The figures are principally based on Berthelot's thermal determinations of the calorific capacity of the gramme molecule, the figure for which, if divided by the molecular weight, gives the heat generated per gramme of the substance. An attempt is made to give the correct values of the specific heat at high temperatures, with a view to the bearing of this property on the theory of the gas engine, and the possibly erroneous ideas as to the supposed effects of dissociation, which have been much overrated. The thermo-physical properties of carbon are more fully tabulated than has hitherto been attempted, with a view to explain the variations due to allotropism.

Heat and Combustion.

There are in practice only two elementary fuels, carbon and hydrogen. They generate heat by union with oxygen, and their compounds are also available as fuels.

Heat is measured in units. The British thermal unit B.Th.U. is the amount of heat necessary to raise 1 pound of water from 60° F. to 61° F., and its mechanical equivalent is J = 778 pounds raised 1 foot in the latitude of Manchester; this last an unnecessary refinement in engineering.

The metrical or French calorie is the amount of heat necessary to raise 1 gramme of water 1° C. This is the 'petit calorie.' The great calorie is the heat necessary to raise 1 kilogram of water through 1° C. The mechanical equivalent is 427 kilograms raised 1 metre at the latitude of Paris; this latter refinement being unnecessary in engineering. The following table gives the ratios of English and French units:

1 Calorie = ·001 great calorie.	1 B.Th.U. = 1055 joules = 778 foot-pounds (until recently the accepted value was 772).
1 Great calorie = 3·968 B.Th.U.	1 Great calorie = 3087·3 foot-pounds.
1 B.Th.U. = 0·252 great calorie.	1 B.Th.U. = 107·6 kilog. metres.
1 Great calorie = 427 kilog. metres.	

Chemists use somewhat different terms and state calorific measurements in terms of the molecule. The gramme molecule of hydrogen is the unit employed. One gramme molecule of hydrogen, H_2, taken at 0° C. and 760 mm. of pressure of a mercury column, weighs 2 grammes and has a volume of 22·32 litres. The molecular weight of any other simple or compound gas is the weight which occupies the volume occupied by 2 grammes of hydrogen, that is 22·32 litres. The molecular specific heat of a gas is the heat of this volume in 'petit calories.' Then the molecular heat divided by the molecular weight will give the specific heat per unit weight or gramme; and the molecular heat divided by 22·32 will give the specific heat per unit of volume.

The specific heat of a gas is usually stated at constant pressure and at constant volume. In a perfect gas the ratio of these two is about 1·4 at ordinary temperatures. This is an erroneous way of putting it. The difference is really due to work done on the atmosphere in expanding to constant pressure. This work is invariable at 1·94 calories. The true ratio of specific heat at constant pressure or Cp to that at constant volume Cv, is thus properly stated, $Cp = Cv + 1·94$, or usually $= Cv + 2$. Thus, if 22·32 litres of gas are heated 1° C. from 0° C. they will perform work against a column of mercury 760 mm. high to the extent of 1·94 calories at all temperatures. A gas expands when heated 1° C. to an additional bulk $= \frac{1}{273}$ of the bulk occupied at 0° C. Hence the invariable quantity 1·94.

The specific heat of a gas increases with temperature. The number of calories generated by the combustion of a unit weight of a substance if divided by the specific heat of the products of combustion and by the total weight of such products, will give the nominal temperature. The 'theoretical' temperature of combustion is the nominal temperature found by using the specific heat at ordinary temperatures. These nominal temperatures are never attained. The ordinary specific heat of carbon dioxide is quadrupled at 4000° C., and the temperature that might theoretically reach 18000° C., in oxygen in a certain case would not go beyond 4500° C. or thereabouts.

The calorific capacity of fuel may be approximated by calculating the capacity of its constituents of carbon and hydrogen. This is absolutely accurate, subject to allowance for the heat of formation. Thus in the formation of some hydrocarbons, heat is evolved. When these hydrocarbons are burned, the heat which was produced in their original formation cannot be again produced, and the combustion is productive of so much less heat. Others, such, for example, as acetylene, absorb heat when formed, and this substance when burned gives out more heat than corresponds with its carbon and hydrogen. This is one reason for its brilliance, and accounts for its explosive tendency.

HEAT OF COMBUSTION OF SUBSTANCES.

	Calories.	B.Th.U.	Authority.
Cellulose	4,200	7,560	Berthelot
Soft resinous wood	5,050	9,090	Gottlieb
Hard wood	4,750	8,550	"
Peat	5,940	10,692	Bainbridge
Cane sugar	3,961	7,130	Berthelot
Asphalt	9,532	17,159	Slossom & Colburn
Pitch	8,400	15,120	Anon.
Naphthalin	9,690	16,842	Berthelot
Paraffin	11,000	19,800	Mahler
Tallow	9,500	17,100	Stohmann
Sulphur	2,500	4,500	Berthelot
Petroleum	9,600 to 11,000	17,280 to 19,800	Various
Schist oil	9,000 to 10,000	16,200 to 18,000	"
Heavy coal gas oil	8,900	16,020	Ste-Claire Deville
Cotton oil	9,500	17,100	Anon.
Rape oil	9,489	17,080	Stohmann
Olive oil	9,473	17,051	"
Sperm-oil	10,000	18,000	Gibson

Combustion of Carbon.

Carbon exists only as a solid and is found in three forms or allotropic modifications: (*a*) the diamond; (*b*) graphite; (*c*) amorphous, as charcoal. The heat generated by the perfect combustion of each of these forms is peculiar to that form. Carbon exists in liquid form only in combination with other substances and does not vaporise except at 3600° C. The total heat of combustion of carbon is 11·646 calories per gramme from the state (*a*). Of this amount ·2783 calories disappear in converting the diamond to the amorphous state (*c*); 3·231 calories are absorbed in vaporising the carbon; and 2·4533 calories are set free by its conversion into monoxide CO. 5·684 calories are then produced by the second oxidation of this CO into dioxide=CO_2. In practice the only available heat is that which is set free after vaporising the carbon, *i.e.* 8·137 calories. The following table gives these characteristics in brief, of converting 1 gramme of carbon.

	Calories.
1. Converting diamond to graphite	= ·041
2. " graphite to amorphous	= ·237
3. " diamond to amorphous (1)+(2)	= ·278
4. " amorphous to monoxide CO	= 2·453
5. " monoxide to dioxide	= 5·684
6. Vaporising amorphous carbon (5) − (4)	= 3·231
7. Total energy generated converting carbon vapour to dioxide (1)+(2)+(4)+(5)+(6)	= 11·646
8. Total available heat in practice (7) − (3) − (6)	= 8·137

The difference between (7) and (8) represents expenditure in unlocking the crystal form of the diamond (3) and in converting the carbon to gas (5). The latent heat of vaporisation of carbon is thus 3·231 or about half that of steam.

Hydrogen is known in three states, liquid, solid, and gaseous. The liquid and solid states are those of low temperature. All practical determinations start from the gaseous state. The following figures are found in the combustion of 1 gramme of hydrogen:

	Calories generated.
1. Converting hydrogen to water gas, H_2O,	29·15
2. " " " liquid	34·50
3. " " " solid	35·2

The ordinary available heat is that of (1) only; (2) being only partially secured when the products of combustion are cooled considerably below 100° C.

Stated per pound, carbon yields 14,500 British heat units, and hydrogen 52,000 to 62,100 according to the final temperature. The first oxidation of 1 lb. of carbon to monoxide yields barely 4,500 heat units: the further oxidation of the resulting carbonic oxide yielding fully 10,000 units.

The difference of the two oxidations is due to the rendering latent of about half the heat of the first oxidation in gasifying the solid carbon. The following equivalent units are useful:

1 Calorie per square metre = 0·369 B.Th.U. per square foot.
1 B.Th.U. per square foot = 2·713 calorie per square metre.
1 Calorie per kilogram = 1·800 B.Th.U. per pound.
1 B.Th.U. per pound = 0·556 calorie per kilogramme.

(*Continued on p.* 226.)

Name.	Symbol.	Density. H=1	Molecular Weight.	Lbs. per cubic ft.	Cubic ft. per lb.	Grams per litre.	Litres per gram.	Required to burn one unit. Weight. Air.	Weight. Ox.	Volume Air.	Volume O.
Air	O_{23} N_{76} X_1	14·44	—	·08073	12·385	1·29318	·773	—	—	—	—
Ammonia	NH_3	8·5	17	·05324	18·783	·761	1·313	6·13	1·41	3·58	·1
Carbon C. Diamond	—	—	12	—	—	—	to CO / „ CO_2	5·797 / 11·594	1·334 / 2·667	—	—
Carbon C. Graphite	—	—	„	—	—	—	to CO_2	do.	do.	—	—
Carbon C. Amorphous	—	—	„	—	—	—	to CO / „ CO_2	„	„	—	—
Carbon C. Vapour	—	12	„	·06696	14·930	1·0727	·932	„	„	9·54	2·0
Carbon dioxide	CO_2	22	44	·12344	8·147	1·967	·508	—	—	—	—
Carbonic oxide	CO	14	28	·07817	12·80	1·2515	·800	2·484	·571	2·381	·5
Carbon bisulphide	CS_2	38	76	·21242	4·706	3·4058	·2947	5·478	1·26	14·30	3·0
Hydrogen	H_2	1	2	·00559	178·83	·08961	11·16	34·785	8·000	2·39	·5
Oxygen	O_2	16	32	·08926	11·203	1·4298	·699	—	—	—	—
Nitrogen	N_2	14	28	·07845	12·763	1·25616	·796	—	—	—	—
Steam	H_2O	9	18	·05022	19·912	·8047	1·242	—	—	—	—
Steam at 2,000°	H_2O	—	„	—	—	—	—	—	—	—	—
Steam at 4,000°	H_2O	—	„	—	—	—	—	—	—	—	—
Acetylene	C_2H_2	13	26	·07267	13·456	1·190	·840	13·378	3·077	11·93	2·5
Benzene	C_6H_6	39	78	·208	4·808	3·333	·303	13·378	3·077	35·80	7·5
Ethylene	C_2H_4	14	28	·07814	12·797	1·2519	·799	14·903	3·428	14·30	3·0
Ethane	C_2H_6	15	30	·08565	11·950	1·3415	·746	16·484	3·733	16·70	3·5
Methane	CH_4	8	16	·04466	22·391	·7155	1·397	17·392	4·000	9·54	2·0
Ethylene chloride	$C_2H_4Cl_2$	49·5	99	·2767	3·631	4·4357	·22626	3·855	·808	11·93	2·5
Ethyl	C_2H_6O	23	46	·12857	7·775	2·061	·287	9·074	2·037	14·30	3·0
Methyl	CH_4O	16	32	·08926	11·203	1·4298	·699	6·521	1·500	7·15	1·5
Cyanogen	C_2N_2	26	52	·1453	6·88	2·338	·427	5·348	1·23	9·54	2·0
Glycerine	$C_3H_8O_3$	—	92	—	—	—	—	18·148	4·174	16·70	3·5
Blast Furnace Gas. $[CO]_{27}$ N_{68} $(CO_2)_5$ H_2		14±	—	·079	12·65	1·2515	·800	1·00 / ·721	·22 / ·166	·82	·2
Producer Gas, $[Sundry]_{1·5}$	$[CO]_{25}$ N_{68} $[CO_2]2\frac{1}{2}$ $[CH_4]_2$	14±	—	·079	12·65	1·2515	·800	·99 / ·721	·21 / ·166	—	—
Water Gas, $[CO]_{76}$ $[CH_4]_2$ $[Sundry]_{7·5}$ $(CO_2)_{10}$ $N2\frac{1}{2}$		8±	—	·045	22·5	·726	1·40	3·878	·788	—	—
Coal Gas, &c., 16 H_2 $[CH_4]_{37}$ $[CO]_{12·5}$ N_4		4·7	—	·032	31·6	·516	1·975	13·89	2·81	6·16	1·2
Natural Gas $[CH_4]_{90}$ N_6 [Sundry]		8	—	·045	22·5	·726	1·40	15·00	3·06	—	—

Nominal temp. of combustion.				Heat generated by combustion of one					Heat of formation at 15° per Molecule
Air.		Oxygen.		Lb.	Cubic foot.	Gram.	Litre.	Molecule.	
F.°	C.°	F.°	C.°	B.Th.U.	B.Th.U.	Cal.	Cal.	Cal.	Cal.
—	—	—	—	—	—	—	—	—	—
3762	2090	8278	4599	9666	514·6	5·371	4·087	91·3	12·2 gas 16.6 liq.
2402	1317	6880	3804	3915	—	2·175	—	26·1	·50 [1]
4786	2718	17780	9879	14146	—	7·859	—	94·31	3·34 [2]
4812	2659	17875	9931	14222	—	7·901	—	94·81	2·84 [2] — ·50 [3]
2673	1485	7725	4292	4415	—	2·453	—	29·44	— 2·84 [1]
4988	2753	18440	10226	14647	—	8·137	—	97·65	— 3·34 [3]
6955	3846	25752	14290	20461	1410	11·367	12·193	136·41	−38·76 [2] −42·1 [3]
—	—	—	—	—	—	—	—	—	68·20 [4] 94·31 [3] 97·65 [2]
3494	1923	12892	7144	4383	342	2·436	3·047	68·2	26·1 [3] 29·4 [2]
6590	3661	24271	13484	9344	1985	5·197	17·66	394·5	−25·4 gas −19 liq.
—	(Water Vapour)			52290	293	29·15	2·612	58·3 gas 69 liq. 70·4 sol.	—
4813	2674	12108	6727	62100	347	34·50	3·091		
—	—	—	—	Water Liquid				—	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	Solid = 70·4 Liq. = 69·0 Gas = 58·3	per H_2
—	—	—	—	—	—	—	—	—	50·6
—	—	—	—	—	—	—	—	—	37·1
6120	3400	20340	11300	21856	1624	12·142	14·46	315·7	−58·1
5022	2790	16830	9350	18094 17930	3764	10·052 9·960	33·496	784·1 gas 776·9 liq.	− 1·8 sol. − 4·1 liq −11·3 gas
5400	3000	16886	9381	21927	1744	12·182	15·250	341·1	−14·6
4354	2419	14848	8249	22338	1912	12·410	16·641	372·3	23·3
4036	2245	14348	7971	24017	1073	13·343	9·547	213·5	18·9
5144	2858	13179	7321	5490	1511·8	3·050	13·52	302·	34·4 gas 41 liq.
4630	2573	12583	6690	12744	1639·1	7·080	14·54	325·7	59·8 gas 69·9 liq.
4186	2325	10216	5675	9596	856·5	5·331	7·627	170·6	53·3 gas 61·7 liq.
6099	3388	18222	10125	9086	1320·6	5·048	12·02	262·5	−73·9 gas −68·5 liq.
4000	2222	8078	4488	7770	—	4·317	—	397·2	161·7 liq. 165·6 sol.
2160	1200	4500	2500	1223 to 1237	96·7 97·8	·700	·900	—	—
3440 2160	1910 1200	4500	2500	1265 to 2530	100 to 200	·773 to 1·370	·9674 to 1·713	—	—
4850	2700	—	—	4230 to 5458	330 to 700	2·35 to 3·03	3·00 to 6·32	—	—
4500	2500	—	—	21400	685	11·9	6·099	—	—
4200	2333	—	—	24444	1100	13·58	10·0	—	—

[1] From Graphite. [2] From Amorphous Carbon. [3] From Diamond. [4] From Carbonic Oxide.

Name.	Critical T.° and Pressure (Atmospheres).				Temp.		Density of liquid.
	Lower limit.		Upper limit.		Boil.	Fusion.	
	T.°C. Absol.	Atmos.	T.°C.	Atmos.	C.°	C.°	Water =
Air	133	39	−192·2	—	−192·2	—	·938
Ammonia	403	115	—	—	− 38·5	− 75	·686
Carbon C. Diamond	—	—	—	—	3600	—	—
Carbon C. Graphite	—	—	—	—	,,	—	—
Carbon C. Amorphous	—	—	—	—	,,	—	—
Carbon C. Vapour	—	—	—	—	,,	—	—
Carbon dioxide	306	77	—	—	− 78·2	−115	·83
Carbonic oxide	137·5	35·5	—	—	− 190	−207	—
Carbon bisulphide	546	77·9	277·55	95·86	46·2	−116	1·293
Hydrogen	39	20	—	—	− 243	—	·071
Oxygen	154·2	50·8	—	—	−181·4	−211+	1·124
Nitrogen	127	35	—	—	−194·4	−203	·855
Steam	—	—	370	195·5	100	0	1·00
Steam at 2,000°	—	—	—	—	—	—	—
Steam at 4,000°	—	—	—	—	—	—	—
Acetylene	310	68	—	—	− 85	− 81	·451
Benzene	569·7	60·5	—	—	80·8	4·5	·899
Ethylene	283	51	—	—	−103	−169	—
Ethane	307	50·2	—	—	− 93	−151+	—
Methane	200	56·8	—	—	−164	−185·5	·415
Ethylene chloride	—	—	283	—	84·9	—	1·28
Ethyl	235·39	66·78	—	—	78·3	− 90+	·809
Methyl	202·76	72·85	233	69·7	66·8	—	·81
Cyanogen	7·2	3·6	124	61·7	− 20·7	− 40	·87
Glycerine	—	—	—	—	290·4	17	1·26
Blast Furnace Gas	—	—	—	—	—	—	—
Producer Gas &c.	—	—	—	—	—	—	—

[The + sign indicates that the actual temperature is lower than that given.]

Water Gas, &c.	—	—	—	—	—	—	—
Coal Gas, &c.	—	—	—	—	—	—	—
Natural Gas	—	—	—	—	—	—	—

Liquid.	Specific heat. Water =1 Constant Press.	Constant Vol.	Molecular. Constant Press.	Constant Vol.	Elementary sp. heat at high temp.	Temp. of ignition.	Heat of solution.	a ✡
—	·2375	·1686	—	—	—	— —	—	·0010
Sol.	·508	·391	9·64 gas / 15·1 liq.	7·6	8·51+·0053T	— —	4·1	·0071
·1468	—	—	6·85 at	200°	11·3 at 1000°	— —	—	—
·285					14·2 „ 2000°			
·2018	—	—	7·12 at	200°	18·8 „ 3600°	— —	—	—
·2415	—	—	4·6 at	100°	—	— —	—	—
—	·285	—	6·85	—	8·42+·00144 T at 1000° to 3600°	— —	—	—
—	·216	·171	8·4 + ·0106 T	6·4 + ·0106T	19·1+·0030 (T− 2000°)=25·1 at 4000°	— —	5·6	·0084
—	·245	·173	6·8	4·8	4·8+·0032(T−1600°)	— —	—	·0010
·20884	·157	·130	21·7 gas / 18·2 liq.	—	10+·0746 T 80° to 230°	— —	—	—
—	3·410	2·4146	6·82	4·8	4·8+·0032 (T− 1600°)=14·1 at 4500°	— —	—	·0010
—	·217	·1548	6·95	4·95	4·95+·00324(T−1600°)	— —	—	·0010
—	·244	·173	6·83	4·8	4·8+·0032(T−1600°)	— —	—	·0010
1·0 liq. ·504 solid	·479	·370	8·65	6·65	16·2+·038(T - 2000°)	— —	—	—
—	—	·9	—	16·2	—	— —	—	—
—	—	1·32	—	23·8	—	— —	—	—
—	·373	—	9·7	—	—	580 —	5·3	—
·43602	·3754	·350	34 liq. 29·2 gas (116°to218°)	—	17·45+·0798T	— —	—	·0510
—	·404	·332	9·42 at 0° 14·0 at 200°	—	9·42+·0231T	— —	—	·0137
—	—	—	—	—	—	616 —	—	—
—	·593	·468	9·5 100° to 200°	—	—	667 —	—	—
—	·23	liq.=28·9+·0044T gas=22·7 at 111° to 211°		—	—	— —	—	—
·60 liq. ·50 gas	·451	·320	51·2 liq. 20·8° (110° to 220°		—	— —	2·5	—
·66 liq. ·46 gas	—	—	21·4 liq. 14·7 gas (101°to225°		—	— —	2·0	—
—	—	—	—	—	—	— —	6·8 gas 1·4 liq.	—
—	—	—	—	—	—	— —	5·4	—

[NOTE.—Gases expand by heat to the extent of $\frac{1}{273}$ of their bulk at 0° C. for each degree Centigrade, or $\frac{1}{491{\cdot}4}$ of their bulk at 32° F. for each degree Fahr.

✡ The specific heat of gases varies with the temperature, being more for higher temperatures. At the absolute zero the values of the molecular heat of all gases seem to converge at 6·5 for constant pressure values. Lechatelier therefore gives a formula for specific heat $Cp = 6{\cdot}5 + a\mathrm{T}$, where T is the absolute temperature Centigrade and a is a coefficient greater according to the complexity of the molecule. For values of a see table. This has an important bearing on the theory of the gas engine.]

[T = Temperature Centigrade.]

—	—	—	—	—	—	— —	—	—

These calories are the great calories (p. 220.)

For thermo-chemical tables of gases see pp. 222–225.

The temperature produced by combustion is largely dependent upon the weight of the resultant product. Thus 1 lb. of hydrogen when burned to water vapour will produce 52,380 heat units which have to be divided among the 9 lbs. of water. The nominal temperature is 14,375° F which, however, is based on the supposititious constancy of the specific heat; 1 lb. of carbon however, which only generates about 14,500 heat units, produces only 3⅔ lbs. of gas, and the nominal resulting temperature is 18,457. These are for combustion in oxygen. With air the additional weight of nitrogen still further reduces the nominal temperatures to about 5,000° in each case.

The percentage of each constituent of a mixed product must be multiplied by the specific heat in order to find the true valency of that product in the calculation of temperature. To find the mean specific heat of a mixture of gases, the weight of each gas is to be multiplied by its specific heat. The products are to be added together and divided by the sum of the weights of all the gases. The result is the mean specific heat. Then the temperature of combustion is found by dividing the total heat of combustion of the combustible gases by the weight of products and by the mean specific heat.

Similarly the calorific value of a mixed gas is found by multiplying the weight of each gas by its calorific value per pound, adding the products together and dividing by the total weight. The result is the thermal value per pound of the mixed gas.

Boiling-points of Saturated Solutions of Various Salts.

Salt.	C.°	F.°	Salt.	C.°	F.°
Sodic nitrate	120·7	249·5	Hydrosodic phosphate	106·6	224
Potassic nitrate	115·7	240	Sal-ammoniac	114·2	237·6
,, chlorate	104	219·2	Calcic chloride	179·4	355
Sodic chloride	108·2	227	Potassic acetate	169	336
Potassic chloride	108	226·4	,, carbonate	134·7	275
Sodic carbonate	104·6	220	Calcic nitrate	151	304
,, acetate	124·5	256	Strontic chloride	118	244
Baric chloride	104·2	220	Potassic tartrate	114·4	238

Boiling-points of Water at Various Pressures.

Barometer in Inches.

Boiling-point. F.°	Barometer. Inches.	Boiling-point. F.°	Barometer. Inches.	Boiling-point. F.°	Barometer. Inches.	Boiling-point. F.°	Barometer. Inches.
185	17·047	193	20·254	201	23·937	209	28·183
186	17·421	194	20·687	202	24·441	210	28·744
187	17·803	195	21·124	203	25·014	211	29·331
188	18·196	196	21·576	204	25·468	212	29·922
189	18·593	197	22·030	205	25·992	213	30·516
190	18·992	198	22·498	206	26·529	214	31·120
191	19·407	199	22·965	207	27·068	215	31·730
192	19·822	200	23·454	208	27·614	216	32·350

Barometer in Millimètres.

Boiling-point. C.°	Barometer. Millimètres.	Boiling-point. C.°	Barometer. Millimètres.	Boiling-point. C.°	Barometer. Millimètres.	Boiling-point. C.°	Barometer. Millimètres.
85·5	441·62	89·5	515·53	93·5	599·49	97·5	694·56
86	450·34	90	525·45	94	610·74	98	707·26
86·5	459·21	90·5	535·53	94·5	622·17	98·5	720·15
87	468·22	91	545·78	95	633·78	99	733·21
87·5	477·38	91·5	556·19	95·5	645·57	99·5	746·50
88	486·69	92	566·76	96	657·54	100	760·00
88·5	496·15	92·5	577·50	96·5	669·69	100·5	773·71
89	505·76	93	588·41	97	682·03	101	787·63

Dilatation or Expansion of Substances per Degree of Fahrenheit Scale.

Temperatures.	Solids.	Linear. (*a.*)	Surface. (*b.*)	Volume. (*c.*)
32° to 212°	Glass	0·00000478	0·00000956	0·00001434
212 „ 392		0·00000546	0·00001093	0·00001639
392 „ 572		0·00000660	0·00001320	0·00001980
32 „ 212	Wrought iron	0·00000656	0·00001312	0·00001968
212 „ 572		0·00000895	0·00001790	0·00002686
32 „ 212	Soft, good iron	0·00000680	0·00001360	0·00002040
32 „ 212	Cast iron	0·00000618	0·00001236	0·00001854
32 „ 212	„ steel	0·00000600	0·00001200	0·00001800
32 „ 212	Hardened steel	0·00000689	0·00001378	0·00002067
32 „ 212	Copper	0·00000955	0·00001910	0·00002865
212 „ 572		0·00001092	0·00002184	0·00003276
32 „ 212	Lead	0·00001580	0·00003160	0·00004740
32 „ 212	Gold, pure	0·00000815	0·00001630	0·00002445
32 „ 212	„ hammered	0·00000830	0·00001660	0·00002490
32 „ 212	Silver, pure	0·00001060	0·00002120	0·00003180
32 „ 212	„ hammered	0·00001116	0·00002232	0·00003348
32 „ 212	Brass, common cast	0·00001043	0·00002086	0·00003129
32 „ 212	„ wire or sheet	0·00001075	0·00002150	0·00003225
32 „ 212	Platinum, pure	0·00000491	0·00000982	0·00001473
212 „ 572		0·00000520	0·00001040	0·00001560
32 „ 212	Palladium	0·00000555	0·00001110	0·00001665
32 „ 212	Roman cement	0·00000797	0·00001594	0·00002391
32 „ 212	Platinum, hammered	0·00000530	0·00001060	0·00001590
32 „ 212	Zinc, pure or cast	0·00001633	0·00003266	0·00004899
32 „ 212	„ hammered	0·00001722	0·00003444	0·00005166
32 „ 212	Tin, cast	0·00001207	0·00002414	0·00003621
32 „ 212	„ hammered	0·00001500	0·00003000	0·00004500
32 „ 212	Fire-brick	0·00000275	0·00000470	0·00000705
32 „ 212	Good red brick	0·00000305	0·00000610	0·00000915
32 „ 212	Marble	0·00000613	0·00001226	0·00001839
32 „ 212	Granite	0·00000438	0·00000876	0·00001314
32 „ 212	Bismuth	0·00000773	0·00001546	0·00002319
32 „ 212	Antimony	0·00000602	0·00001204	0·00001806
32 „ 212	Palladium	0·00000555	0·00001110	0·00001665
32 „ 212	Mercury	0·00003333	0·00006666	0·00010000
212 „ 392		0·00003416	0·00006833	0·00010250
392 „ 572		0·00003500	0·00007000	0·00010500
32 „ 212	Water	0·00008806	0·00017612	0·00026420
212 „ 392		0·00017066	0·00034133	0·00051020
392 „ 572		0·00018904	0·00037808	0·00056713
32 „ 212	Salt, dissolved	0·00009250	0·00018560	0·00027780
32 „ 212	Sulphuric acid	0·00011111	0·00022222	0·00033333
32 „ 212	Turpentine and ether	0·00012966	0·00025933	0·00038900
32 „ 212	Oil, common	0·00014814	0·00029629	0·00044444
32 „ 212	Alcohol and nitric acid	0·00015151	0·00030302	0·00055555
32 „ 212	All permanent gases	0·00069416	0·00138832	0·00208250

The superficial expansion is twice the linear, and the cubical expansion three times the linear. The coefficient of expansion of an alloy is equal to the mean coefficients of expansion of the volumes of the metals composing it.

If a bar is *increased* in length from l to L by an *increase* of temperature of $t°$, then

$$L = l(1 + at°).$$

If a bar is *decreased* in length from L to l by a *decrease* of temperature $t°$, then

$$l = \frac{L}{1 + at°}.$$

Change in Density of a Body by Change in Heat.

If *decrease* in density be from d to d' by an *increase* of temperature of $t°$, then

$$d' = \frac{d}{1 + ct°}.$$

If *increase* in density be from d' to d by a *decrease* of temperature of $t°$, then

$$d = d'(1 + \alpha t°).$$

1. Solids have a much smaller coefficient of expansion than liquids.

2. The coefficient of expansion of liquids increases with the temperature.

3. The coefficient of expansion of a liquid which only preserves its state under very great pressure is probably very great.

Expansion of Air by Heat.

Dry air expands or contracts uniformly ·002039 its volume per F.° difference under *constant pressure*.

If the *volume is constant* and the pressure varies, then the coefficient per F.° is ·002036.

Reduction of Volume of Liquids under Pressure.

An ordinary liquid under a pressure of 200,000 lbs. per sq. in. loses in volume about 33 per cent.

The following shows the percentage of reduction of volume under a pressure of 1 atmosphere (14·7 lbs. per square inch) :—

	Per Cent.		Per Cent.		Per Cent.		Per Cent.
Alcohol . . .	·00216	Ether . . .	·006158	Mercury . .	·000265	Water . . .	·004663

Flash Temperatures.

Dr. H. Holm finds that the temperature at which substances in contact with atmospheric air at ordinary pressures will catch fire are, among others :—Lighting gas, 600° C ; benzine, 415° C. ; petroleum, 380° C. ; gas oil, 350° C. ; machine oil, 380° C. ; coal tar, 500° C. ; tar oil, 580° C. ; and benzol, 520° C. These temperatures are greatly influenced by the presence of other substances, which act as catalysers. This is especially the case with hydrogen, methane, and ethane, not ethylene or acetylene. Among solids it is the substances with the biggest molecules which most readily burst into flame. As a broad rule, the nearer a substance is to a gaseous condition, the higher the temperature to which it must be exposed before it will kindle : but this depends also on the chemical constitution.

See also page 211.

SOUND.

The intensity of sound decreases as the square of the distance.

The intensity of sound increases as the square of the amplitude of the vibrations of the sonorous body.

The intensity of sound depends on the density of the air in the place at which it is produced.

The intensity of sound is greater in the direction of the wind than in the contrary direction.

Velocity of Sound through Air.

Sound travels at the rate of 1126 feet (·213 miles) (343 metres) in a second through air at a temperature of 16° C.

If

v = velocity in feet per second ;
$t°$ = temperature of the air, Fahr. scale ;
D = distance in feet the sound travels in the time, T ;

then,

$$v = 1089{\cdot}42\ \sqrt{1 + 0{\cdot}00208\ (t° - 32)};\quad D = 1089{\cdot}42T\ \sqrt{1 + {\cdot}00208\ (t° - 32)},$$

$$T = D \div v.$$

EXAMPLE.—A ship at sea was seen to fire a cannon, and 6·5 seconds (T) afterwards the report was heard ; the temperature ($t°$) of the air was 60°. Required, the distance (D) to the ship.

$$D = 1089{\cdot}42 \times 6{\cdot}5\ \sqrt{1 + {\cdot}00208\ (60° - 32)} = 7{,}300 \text{ feet, or } 1{\cdot}38 \text{ mile.}$$

The velocity of sound in water is about four times that in air.

Velocity of sound in sea water $= 4756 + 13{\cdot}8\,t - 0{\cdot}12\,t^2 + 3{\cdot}73$ (S-35) (ft./sec.), where $t°$ = temperature, and S = salinity in parts per thousand. This formula holds over the temperature range 6°–17° C. and for salinities of about 35 per cent.

(*F. E. Smith, F.R.S., Royal Institution Lecture, Feb.* 25, 1924.)

Distances at which Sounds can be Heard.

Descriptions of Sounds.	Audible at a Distance of	
	Feet.	Miles.
A powerful human voice in the open air, no wind	460	0·087
Report of a musket	16,000	3·02
Drum	10,500	2
Music, strong brass band	15,840	3
Cannonading, very strong	475,000	90
In a barely observable breeze a strong human voice with the wind can be heard	15,840	3

Velocity of Sound through Solid Substances in Feet per Second.

Metals.				Woods.			
Lead	4,000	Copper	11,700	Pine	10,900	Elm	13,500
Gold	5,700	Steel wire	15,500	Oak	12,600	Fir	15,200
Silver	8,550	Iron	16,800	Ash	13,300	Aspen	16,700

Speaking-Tubes.

The greatest distance at which a sound signal, strongly and clearly given, can be heard through a straight line of tube, without branches, is about 1,500 ft., and cannot exceed 1,650 ft.

The best sizes for speaking-tubes are 1·2 in. for distances below, and 2·1 ins. for those above 650 ft., in single lines; and for branched systems up to 160 ft., ·80 in.; 160 to 500 ft., 1 in.; 500 to 1,000 ft., 1·3 in.; above 1,000 ft., 2·1 ins. Below 1·2 in. the frictional resistance to the sound waves is too great, and above 2·1 ins. it is beyond the power of the average human voice to set the enclosed air in vibration with the necessary intensity.

The greater the diameter of the tube the louder must the voice and the clearness of the articulation of the speaker be.

Vowel sounds are more readily heard than consonants, and longer rather than short accented ones.

Sheet zinc, on account of its low elasticity, is the best material for tubes, although in most cases galvanised iron may be preferred on account of the readiness with which it transmits knocker signals.

Screwed collars are preferable to flanges for joining the tubes.

The tubes must be as smooth as possible inside, and sudden changes of section are to be avoided.

Although the best method of isolating the tubes is to inclose them in earth or masonry, it will be more convenient in most cases to use earthenware pipes as casings suspended from the roof of the levels, which need only be solidly clamped at the stations.

Changes in the direction of the line and branch connections are best made by curves of not less than 16 ft. radius. When there are many branches, these should be only signalling points, the others being all receiving stations. If, however, a line is required for giving signals from both ends, it may be utilised for intermediate points by short receiving branches, about 16 ft. long, connected with the main line by proper curves. The number of these branches should not, however, be more than two for a 1·6-in. tube of 1,000 ft., or three for one of 2·1 ins. and 1,300 ft. In cases of greater complexity it is better to establish repeating stations at intervals of about 650 ft.

The best call signals for great distances are made by striking the side of the tube; but a bugle may be used, if it is pressed close to the mouthpiece. Whistles are inaudible except at short distances.

The oval or elliptical mouthpieces commonly used on short lines are quite useless. The most convenient arrangement is to make the end of the tube slightly conical, widened to about 1·5 in. in diameter, and cover it with a flat wooden ring, like a telephone, which can be used either for speaking or hearing with the minimum loss of sound.

OPTICS.

LIGHT.

Decomposition of Light in the Spectrum.

Colours.	Maximum Ray.	Combination of Colours.		
		Primary.	*Secondary.*	*Tertiary.*
Violet Indigo Blue	Chemical Electrical	Blue Yellow	Green	Dark Green
Green Yellow Orange	Light	Blue Red	Purple	Brown
Red	Heat	Yellow Red	Orange	

All the colours of the spectrum mixed together make white, which is proved by the decomposition of white light, which makes the seven colours.

Velocity of Light.

Velocity of light $= 3 \cdot 004 \times 10^{10}$ cms. per sec. Mean wave length $= 5 \cdot 3 \times 10^{-5}$ cms.

The velocity of light through the atmosphere is 186,330 miles per second (*Newcomb*). The velocity of light through transparent bodies is not known, but probably varies inversely as the square root of the specific gravity of the transparent substance.

Light passes from the sun to the earth ($1 \cdot 487 \times 10^{13}$ cms. = 92,390,000 miles [*Everett*]) in eight minutes, at which velocity light can pass around the earth in one-eighth of a second.

To find the Focal Length of a Convex Mirror.

Use as object an opaque screen, with a hole and pin-point, and painted white, or covered with white paper.

Set up on the bench, in line, say, with the left edge of the hole, the convex mirror and an auxiliary biconvex lens of short focal length (6 ins. or so), and adjust the lens so that the image of the hole and pin-point is formed side by side with the object. The centre of the mirror is now at the point at which the image would be formed by the lens alone; this position may either be calculated or found (after noting the position of the mirror and then removing it) by means of a screen. Thus the radius is easily measured.

If the focal length of the mirror be greater than f, that of the lens, the simplest way of adjusting is to put the lens as close as possible to the mirror, put the object at principal focus of lens, and move the object back until the image is formed as above.

If, however, the focal length be less, we can be sure of finding the position by putting the mirror at a distance of 4 f from the object, and the lens at 2 f, and moving the lens back until the desired position is reached.

To find the Focal Length of a Concave Lens.

Use an object like the one mentioned above, an auxiliary convex lens (say, 6 ins. focal length) to produce a convergent beam, and an auxiliary plane mirror, placed beyond the concave lens.

Adjust until the image is formed side by side with the object, as before; then the rays must be emerging parallel to one another from the concave lens, and hence the convergent beam from the convex lens will (when the concave lens and mirror are removed) form an image at the principal focus of the concave lens. A direct measure can thus be made of the focal length.

(*E. Budden.*)

Photographic Lens Apertures.

Stops or apertures are openings in the lens diaphragms which determine the amount of light admitted to the sensitive plate in a camera. They are usually expressed as fractions of the lens focus, *i.e.* with an 8-in. focus lens a stop or aperture 1 in. in diameter would be known as $f8$—*viz.* it would divide into the focal length eight times: $f16$ would be $\frac{1}{2}$ in. diameter, and so on.

The exposure required varies inversely as the area of the opening. The apertures mostly in use are $f5 \cdot 6$, $f8$, $f11$, $f16$, $f22$, $f32$, $f45$, and $f64$, and each will be half the area and require twice the exposure of the next larger aperture. *E.g.*, if $f11$ requires 1 second $f16$ would require 2 seconds and $f8$ only half a second.

If the diameter of any one aperture be known the remainder can be ascertained by the method shown in fig. 2.

Say the diameter of $f11$ is $\frac{3}{4}$ in., set off $f11$ as one side of a right-angled triangle ABC; then BD, at right angles to the hypotenuse, would give the diamter of $f16$, DE would give $f22$, and A the diamter of $f8$, and so on as indicated.

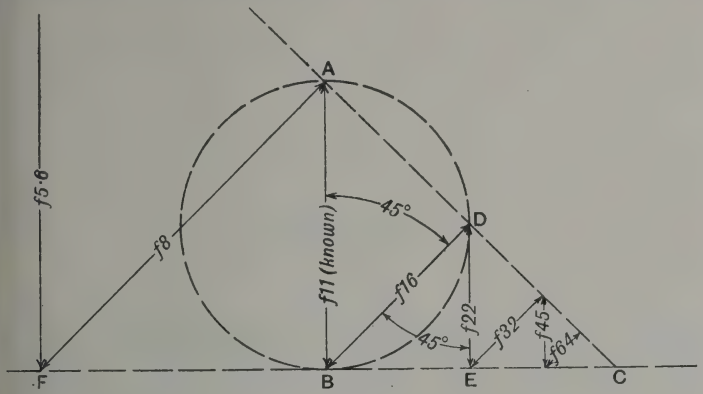


FIG. 2.

Theoretically $f8$ in one lens should be of the same exposure value as $f8$ in any other lens of whatever make or focus, but loss due to refraction, etc., must vary according to the number of component parts, and a compound lens containing many surfaces would obviously be slightly slower than one of the simplest form.

Luminous Energy.

In a series of lectures on 'Flame,' at the Royal Institution, Sir James Dewar illustrated in a striking form a fact which has long occupied the attention of scientists in relation to the energy expended in the production of light. The following figures show how utterly imperfect are the various lighting devices now employed on a basis of scientific efficiency:—

Lighting Device.	Percentage of Light.	Non-Luminous Energy.
Candle	2	98
Oil	2	98
Coal Gas	2	98
Incandescent lamp	3	97
Arc lamp	10	90
Magnesium lamp	15	85
Cuban firefly	99	1

SECTION V

PART I

WEIGHTS AND SPECIFIC GRAVITIES—WEIGHT OF SHEET, BAR, AND BALL METALS—WEIGHT OF PIPES AND TUBES —WEIGHT OF WIRE—WEIGHT OF NAILS AND SCREWS— THICKNESSES OF PIPES — SPECIFICATION FOR CAST IRON PIPES (pp. 235-278)

PART II

STRENGTH OF MATERIALS—STRENGTH OF WIRE, CHAINS, AND ROPES—BRITISH STANDARD SPECIFICATIONS FOR STRUCTURAL STEEL—ADMIRALTY TESTS FOR STEEL AND IRON—STRENGTH OF TUBES, RINGS, CHAINS, SLINGS, AND ROPES (pp. 279-309)

SECTION V

PART I

WEIGHTS AND SPECIFIC GRAVITIES—WEIGHT OF SHEET, BAR, AND BALL METALS—WEIGHT OF PIPES AND TUBES—WEIGHT OF WIRE—WEIGHT OF NAILS AND SCREWS — THICKNESSES OF PIPES — SPECIFICATION FOR CAST IRON PIPES.

WEIGHTS AND SPECIFIC GRAVITIES.

ATOMIC WEIGHTS.

Name.	Symbol.	Atomic Weight.		Name.	Symbol.	Atomic Weight.	
		O = 16.	H = 1.			O = 16.	H = 1.
Aluminium	Al	27·1	26·78	Glucinum (*Beryllium*)	Gl	9·1	9·03
Antimony	Sb	120·2	119·24	Gold	Au	197·2	195·63
Argon	A	39·88	39·56	Helium	He	3·99	3·93
Arsenic	As	74·96	74·21	Holmium	Ho	163·5	162·2
Barium	Ba	137·37	136·27	Hydrogen	H	1·008	1·00
Bismuth	Bi	208·0	206·34	Indium	In	114·8	113·8
Boron	B	11·0	10·9	Iodine	I	126·92	125·91
Bromine	Br	79·92	79·28	Iridium	Ir	193·1	191·56
Cadmium	Cd	112·4	111·5	Iron	Fe	55·84	55·40
Cæsium	Cs	132·81	131·75	Krypton	Kr	82·92	82·26
Calcium	Ca	40·07	39·77	Lanthanum	La	139·0	137·9
Carbon	C	12·00	11·9	Lead	Pb	207·10	205·45
Cerium	Ce	140·25	139·0	Lithium	Li	6·94	6·88
Chlorine	Cl	35·46	35·17	Lutetium	Lu	174·0	172·5
Chromium	Cr	52·0	51·58	Magnesium	Mg	24·32	24·12
Cobalt	Co	58·97	58·4	Manganese	Mn	54·93	54·4
Columbium (*Niobium*)	Cb	93·5	92·75	Mercury	Hg	200·6	198·41
Copper	Cu	63·57	63·06	Molybdenum	Mo	96·0	95·23
Dysprosium	Dy	162·5	161·2	Neodymium	Nd	144·3	142·5
Erbium	Er	167·7	166·07	Neon	Ne	20·2	20·04
Europium	Eu	152·0	150·8	Nickel	Ni	58·68	58·21
Fluorine	F	19·0	18·8	Niton (radium emanation)	Nt	222·4	220·6
Gadolinium	Gd	157·3	156·05				
Gallium	Ga	69·9	69·34	Nitrogen	N	14·01	13·9
Germanium	Ge	72·5	71·9	Osmium	Os	190·9	189·38

ATOMIC WEIGHTS (*continued*).

Name.	Sym-bol.	Atomic Weight.		Name.	Sym-bol.	Atomic Weight.	
		O = 16.	H = 1.			O = 16.	H = 1.
Oxygen	O	16·00	15·87	Sulphur	S	32·07	31·82
Palladium	Pd	106·7	105·85	Tantalum	Ta	181·5	179·6
Phosphorus	P	31·04	30·79	Tellurium	Te	127·5	126·49
Platinum	Pt	195·2	193·65	Terbium	Tb	159·2	158·0
Potassium	K	39·10	38·79	Thallium	Tl	204·0	202·38
Praseodymium	Pr	140·6	139·48	Thorium	Th	232·4	230·57
Radium	Ra	226·4	224·1	Thulium	Tu	168·5	166·8
Rhodium	Rh	102·9	102·08	Tin	Sn	119·0	118·05
Rubidium	Rb	85·45	84·77	Titanium	Ti	48·1	47·7
Ruthenium	Ru	101·7	100·9	Tungsten	W	184·0	182·52
Samarium	Sa	150·4	149·2	Uranium	U	238·5	236·6
Scandium	Sc	44·1	43·75	Vanadium	V	51·0	50·65
Selenium	Se	79·2	78·6	Xenon	X	130·2	129·16
Silicon	Si	28·3	28·07	Ytterbium	Yb	172·0	170·73
Silver	Ag	107.88	107·02	Yttrium	Y	89·0	88·3
Sodium	Na	23.0	22·81	Zinc	Zn	65·37	64·85
Strontium	Sr	87·63	86·93	Zirconium	Zr	90·6	89·88

Weight of Water.

Pure water weighs 62·288 lbs. avoir. per cubic foot at 62° F. (16·6° C.) (*International Bureau of Standards, Parts*, 1921).

The following shows the principal weights, etc., of water:

Detail.	Fresh.	Salt.
Greatest density at	39·2° F.	Freezing-point
1 cubic foot at 62° F. weighs	62·288 lbs.	64 lbs.
1 cubic inch " "	0·036047 lb.	0·037037 lb.
1 cubic foot " equals	6·2288 gals.	
1 gallon 62° at F. weighs	10 lbs.	10·3 lbs.
1 ton equals	35·962 cub. ft.	35 cub. ft.
1 ton contains	224 gals.	217 gals.
Freezes at	32° F.	27·4° F.

From 4° C. water expands regularly as the temperature rises; so that 1,000 parts at 0° C. become at 0° = 1,000·00, at 4° = 999·88, at 10° = 1,000·14, at 20° = 1,001·67, at 30° = 1,004·21, at 40° = 1,007·61, at 50° = 1,011·93, at 60° = 1,016·86, at 70° = 1,022·43, at 80° = 1,028·73, at 90° = 1,035·58, at 100° = 1,043·03.

See also Section XXV., HYDRAULICS.

To obtain Weight of a Gas.

If

P = Absolute pressure in lbs. per sq. in.;
V = Volume in cu. ft.;
W = Weight in lbs.;
T = Absolute temperature = F.° + 460;
a = Atomic weight.

then,

$$W = \frac{PVa}{10{\cdot}7\,T} = 0{\cdot}00935\,\frac{PVa}{T}.$$

Thus to get the weight of 10·3 cu. ft. of CO_2 ($a = 12{\cdot}00 + (16 \times 2) = 44$) at 180 F.° and 14 lbs. absolute pressure:

$$W = 0{\cdot}00935\,\frac{14 \times 10{\cdot}3 \times 44}{180 + 460} = 0{\cdot}926 \text{ lbs.}$$

Specific Gravity.

The specific gravity of any substance in the C.G.S. system is its weight in grammes per cubic centimetre.

The relative specific gravity of a body is its weight as compared with that of an equal bulk of some other body which is adopted as a standard of comparison. For other substances than air and gases generally, pure water is the usual standard; and since the weight of a given bulk of water varies somewhat with its temperature, and also with the state of the air, the former is assumed to be 62° F., and the latter at 30 ins. at sea-level.

To find Specific Gravity.

Solids.

W = weight of a body in the air;
S = specific gravity of the body,
W = weight of the body (heavier than water) immersed in water;

then,

$$W - W : W = 1 : S. \quad S = \frac{W}{W - W}.$$

When the body is lighter than water, annex to it a heavier body that is able to sink the lighter one.

S = specific gravity of the heavier annexed body;
s = specific gravity of the lighter body;
W = weight of the two bodies in air;
W = weight of the two bodies in water;
w = weight of the heavier body in air;
w = weight of the lighter body in air;

then,

$$s = \frac{w}{W - W - \frac{w}{S}},$$

A simple way to obtain the specific gravity of a wood is to form it into a parallel rod, and place it vertically in water; then, when in equilibrium, the immersed end is to the whole rod as the specific gravity is to 1.

Liquids.

Measure the weight of a stoppered-glass bottle; then fill the same with distilled water and weigh it again; the difference between the two measurements gives the weight of the distilled water. Then completely empty out the water and refill the bottle with the liquid whose specific gravity is required and again weigh; this weight less the weight of the bottle gives the weight of the liquid; this weight divided by the weight of the water gives the specific gravity of the liquid.

In practice it is convenient to employ a bottle (called a specific gravity bottle) that holds exactly 10 grammes of distilled water at 4° C., because, when such a bottle is filled with the liquid under trial the weight in centigrammes of the liquid taken at 0° C. represents the specific gravity at once, without calculation. For convenience a counterpoise of brass is adjusted to the weight of the bottle.

Gases.

Measure in the same way as liquids, taking Air as the standard. A large and very light, *i.e.* thin, glass vessel must be used for the purpose, otherwise the weight of the glass will swamp, as it were, the weight of the enclosed gas, and accurate results cannot be obtained. Certain corrections have to be made in practice, for great accuracy.

To find the Specific Gravity of a mixture of given volumes of any number of fluids whose specific gravities are given.

If $V_1, V_2, V_3, \ldots V_n$ be the volumes of the fluids whose respective specific gravities are $s_1, s_2, s_3, \ldots s_n$, and S the specific gravity of the mixture, then

$$S = \frac{V_1 s_1 + V_2 s_2 + V_3 s_3 + \ldots V_n s_n}{V_1 + V_2 + V_3 + \ldots V_n}.$$

To find the Specific Gravity of a mixture of given weights of any number of fluids whose specific gravities are given.

If $W_1, W_2, W_3, \ldots W_n$ be the weights of the fluids whose respective specific gravities are $s_1, s_2, s_3, \ldots s_n$, and S the specific gravity of the mixture, then

$$S = \frac{W_1 + W_2 + W_3 + \ldots W_n}{\frac{W_1}{s_1} + \frac{W_2}{s_2} + \frac{W_3}{s_3} + \ldots \frac{W_n}{s_n}}.$$

To Discover the Adulteration in Metals, or to find the Proportions o Two Ingredients in a Compound.

$$w = \frac{W - s(W - W)}{1 - \frac{s}{S}}.$$

EXAMPLE.—A metal compounded of silver and gold weighs, W=6 pounds in the air, and in water, W=5·636 pounds. Required the proportions of silver and gold.
S=19·36 specific gravity of gold. s=10·51 specific gravity of silver.

$$\text{Weight } w = \frac{6 - 10{\cdot}51(6 - 5{\cdot}636)}{1 - \frac{10{\cdot}51}{19{\cdot}36}} = 4{\cdot}755 \text{ pounds of gold.}$$
and 1·245 pounds of silver.

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SOLIDS AND LIQUIDS.

(Specific gravity × 62·288 = weight of cubic foot in lbs.
" " × ·03604 = " " inch "

Substance	Sp. Gr.	Weight of a Cubic Foot.	Substance.	Sp. Gr.	Weight of a Cubic Foot.	Substance.	Sp. Gr.
			Metals.				
		Lbs.			Lbs.		
Aluminium, wrought	2·67	167	Iron, white	7·50	467	Palladium	11·40
" cast	2·56	160	" grey	7·20	449	Phosphor bronze, cast	8·60
Antimony	6·71	418	" Eglinton hot-blast	6·97	435	Platinum, hammered	20·30
Arsenic	5·76	359	" Reunie	6·98 to 7·11	435 to 444	" native	16·00
Barium	·47	29	" Mean for ordinary calculations	7·22	450	" rolled	22·10
Bismuth	9·90	617	" wrought, least and greatest density	7·47 to 7·81	466 to 487	Potassium, 50°	·87
Boron	2·00	125	" common bar	7·55	471	Red-lead	8·94
Brass, cast	8·10	505	" puddled slab	7·53 to 7·60	469·5 to 474	Rhodium	10·65
" sheet, 75 Cu., 25 Zn.	8·45	527	" various irons, tested by Mr. Kirkaldy	7·5 to 7·8	468 to 486	Ruthenium	8·60
" yellow, 66 Cu., 34 Zn.	8·30	518	" " average	7·65	477	Silicium	4·50
" Muntz metal, 60 Cu., 40 Zn.	8·20	511	" Yorkshire iron bar	7·76	484	Silver, pure cast	10·47
Bromine	3·00	187	" Lowmoor plates, 1½–3 ins. thick	7·81	487	" " hammered	10·50
Bronze (gun-metal)			" Mean for ordinary calculations	7·70	480	Sodium	·97
84 Cu., 16 Tin	8·56	534	Lead, cast	11·40	710	Steel, least and greatest density	7·73 to 7·90
83 " 17 "	8·46	528	" rolled	11·40	710	" homogeneous metal	7·90
81 " 19 " (mill bearings)	8·46	528	Lithium	·59	37	" blistered	7·82
" 79 Cu., 21 Tin	8·73	544	Magnesium	1·75	109	" crucible, average	7·84
90 " 10 "	8·50	530·6	Manganese	8·00	498	" cast, average	7·85
Cadmium	8·65	539	Mercury — 40°	15·60	972	" Bessemer, average	7·85
Calcium	1·58	98	" + 32°	13·60	847	" Mean for ordinary calculations	7·85
Chromium	5·00	311	" 60°	13·60	847	Strontium	2·54
Cinnabar	8·10	504	" 212°	13·40	835	Tellurium	6·11
Cobalt	8·60	536	Molybdenum	8·60	536	Thalium	11·85
Columbium	6·00	374	Nickel, hammered	8·67	541	Tin, Cornish, hammered	7·39
Copper, cast	8·79	547	" cast	8·28	516	" Cornish, pure	7·29
" sheet	8·81	549	Osmium	21·4	1,334	Titanium	5·30
" hammered	8·92	556				Tungsten	17·00
" wire	8·91	555				Uranium	18·33
Gold, pure cast	19·30	1,200				Wolfram	7·12
" hammered	19·40	1,210				Zinc, cast	6·86
" 22 carats fine	17·50	1,090				" rolled	7·19
" 20 " "	15·71	978					
Iridium	18·71	1,170					
hammered	23·00	1,430					
Iron, cast, least and greatest density	6·90 to 7·50	430 to 467					

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SOLIDS AND LIQUIDS (*continued*).

Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.
			Stones, Earths, &c.					
		Lbs.			Lbs.			Lbs.
te	2·59	161	Emery . . .	4·00	249	Pearl, Oriental .	2·65	165
baster, white .	2·73	170	Flint, black . .	2·58	161	Peat	·60	37
„ yellow .	2·70	168	„ white . .	2·50	156		1·33	83
m	1·71	106	Fluorine	1·32	82	Phosphorus . .	1·77	110
ber	1·08	67	Garnet	4·19	261	Plaster of Paris .	1·18	73
bergris . . .	·87	54	„ black . .	3·75	233	Plumbago . . .	2·10	131
estos, starry .	3·07	191	Glass, bottle . .	2·73	170	Porcelain, China .	2·30	143
haltum .	·91	57	„ Crown . .	2·49	155	Porphyry, red . .	2·77	173
	1·65	103	„ flint . .	2·93	182	Pumice-stone . .	·92	57
ytes, sul-	4·00	249		3·20	199	Quartz	2·66	166
hate . . .	4·87	303	„ green . .	2·64	164	Red-lead . . .	8·94	557
alts . . .	2·74	171	„ optical . .	3·45	215	Resin	1·09	68
	2·86	178	„ white . .	2·89	180	Rock, crystal . .	2·74	171
ax	1·71	106	„ window .	2·64	164	Rotten-stone . .	1·98	123
ck . . .	1·90	118	Granite, Egyptian			Ruby	4·28	267
	1·37	85	red . .	2·65	165	Salt, common . .	2·13	133
, fire . . .	2·20	137	„ Patapsco .	2·64	164	Saltpetre . . .	2·09	130
, (pressed)in			„ Quincy .	2·65	165	Sand, coarse . .	1·80	112
cement .	2·17	135	„ Scotch .	2·63	164	„ common .	1·67	104
„ work in	1·80	112	„ Susque-			„ damp and		
mortar	2·00	125	hannah .	2·70	168	loose . .	1·39	87
bon	3·50	219	Gravel, common .	1·75	109	„ dried and		
nent, Portland	1·30	81	Grindstone . . .	2·14	133	loose . .	1·56	97
„ Roman .	1·56	97	Gypsum, opaque .	2·17	135	„ dry . . .	1·42	88
lk . . .	1·52	95	Hone, white, razor	2·88	179	„ siliceous .	1·70	106
	2·78	173	Hornblende . .	3·54	220	Sapphire . . .	3·99	248
rysolite . . .	2·78	173	Iodine	4·94	308	Schorl	3·17	197
y	1·93	120	Jet	1·30	81	Shale	2·60	162
with gravel	2·48	154	Lime, hydraulic .	2·75	171	Slate	2·90	181
l, anthra-	1·44	90	„ quick- . .	·80	50		2·67	166
cite .	1·64	102	Limestone, green	3·18	198	„ purple . .	2·78	173
Cannel .	1·24	77	„ white	3·16	197	Smalt	2·44	152
	1·32	82	Magnesia, car-			Spar, calcareous .	2·74	171
Derbyshire .	1·29	80	bonate . .	2·40	149	„ Feld, blue .	2·69	168
Newcastle .	1·27	79	Marble, Adelaide.	2·72	169	„ „ green	2·70	168
Scotch .	1·26	79	„ African .	2·71	169	„ Fluor . . .	3·40	212
	1·30	81	„ Biscayan,			Stalactite . . .	2·42	151
Wales, mean	1·32	82	black .	2·70	168	Stone, Bath . .	1·96	122
ge	1·00	62	„ Carrara .	2·72	169	„ Basalt . .	2·63	164
ncrete, mean .	2·00	124	„ common .	2·69	168	„ Bristol . .	2·51	156
pal	1·05	65	„ Egyptian	2·67	166	„ Caen, Nor-		
ral, red . . .	2·70	168	„ French .	2·65	165	mandy .	2·07	129
, white . .	2·55	159	„ Italian,			„ common .	2·52	157
rnelian . . .	2·61	163	white .	2·71	169	„ Craigleith .	2·32	144
mond, Oriental	3·52	219	„ Parian .	2·84	177	„ Kentish		
„ Brazilian	3·44	214	Marl, mean . .	1·75	109	rag . .	2·65	165
rth, common			Mica	2·80	174	„ Portland .	2·37	148
soil . .	2·19	136	Millstone . . .	2·48	154	„ sandstone .	2·20	137
„ loose . .	1·50	93	Mortar . . .	1·38	86	Sulphur, native .	2·03	126
„ moist sand	2·05	128		1·75	109	Talc, mean . . .	2·50	156
„ mould,			Mud	1·63	102	„ black . . .	2·90	181
fresh .	2·05	128	Nitre	1·90	118	Tile	1·82	113
„ rammed .	1·60	100	Opal	2·11	131	Topaz, Oriental .	4·01	250
„ rough sand	1·92	120	Oyster-shell . .	2·09	130	Trap	2·72	169
„ with gravel	2·02	126	Paving-stone . .	2·42	151	Turquoise . . .	2·75	171

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SOLIDS AND LIQUIDS (*continued*).

Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.
Miscellaneous.								
		Lbs.			Lbs.			Lbs.
Asphaltum	·91	57	Gum Arabic	1·45	90	Mastic	1·07	66
	1·65	103	Gunpowder, loose	·90	56	Myrrh	1·36	85
Atmospheric air	·00121	·075	„ shaken	1·00	62	Opium	1·34	84
Beeswax	·97	60	„ solid	1·55	97	Soap, Castile	1·07	56
Butter	·94	59		1·80	112	Spermaceti	·94	59
Camphor	·99	62	Gutta-percha	·98	61	Starch	·95	59
Caoutchouc	·90	56	Horn	1·69	105	Sugar	1·61	100
Egg	1·09	68	Ice, at 32°	·92	57		1·33	83
Fat of beef	·92	57	Indigo	1·01	63	„ ·66	·97	60
„ hogs	·94	59	Isinglass	1·11	69	Tallow	·94	59
„ mutton	·92	57	Ivory	1·83	114	Wax	·96	60
Gamboge	1·22	76	Lard	·95	59		·97	61
Liquids.								
Acid, acetic	1·06	66	Alcohol, proof spirit, 50 per cent., 80°	·88	55	Oil, olive	·92	57
„ benzoic, solid	·67	42				„ palm	·97	60
„ citric, solid	1·03	64				„ petroleum	·88	55
„ oxalic „	1·64	102				„ rape	·91	57
„ fluoric	1·50	93	Ammonia, 27·9 per cent.	·89	55	„ sunflower	·93	58
„ hydrochloric	1·20	75	Aquafortis, double	1·30	81	„ turpentine	·87	54
„ nitric	1·22	76	„ single	1·20	75	„ whale	·92	57
„ phosphoric	1·56	97	Beer	1·03	64	Spirit, rectified	·82	51
„ phosphoric, solid	2·80	174	Bitumen, liquid	·85	53	Tar	1·02	64
„ sulphuric	1·85	115	Blood (human)	1·05	65	Vinegar	1·08	67
Alcohol, pure, 60°	·79	49	Brandy, $\frac{5}{6}$ of spirit	·92	57	Water, Dead Sea	1·24	77
„ 95 per cent.	·82	51	Cider	1·02	64	„ 60°	1·00	62
„ 80 „	·86	54	Ether, acetic	·87	54	„ 212°	·96	59
„ 50 „	·93	58	„ muriatic	·85	53	„ distilled, 39°	1·00	62
„ 40 „	·95	59	„ sulphuric	·72	45	„ Mediterranean	1·03	64
„ 25 „	·97	60	Glycerine	1·28	79·5	„ rain	1·00	62
„ 10 „	·99	61	Honey	1·45	90	„ sea	1·03	64
„ 5 „	·99	62	Milk	1·03	64	Wine, Burgundy	·99	62
„ proof spirit, 50 per cent., 60°	·93	58	Oil, anise-seed	·99	62	„ Champagne	1·00	62
			„ codfish	·92	57	„ Madeira	1·04	64
			„ linseed	·94	59	„ port	1·00	62
			„ naphtha	·85	53			

Woods (dry). (*H. Stone.*)

Acacia or Locust (Robinia)	·58–·83	36–52	Ash, Mountain or Rowan	·57–·94	35½–58½	Blackbutt	·74	46
Alder, black or common	·42–·64	26–39¾	„ Mountain (of Queensland)	·73	45½	Blackthorn	·67–·71	41⅞–44½
Almond	·85–·88	53–56	„ Nova Scotia	·71	44½	Boxwood, Cape (Gonioma Kamassi)	·93	58
Apple	·66–·84	41–52½	Assegai wood (Cape)	·96	60	„ Cape or East London (Buxus Macowani)	1·19	74
Arbor vitæ	·38–·54	23⅝–33⅝	Bamboo	·40	25	„ English	·99–1·02	61½–63½
Ash, American (Fraxinus Americana, L.)	·65–·83	40⅝–52	Bay	·82	51	„ Turkey	1·08	67
			Beech	·66–·83	41–52	„ West Indian	·79	49
„ American, Arkansas or white	·36–·57	22½–35⅝	„ Cape (Benkenhout)	·63–·74	29½–46	Bulletwood (Mimasops Balata)	·84	52
„ European or common	·52–·95	32½–59	„ Australian white	·53	32¾			
			Birch, American	·60–·77	37½–48			
			„ European	·47–·77	29½–48			

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SOLIDS AND LIQUIDS (*continued*).

Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.
			Woods (dry) (continued).			*(H. Stone.)*		
		Lbs.			Lbs.			Lbs.
letwood, pecies unnown, but ore commonly met with	1·20	75	Filbert, *see* Hazel			Mahogany, East Indian	·69	43
			Fir, Danzig	·48–·75	29⅝–47	„ Cuba	·72–·82	44⅞–51
			„ Riga	·51–·66	31⅞–41	„ Honduras	·56–·69	35–42⅝
			„ Silver	·36–·60	23–37½	„ Mexican	·61–·79	38½–49½
			„ Spruce	·35–·60	21⅞–37½	„ Panama	·47	29½
			Fustic	·63	39	„ red (Australia)	1·11	69
tternut, *see* Hickory			Greenheart, Trop. (America)	1·03–1·20	64–75	„ Spanish	·86	53½
mpeachy, *see* Logwood			„ Demerara	1·02–1·20	63½–74½	Maple, Bird's-eye	·58	36
nphor wood (Borneo)	·90–1·06	55⅝–65⅝	Gum, blue	·69–1·11	43–69	„ hard	·53–·80	33–50
ar, Cuba	·37–·53	23¼–33¼	„ grey (Australia)	1·00	62½	„ soft	·53–·71	32⅞–44
„ Pencil or Virginian	·40–·60	25–37½	„ red (America) *see* Satin Walnut			„ Sugar	·58–·81	36–50⅛
„ Indian	1·32	82	„ Sweet, *see* Satin Walnut			Mastic	·85	53
„ red (Australia)	·43–·59	26½–36½	Hackmatack (American Larch)	·63	39	Mora	1·08–1·10	67½–68½
„ white(Australia)	·33–·53	20½–33	Hackia	·82–·96	51–59½	Mulberry	·56–·90	35–56
arcoal, pine	·44	27½	Hawthorn	·81–·91	50½–56⅝	Oak, African	·83–1·09	51½–68
„ fresh burned	·38	23⅝	Hazel	·56–·71	35–44¼	„ American,red	·84–·88	52⅜–54½
„ oak	1·57	98	Hemlock	·69	23	„ „ white	·94–1·05	58⅝–65⅝
„ soft wood	·28	17½	Hickory, Bitternut	·78	47	„ Baltimore	·70–·82	43⅝–51½
„ triturated	1·38	86½	„ Butternut or Shellbark	·69–·83	43–52	„ Canadian	—	54½
erry, American	·59	36⅞	„ Pig-nut	·79–·82	49½–51⅞	„ Dantzig	·76–·96	47½–56
„ English	·54–·71	33½–44½	Holly	·76–·94	47½–58⅞	„ Desert or She-oak (Australia)	1·14	71¼
estnut, sweet or Spanish	·60–·72	37½–45	Honeysuckle (New Zealand)	·74–·81	46¼–50½	„ Dutch or Rhenish	·94–1·10	58⅝–68½
„ Horse	·51–·63	32–39½	Hornbeam	·62–·82	38⅝–51¼	„ English	·69–1·04	43–64½
ron	·72	45	Ironbark, red (Australia)	·98–1·16	61–72½	„ Forest or She-oak (Australia)	·78–·85	48⅝–53
cus or Cocos	1·48–1·61	92–100	Ironwood, Pynkado	1·15–1·27	71⅞–79	„ Italian or Modena	1·06–1·15	66–71¾
gwood,Jamaica	1·08	67	Jackwood	·56–·71	35–44½	„ Italian or Tuscan	1·07–1·08	66½–67½
rk	·24	15	Jarrah	·81–1·05	50½–65½	„ Sardinian	·95–1·03	59–64
ttonwood (N. America)	·55	34½	Jasmine	·77	48¼	„ Silky (Australia)	·60	37½
abwood (British Guiana)	·63	39½	Juniper	·53–·70	33–43⅝	„ Spanish or white (America)	·87–1·00	54¼–62
press, Spanish	·65	40½	Karri	·85–1·02	53–63⅜	„ Stettin	·56	35
nson	·76–·84	47½–52½	Kauri or Cowrie Pine	·51–·60	32–37½	Olive	·87	54
game wood	·79	49	Lancewood (Jamaica orCuba)	·83–1·01	52–63	Orange	·71–·93	44–58
gwood, common	·77–·83	48–51½	Larch	·44–·80	27½–50	Orham	·51	32
„ red (American)	·77–·81	48–50½	„ Russian	·59–·70	36⅞–43⅝	Padouk	1·00	63–62
ony, black or Billetwood	·98–1·14	61–71	Lemon	·71–·80	44–50	Pear	·66–·72	41½–45
ony, Indian	1·21	75½	Lignum vitæ Guayaquil	·79	49	„ white (Cape)	·79–·98	49–61
„ Macassar	·98–1·24	61–77	„ Jamaica	1·61–1·43	72½–89	Persimmon	·71–·85	44⅛–53
„ Purple (Ceylon)	·86	53⅞	„ Maracaibo	1·11	69	Pine, American Pitch	·50–·92	31⅛–57⅛
der	·54–·76	33¾–47¼	Lime or Linden	·32–·59	20–36⅞	„ Corsican	·38–·76	23¾–47½
m, American or Rock	·69–·73	43–45½	Locust, *see* Acacia			„ red or yellow (Pinus sylvestris or Scots fir)	·31–·74	19¼–46½
„ „ or white	·65	40½	Logwood	·92	57	„ red(Canada)	·51–·59	32–36⅞
„ common or European	·56–·82	35–51¼	Mahoe, blue	·71–·79	44½–49½	„ white (Pinus strobus)	·31–·56	19¼–35

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SOLIDS AND LIQUIDS (*continued*).

Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	Weight of a Cubic Foot.	Substance.	Specific Gravity.	W of a Cu Fo
Woods (*dry*) (continued).						(*H. Stone.*)		
		Lbs.			Lbs.			
Pine, white (Australia)	·43–·49	27–30½	Quince	·71	44	Teak	·62	
„ yellow (Canada)	·43–·60	26½–37½	Rosewood, Indian	·73–1·03	45½–64	Tewart	1·16–1·20	72
Plane, Eastern or European	·49–·68	30½–42½	Sabien	·70	43½	Waibaima	·92	
„ Western or American	·57	35½	„ Cuba	·89–·94	55½–58½	Wallaba	1·05	
Plum	·64–·90	40–56	„ fromTunas de Zaza	1·00	62½	Walnut, American or black	·46–·88	28
Pomegranate	1·36	84½	Sappan	·96–·98	60–61	„ Cape or Stinkwood	—	
Poon	·58	36½	Sassafras	·48	30	„ English or Italian	·63–·71	39
Poplar, American	·39–·48	24½–30	Satin-walnut, *see* Walnut			„ Satin, Red Gum, or Californian Red Gum	·59–·96	36½
„ aspen	·43–·56	26½–35	Satinwood(Ceylon)	·98–1·04	61–65			
„ black	·39–·52	24½–32½	„ (EastIndia)	79–·98	49–61			
„ white	·40–·57	25–35½	Siniaruba, Bitterwood	·48	30			
Purpleheart (BritishGuiana, Kooroobooilli)	·85	53	Spruce, European	·35–·60	21½–37½	Washiba or Bowwood	·88	
Purpleheart (BritishGuiana, Marawinaroo)	1·00	62	„ (Canada)	·45–·51	28½–32	Whitewood, Canadian or Canary	·45–·62	28
Purpleheart (Demerara)	·81	50½	Stonewood	·93	58	Willow, common or Goat	·43–·63	27
Quassia	·54	33¾	Sneezewood	1·08	67½	Willow, white	·43–·50	26½
			Sycamore, American, *see* Plane			Yew	·74–·94	46
			„ European	·47–·79	29–49			
			Tamarack, *see* Hackmatack					

SPECIFIC GRAVITIES OF WOODS.

The specific gravity or weight per cubic inch or cubic foot of woods can never be expressed by a fixed value. Wood varies in the same tree from the root to the branches, becoming lighter upwards, and again varies from the lower branches to the top in the reverse way, *i.e.* it becomes heavier upwards. It also varies from within outwards, and also varies according to the time of year, starch being accumulated at one season and used up at another. No two pieces of wood can be found of the same specific gravity except by accident, or by taking two small pieces from the same annual ring, which would rarely occur in practice. Hence it is misleading to work out specific gravities of woods to several places of decimals. Moreover, wood is hygroscopic, and however dry a specimen may be, a different result will be obtained with every movement of the barometer. The term 'dry weight' is merely an expression of convenience, and most of the figures given in the foregoing table have been calculated from specimens which have been kept in a dry room at ordinary temperatures, and which have ceased to lose weight. Wood dried by artificial means at high temperatures gains weight by absorbing moisture, this absorption taking place from the moment the wood is withdrawn from the desiccator.

Drying and Seasoning of Woods.

There is no difference between 'drying' and 'seasoning,' and the terms may be regarded as synonymous. Too rapid drying may be injurious to a wood, and hence seasoning has come to be regarded as something different from drying, but it is only so in certain cases, and is disputed even in these. Some foresters maintain that a few rings of wood nearest the heart pass from the condition of sapwood into that of heartwood during seasoning, and that therefore the amount of useable timber is increased thereby. (*H. Stone.*)

See also pp. 459–466.

SPECIFIC GRAVITIES OF EBONITE.

Black qualities, approx., **1·2** ; Red qualities, approx., **1·6**; Mottled quality, 1·33.

Specific Gravities of Elastic Fluids.

1 cubic foot of dry atmospheric air at 62° F. and at normal pressure weighs 532·5 grains. Its assumed gravity of 1 is the unit for elastic fluids.

Fluid	Specific Gravity Compared with Air.	Fluid.	Specific Gravity Compared with Air.
Atmospheric air	1	Sulphuretted hydrogen	1·17
Ammonia	·589	Sulphurous acid	2·21
Carbonic anhydride	1·52	Steam, 212°	·4883
„ oxide	·972	Smoke of bituminous coal	·102
Carburetted hydrogen	·559	„ coke	·105
Chlorine	2·47	„ wood	·09
Chloro-carbonic	3·389	Vapour of alcohol.	1·613
Cyanogen	1·815	„ bisulphide of carbon	2·64
Gas, coal	·4	„ bromine	5·1
	·752	„ chloric ether	3·44
Hydrogen	·069	„ ether	2·586
Hydrochloric acid	1·278	„ hydrochloric ether	2·255
Hydrocyanic „	·942	„ iodine	8·675
Nitrogen	·972	„ nitric acid	3·75
Nitric oxide	1·094	„ spirits of turpentine	4·763
Nitrous acid	2·638	„ sulphuric acid	2·7
„ oxide	1·527	„ „ ether	2·586
Oxygen	1·102	„ sulphur	2·214
Phosphuretted hydrogen	1·77	„ water	·623

Weight of Metals

Weight in Lbs. of 1 Cubic Inch of Metals.

Aluminium = 0·09	Copper = 0·32	Tin	= 0·263
Brass = 0·3	Lead = 0·41	Wrought iron	= 0·28
Cast iron = 0·26	Steel = 0·282	Zinc	= 0·253
	Water = 0·03617		

Example.—Cast iron block 4 × 2 × 3 ins. = 4 × 2 × 3 × 0·26 = 6·24 lbs.

Weight of Sheet, Bar, and Ball Metals.

Weight of a Square Foot of Sheet Metals.

Thickness.	Weight in Lbs.			Thickness.	Weight in Lbs.		
Inch.	Iron.	Copper.	Brass.	Inch.	Iron.	Copper.	Brass.
½	20·21	23·12	21·87	1/16	2·52	2·89	2·73
·450	18·19	20 80	19·68	·055	2·22	2·54	2·40
·437	17·66	20·20	19·11	·048	1·94	2·22	2·10
7/16	15·15	17·34	16·40	·042	1·69	1·94	1·83
·340	13·74	15·72	14·87	·035	1·41	1 62	1·53
5/16	12·63	14·45	13·67	·033	1·33	1·52	1·44
·284	11·47	13·13	12·42	·029	1·17	1·34	1·27
·261	10·55	12·06	11·41	·028	1·13	1·29	1·22
¼	10·10	11·56	10·94	·025	1·01	1·15	1·09
·217	8·77	10·03	9·49	·021	·85	·97	·92
·208	8·40	9·62	9·10	·020	·81	·92	·87
3/16	7·57	8·67	8·20	·018	·73	·83	·79
166	6·71	7·67	7·26	·015	·60	·69	·65
·158	6·38	7·30	6·91	·013	·52	·60	·57
·137	5·54	6·33	5·99	·012	·48	·55	·52
1/8	5·05	5·78	5·47	·010	·40	·46	·43
·109	4·40	5·04	4·77	·009	·36	·41	·40
·094	3·80	4·34	4·11	·008	·32	·37	·35
·080	3·23	3·70	3·50	·007	·28	·32	·30
·072	2·91	3·32	3·15	·005	·20	·23	·22

Weight of Sheet, Bar, and Ball Cast Iron.

(1 cubic foot weighs 450 lbs.)

Sheet. Thickness or Diameter.		Sheet. Weight of a Square Foot.	Bar. Weight of a *Square* Bar, 1 Foot long.	Bar. Weight of a *Round* Bar, 1 Foot long.	Ball. Weight of a Ball.
Ins.	Ft.	Lbs.	Lbs.	Lbs.	Lbs.
1/32	·0026	1·173	·003	·002	—
1/16	·0052	2·344	·012	·010	—
3/32	·0078	3·516	·027	·021	·0001
1/8	·0104	4·687	·048	·038	·0003
5/32	·0130	5·861	·076	·060	·0005
3/16	·0156	7·032	·110	·086	·0009
7/32	·0182	8·203	·150	·118	·0014
1/4	·0208	9·375	·195	·154	·0021
9/32	·0234	10·54	·247	·194	·0030
5/16	·0260	11·73	·305	·240	·0042
11/32	·0287	12·89	·370	·290	·0056
3/8	·0313	14·06	·440	·346	·0072
13/32	·0339	15·24	·516	·400	·0092
7/16	·0365	16·41	·598	·470	·0114
15/32	·0391	17·56	·687	·540	·0140
1/2	·0417	18·75	·781	·610	·0170
9/16	·0469	21·10	·989	·777	·0243
17/32	·0521	23·44	1·221	·959	·0334
9/16	·0573	25·79	1·478	1·161	·0444
5/8	·0625	28·12	1·758	1·381	·0575
21/32	·0677	30·47	2·064	1·621	·0732
11/16	·0729	32·81	2·393	1·880	·0913
23/32	·0781	35·16	2·747	2·158	·1124
1	·0833	37·50	3·125	2·455	·1363
1/16	·0885	39·84	3·528	2·771	·1636
1/8	·0938	42·19	3·955	3·107	·1942
3/16	·0990	44·53	4·407	3·461	·2284
1/4	·1042	46·87	4·883	3·835	·2664
5/16	·1094	49·22	5·384	4·229	·3084
3/8	·1146	51·57	5·909	4·640	·3546
7/16	·1198	53·91	6·461	5·073	·4058
1/2	·1250	56·26	7·033	5·523	·4603
9/16	·1302	58·60	7·632	5·993	·5204
5/8	·1354	60·94	8·253	6·484	·5852
11/16	·1406	63·28	8·900	6·991	·6555
3/4	·1458	65·63	9·572	7·518	·7310
13/16	·1510	67·97	10·27	8·064	·8122
7/8	·1563	70·32	10·99	8·630	·8991
15/16	·1615	72·66	11·73	9·215	·9920
2	·1667	75·01	12·50	9·821	1·073
1/8	·1771	79·70	14·11	11·09	1·308
1/4	·1875	84·40	15·83	12·43	1·554
3/8	·1979	89·07	17·63	13·85	1·827
1/2	·2083	93·75	19·54	15·34	2·131
5/8	·2188	98·44	21·54	16·56	2·467
3/4	·2292	103·2	23·64	18·56	2·835
7/8	·2396	107·8	25·84	20·29	3·241
3	·2500	112·6	28·13	22·10	3·682

Sheet. Thickness or Diameter.		Sheet. Weight of a Square Foot.	Bar. Weight of a *Square* Bar, 1 Foot long.	Bar. Weight of a *Round* Bar, 1 Foot long.	Ball. Weight of a Ball.
Ins.	Ft.	Lbs.	Lbs.	Lbs.	Lbs.
3 1/4	·2604	117·3	30·52	23·97	4·162
1/8	·2708	121·8	33·01	25·93	4·681
3/8	·2813	126·5	35·60	27·95	5·243
1/2	·2917	131·2	38·28	30·07	5·846
5/8	·3021	135·9	41·07	32·25	6·498
3/4	·3125	140·6	43·95	34·51	7·193
7/8	·3229	145·3	46·93	36·85	7·934
4	·3333	150·0	50·01	39·27	8·726
1/8	·3438	154·7	53·18	41·77	9·572
1/4	·3542	159·3	56·46	44·33	10·47
3/8	·3646	164·0	59·82	46·99	11·42
1/2	·3750	168·7	63·33	49·71	12·43
5/8	·3854	173·4	66·86	52·52	13·49
3/4	·3958	178·1	70·52	55·39	14·62
7/8	·4063	182·8	74·28	58·34	15·81
5	·4167	187·5	78·12	61·37	17·05
1/8	·4271	192·2	82·10	64·47	18·35
1/4	·4375	196·9	86·14	67·65	19·73
3/8	·4479	201·6	90·29	70·52	21·18
1/2	·4583	206·2	94·54	74·26	22·68
5/8	·4688	210·9	98·89	77·66	24·27
3/4	·4792	215·6	103·3	81·16	25·93
7/8	·4896	220·3	107·9	84·72	27·41
6	·5000	225·0	112·5	88·36	29·44
1/4	·5208	234·4	122·1	95·89	33·28
1/2	·5417	243·8	132·0	103·7	37·44
3/4	·5625	253·1	142·4	111·9	41·94
7	·5833	262·5	153·2	120·2	46·77
1/4	·6042	271·9	164·2	129·0	51·97
1/2	·6250	281·3	175·8	138·1	57·54
3/4	·6458	290·7	187·7	147·4	63·47
8	·6667	300·0	200·1	157·0	69·82
1/4	·6875	309·4	212·7	167·0	76·58
1/2	·7083	318·8	225·8	177·3	83·74
3/4	·7292	328·2	239·3	187·9	91·35
9	·7500	337·4	253·1	198·8	99·42
1/4	·7708	346·8	267·4	210·0	107·9
1/2	·7917	356·2	282·1	221·5	116·8
3/4	·8125	365·6	297·0	233·3	126·3
10	·8333	375·0	312·5	245·5	136·3
1/4	·8542	384·4	328·4	257·8	146·8
1/2	·8750	393·7	344·5	270·6	157·9
3/4	·8958	403·1	361·2	283·7	169·3
11	·9167	412·5	378·2	297·0	181·5
1/4	·9375	421·9	395·5	310·6	194·2
1/2	·9583	431·2	413·3	324·6	207·3
3/4	·9792	440·6	431·4	338·8	219·2
12	1 Foot	450·0	450·0	353·4	235·6

Weight of Wrought Iron and Steel.

(The Table gives the weights for wrought iron, 1 cubic foot of wrought iron being taken to
igh 485 lbs. For steel an addition of about 1 lb. in 100 lbs. must be made to the tabular
ounts.)

Thickness or Diameter in Inches.	Thickness or Diameter in Decimals of a Foot.	Weight of a *Square Foot* in Pounds.	Weight of a *Square* Bar, 1 Foot long, in Pounds.	Weight of a *Round* Bar, 1 Foot long, in Pounds.	Weight of *Balls* in Pounds.	Thickness or Diameter in Inches.	Thickness or Diameter in Decimals of a Foot.	Weight of a *Square Foot* in Pounds.	Weight of a *Square* Bar, 1 Foot long, in Pounds.	Weight of a *Round* Bar, 1 Foot long, in Pounds.	Weight of *Balls* in Pounds.
	·0026	1·263	·0033	·0026	—	3 1/16	·2604	126·3	32·89	25·83	4·484
1/16	·0052	2·526	·0132	·0104	—		·2708	131·4	35·57	27·94	5·045
	·0078	3·789	·0296	·0233	·0001	3/16	·2813	136·4	38·37	30·13	5·649
1/8	·0104	5·052	·0526	·0414	·0003		·2917	141·5	41·26	32·41	6·301
	·0130	6·315	·0823	·0646	·0005	1/4	·3021	146·5	44·26	34·76	7·000
3/16	·0156	7·578	·1184	·0930	·0009		·3125	151·6	47·37	37·20	7·750
	·0182	8·841	·1612	·1266	·0015		·3229	156·6	50·57	39·72	8·550
1/4	·0208	10·10	·2105	·1653	·0023	4	·3333	161·7	53·89	42·33	9·405
	·0234	11·37	·2665	·2093	·0033	1/16	·3438	166·7	57·31	45·01	10·32
5/16	·0260	12·63	·3290	·2583	·0045		·3542	171·8	60·84	47·78	11·28
	·0287	13·89	·3980	·3126	·0060	1/8	·3646	176·8	64·47	50·63	12·31
3/8	·0313	15·16	·4736	·3720	·0078		·3750	181·9	68·20	53·57	13·39
	·0339	16·42	·5558	·4365	·0098	3/16	·3854	186·9	72·05	56·59	14·54
7/16	·0365	17·68	·6446	·5063	·0123		·3958	192·0	75·99	59·69	15·75
	·0391	18·95	·7400	·5813	·0151	1/4	·4063	197·0	80·05	62·87	17·03
1/2	·0417	20·21	·8420	·6613	·0184	5	·4167	202·1	84·20	66·13	18·37
	·0469	22·73	1·066	·8370	·0262		·4271	207·1	88·47	69·48	19·78
9/16	·0521	25·26	1·316	1·033	·0359	1/16	·4375	212·2	92·83	72·91	21·26
	·0573	27·79	1·592	1·250	·0478		·4479	217·2	97·31	76·43	22·82
5/8	·0625	30·31	1·895	1·488	·0620	1/8	·4583	222·3	101·9	80·02	24·45
	·0677	32·84	2·223	1·746	·0788		·4688	227·3	106·6	83·70	26·16
11/16	·0729	35·37	2·579	2·025	·0985	3/16	·4792	232·4	111·4	87·46	27·94
	·0781	37·89	2·960	2·325	·1211		·4896	237·5	116·3	91·31	29·80
3/4	·0833	40·42	3·368	2·645	·1470	6	·5000	242·5	121·3	95·23	31·74
1/16	·0885	42·94	3·803	2·986	·1763	1/4	·5208	252·6	131·6	103·3	35·88
1/8	·0938	45·47	4·263	3·348	·2093	5/16	·5417	262·7	142·3	111·8	40·36
	·0990	48·00	4·750	3·730	·2461		·5625	272·8	153·5	120·5	45·19
3/16	·1042	50·52	5·263	4·133	·2870	7	·5833	282·9	165·0	129·6	50·40
1/4	·1094	53·05	5·802	4·557	·3323	1/4	·6042	293·0	177·0	139·0	56·00
5/16	·1146	55·57	6·368	5·001	·3820	5/16	·6250	303·1	189·5	148·8	62·00
	·1198	58·10	6·960	5·466	·4365		·6458	313·2	202·3	158·9	68·40
3/8	·1250	60·63	7·578	5·952	·4960	8	·6667	323·3	215·6	169·3	75·24
	·1302	63·15	8·223	6·458	·5606	1/4	·6875	333·4	229·3	180·1	82·52
7/16	·1354	65·68	8·893	6·985	·6306	5/16	·7083	343·5	243·4	191·1	90·25
1/2	·1406	68·20	9·591	7·533	·7062		·7292	353·6	247·9	202·5	98·45
	·1458	70·73	10·31	8·101	·7876	9	·7500	363·8	272·8	214·3	107·1
9/16	·1510	73·26	11·07	8·690	·8750	1/4	·7708	373·9	288·2	226·3	116·3
5/8	·1563	75·78	11·84	9·300	·9688	5/16	·7917	384·0	304·0	238·7	126·0
11/16	·1615	78·31	12·64	9·930	1 069		·8125	394·1	320·2	251·5	136·2
	·1667	80·83	13·47	10·58	1·176	10	·8333	404·2	336·8	264·5	146·9
3/4	·1771	85·89	15·21	11·95	1·410	1/4	·8542	414·3	353·9	277·9	158·2
1/16	·1875	90·94	17·05	13·39	1·674	5/16	·8750	424·4	371·3	291·6	170·1	
	·1979	95·99	19·00	14·92	1·969		·8958	434·5	389·2	305·7	182·6
1/8	·2083	101·0	21·05	16·53	2·296	11	·9167	444·6	407·5	320·1	195·6
3/16	·2188	106·1	23·21	18·23	2·658	1/4	·9375	454·7	426·3	334·8	209·2
1/4	·2292	111·2	25·47	20·01	3·056	5/16	·9583	464·8	445·4	349·8	223·5
5/16	·2396	116·2	27·84	21·87	3·492		·9792	474·9	465·0	365·2	238·4
3	·2500	121·3	30·31	23·81	3·968	12	1 Foot	485·0	485·0	380·9	253·9

Weight of Balls of Various Metals.

Diameter	Cast Lead.	Cast Copper.	Cast Brass.	Cast Iron.	Diameter	Cast Lead.	Cast Copper.	Cast Brass.	Cast Iron.
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Ins.	Lbs.	Lbs.	Lbs.	Lbs.
½	·026	·021	·019	·017	5	26·0	20·8	18·6	17·0
¾	·088	·070	·063	·058	¼	30·1	24·1	21·5	19·8
1	·209	·167	·148	·136	½	34·7	27·7	24·7	22·7
¼	·408	·325	·290	·266	¾	39·6	31·7	28·3	25·9
½	·705	·562	·501	·460	6	45·0	36·0	32·0	29·4
¾	1·12	·893	·795	·731	½	57·2	45·8	40·8	37·4
2	1·67	1·33	1·19	1·07	7	71·5	57·2	50·9	46·8
¼	2·38	1·90	1·69	1·55	½	88·0	70·3	62·6	57·5
½	3·25	2·60	2·32	2·13	8	106	85·3	76·0	69·8
¾	4·34	3·47	3·09	2·83	½	127	102	91·2	83·7
3	5·63	4·50	4·01	3·68	9	151	121	108	99·4
¼	7·15	5·72	5·10	4·68	½	178	143	127	117
½	8·94	7·14	6·36	5·85	10	208	167	148	136
¾	11·0	8·79	7·83	7·19	½	241	193	172	158
4	13·4	10·7	9·50	8·73	11	277	222	198	182
¼	16·0	12·8	11·4	10·5	½	317	253	226	207
½	18·9	15·2	13·5	12·4	12	360	288	257	236
¾	22·7	17·9	15·9	14·6					

Weight of Hexagon Rod Metal.

Weight of hexagon rod metal, measured across sides = weight of square metal × ·86602.

Weight of Octagon Rod Metal.

Weight of octagon rod metal, measured across sides = weight of square metal × ·82843.

Weight of Flat Rolled Iron per Foot Run.

Width.	Thickness of Metal in Parts of an Inch.											
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
Ins.	Lb.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs
1	·2083	·4166	·6250	·8333	1·042	1·250	1·458	1·666	2·083	2·500	2·916	3·33
1/8	·2344	·4688	·7033	·9375	1·172	1·406	1·640	1·875	2·344	2·812	3·280	3·77
1/4	·2605	·5210	·7810	1·042	1·303	1·563	1·823	2·083	2·605	3·125	3·646	4·16
3/8	·2865	·5730	·8595	1·146	1·432	1·719	2·006	2·292	2·864	3·438	4·012	4·58
1/2	·3125	·6250	·9375	1·250	1·562	1·875	2·188	2·500	3·125	3·750	4·375	5·00
5/8	·3385	·6771	1·015	1·354	1·692	2·031	2·370	2·708	3·384	4·062	4·740	5·41
3/4	·3646	·7292	1·094	1·458	1·823	2·188	2·550	2·916	3·646	4·375	5·105	5·83
7/8	·3906	·7812	1·172	1·562	1·953	2·344	2·735	3·125	3·906	4·688	5·470	6·25
2	·4166	·8333	1·25	1·666	2·083	2·500	2·916	3·333	4·166	5·000	5·833	6·66
1/8	·4427	·8855	1·328	1·771	2·214	2·656	3·098	3·542	4·428	5·312	6·196	7·08
1/4	·4688	·9375	1·406	1·875	2·344	2·812	3·281	3·750	4·688	5·624	6·562	7·50
3/8	·4948	·9895	1·484	1·979	2·474	2·968	3·463	3·958	4·948	5·936	6·926	7·9
1/2	·5210	1·042	1·562	2·083	2·605	3·125	3·646	4·166	5·210	6·250	7·291	8·33
5/8	·5470	1·094	1·641	2·187	2·735	3·282	3·829	4·375	5·470	6·564	7·658	8·75
3/4	·5730	1·146	1·719	2·292	2·865	3·438	4·011	4·583	5·730	6·876	8·022	9·16
7/8	·5990	1·198	1·797	2·396	2·995	3·594	4·193	4·792	5·990	7·188	8·386	9·58
3	·625	1·250	1·875	2·500	3·125	3·750	4·375	5·000	6·250	7·500	8·750	10·00
1/8	·6515	1·303	1·954	2·605	3·257	3·908	4·560	5·210	6·514	7·816	9·120	10·42
1/4	·6770	1·354	2·031	2·708	3·385	4·062	4·739	5·416	6·770	8·124	9·478	10·83
3/8	·7031	1·406	2·109	2·812	3·516	4·218	4·921	5·625	7·032	8·436	9·842	11·25
1/2	·7291	1·458	2·188	2·916	3·646	4·375	5·105	5·833	7·291	8·750	10·21	11·66
5/8	·7555	1·511	2·266	3·021	3·777	4·533	5·288	6·042	7·554	9·066	10·58	12·08
3/4	·7812	1·562	2·343	3·125	3·906	4·686	5·468	6·25	7·812	9·372	10·94	12·50
7/8	·8070	1·614	2·421	3·229	4·035	4·842	5·65	6·458	8·070	9·684	11·30	12·91

WEIGHT OF FLAT ROLLED IRON PER FOOT RUN (*continued*).

Thickness of Metal in Parts of an Inch.											
$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
·8333	1·666	2·500	3·333	4·166	5·000	5·833	6·666	8·333	10·00	11·66	13·33
·8595	1·719	2·578	3·438	4·297	5·166	6·016	6·875	8·594	10·31	12·03	13·75
·8855	1·771	2·656	3·542	4·427	5·312	6·198	7·083	8·854	10·62	12·40	14·16
·9115	1·823	2·734	3·646	4·557	5·468	6·380	7·291	9·114	10·94	12·76	14·58
·9375	1·875	2·812	3·750	4·687	5·624	6·562	7·500	9·374	11·25	13·12	15·00
·9636	1·927	2·891	3·854	4·818	5·782	6·745	7·708	9·636	11·56	13·49	15·42
·9895	1·979	2·968	3·958	4·947	5·936	6·926	7·917	9·894	11·87	13·85	15·83
1·016	2·031	3·048	4·062	5·080	6·096	7·112	8·125	10·16	12·19	14·22	16·25
1·042	2·083	3·125	4·166	5·210	6·25	7·291	8·333	10·42	12·50	14·58	16·66
1·068	2·136	3·204	4·271	5·340	6·408	7·476	8·542	10·68	12·81	14·95	17·08
1·094	2·188	3·282	4·375	5·470	6·564	7·658	8·750	10·94	13·13	15·31	17·50
1·120	2·240	3·360	4·479	5·600	6·720	7·840	8·958	11·20	13·44	15·68	17·92
1·146	2·292	3·438	4·584	5·730	6·876	8·022	9·167	11·46	13·75	16·04	18·33
1·172	2·344	3·516	4·687	5·860	7·032	8·204	9·375	11·72	14·06	16·40	18·75
1·198	2·396	3·594	4·791	5·990	7·188	8·386	9·583	11·98	14·37	16·77	19·16
1·224	2·448	3·672	4·896	6·120	7·344	8·568	9·792	12·24	14·69	17·13	19·58
1·250	2·500	3·750	5·000	6·250	7·500	8·750	10·00	12·50	15·00	17·50	20·00
1·276	2·552	3·828	5·104	6·380	7·656	8·932	10·21	12·76	15·31	17·86	20·42
1·302	2·604	3·906	5·208	6·510	7·812	9·114	10·42	13·02	15·62	18·23	20·83
1·328	2·657	3·984	5·313	6·640	7·968	9·297	10·63	13·28	15·93	18·59	21·25
1·354	2·708	4·063	5·417	6·770	8·126	9·480	10·83	13·54	16·25	18·96	21·66
1·381	2·761	4·143	5·521	6·906	8·286	9·668	11·04	13·81	16·57	19·33	22·08
1·406	2·813	4·218	5·625	7·030	8·436	9·843	11·25	14·06	16·87	19·69	22·50
1·432	2·864	4·296	5·729	7·160	8·592	10·02	11·46	14·32	17·18	20·04	22·92
1·458	2·916	4·375	5·833	7·291	8·750	10·20	11·66	14·58	17·50	20·42	23·33
1·484	2·969	4·452	5·938	7·420	8·904	10·39	11·87	14·84	17·81	20·78	23·75
1·511	3·021	4·533	6·042	7·555	9·066	10·58	12·08	15·11	18·13	21·16	24·16
1·536	3·073	4·608	6·146	7·680	9·216	10·75	12·29	15·36	18·43	21·50	24·58
1·562	3·125	4·686	6·250	7·810	9·372	10·93	12·50	15·62	18·74	21·86	25·00
1·588	3·177	4·764	6·354	7·940	9·528	11·12	12·71	15·88	19·05	22·24	25·42
1·615	3·229	4·845	6·458	8·075	9·690	11·31	12·92	16·15	19·38	22·62	25·83
1·641	3·281	4·923	6·562	8·205	9·846	11·48	13·13	16·41	19·69	22·96	26·25
1·666	3·333	5·000	6·666	8·333	10·00	11·66	13·33	16·66	20·00	23·33	26·66
1·693	3·386	5·079	6·771	8·455	10·15	11·85	13·54	16·91	20·30	23·70	27·08
1·719	3·438	5·157	6·875	8·595	10·31	12·03	13·75	17·19	20·61	24·06	27·50
1·745	3·489	5·235	6·979	8·725	10·47	12·21	13·96	17·45	20·94	24·42	27·92
1·771	3·542	5·313	7·083	8·855	10·63	12·40	14·17	17·71	21·26	24·80	28·33
1·797	3·594	5·391	7·188	8·985	10·78	12·58	14·37	17·97	21·56	25·16	28·75
1·823	3·646	5·469	7·292	9·115	10·94	12·76	14·58	18·23	21·88	25·52	29·17
1·849	3·698	5·547	7·396	9·245	11·09	12·94	14·79	18·49	22·18	25·88	29·58
1·875	3·750	5·625	7·500	9·375	11·25	13·12	15·00	18·75	22·50	26·24	30·00
1·901	3·802	5·703	7·604	9·505	11·41	13·31	15·21	19·00	22·81	26·62	30·42
1·927	3·854	5·781	7·708	9·635	11·56	13·49	15·42	19·27	23·12	26·98	30·83
1·953	3·906	5·859	7·812	9·765	11·72	13·67	15·62	19·53	23·44	27·34	31·25
1·979	3·958	5·937	7·916	9·895	11·87	13·85	15·84	19·79	23·74	27·70	31·67
2·005	4·010	6·015	8·021	10·02	12·03	14·04	16·04	20·04	24·06	28·08	32·08
2·031	4·062	6·093	8·125	10·16	12·18	14·21	16·25	20·32	24·36	28·42	32·50
2·057	4·114	6·171	8·229	10·29	12·34	14·40	16·46	20·58	24·68	28·80	32·92
2·083	4·166	6·250	8·333	10·41	12·50	14·58	16·66	20·82	25·00	29·16	33·33
2·109	4·219	6·327	8·438	10·55	12·65	14·76	16·87	21·10	25·30	29·52	33·75
2·135	4·270	6·405	8·541	10·67	12·81	14·94	17·08	21·34	25·62	29·88	34·17
2·162	4·323	6·486	8·646	10·81	12·97	15·13	17·29	21·62	25·94	30·26	34·58
2·188	4·375	6·564	8·750	10·94	13·13	15·31	17·50	21·88	26·26	30·62	35·00
2·214	4·427	6·642	8·854	11·07	13·28	15·50	17·71	22·14	26·56	31·00	35·42
2·239	4·479	6·717	8·958	11·20	13·43	15·67	17·92	22·40	26·86	31·34	35·83
2·266	4·531	6·798	9·062	11·33	13·59	15 86	18·12	22·66	27·18	31·72	36·25
2·291	4·583	6·873	9·166	11·46	13·75	16·04	18·33	22·90	27·50	32·08	36·66
2·318	4·636	6·954	9·271	11·59	13·91	16·22	18·54	23·18	27·82	32·44	37·08
2·344	4·688	7·032	9·375	11·72	14·06	16·40	18·75	23·44	28·12	32·80	37·50
2·370	4·740	7·110	9·479	11·85	14·22	16·59	18·96	23·70	28·44	33·18	37·92
2·395	4·791	7·185	9·582	11·97	14·37	16·76	19·16	23·94	28·74	33·52	38·33
2·422	4·844	7·266	9·688	12·11	14·53	16·95	19·37	24·22	29·06	33·90	38·75
2·448	4·896	7·344	9·792	12·24	14·68	17·13	19·58	24·48	29·36	34·26	39·16
2·474	4·948	7·422	9·896	12·37	14·84	17·32	19·79	24·74	29·68	34·64	39·58
2·500	5·000	7·500	10·00	12·50	15·00	17·50	20·00	25·00	30·00	35·00	40·00

Weight of Flat Steel per Foot Run.

Width.	Thickness of Metal in Parts of an Inch.							
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
$\frac{1}{8}$	·0532	·1063	·1595	·2127	·2658	·3190	·3722	·4253
$\frac{1}{2}$	·2127	·4253	·6380	·8507	1·063	1·276	1·489	1·701
$\frac{5}{8}$	·2658	·5317	·7975	1·063	1·329	1·595	1·861	2·127
$\frac{3}{4}$	·3190	·6380	·9570	1·276	1·595	1·914	2·233	2·552
$\frac{7}{8}$	·3722	·7443	1·117	1·489	1·861	2·233	2·605	2·977
1	·4253	·8507	1·276	1·701	2·127	2·552	2·976	3·403
$1\frac{1}{8}$	·4785	·9570	1·436	1·914	2·393	2·871	3·350	3·828
$1\frac{1}{4}$	·5317	1·063	1·595	2·127	2·658	3·190	3·722	4·253
$1\frac{3}{8}$	·5849	1·170	1·755	2·339	2·924	3·509	4·094	4·679
$1\frac{1}{2}$	·6380	1·276	1·914	2·552	3·190	3·828	4·466	5·104
$1\frac{3}{4}$	·7444	1·489	2·233	2·977	3·722	4·466	5·211	5·955
2	·8507	1·701	2·552	3·403	4·253	5·104	5·955	6·806
$2\frac{1}{4}$	·9570	1·914	2·871	3·828	4·785	5·742	6·699	7·656
$2\frac{1}{2}$	1·063	2·127	3·190	4·253	5·317	6·380	7·444	8·507
$2\frac{3}{4}$	1·170	2·339	3·509	4·679	5·849	7·018	8·188	9·358
3	1·276	2·552	3·828	5·104	6·380	7·656	8·932	10·208
$3\frac{1}{4}$	1·382	2·765	4·147	5·530	6·912	8·294	9·677	11·059
$3\frac{1}{2}$	1·489	2·977	4·466	5·955	7·444	8·932	10·421	11·910
$3\frac{3}{4}$	1·595	3·190	4·785	6·380	7·975	9·570	11·165	12·760
4	1·701	3·403	5·104	6·806	8·507	10·208	11·910	13·611
$4\frac{1}{4}$	1·808	3·615	5·423	7·231	9·039	10·846	12·654	14·462
$4\frac{1}{2}$	1·914	3·828	5·742	7·656	9·570	11·484	13·398	15·313
$4\frac{3}{4}$	2·020	4·041	6·061	8·082	10·102	12·122	14·143	16·163
5	2·127	4·254	6·380	8·507	10·634	12·760	14·887	17·014
$5\frac{1}{2}$	2·339	4·679	7·018	9·358	11·697	14·037	16·376	18·715
6	2·552	5·104	7·656	10·208	12·761	15·313	17·865	20·417

Weight of Round, Octagonal, and Square Steel per Foot Run.

Diam.	Round.	Octag.	Square.	Diam.	Round.	Octag.	Square.	Diam.	Round.	Octag.	Square.
In.	Lb.	Lb.	Lb.	Ins.	Lbs.	Lbs.	Lbs.	Ins.	Lbs.	Lbs.	Lbs.
$\frac{1}{16}$	·010	·011	·013	$\frac{5}{8}$	1·044	1·101	1·329	$1\frac{3}{8}$	5·053	5·230	6.43
$\frac{1}{8}$	·041	·044	·053	$\frac{11}{16}$	1·263	1·332	1·608	$1\frac{7}{16}$	6·013	6·343	7·65
$\frac{3}{16}$	·094	·099	·119	$\frac{3}{4}$	1·503	1·586	1·914	$1\frac{1}{2}$	7·057	7·444	8·98
$\frac{1}{4}$	·167	·176	·213	$\frac{13}{16}$	1·764	1·861	2·246	$1\frac{9}{16}$	8·185	8·633	10·42
$\frac{5}{16}$	·261	·275	·332	$\frac{7}{8}$	2·046	2 158	2·605	$1\frac{5}{8}$	9·396	9·910	11·96
$\frac{3}{8}$	·376	·396	·478	$\frac{15}{16}$	2·349	2·478	2·991	$1\frac{11}{16}$	10·690	11·276	13·61
$\frac{7}{16}$	·511	·539	·651	1	2·673	2·819	3·403	$1\frac{3}{4}$	13·530	14·271	17·22
$\frac{1}{2}$	·668	·706	·851	$1\frac{1}{8}$	3·382	3·568	4·307	$1\frac{13}{16}$	16·703	17·618	21·26
$\frac{9}{16}$	·845	·892	1·077	$1\frac{1}{4}$	4·176	4·405	5·317	$1\frac{7}{8}$	20·211	21·318	25·73

(Diameter of octagon steel is measured acrossides.)

Weight of Rolled Lead, Copper, and Brass: Sheets and Bars.

Thickness or Diameter, or Side.	Lead.			Copper.			Brass.			Thickness or Diameter, or Side
	Sheets, per Square Foot.	Square Bars, 1 Foot long.	Round Bars, 1 Foot long.	Sheets, per Square Foot.	Square Bars, 1 Foot long.	Round Bars, 1 Foot long.	Sheets, per Square Foot.	Square Bars, 1 Foot long.	Round Bars, 1 Foot long.	
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Ins.
$\frac{1}{32}$	1·86	·005	·004	1·44	·004	·003	1·36	·004	·003	$\frac{1}{32}$
$\frac{1}{16}$	3·72	·019	·015	2·89	·015	·012	2·71	·014	·011	$\frac{1}{16}$
$\frac{3}{32}$	5·58	·044	·034	4·33	·034	·027	4·06	·032	·025	$\frac{3}{32}$
$\frac{1}{8}$	7·44	·078	·061	5·77	·060	·047	5·42	·056	·044	$\frac{1}{8}$
$\frac{5}{32}$	9·30	·121	·095	7·20	·094	·074	6·75	·088	·069	$\frac{5}{32}$
$\frac{3}{16}$	11·2	·174	·137	8·66	·135	·106	8·13	·127	·100	$\frac{3}{16}$
$\frac{7}{32}$	13·0	·237	·187	10·1	·184	·144	9·50	·173	·136	$\frac{7}{32}$
$\frac{1}{4}$	14·9	·310	·244	11·5	·240	·189	10·8	·226	·177	$\frac{1}{4}$
$\frac{5}{16}$	18·6	·485	·381	14·4	·376	·295	13·5	·353	·277	$\frac{5}{16}$
$\frac{3}{8}$	22·3	·698	·548	17·3	·541	·425	16·3	·508	·399	$\frac{3}{8}$

WEIGHT OF ROLLED LEAD, COPPER, AND BRASS: SHEETS AND BARS—*continued.*

Thickness or Diameter, or Side.	LEAD. Sheets, per Square Foot.	LEAD. Square Bars, 1 Foot long.	LEAD. Round Bars, 1 Foot long.	COPPER. Sheets, per Square Foot.	COPPER. Square Bars, 1 Foot long.	COPPER. Round Bars, 1 Foot long.	BRASS. Sheets, per Square Foot.	BRASS. Square Bars, 1 Foot long.	BRASS. Round Bars, 1 Foot long.	Thickness or Diameter, or Side.
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Ins.
1/16	26·0	·950	·746	20·2	·736	·578	19·0	·691	·543	1/16
1/8	29·8	1·24	·974	23·1	·962	·755	21·7	·903	·709	1/8
9/16	33·5	1·57	1·23	26·0	1·22	·955	24·3	1·14	·900	9/16
5/8	37·2	1·94	1·52	28·9	1·50	1·18	27·1	1·41	1·11	5/8
11/16	40·9	2·34	1·84	31·7	1·82	1·43	29·8	1·70	1·34	11/16
3/4	44·6	2·79	2·19	34·6	2·16	1·70	32·5	2·03	1·60	3/4
13/16	48·3	3·27	2.57	37·5	2·55	1·99	35·2	2·38	1·87	13/16
7/8	52·1	3·80	2·98	40·4	2·94	2·31	37·9	2·76	2·17	7/8
15/16	56·0	4·37	3·42	43·3	3·38	2·65	40·6	3·18	2·49	15/16
1	59·5	4·96	3·90	46·2	3·85	3·02	43·3	3·61	2·84	1
1 1/16	66·9	6·27	4·92	52·0	4·87	3·82	48·7	4·57	3·60	1 1/16
1 1/8	74·4	7·75	6·09	57·7	6·01	4·72	54·2	5·64	4·43	1 1/8
1 3/16	81·8	9·37	7·37	63·5	7·28	5·72	59·6	6·82	5·37	1 3/16
1 1/4	89·3	11·2	8·77	69·3	8·65	6·80	65·0	8·12	6·38	1 1/4
1 3/4	104	15·2	11·9	80·8	11·8	9·25	75·9	11·1	8·68	1 3/4
2	119	19·8	15·6	92·3	15·4	12·1	86·7	14·4	11·3	2

WEIGHT OF SHEET LEAD.

Lbs. per Sq. Ft.	Thickness. Inch.	Lbs. per Sq. Ft.	Thickness. Inch.	Lbs. per Sq. Ft.	Thickness. Inch.	Lbs. per Sq. Ft.	Thickness. Inch.	Lbs. per Sq. Ft.	Thickness. Inch.	Lbs. per Sq. Ft.	Thickness. Inch.
2·5	·042	4	·068	6	102	8	·136	10	·170	14	·237
3	·051	5	·085	7	119	9	·153	12	·203	16	·271

WEIGHT OF SHEET ZINC.

Gauge No.	Approximate Thickness. In.	Approximate Thickness. Mm.	Approximate weight per square foot. lbs.	oz.	drms.	Approximate weight of Sheets. 36 ins. × 72 ins. lbs.	oz.	drms.	36 ins. × 84 ins. lbs.	oz.	drms.	36 ins. × 96 ins. lbs.	oz.	drms.
3	0·007	0·171	...	3	15	4	6	14	5	2	11	5	14	8
4	0·008	0·209	...	4	13	5	6	10	6	5	1	7	3	8
5	0·010	0·247	...	5	11	6	6	6	7	7	7	8	8	8
6	0·011	0·291	...	6	11	7	8	6	8	12	7	10	0	8
7	0·013	0·337	...	7	12	8	11	8	10	2	12	12	10	0
8	0·015	0·386	...	8	14	9	15	12	11	10	6	13	5	0
9	0·018	0·450	...	10	5	11	9	10	13	8	9	15	7	8
10	0·020	0·500	...	11	7	12	13	14	15	0	3	17	2	8
12	0·026	0·660	...	15	2	17	0	4	19	13	10	22	11	0
14	0·032	0·820	1	2	12	21	1	8	24	9	12	28	2	0
16	0·043	1·080	1	8	12	27	13	8	32	7	12	37	2	0
18	0·053	1·340	1	14	11	34	8	6	40	4	7	46	0	8
20	0·063	1·600	2	4	10	41	3	4	48	1	2	54	15	0
22	0·077	1·960	2	12	14	50	7	12	58	14	6	67	5	0
24	0·091	2·320	3	5	3	59	13	6	69	12	15	79	12	8
26	0·105	2·680	3	13	7	69	1	14	80	10	3	92	2	8

SPECIFICATION OF SHEET METALS.

When specifying for sheet metals, care should be taken that the nature of the gauge is stated, *i.e.* whether it is S.W.G., B.W.G., or Trade Gauge. In the case of 'Sheet Zinc,' for example, the Trade Gauge No. 20 is 0·063 in. (see above, and Index, 'Sheet Zinc Trade Gauge'), but this if expressed in S.W.G. is 0·36 in. (see Index, 'Standard Wire Gauge').

WEIGHT AND ELECTRICAL VALUE OF ALUMINIUM BAR AND STRIP.

Dimensions.		Sectional Area.	Weight.	Resistance at 20° C.	Current-carrying Capacity.	
Width.	Thickness.	Sq. ins.	Lbs. per ft.	Microhms per ft.	Amps. for 30° C. rise.	Amps. at 650 per sq. in.
6	$\frac{1}{2}$	3·000	3·510	4·47	1,940	1,950
6	$\frac{3}{8}$	2·250	2·633	5·96	1,692	1,461
6	$\frac{1}{4}$	1·500	1·755	8·95	1,397	975
5	$\frac{1}{2}$	2·500	2·935	5·36	1,649	1,625
5	$\frac{3}{8}$	1·875	2·195	7·15	1,430	1,219
5	$\frac{1}{4}$	1·250	1·463	10·72	1,179	812
5	$\frac{5}{16}$	0·937	1·096	14·3	1,029	609
$4\frac{1}{2}$	$\frac{1}{2}$	2·250	2·633	5·96	1,500	1,461
$4\frac{1}{2}$	$\frac{3}{8}$	1·687	1·972	7·95	1,300	1,097
$4\frac{1}{2}$	$\frac{1}{4}$	1·125	1·318	11·9	1,070	731
$4\frac{1}{2}$	$\frac{5}{16}$	0·844	0·988	15·9	933	549
4	$\frac{3}{4}$	3·000	3·510	4·47	1,660	1,950
4	$\frac{1}{2}$	2·000	2·340	6·70	1,348	1,300
4	$\frac{3}{8}$	1·500	1·755	8·95	1,169	975
4	$\frac{1}{4}$	1·000	1·170	13·4	960	650
4	$\frac{3}{16}$	0·750	0·878	17·9	836	487
4	$\frac{1}{8}$	0·500	0·585	26·8	692	325
$3\frac{1}{2}$	$\frac{1}{2}$	1·750	2·050	7·67	1,197	1,138
$3\frac{1}{2}$	$\frac{1}{4}$	0·875	1·022	15·3	849	569
$3\frac{1}{2}$	$\frac{1}{8}$	1·625	1·901	8·25	1,122	1,057
$3\frac{1}{4}$	$\frac{1}{4}$	0·812	0·950	16·5	793	527
3	$\frac{3}{8}$	1·125	1·318	11·9	902	731
3	$\frac{1}{4}$	0·750	0·878	17·9	737	487
3	$\frac{3}{16}$	0·562	0·658	23·9	641	365
$2\frac{3}{4}$	$\frac{1}{4}$	0·687	0·804	19·5	680	446
$2\frac{9}{16}$	$\frac{3}{8}$	0·961	1·124	14·0	783	625
$2\frac{1}{2}$	$\frac{1}{2}$	1·250	1·462	10·72	890	812
$2\frac{1}{2}$	$\frac{3}{8}$	0·937	1·096	14·30	766	609
$2\frac{1}{2}$	$\frac{5}{16}$	0·781	0·914	17·2	698	508
$2\frac{1}{2}$	$\frac{1}{4}$	0·625	0·731	21·5	624	406
$2\frac{1}{4}$	$\frac{3}{4}$	1·687	1·972	7·95	1,020	1,097
$2\frac{1}{4}$	$\frac{1}{2}$	1·125	1·318	11·9	814	731
$2\frac{1}{4}$	$\frac{3}{8}$	0·844	0·988	15·9	698	549
$2\frac{1}{4}$	$\frac{5}{16}$	0·703	0·823	19·1	636	457
$2\frac{1}{4}$	$\frac{1}{4}$	0·562	0·658	23·9	568	365
$2\frac{1}{4}$	$\frac{3}{16}$	0·422	0·494	31·8	493	274
2	$\frac{3}{4}$	1·500	1·755	8·95	926	975
2	$\frac{1}{2}$	1·250	1·463	10·72	834	812
2	$\frac{3}{8}$	1·000	1·170	13·4	736	650
2	$\frac{1}{4}$	0·750	0·878	17·9	630	487
2	$\frac{5}{16}$	0·625	0·731	21·5	672	406
2	$\frac{1}{8}$	0·500	0·585	26·8	511	325
2	$\frac{3}{16}$	0·375	0·439	35·8	442	244
2	$\frac{1}{16}$	0·250	0·293	53·7	364	162
$1\frac{13}{16}$	$\frac{5}{16}$	0·566	0·662	23·7	525	368
$1\frac{13}{16}$	$\frac{1}{8}$	1·093	1·280	12·25	747	710
$1\frac{3}{4}$	$\frac{1}{2}$	0·875	1·022	15·32	657	569
$1\frac{3}{4}$	$\frac{1}{4}$	0·437	0·512	30·7	453	284
$1\frac{3}{4}$	$\frac{1}{16}$	0·328	0·384	40·9	392	213
$1\frac{5}{8}$	$\frac{1}{8}$	0·219	0·256	61·3	322	142
$1\frac{5}{8}$	$\frac{1}{4}$	0·406	0·475	33·0	425	264
$1\frac{5}{8}$	$\frac{3}{16}$	0·305	0·357	44·0	368	198
$1\frac{5}{8}$	$\frac{1}{8}$	0·203	0·238	66·1	301	132
$1\frac{1}{2}$	$\frac{1}{2}$	0·750	0·878	17·9	577	487
$1\frac{1}{2}$	$\frac{3}{8}$	0·562	0·658	23·9	492	365
$1\frac{1}{2}$	$\frac{1}{4}$	0·375	0·439	35·8	396	244
$1\frac{1}{2}$	$\frac{3}{16}$	0·281	0·329	47·7	342	183
$1\frac{1}{2}$	$\frac{1}{8}$	0·188	0·220	71·4	280	122

(The British Aluminium Co. Ltd.)

WEIGHT OF SHEET ALUMINIUM.

Size S.W.G.	Birmingham Sheet Gauge. Old Style	Birmingham Sheet Gauge. Legalized. 1914.	Thickness. Inches.	Thickness. Mm.	Weight in lbs. per Sq. Ft.
			0·375	9·53	5·26
		1	0·353	8·96	4·96
1/0			0·324	8·23	4·55
			0·312	7·93	4·38
	39		0·289	7·34	4·06
	38		0·278	7·06	3·90
	37		0·270	6·86	3·79
	36	4	0·250	6·35	3·51
4			0·232	5·89	3·26
	34		0·216	5·49	3·03
	33		0·200	5·08	2·81
6			0·192	4·88	2·70
	32		0·182	4·62	2·56
	31		0·166	4·22	2·33
		8	0·157	3·99	2·20
9			0·144	3·66	2·02
	29		0·136	3·45	1·91
		10	0·125	3·18	1·76
11			0·116	2·95	1·63
		11	0·111	2·82	1·56
	26		0·100	2·54	1·41
13			0·092	2·34	1·29
		13	0·088	2·24	1·24
14			0·080	2·03	1·12
	23		0·077	1·96	1·08
		15	0·070	1·78	0·982
	20		0·065	1·65	0·914
	19		0·063	1·60	0·885
	18		0·060	1·53	0·843
	17		0·055	1·40	0·773
		18	0·050	1·27	0·702
	15		0·047	1·19	0·660
	14		0·042	1·07	0·590
		20	0·039	0·991	0·548

Size. S.W.G.	Birmingham Sheet Gauge. Old Style.	Birmingham Sheet Gauge. Legalized 1914.	Thickness. Inches.	Thickness. Mm.	Weight in lbs. per Sq. Ft.
20			0·036	0·914	0·506
21			0·032	0·813	0·449
22		23	0·028	0·711	0·393
		24	0·025	0·635	0·351
	9		0·023	0·584	0·323
	8		0·021	0·533	0·295
	7		0·019	0·483	0·267
		27	0·017	0·432	0·239
	6		0·0160	0·406	0·225
28			0·0148	0·376	0·208
		29	0·0139	0·353	0·195
30			0·0124	0·315	0·174
	4		0·0120	0·305	0·169
		31	0·0110	0·279	0·155
33	3		0·0105	0·267	0·147
34			0·0092	0·233	0·129
		33	0·0087	0·221	0·122
	1		0·0080	0·203	0·112
36			0·0076	0·193	0·107
37			0·0068	0·172	0·0916
38			0·0060	0·152	0·0843
39			0·0052	0·132	0·0731
41			0·0044	0·112	0·0618
42			0·0040	0·102	0·0562
43			0·0036	0·0915	0·0506
44			0·0032	0·0813	0·0450
45			0·0028	0·0711	0·0394
46		44	0·0024	0·0610	0·0337
47			0·0020	0·0508	0·0281
		47	0·0017	0·0432	0·0239
		48	0·0015	0·0381	0·0211
49		50	0·0012	0·0305	0·0169
50			0·0010	0·0254	0·0140

The above weights are subject to the usual manufacturing tolerances.

	Aluminium.	Brass.	Copper.	Steel.
Specific Gravity	2·71	8·45	8·89	7·8
Ratio of Weights	1·00	3·12	3·28	2·88

(*The British Aluminium Co. Ltd.*)

WEIGHT OF ANGLE AND TEE IRON PER FOOT RUN.

Breadth (Flanges Added).	Thickness in Fractions of an Inch.													
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs
2	1·13	1·46	1·76	2·03										
2¼	1·29	1·67	2·02	2·34										
2½	1·45	1·88	2·28	2·66	3·01									
2¾	1·60	2·08	2·54	2·97	3·37									
3	1·76	2·29	2·80	3·28	3·74	4·17								
3¼	1·91	2·50	3·06	3·59	4·10	4·58								
3½	2·07	2·71	3·32	3·91	4·47	5·00	5·51							
3¾	2·23	2·92	3·58	4·22	4·83	5·42	5·98							
4	2·38	3·13	3·84	4·53	5·20	5·83	6·45	7·03						
4¼	2·54	3·33	4·10	4·84	5·56	6·25	6·91	7·55						
4½	2·70	3·54	4·36	5·16	5·92	6·67	7·38	8·07	8·74					
4¾	2·85	3·75	4·62	5·47	6·29	7·08	7·85	8·59	9·31					
5	3·01	3·96	4·88	5·78	6·65	7·50	8·32	9·11	9·88	10·63				
5¼	3·16	4·17	5·14	6·09	7·02	7·92	8·79	9·64	10·46	11·25				
5½	3·32	4·38	5·40	6·41	7·38	8·33	9·26	10·16	11·03	11·88	12·70			
5¾	3·48	4·58	5·66	6·72	7·75	8·75	9·73	10·68	11·60	12·50	13·37			
6	3·63	4·79	5·92	7·03	8·11	9·17	10·20	11·20	12·17	13·13	14·05	14·95		
6¼	3·79	5·00	6·18	7·34	8·48	9·58	10·66	11·72	12·75	13·75	14·73	15·68		
6½	3·95	5·21	6·45	7·66	8·84	10·00	11·13	12·24	13·32	14·38	15·40	16·41	17·38	
6¾	4·10	5·42	6·71	7·97	9·21	10·42	11·60	12·76	13·89	15·00	16·08	17·13	18·16	
7	4·26	5·63	6·97	8·28	9·57	10·83	12·07	13·28	14·47	15·63	16·76	17·86	18·95	20·
7¼	4·41	5·83	7·23	8·59	9·93	11·25	12·54	13·80	15·04	16·25	17·43	18·59	19·73	20·
7½	4·57	6·04	7·49	8·91	10·30	11·67	13·01	14·32	15·61	16·88	18·11	19·32	20·51	21·
7¾	4·73	6·25	7·75	9·22	10·66	12·08	13·48	14·84	16 18	17·50	18·79	20·05	21·29	22·
8	4·88	6·46	8·01	9·53	11·03	12·50	13·95	15·36	16·76	18·13	19·47	20·78	22·07	23·
8¼	5·04	6·67	8·27	9·84	11·39	12·92	14·41	15·89	17·33	18·75	20·14	21·51	22·85	24·
8½	5·20	6·88	8·53	10·16	11·76	13·33	14·88	16·41	17·90	19·38	20·82	22·24	23·63	25·
8¾	5·35	7·08	8·79	10·47	12·12	13·75	15·35	16·93	18·48	20·00	21·50	22·97	24·41	25·
9	5·51	7·29	9·05	10·78	12·49	14·17	15·82	17·45	19·05	20·63	22·17	23·70	25·20	26·
9¼	5·66	7·50	9·31	11·09	12·85	14·58	16·29	17·97	19·62	21·25	22·85	24·43	25·98	27·
9½	5·82	7·71	9·57	11·41	13·22	15·00	16·76	18·49	20·19	21·88	23·53	25·16	26·76	28·
9¾	5·98	7·92	9·83	11·72	13·58	15·42	17·23	19·01	20·77	22·50	24·20	25·88	27·54	29

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Dimensions, weights per foot, and safe distributed load (calculated at $\frac{1}{4}$ breaking load) of **JOISTS,** in stock ready for immediate delivery.

Sections and weights per foot	4 ft. Tons	6 ft. Tons	8 ft. Tons	10 ft. Tons	12 ft. Tons	14 ft. Tons	16 ft. Tons	18 ft. Tons	20 ft. Tons	22 ft. Tons	24 ft. Tons	26 ft. Tons	28 ft. Tons	32 ft. Tons	36 ft. Tons	40 ft.
lbs.																
3×1½ .. 4	1·48	·98	·74	·59												
3×3 .. 8½	3·37	2·24	1·68	1·35												
4×1¾ .. 5	2·44	1·63	1·22	·98	·81											
4×3 .. 9½	5·01	3·34	2·51	2·01	1·67											
5×3 .. 11	7·26	4·84	3·63	2·90	2·42	2·07	1·81									
5×4½ .. 18	12·1	8·07	6·05	4·84	4·03	3·46	3·03									
6×3 .. 12	9·33	6·22	4·66	3·73	3·11	2·67	2·33	2·07								
6×4½ .. 20	15·4	10·3	7·69	6·15	5·13	4·40	3·85	3·42								
6×5 .. 25	17·8	13·4	10·0	8·03	6·69	5·73	5·02	4·46								
7×4 .. 16	14·9	9·96	7·47	5·97	4·98	4·27	3·73	3·32	2·99							
8×4 .. 18	18·5	12·4	9·27	7·42	6·18	5·30	4·64	4·12	2·74							
8×5 .. 28	25·2	19·8	14·9	11·9	9·92	8·51	7·44	6·62	5·95	5·41						
8×6 .. 35		25·2	19·2	15·3	12·8	11·0	9·59	8·52	7·67	6·97						
9×4 .. 21	24·0	16·0	12·0	9·61	8·01	6·87	6·01	5·34	4·81	4·37	4·01					
9×7 .. 58		44·6	34·0	27·2	22·7	19·4	17·0	15·1	13·6	12·4	11·3					
10×5 .. 30	32·4	25·9	19·4	15·5	12·9	11·1	9·71	8·63	7·77	7·06	6·47	5·97				
10×6 .. 42		36·0	28·2	22·6	18·8	16·1	14·1	12·5	11·3	10·3	9·40	8·68				
12×5 .. 32	35·3	32·6	24·4	19·6	16·3	14·0	12·2	10·9	9·78	8·89	8·15	7·52	6·98			
12×6 .. 44		43·2	35·0	28·0	23·4	20·0	17·5	15·6	14·0	12·7	11·7	10·8	10·0			
12×6 .. 54		54·0	41·7	33·4	27·8	23·8	20·9	18·5	16·7	15·2	13·9	12·8	11·9			
14×6 .. 46		46·7	41·9	33·6	28·0	24·0	21·0	18·6	16·8	15·3	14·0	12·9	12·0			
14×6 .. 57		63·0	50·7	40·6	33·8	29·0	25·4	22·6	20·8	18·5	16·9	15·6	14·5			
15×5 .. 42		50·4	38·0	30·4	25·4	21·7	19·0	16·9	15·2	13·8	12·7	11·7	10·9	9·51		
15×6 .. 59		67·5	55·9	44·7	37·3	31·9	28·0	24·8	22·4	20·3	18·6	17·2	16·0	14·0		
16×6 .. 62		79·2	60·5	48·4	40·3	34·6	30·2	26·9	24·2	22·0	20·2	18·6	17·3	15·1	13·4	
18×7 .. 75		86·9	85·1	68·1	56·7	48·6	42·5	37·3	34·0	30·9	28·4	26·2	24·3	21·3	18·9	17
20×7½ .. 89			103·	89·1	74·2	63·6	55·7	49·5	44·5	40·5	37·1	34·3	31·8	27·8	24·7	22
24×7½ ..100				103·	98·3	84·2	73·7	65·5	59·0	53·6	49·1	45·4	42·1	36·9	32·8	29

Figures to the right of zig-zag line are for spans exceeding 20 times depth of beam. This being the generally accepted limit without undue deflection.

STEEL CHANNELS IN STOCK.

2×1½×1½ about 4½ lbs. per ft. 4×2 ×2 about 8 lbs. per ft.
3×1½ „ 5 „ „ 5×2½×2½ „ 11 „ „
6×3 ×3 „ 14½ „ „
8×3½×3½ „ 23 „ „
10×3½×3½ „ 23½ „ „
12×3½×3½ „ 26 „ „

All in even feet lengths, 5 feet to 30 feet.

The Safe Carrying Loads are approximate, and not guaranteed excepting by special agreement.

WEIGHT OF ANGLE AND TEE IRON PER FOOT RUN (*continued*).

Breadth (Flanges Added).	Thickness in Fractions of an Inch.												
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
0	6·13	8·13	10·09	12·03	13·95	15·83	17·70	19·53	21·34	23·13	24·88	26·61	28·32	30·00
0¼	6·29	8·33	10·35	12·34	14·31	16·25	18·16	20·05	21·91	23·75	25·56	27·34	29·10	30·83
0½	6·45	8·54	10·61	12·66	14·67	16·67	18·63	20·57	22·49	24·38	26·24	28·07	29·88	31·67
0¾	6·60	8·75	10·87	12·97	15·04	17·08	19·10	21·09	23·06	25·00	26·91	28·80	30·66	32·50
1	6·76	8·96	11·13	13·28	15·40	17·50	19·57	21·61	23·63	25·63	27·59	29·53	31·45	33·33
1¼	..	9·17	11·39	13·59	15·77	17·92	20·04	22·13	24·21	26·25	28·27	30·26	32·23	34·17
1½	..	9·38	11·65	13·91	16·13	18·33	20·51	22·66	24·78	26·88	28·95	30·99	33·01	35·00
1¾	..	..	11·91	14·22	16·50	18·75	20·98	23·18	25·35	27·50	29·62	31·72	33·79	35·83
2	..	..	12·17	14·53	16·86	19·17	21·45	23·70	25·92	28·13	30·30	32·45	34·57	36·67
2¼	..	..	..	14·84	17·23	19·58	21·91	24·22	26·50	28·75	30·98	33·18	35·35	37·50
2½	..	..	..	15·16	17·59	20·00	22·38	24·74	27·07	29·38	31·65	33·91	36·13	38·33
2¾	..	..	..	..	17·96	20·42	22·85	25·26	27·64	30·00	32·33	34·64	36·91	39·17
3	..	..	..	..	18·32	20·83	23·32	25·78	28·22	30·63	33 01	35·36	37·70	40·00
3½	..	..	..	..	..	21·67	24·26	26·82	29·36	31·88	34·36	36·82	39·26	41·67
4	..	..	..	..	..	22·50	25·20	27·86	30·51	33·13	35·72	38·28	40·82	43·33
4½	..	..	..	..	..	23·33	26·13	28·91	31·65	34·38	37·07	39·74	42·38	45·00
5	..	..	..	..	..	24·17	27·07	29·95	32·80	35·63	38·42	41·20	43·95	46·67

(Henderson & Glass.)

WEIGHT OF ANGLE AND TEE STEEL PER FOOT RUN.

Breadth (Flanges added.)	Thickness in Fractions of an Inch.											
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2	1·16	1·49	1·79	2·07								
2¼	1·32	1·70	2·06	2·39								
2½	1·47	1·91	2·32	2·71	3·07							
2¾	1·63	2·13	2·59	3·03	3·44							
3	1·79	2·34	2·86	3·35	3·81	4·25						
3¼	1·95	2·55	3 12	3·67	4·18	4·68						
3½	2·11	2·76	3·39	3·98	4·56	5·10	5·62					
3¾	2·27	2·98	3·65	4·30	4·93	5·53	6·10					
4	2·43	3·19	3·92	4·62	5·30	5·95	6·57	7·17				
4¼	2·59	3·40	4·18	4·94	5·67	6·38	7·05	7·70				

WEIGHT OF ANGLE AND TEE STEEL PER FOOT RUN—*continued.*

Breadth (Flanges added).	Thickness in Fractions of an Inch.											
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8
Ins.	Lbs. 2·75	Lbs. 3·61	Lbs. 4·45	Lbs. 5·26	Lbs. 6·04	Lbs. 6·80	Lbs. 7·53	Lbs. 8·23	Lbs. 8·91	Lbs.	Lbs.	Lbs.
4 3/4	2·91	3·83	4·72	5·58	6·42	7·23	8·01	8·77	9·50			
5	3·07	4·04	4·98	5·90	6·79	7·65	8·49	9·30	10·08	10·84		
5 1/4	3·23	4·25	5·25	6·22	7·16	8·08	8·97	9·83	10·67	11·48		
5 1/2	3·39	4·46	5·51	6·53	7·53	8·50	9 44	10·36	11·25	12·11	12·95	
5 3/4	3·55	4·68	5·78	6·85	7·90	8·93	9·92	10·89	11·83	12·75	13·64	
6	3·71	4·89	6·04	7·17	8·27	9·35	10·40	11·42	12·42	13·39	14·33	15·25
6 1/4	3·87	5·10	6·31	7·49	8·65	9·78	10·88	11·95	13·00	14·03	15·02	15·99
6 1/2	4·02	5·31	6·57	7·81	9·02	10·20	11·36	12·48	13·59	14·66	15·71	16·73
6 3/4	4·18	5·53	6·84	8·13	9·39	10·63	11·83	13·02	14·17	15·30	16·40	17·48
7	4·34	5·74	7·11	8·45	9·76	11·05	12·31	13·55	14·76	15·94	17·09	18·22
7 1/4	4·50	5·95	7·37	8·77	10·13	11·48	12·79	14·08	15·34	16·58	17·78	18·97
7 1/2	4·66	6·16	7·64	9·08	10·51	11·90	13·27	14·61	15·92	17·21	18·47	19·71
7 3/4	4·82	6·38	7·90	9·40	10·88	12·33	13·75	15·14	16·51	17·85	19·17	20·45
8	4·98	6·59	8·17	9·72	11·25	12·75	14·22	15·67	17·09	18·49	19·86	21·20
8 1/4	5·14	6·80	8·43	10·04	11·62	13·18	14·70	16·20	17·68	19·13	20·55	21·94
8 1/2	5·30	7·01	8·70	10·36	11·99	13·60	15·18	16·73	18·26	19·76	21·24	22·68
8 3/4	5·46	7·23	8·97	10·68	12·37	14·03	15·66	17·27	18·85	20·40	21·93	23·43
9	5·62	7·44	9·23	11·00	12·74	14·45	16·14	17·80	19·43	21·04	22·62	24·17
9 1/4	5·78	7·65	9·50	11·32	13 11	14·88	16·62	18·33	20·02	21·68	23·31	24·92
9 1/2	5·94	7· 6	9·76	11·63	13·48	15·30	17·09	18·86	20·60	22·31	24·00	25·66
9 3/4	6·10	8·08	10·03	11·95	13·85	15·73	17·57	19·39	21·18	22 95	24·69	26·40
10	6·26	8·29	10·29	12·27	14·22	16·15	18·05	19·92	21·77	23·59	25·38	27·15
10 1/4	6·42	8·50	10·56	12·59	14·60	16·58	18·53	20·45	22·35	24·23	26·07	27·89
10 1/2	6·57	8·71	10·82	12·91	14·97	17·00	19·01	20·98	22·94	24·86	26·76	28·63
10 3/4	6·73	8·93	11·09	13·23	15·34	17·43	19·48	21·52	23·52	25·50	27·45	29·38
11	6·89	9·14	11·36	13·55	15·71	17·85	19·96	22·05	24·11	26·14	28·14	30·12
11 1/4	—	9·35	11·62	13·87	16·08	18·38	20·44	22·58	24·69	26·78	28·83	30·87
11 1/2	—	9·56	11·89	14·18	16·46	18·70	20·92	23·11	25·27	27·41	29·52	31·61
11 3/4	—	—	12·15	14·50	16·83	19·13	21·40	23·64	25·86	28·05	30·22	32·35
12	—	—	12·42	14·82	17·20	19·55	21·87	24·17	26·44	28·69	30·91	33·10

(*Henderson & Glass.*)

EBONITE SHEET.

Thickness.			Approx. Weight per Sheet.					
			36 × 18 ins. (914× 457 m/m.)		24 × 24 ins. (610 × 610 m/m.)		36 × 24 ins. (914 × 610 m/m.)	
Ins.	Ins.	m/m.	lbs.	kgs.	lbs.	kgs.	lbs.	kgs.
...	0·015	0·38	0·42	0·19	0·37	0·17	0·56	0·25
...	0·025	0·64	0·70	0·32	0·63	0·29	0·94	0·43
...	0·040	1·02	1·12	0·51	1·00	0·45	1·50	0·68
...	0·060	1·52	1·68	0·76	1·50	0·68	2·25	1·02
...	0·090	2·29	2·52	1·14	2·25	1·02	3·37	1·53
1/8	0·125	3·18	3·51	1·59	3·12	1·42	4·69	2·13
5/16	0·187	4·75	5·26	2·39	4·67	2·12	7·01	3·18
1/4	0·250	6·35	7·02	3·18	6·25	2·84	9·38	4·26
5/16	0·312	7·93	8·77	3·98	7·80	3·54	11·70	5·31
3/8	0·375	9·53	10·55	4·79	9·37	4·25	14·06	6·38
7/16	0·437	11·10	12·29	5·58	10·92	4·95	16·40	7·44
1/2	0·500	12·70	14·04	6·37	12·50	5·67	18·75	8·51
5/8	0·625	15·88	17·55	7·96	15·62	7·09	23·43	10·63
3/4	0·750	19·05	21·06	9·55	18·74	8·50	28·12	12·76
7/8	0·875	22·23	24·60	11·16	21·86	9·91	32·80	14·88
1	1·000	25·40	28·12	12·76	25·00	11·34	37·50	17·01

EBONITE ROD.

Diameter.			Approx. Weight per 100 metres.	Diameter.			Approx. Weight per 100 metres.
Ins.	Ins.	m/m.	Lbs.	Ins.	Ins.	m/m.	Lbs.
3/32	0·0937		1·18	5/8	0·625		52·35
	0·0984	2½	1·29		0·630	16	53·17
1/8	0·125		2·09	21/32	0·656		57·67
	0·137	3½	2·54		0·669	17	60·00
5/32	0·157	4	3·23	11/16	0·687		63·25
3/16	0·187		4·69		0·709	18	67·30
7/32	0·217	5½	6·28	23/32	0·719		69·27
1/4	0·250		8·37		0·728	18½	71·08
	0·256	6½	8·77	3/4	0·750		75·37
9/32	0·282		10·65		0·768	19½	78·98
	0·295	7½	11·68	25/32	0·781		81·72
5/16	0·312		13·05		0·787	20	83·08
	0·315	8	13·29	13/16	0·812		88·35
11/32	0·344		15·86		0·827	21	91·60
3/8	0·375	9½	18·85	27/32	0·844		95·45
13/32	0·406		22·09		0·866	22	100·5
	0·413	10½	22·90	7/8	0·875		102·6
7/16	0·437		25·60	29/32	0·905	23	110·0
	0·453	11½	27·47	15/16	0·937		117·6
15/32	0·468		29·35		0·945	24	120·0
1/2	0·472	12	29·90	1	1·000	25·4	134·0
	0·500		33·50	1⅛	1·125	28·5	170
17/32	0·532	13½	37·85	1¼	1·25	31·8	210
9/16	0·562		42·33	1⅜	1·375	35·0	253
	0·571	14½	43·66	1½	1·5	38·0	302
19/32	0·594		47·28	1¾	1·75	44·5	410
	0·610	15½	49·90	2	2	50·8	536

Weight of Pipes and Tubes.

D = outer diameter ; b = bore ; t = thickness ; W = weight of 1 ft. length ; k = ·02182 × weight of 1 cubic foot of metal.

$$W = t(D - t)k = t(b + t)k.$$

Weight of Wrought-Iron Pipes per Foot Run (W).

$k = 10{\cdot}55$.

Bore. (b)	Thickness of Metal in Parts of an Inch (t).							
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
$\frac{1}{4}$	·21	·5	·9	1·3	1·9	2·5	3·1	3·9
$\frac{3}{8}$	·3	·7	1·1	1·6	2·3	2·9	3·8	4·6
$\frac{1}{2}$	·4	·83	1·4	2·0	2·7	3·5	4·3	5·3
$\frac{5}{8}$	·46	1·1	1·6	2·3	3·1	3·9	4·9	5·9
$\frac{3}{4}$	·54	1·2	1·9	2·6	3·5	4·5	5·5	6·6
$\frac{7}{8}$	·6	1·3	2·1	2·9	3·9	4·9	6·1	7·3
1	·7	1·5	2·4	3·3	4·3	5·5	6·7	7·9
$1\frac{1}{4}$	·87	1·8	2·9	3·9	5·2	6·4	7·8	9·3
$1\frac{1}{2}$	1·0	2·1	3·3	4·7	5·9	7·4	8·9	10·6
$1\frac{3}{4}$	1·2	2·5	3·8	5·3	6·8	8·4	10·1	11·9
2	1·4	2·8	4·3	5·9	7·6	9·5	11·3	13·2
$2\frac{1}{4}$	1·53	3·1	4·8	6·6	8·5	10·4	12·4	14·5
$2\frac{1}{2}$	1·7	3·5	5·3	7·3	9·3	11·4	13·6	15·9
$2\frac{3}{4}$	1·9	3·8	5·8	7·9	10·1	12·4	14·7	17·2
3	2·03	4·1	6·3	8·6	10·9	13·3	15·9	18·5

Weights of Gas and Steam Pipe.

Gas Sizes.	Gas Pipe.	Steam Pipe.	Gas Sizes	Gas Pipe.	Steam Pipe.
Ins.	Lbs. per Ft.	Lbs. per Ft.	Ins.	Lbs. per Ft.	Lbs. per Ft.
$\frac{3}{8}$	·27	·32	$1\frac{3}{4}$	3·642	4·356
$\frac{1}{4}$	·40	·486	2	4·21	5·07
$\frac{3}{8}$	·56	·68	$2\frac{1}{4}$	4·614	5·49
$\frac{1}{2}$	·84	1·01	$2\frac{1}{2}$	5·349	6·333
$\frac{3}{4}$	1·20	1·43	$2\frac{3}{4}$	5·874	6·953
1	1·67	2·01	3	6·347	7·52
$1\frac{1}{4}$	2·34	2·80	$3\frac{1}{2}$	7·213	8·551
$1\frac{1}{2}$	3·10	3·76	4	8·097	9·601

Standard Weights and Dimensions of Cast-iron Water-main Pipes.

Internal Diam. of Pipe.	Length of each Pipe.	Depth of Socket.	Thickness of Metal.	Mean Weight of each Pipe.	Internal Diam. of Pipe.	Length of each Pipe.	Depth of Socket.	Thickness of Metal.	Mean Weight of each Pipe.
Ins.	Ft. Ins.	Ins.	Ins.	cwt. qrs. lbs.	Ins.	Ft. Ins.	Ins.	Ins.	cwt. qrs. lbs.
2	6 3	3	$\frac{5}{16}$	0 2 0	18	12 4½	4½	$\frac{3}{4}$	14 2 16
3	9 4	3	$\frac{3}{8}$	1 0 14	19	12 4½	4½	—	—
4	9 4	3	$\frac{3}{8}$	1 2 0	20	12 4½	4½	$\frac{3}{4}$	20 0 0
5	9 4	3½	$\frac{7}{16}$	2 0 0	21	12 4½	4½	—	—
6	9 4	3½	$\frac{7}{16}$	2 2 0	22	12 4½	4½	$\frac{3}{4}$	22 3 14
7	9 4	3½	$\frac{1}{2}$	3 1 14	23	12 4	5	—	—
8	9 4	4	$\frac{1}{2}$	3 2 0	24	12 4	5	$\frac{7}{8}$	24 0 0
9	9 4	4	$\frac{1}{2}$	4 2 0	26	12 5	5	—	—
10	9 4	4	$\frac{9}{16}$	5 1 0	28	12 5	5	—	—
11	12 4	4½	$\frac{5}{8}$	—	30	12 5	5	1	35 3 0
12	12 4½	4½	$\frac{5}{8}$	8 2 0	32	12 5	5	—	—
13	12 4½	4½	—	—	34	12 5	5	—	—
14	12 4½	4½	$\frac{5}{8}$	10 2 0	36	12 5	5	1	41 0 0
15	12 4½	4½	$\frac{5}{8}$	11 2 0	40	12 5	5	1⅛	48 2 0
16	12 4½	4½	$\frac{5}{8}$	13 2 0	42	12 5	5	1⅛	50 2 0
17	12 4½	4½	—	—	48	12 5½	5½	1⅛	64 0 0

Weight of Ordinary Copper Pipes per Foot Run (W).

$k = 12 \cdot 105$.

Bore. (b)	Thickness of Metal in Parts of an Inch (t).						
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
$\frac{1}{4}$	·22	·53	·94	1·43	2·01	2·68	3·44
$\frac{1}{2}$	·40	·89	1·47	2·15	2·91	3·75	4·70
$\frac{3}{4}$	·58	1·25	2·01	2·86	3·80	4·83	5·95
1	·76	1·61	2·55	3·58	4·70	5·92	7·25
$1\frac{1}{4}$	·94	1·96	3·09	4·31	5·64	6·98	8·46
$1\frac{1}{2}$	1·12	2·34	3·67	5·01	6·49	8·05	9·71
$1\frac{3}{4}$	1·33	2·66	4·14	5·70	7·36	9·11	10·94
2	1·48	3·04	4·69	6·44	8·27	10·20	12·21
$2\frac{1}{4}$	1·65	3·40	5·23	7·16	9·17	11·27	13·46
$2\frac{1}{2}$	1·83	3·75	5·77	7·87	10·06	12·35	14·72
$2\frac{3}{4}$	2·01	4·11	6·31	8·59	10·96	13·42	15·97
3	2·19	4·47	6·84	9·31	11·85	14·69	17·42

Weight of Ordinary Brass Pipes per Foot Run (W).

$k = 11 \cdot 452$.

Bore. (b)	Thickness of Metal in Parts of an Inch (t).						
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
$\frac{1}{4}$	·23	·56	·99	1·51	2·13	2·83	3·64
$\frac{1}{2}$	·42	·94	1·56	2·27	3·07	3·97	4·96
$\frac{3}{4}$	·61	1·32	2·13	3·02	4·02	5·11	6·29
1	·80	1·70	2·69	3·78	4·96	6·24	7·61
$1\frac{1}{4}$	·99	2·08	3·26	4·54	5·91	7·38	8·94
$1\frac{1}{2}$	1·18	2·46	3·83	5·29	6·85	8·51	10·26
$1\frac{3}{4}$	1·37	2·84	4·40	6·05	7·80	9·64	11·58
2	1·56	3·22	4·96	6·81	8·75	10·78	12·91
$2\frac{1}{4}$	1·75	3·59	5·53	7·56	9·69	11·92	14·23
$2\frac{1}{2}$	1·94	3·97	6·10	8·32	10·64	13·06	15·56
$2\frac{3}{4}$	2·13	4·35	6·67	9·08	11·59	14·19	16·88
3	2·31	4·73	7·24	9·83	12·53	15·32	18·21

Weight of Lead Pipes, Sizes and Weights usually Manufactured.

Bore.	Length.	Weight and Thickness of each Length.					
		Common.		Middling.		Strong.	
		Thickness.	Weight.	Thickness.	Weight.	Thickness.	Weight.
Ins.	Ft.	In.	Lbs.	In.	Lbs.	In.	Lbs.
$\frac{1}{2}$	15	·11	16	·15	22	·17	26
$\frac{3}{4}$	15	·12	24	·13	27	·15	30
1	15	·12	30	·15	39	·16	42
$1\frac{1}{4}$	12	·14	36	·16	44	·20	53
$1\frac{1}{2}$	12	·16	48	·18	56	·21	67
2	10	·15	50	·18	60	·21	70
$2\frac{1}{2}$	10	·17	70	·21	86	·24	100

Formulæ for Weight of Lead Piping.

$15 \cdot 517\,(D-t)\,t$ lbs. per foot; $81930\,(D-t)\,t$ lbs. per mile; $36 \cdot 576\,(D-t)\,t$ tons per mile; where D = external diameter in inches, t = thickness in inches.

APPROXIMATE WEIGHTS
(Based on the Imperial

Thickness, I.W.G. Ins. (*t*) m/m.	15 ·072 1·829	14 ·080 2·032	13 ·092 2·337	12 ·104 2·642	11 ·116 2·946	10 ·128 3·251	9 ·144 3·658	8 ·160 4·064	7 ·176 4·470	6 ·192 4·877	5 ·212 5·385
External Diam. Ins. (*D*).											WEIGHT PE
1	0·700	0·771	0·875	0·976	1·074	1·169	1·291	1·407	1·519	1·624	1·749
1 1/8	0·794	0·875	0·995	1·112	1·226	1·336	1·479	1·617	1·749	1·876	2·027
1 1/4	0·888	0·980	1·116	1·248	1·377	1·504	1·668	1·826	1·979	2·127	2·304
1 3/8	0·982	1·085	1·236	1·384	1·529	1·671	1·856	2·036	2·210	2·378	2·582
1 1/2	1·077	1·190	1·356	1·520	1·681	1·839	2·045	2·245	2·440	2·630	2·859
1 5/8	1·171	1·294	1·477	1·656	1·833	2·007	2·233	2·455	2·671	2·881	3·137
1 3/4	1·265	1·399	1·597	1·793	1·985	2·174	2·422	2·664	2·901	3·132	3·414
1 7/8	1·359	1·504	1·718	1·929	2·137	2·342	2·610	2·873	3·131	3·384	3·692
2	—	1·608	1·838	2·065	2·288	2·509	2·799	3·083	3·362	3·635	3·969
2 1/8	—	1·713	1·959	2·201	2·440	2·677	2·987	3·292	3·592	3·886	4·247
2 1/4	—	1·818	2·079	2·337	2·592	2·844	3·176	3·502	3·822	4·138	4·524
2 3/8	—	—	2·199	2·473	2·744	3·012	3·364	3·711	4·053	4·389	4·802
2 1/2	—	—	2·320	2·609	2·896	3·179	3·553	3·921	4·283	4·640	5·079
2 5/8	—	—	2·440	2·745	3·048	3·347	3·741	4·130	4·514	4·892	5·357
2 3/4	—	—	2·561	2·882	3·200	3·514	3·930	4·339	4·744	5·143	5·634
2 7/8	—	—	2·681	3·018	3·351	3·682	4·118	4·549	4·974	5·394	5·912
3	—	—	2·802	3·154	3·503	3·850	4·307	4·758	5·205	5·646	6·189
3 1/8	—	—	—	3·290	3·655	4·017	4·495	4·968	5·435	5·897	6·467
3 1/4	—	—	—	3·426	3·807	4·185	4·684	5·177	5·665	6·148	6·744
3 3/8	—	—	—	3·562	3·959	4·352	4·872	5·387	5·896	6·400	7·022
3 1/2	—	—	—	3·698	4·111	4·520	5·061	5·596	6·126	6·651	7·299
3 5/8	—	—	—	3·835	4·262	4·687	5·249	5·806	6·357	6·902	7·577
3 3/4	—	—	—	3·971	4·414	4·855	5·438	6·015	6·587	7·154	7·854
3 7/8	—	—	—	4·107	4·566	5·022	5·626	6·224	6·817	7·405	8·132
4	—	—	—	4·247	4·718	5·190	5·815	6·434	7·048	7·656	8·410
4 1/4	—	—	—	4·506	5·022	5·525	6·192	6·853	7·509	8·159	8·965
4 1/2	—	—	—	4·776	5·325	5·860	6·569	7·272	7·969	8·662	9·520
4 3/4	—	—	—	5·056	5·631	6·195	6·946	7·690	8·430	9·164	10·075
5	—	—	—	5·336	5·937	6·530	7·323	8·109	8·891	9·667	10·630
5 1/4	—	—	—	5·600	6·243	6·866	7·700	8·528	9·352	10·170	11·185
5 1/2	—	—	—	5·876	6·549	7·201	8·077	8·947	9·812	10·672	11·740
5 3/4	—	—	—	6·152	6·857	7·536	8·454	9·366	10·273	11·175	12·295
6	—	—	—	6·432	7·164	7·871	8·831	9·785	10·734	11·678	12·850
6 1/4	—	—	—	6·715	7·471	8·213	9·208	10·204	11·195	12·180	13·405
6 1/2	—	—	—	7·000	7·778	8·555	9·585	10·623	11·655	12·683	13·960
6 3/4	—	—	—	7·273	8·087	8·897	9·962	11 042	12·116	13·186	14·515
7	—	—	—	7·556	8·393	9·239	10·339	11·460	12·577	13·688	15·070
7 1/4	—	—	—	7·834	8·700	9·581	10·716	11·880	13·038	14·191	15·625
7 1/2	—	—	—	8·115	9·007	9·923	11·083	12·300	13·499	14·694	16·180
7 3/4	—	—	—	8·383	9·314	10·265	11·460	12·720	13·959	15·196	16·735
8	—	—	—	8·664	9·621	10·607	11·847	13·135	14·420	15·699	17·290
8 1/4	—	—	—	8·943	9·928	10·949	12·224	13·554	14·880	16·204	17·845
8 1/2	—	—	—	9·227	10·235	11·291	12·601	13·973	15·340	16·710	18·400
8 3/4	—	—	—	9·516	10·542	11·633	12·978	14·400	15·800	17·216	18·955
9	—	—	—	9·807	10·850	11·985	13·355	14·818	16·260	17·722	19·510
9 1/4	—	—	—	10·073	11·158	12·327	13·732	15·230	16·720	18·230	20·065
9 1/2	—	—	—	10·342	11·466	12·669	14·109	16·656	17·180	18·738	20·620
9 3/4	—	—	—	10·604	11·774	13·011	14·486	16·070	17·640	19·230	21·175
10	—	—	—	10·878	12·082	13·353	14·863	16·507	18·100	19·735	21·730
10 1/4	—	—	—	11·156	12·390	13·695	15·240	16·922	18·563	20·242	22·285
10 1/2	—	—	—	11·428	12·698	14·042	15·617	17·344	19·024	20·753	22·840
10 3/4	—	—	—	11·687	13·006	14·384	15·994	17·768	19·482	21·255	23·395
11	—	—	—	11·952	13·314	14·726	16·371	18·185	19·940	21·756	23·95
11 1/2	—	—	—	12·516	13·930	15·410	17·125	19·016	20·860	22·758	25·05
12	—	—	—	13·050	14·550	16·100	17·878	19·855	21·780	23·760	26·20

WROUGHT-IRON TUBES.

(Standard Wire Gauge.) $W = t(D-t)10{\cdot}472$.

4	3	2	1	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	Thickness, I.W.G. Ins. (t) m/m.
·232	·252	·276	·300	·125	·187	·250	·313	·375	·437	·500	
5·893	6·401	7·010	7·620	3·175	4·762	6·350	7·937	9·525	11·112	12·700	
WEIGHT IN POUNDS (W).											External Dia. Ins. (D).
1·866	1·974	2·092	2·199	1·145	1·595	1·963	2·250	2·454	2·577	2·618	1
2·169	2·304	2·454	2·592	1·309	1·841	2·291	2·659	2·945	3·150	3·272	$1\frac{1}{8}$
2·473	2·634	2·815	2·984	1·473	2·086	2·618	3·068	3·436	3·723	3·927	$1\frac{1}{4}$
2·777	2·963	3·176	3·377	1·636	2·332	2·945	3·477	3·927	4·295	4·581	$1\frac{3}{8}$
3·081	3·293	3·538	3·770	1·800	2·577	3·272	3·886	4·418	4·868	5·236	$1\frac{1}{2}$
3·384	3·623	3·899	4·163	1·963	2·822	3·600	4·295	4·909	5·440	5·890	$1\frac{5}{8}$
3·688	3·953	4·260	4·555	2·127	3·068	3·927	4·704	5·400	6·013	6·545	$1\frac{3}{4}$
3·992	4·283	4·621	4·948	2·291	3·313	4·254	5·113	5·890	6·586	7·199	$1\frac{7}{8}$
4·295	4·613	4·983	5·341	2·454	3·559	4·581	5·522	6·381	7·159	7·854	2
4·599	4·943	5·344	5·733	2·618	3·804	4·909	5·931	6·872	7·731	8·508	$2\frac{1}{8}$
4·903	5·273	5·705	6·126	2·782	4·050	5·236	6·340	7·363	8·304	9·163	$2\frac{1}{4}$
5·206	5·602	6·067	6·519	2·945	4·295	5·563	6·749	7·854	8·877	9·817	$2\frac{3}{8}$
5·510	5·932	6·428	6·911	3·109	4·541	5·890	7·159	8·345	9·449	10·472	$2\frac{1}{2}$
5·814	6·262	6·789	7·304	3·272	4·786	6·218	7·568	8·836	10·022	11·126	$2\frac{5}{8}$
6·117	6·592	7·150	7·697	3·436	5·031	6·545	7·977	9·327	10·595	11·781	$2\frac{3}{4}$
6·421	6·922	7·512	8·090	3·600	5·277	6·872	8·386	9·818	11·167	12·435	$2\frac{7}{8}$
6·725	7·252	7·873	8·482	3·763	5·522	7·200	8·795	10·308	11·740	13·090	3
7·028	7·582	8 234	8·875	3 927	5·768	7·527	9·204	10·799	12·313	13·744	$3\frac{1}{8}$
7·332	7·911	8·596	9·268	4·091	6·013	7·854	9·613	11·290	12·885	14·399	$3\frac{1}{4}$
7·636	8·241	8·957	9·660	4·254	6·259	8·181	10·022	11·781	13·458	15·053	$3\frac{3}{8}$
7·940	8 571	9·318	10·053	4·418	6·504	8·508	10·431	12·272	14·031	15·708	$3\frac{1}{2}$
8·243	8·901	9·679	10·446	4·581	6·750	8·836	10·840	12·763	14·604	16·362	$3\frac{5}{8}$
8·547	9·231	10·041	10·838	4·745	6·995	9·163	11·249	13·254	15·176	17·017	$3\frac{3}{4}$
8·851	9 561	10·402	11·231	4·908	7·240	9·490	11·658	13·745	15·749	17·671	$3\frac{7}{8}$
9·154	9·891	10·763	11·624	5·072	7·486	9·817	12·067	14·235	16·322	18·326	4
9·762	10·550	11·486	12·409	5·400	7·977	10·472	12·885	15·217	17·467	19·635	$4\frac{1}{4}$
10·369	11·210	12·208	13·195	5·727	8·468	11·126	13·704	16·199	18·612	20·944	$4\frac{1}{2}$
10·976	11·870	12·931	13·980	6·054	8·959	11·781	14·522	17·181	19·758	22·253	$4\frac{3}{4}$
11·584	12·530	13·654	14·765	6·381	9·450	12·435	15·340	18·162	20·903	23·562	5
12·191	13·189	14·376	15·551	6·709	9·940	13·090	16·158	19·144	22·048	24·871	$5\frac{1}{4}$
12·798	13·849	15·099	16·336	7·036	10·431	13·744	16·976	20·126	23·194	26·180	$5\frac{1}{2}$
13·406	14·509	15·821	17·122	7·363	10·922	14·399	17·794	21·108	24·339	27·489	$5\frac{3}{4}$
14·013	15·169	16·544	17·907	7·690	11·413	15·053	18·612	22·090	25·485	28·798	6
14·621	15·828	17·266	18·692	8·017	11·904	15·708	19·430	23·071	26·630	30·107	$6\frac{1}{4}$
15·228	16·488	17·989	19·478	8·345	12·395	16·362	20·249	24·053	27·775	31·416	$6\frac{1}{2}$
15·835	17·184	18·712	20·263	8·672	12·886	17·017	21·067	25·035	28·921	32·725	$6\frac{3}{4}$
16·443	17·807	19·434	21·048	8·999	13·376	17·671	21·885	26·017	30·066	34·034	7
17·050	18·467	20·157	21·834	9·327	13·867	18·326	22·703	26·998	31·212	35·343	$7\frac{1}{4}$
17·658	19 127	20·879	22·619	9·654	14·358	18·980	23·521	27·980	32·357	36·652	$7\frac{1}{2}$
18·265	19·787	21·602	23·405	9·981	14·849	19·635	24 339	28·962	33·502	37·961	$7\frac{3}{4}$
18·872	20·446	22·324	24·190	10·308	15·340	20·289	25·157	29·944	34·648	39·270	8
19·480	21·106	23·047	24·976	10·636	15·831	20·944	25·975	30·925	35·793	40·579	$8\frac{1}{4}$
20·087	21·766	23·769	25·761	10·963	16·322	21·598	26·794	31·907	36·938	41·888	$8\frac{1}{2}$
20·694	22·426	24·492	26·546	11·290	16·813	22·253	27·612	32·889	38·084	43·197	$8\frac{3}{4}$
21·302	23·085	25·215	27·332	11·617	17·303	22·907	28·430	33·871	39 229	44·506	9
21·909	23·745	25·937	28·117	11·945	17·794	23·562	29·248	34·852	40·375	45·815	$9\frac{1}{4}$
22·517	24·405	26·660	28·903	12·272	18·285	24·216	30·066	35·834	41·520	47·124	$9\frac{1}{2}$
23·124	25·065	27·382	29·688	12·599	18·776	24·871	30·884	36·816	42·665	48·433	$9\frac{3}{4}$
23·731	25·724	28·105	30·473	12·926	19·267	25·525	31·702	37·708	43·811	49·742	10
24·338	26·383	28·828	31·258	13·253	19·758	26·179	32·520	38·780	45·957	51·052	$10\frac{1}{4}$
24·945	27 042	29·551	32·043	13·580	20·249	26·833	33·338	39·762	46·103	52·361	$10\frac{1}{2}$
25·535	27·702	30·274	32·828	13·910	20·740	27·487	34·156	40·744	47·250	53·670	$10\frac{3}{4}$
26·162	28·362	31·002	33·613	14·237	21·231	28·141	34·974	41·726	48·396	54·980	11
27·376	29·682	32·445	35·183	14·897	22·213	29·450	36·610	43·690	50·690	57·600	$11\frac{1}{2}$
28·590	31·002	33·891	36·753	15·550	23·195	30·758	38·246	45·654	52·984	60·215	12

(*John Spencer, Ltd.*)

Weight of Cast-Iron Pipes per Foot Run.

Wt = Thickness (Bore + Thickness) 9·85.

Inner Diam. or Bore in Inches.	Thickness of Metal in Inches.												
	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1¾	2
	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.	Wt. in Lbs.
1	3·07	5·07	7·38	9·99	12·9	16·2	19·7	23·5	27·7	32·1	36·9	47·4	59·1
1 ¼	3·69	6·00	8·61	11·5	14·8	18·3	22·2	26·3	30·8	35·5	40·6	51·7	64·0
1 ½	4·30	6·92	9·84	13·1	16·6	20·5	24·6	29·1	33·8	38·9	44·3	56·0	68·9
1 ¾	4·92	7·84	11·1	14·6	18·5	22·6	27·1	31·8	36·9	42·3	48·0	60·3	73·8
2	5·53	8·76	12·3	16·2	20·3	24·8	29·5	34·6	40·0	45·7	51·7	64·6	78·7
2 ¼	6·15	9·69	13·5	17·7	22·2	26·9	32·0	37·4	43·1	49·0	55·4	68·9	83·7
2 ½	6·76	10·6	14·8	19·2	24·0	29·1	34·5	40·1	46·1	52·4	59·1	73·2	88·6
2 ¾	7·37	11·5	16·0	20·8	25·9	31·2	36·9	42·9	49·2	55·8	62·7	77·5	93·5
3	7·98	12·5	17·2	22·3	27·7	33·4	39·4	45·7	52·3	59·2	66·4	81·8	98·4
3 ¼	8·60	13·4	18·5	23·8	29·5	35·5	41·8	48·3	55·4	62·3	70·1	86·1	103
3 ½	9·21	14·3	19·7	25·4	31·4	37·7	44·3	51·2	58·4	65·9	73·8	90·4	108
3 ¾	9·83	15·2	20·9	26·9	33·2	39·8	46·8	54·0	61·5	69·3	77·5	94·7	113
4	10·3	16·1	22·2	28·6	35·1	42·0	49·2	56·7	64·6	72·7	81·2	99·0	118
4 ¼	11·1	17·1	23·4	30·0	36·9	44·1	51·7	59·5	67·7	76·1	84·9	103	123
4 ½	11·7	18·0	24·6	31·5	38·8	46·3	54·1	62·3	70·7	79·5	88·6	108	128
4 ¾	12·3	18·9	25·8	33·1	40·6	48·5	56·6	65·0	73·8	83·9	92·3	112	133
5	12·9	19·8	27·1	34·6	42·5	50·6	59·1	67·8	76·9	87·2	96·0	116	138
5 ¼	13·5	20·8	28·3	36·1	44·3	52·8	61·5	70·6	80·0	90·6	99·6	121	143
5 ½	14·2	21·7	29·5	37·7	46·1	54·9	64·0	73·3	83·0	94·0	103	125	148
5 ¾	14·8	22·6	30·8	39·2	48·0	57·1	66·4	76·1	86·1	97·4	107	129	153
6	15·4	23·5	32·0	40·8	49·8	59·2	68·9	78·9	89·2	99·8	111	134	158
6 ½	16·6	25·4	34·5	43·8	53·5	63·5	73·8	84·4	95·3	107	118	142	167
7	17·8	27·2	36·9	46·9	57·2	67·8	78·7	89·4	102	113	126	151	177
7 ½	19·1	29·1	39·4	50·0	60·9	72·1	83·7	95·5	108	120	133	159	187
8	20·3	30·9	41·8	53·1	64·6	76·4	88·6	101	114	127	140	168	197
8 ½	21·5	32·8	44·3	56·1	68·3	80·7	93·5	107	120	134	148	177	207
9	22·8	34·6	46·8	59·2	72·0	85·1	98·4	112	126	140	155	185	217
9 ½	24·0	36·4	49·2	62·3	75·7	89·3	103	118	132	147	163	194	226
10	25·1	38·3	51·7	65·3	79·4	93·6	108	123	138	154	170	202	235
10 ½	26·4	40·1	54·1	68·4	83·0	97·9	113·2	129	145	161	177	211	245
11	27·6	42·0	56·6	71·5	86·7	102	118	134	151	168	185	220	255
11 ½	28·8	43·8	59·1	74·6	90·4	107	123	140	157	174	192	228	265
12	30·0	45·7	61·5	77·7	94·1	111	128	145	163	181	199	237	275
13	32·5	49·4	66·4	83·8	102	120	138	156	175	195	214	254	294
14	35·0	53·1	71·4	89·4	109	128	148	168	188	208	229	271	314
15	37·4	56·7	76·3	96·1	116	137	158	179	200	222	244	289	334
16	39·1	60·4	81·2	102	124	145	167	190	212	235	258	306	353
17	42·3	64·1	86·1	108	131	154	177	201	225	249	273	323	373
18	44·8	67·8	91·0	115	139	163	187	212	237	262	288	340	393
19	47·3	71·5	96·0	121	146	171	197	223	249	276	303	357	412
20	49·7	75·2	101	127	153	180	207	234	261	289	317	375	432
21	52·2	78·9	106	133	161	188	217	245	274	303	332	392	452
22	54·6	82·6	111	139	168	196	227	256	286	316	347	409	471
23	57·1	86·3	116	145	175	206	236	267	298	330	362	426	491
24	59·6	89·9	121	152	183	214	246	278	311	343	375	444	511
25	62·0	93·6	126	158	190	223	256	289	323	357	391	461	531
26	64·5	97·3	131	164	198	231	266	300	335	370	406	478	550
27	66·9	101	135	170	205	240	276	311	348	384	421	495	570
28	69·4	105	140	176	212	249	286	323	360	397	436	512	590
29	71·8	109	145	182	220	257	295	334	372	411	450	530	609
30	74·2	112	150	188	227	266	305	345	384	424	465	547	629
31	76·7	116	155	195	234	275	315	356	397	438	480	564	649
32	79·1	120	160	201	242	283	325	367	409	451	495	581	668
33	81·6	123	165	207	249	292	335	378	421	465	509	598	688
34	84·1	127	170	213	257	300	345	389	434	479	524	616	709
35	86·5	131	175	219	264	309	354	400	446	492	539	633	726
36	89·0	134	180	225	271	318	364	411	458	506	554	650	746
42	104	156	210	262	315	370	423	478	532	588	644	753	864
48	119	178	239	298	359	422	482	544	605	669	733	856	982

Dimensions.			Spigot and Faucet Joints.			Turned and Bored Joints.			Flanged Joints.					
Inside Diameter.	(A) Thickness of Metal.	Length exclusive of Faucet.	Average Weight per Pipe.			Average Weight per Pipe.			Inside Diameter.	(B) Thickness of Metal.	Length over Flanges.	Average Weight per Pipe.		
Ins.	Ins.	Ft.	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.	Ins.	Ins.	Ft.	Cwts.	Qrs.	Lbs.
$\frac{3}{4}$	$\frac{7}{32}$	$4\frac{1}{2}$			$14\frac{1}{2}$				2	$\frac{5}{16}$	6		1	21
1	$\frac{1}{4}$	6			22		1	0	$2\frac{1}{2}$	$\frac{5}{16}$	9		3	2
$1\frac{1}{4}$	$\frac{1}{4}$	6			26		1	5	$2\frac{1}{2}$	$\frac{1}{2}$	9	1	1	7
$1\frac{1}{2}$	$\frac{1}{4}$	6		1	2		1	7	3	$\frac{5}{16}$	9	1	0	0
$1\frac{1}{2}$	$\frac{9}{32}$	6		1	7		1	13	3	$\frac{3}{8}$	9	1	0	13
2	$\frac{1}{4}$	6		1	14		1	20	3	$\frac{1}{2}$	9	1	2	0
2	$\frac{5}{16}$	6		1	22		2	0	3	$\frac{5}{8}$	9	2	0	0
2	$\frac{11}{32}$	6		2	0		2	8	$3\frac{1}{2}$	$\frac{3}{8}$	9	1	1	3
$2\frac{1}{2}$	$\frac{5}{16}$	6		2	0		2	7	$3\frac{1}{2}$	$\frac{1}{2}$	9	1	3	0
$2\frac{1}{2}$	$\frac{5}{16}$	9		3	0		3	10	4	$\frac{3}{8}$	9	1	1	21
$2\frac{1}{2}$	$\frac{11}{32}$	9		3	14		3	21	4	$\frac{7}{16}$	9	1	2	24
3	$\frac{5}{16}$	9		3	14		3	21	4	$\frac{1}{2}$	9	2	0	0
3	$\frac{11}{32}$	9	1	0	0	1	0	7	4	$\frac{5}{8}$	9	2	2	4
3	$\frac{3}{8}$	9	1	0	10	1	0	17	$4\frac{1}{2}$	$\frac{1}{2}$	9	2	0	21
$3\frac{1}{2}$	$\frac{5}{16}$	9	1	0	14	1	0	21	$4\frac{1}{2}$	$\frac{9}{16}$	9	2	2	0
4	$\frac{11}{32}$	9	1	1	14	1	1	21	5	$\frac{1}{2}$	9	2	1	21
4	$\frac{3}{8}$	9	1	2	0	1	2	7	5	$\frac{5}{8}$	9	3	0	14
$4\frac{1}{2}$	$\frac{11}{32}$	9	1	2	14	1	2	21	$5\frac{1}{2}$	$\frac{1}{2}$	9	2	2	14
5	$\frac{3}{8}$	9	1	3	14	1	3	21	6	$\frac{7}{16}$	9	2	2	0
5	$\frac{13}{32}$	9	2	0	0	2	0	7	6	$\frac{1}{2}$	9	2	3	14
$5\frac{1}{2}$	$\frac{3}{8}$	9	2	0	11	2	0	18	6	$\frac{5}{8}$	9	3	2	14
6	$\frac{13}{32}$	9	2	1	14	2	1	14	7	$\frac{1}{2}$	9	3	1	7
6	$\frac{7}{16}$	9	2	2	0	2	2	9						
7	$\frac{7}{16}$	9	2	3	14	2	3	24						
7	$\frac{1}{2}$	9	3	1	4	3	1	14						

(Macfarlane, Strang & Co., Ltd.)

THICKNESSES AND WEIGHTS OF SCREWED AND SOCKETED TUBES.

Nominal Bore.	External Diameter.	Length of Screw on Tubes.	Pitch of Screw, No. of Threads, per in.	Thickness of Tubes Wire Gauge No.			Approximate Weight in lbs. per Foot.		
Ins.	Ins.	Ins.		Gas.	Water.	Steam.	Gas.	Water.	Steam.
$\frac{1}{8}$	$\frac{13}{32}$	$\frac{3}{8}$	28	14	13	12	0·278	0·306	0·337
$\frac{1}{4}$	$\frac{17}{32}$	$\frac{7}{16}$	19	14	13	12	0·385	0·428	0·472
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{1}{2}$	19	13	12	11	0·582	0·644	0·703
$\frac{1}{2}$	$\frac{27}{32}$	$\frac{5}{8}$	14	12	11	10	0·818	0·896	0·973
$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$	14	11	10	9	1·165	1·268	1·403
1	$1\frac{11}{32}$	$\frac{7}{8}$	11	10	9	8	1·653	1·833	2·008
$1\frac{1}{4}$	$1\frac{11}{16}$	1	11	9	8	7	2·367	2·598	2·827
$1\frac{1}{2}$	$1\frac{29}{32}$	$1\frac{1}{8}$	11	8	7	6	2·973	3·237	3·500
$1\frac{3}{4}$	$2\frac{5}{32}$	$1\frac{1}{8}$	11	8	7	6	3·406	3·710	4·019
2	$2\frac{3}{8}$	$1\frac{1}{8}$	11	8	7	6	3·786	4·128	4·473
$2\frac{1}{4}$	$2\frac{5}{8}$	$1\frac{1}{4}$	11	7	6	5	4·602	4·980	5·447
$2\frac{1}{2}$	3	$1\frac{1}{4}$	11	7	6	5	5·338	5·779	6·323
3	$3\frac{1}{2}$	$1\frac{3}{8}$	11	7	6	5	6·309	6·834	7·483
$3\frac{1}{2}$	4	$1\frac{1}{2}$	11	7	6	5	7·265	7·873	8·627
4	$4\frac{1}{2}$	$1\frac{5}{8}$	11	7	6	5	8·253	8·945	9·803
$4\frac{1}{2}$	5	$1\frac{5}{8}$	11	7	6	5	9·230	10·006	10·969
5	$5\frac{1}{2}$	$1\frac{3}{4}$	11	7	6	5	10·232	11·091	12·159
6	$6\frac{1}{2}$	2	11	7	6	5	12·305	13·332	14·609

The above dimensions are subject to the usual working allowances.

(Stewarts & Lloyds, Ltd.)

Description.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.
Pipes	0 2 0	1 0 14	1 2 0	2 0 0	2 2 0	3 1 14	3 2 0	4 1 0	6 3 0		8 2 0		10 2 0	11 2 0	13 2 0	
Bends $\frac{1}{8}$-in.	0 1 6	0 2 0	0 3 4	1 0 0	1 1 7	1 3 7	2 2 0	3 0 4	3 2 0		4 1 9		5 3 0	6 0 0	7 0 0	
Bends $1\frac{1}{8}$ in.	0 1 7	0 2 2	0 3 0	0 3 27	1 1 7	1 3 25	2 2 7	3 0 4	3 1 14		4 1 7		5 2 0	6 1 0	6 3 0	
Bends $\frac{1}{4}$ in.	0 1 7	0 2 7	0 3 7	1 0 16	1 2 0	1 3 14	2 2 7	3 0 21	3 1 21		4 1 0		5 3 0	6 2 6	7 1 0	
Cross-pipe	0 2 21	0 3 18	1 0 14	1 1 7	1 3 21	2 1 21	2 3 0	4 0 0	4 3 0		6 2 0		6 2 0	10 0 0	10 2 0	
S bend	0 1 21	0 2 0	0 3 21	1 0 4	1 3 0	2 0 0	2 3 0	3 1 0	3 3 0		5 2 0					
Bevel arm-piece or Y-piece spigots	0 2 0	0 3 0	1 0 7	1 1 14	1 2 7	2 0 9	2 3 0	3 1 0	4 1 0		6 2 0	Made to Drawings.				
Bevel arm-piece or Y-piece sockets	0 2 7	0 3 14	1 0 21	1 2 0	1 3 0	2 1 7	2 3 0	3 1 0	4 3 0		6 2 0					
Arm-pipe or branch	0 3 0	0 3 21	1 1 0	1 1 21	1 3 7	2 1 14	3 0 0	3 2 0	4 3 14		5 2 0		8 0 0	9 1 0	9 2 14	
Tee-pipe	0 1 7	0 3 0	1 0 0	1 1 13	1 2 4	2 1 0	3 1 0	3 2 14	4 0 0		5 1 7		7 2 14	9 0 0	9 1 0	
Wash-out pipe	0 2 14	0 2 21	0 3 21	1 0 16	1 1 14	1 2 14	1 3 20	2 2 0	3 0 0		1 2 0		1 3 0	2 0 0	2 3 0	
Collar or thimble	0 0 20	0 0 24	0 1 4	0 1 14	0 2 0	0 2 21	0 3 14	1 0 0	1 1 10		1 2 2		1 3 14	1 3 25	2 0 18	
Cap	0 0 12	0 0 18	0 0 24	0 1 2	0 1 12	0 2 0	0 2 14	0 3 0	0 3 9		1 0 4		1 1 21	1 2 7	1 3 0	
Reducers	3″–2″	4″–3″	5″–4″	6″–5″	7″–6″	8″–7″	9″–8″	10″–9″	12″–10″		14″–12″	Made to Drawings.				
	0 1 0	0 2 0	0 2 7	0 3 14	1 0 0	1 1 10	1 3 21	2 0 0	2 3 21		3 3 18					

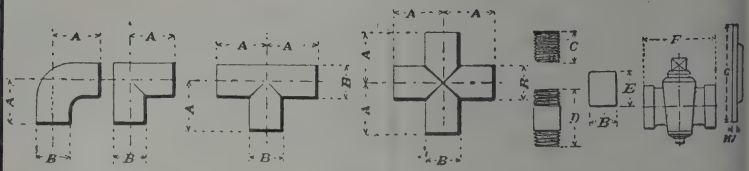
Description.	18	19	20	21	22	23	24	26	28	30	32	34	36	40	42	48
	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.	c.q.lbs.
Pipes	14 2 16		20 0 0		22 3 14		24 0 0			35 3 0			41 0 0	48 2 0	50 2 0	64 0 0
Bends $\frac{1}{16}$ in.	7 3 7		9 1 21													
Bends $\frac{1}{8}$ in.	7 2 7		11 1 14				13 0 7			18 3 0						
Bends $\frac{1}{4}$ in.	7 3 16		10 3 21				13 1 6									
Cross-pipe	11 2 0		14 0 0				17 0 0									
S bend																
Bevel arm-piece or Y-piece spigots																
Bevel arm-piece or Y-piece sockets								Made Specially to Drawings.								
Arm-pipe or branch	10 2 0		12 0 0				15 0 0									
Tee-pipe	10 1 0		11 2 0				14 1 10									
Wash-out pipe	3 1 0		4 0 0													
Collar or thimble	3 0 25		3 2 10				5 2 10									
Cap	2 1 0		3 0 0				4 2 10									
Reducers																

Pipes 2-in. bore in 6 ft. 3 ins. lengths ; 3-in. bore to 9 ins., 9 ft. 4 ins. lengths ; 9-in. bore to 48 ins., 12 ft. 4 ins. lengths.

The pipes are vertically cast in dry sand, socket down, and are tested to a pressure of 500 feet head (216 lbs. per sq. in.) of water ; the fittings are tested to the same pressure.

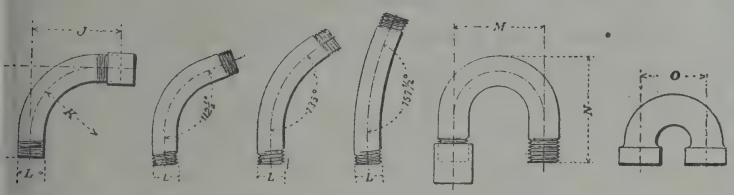
(*The Staveley Coal and Iron Co.*)

APPROXIMATE DIMENSIONS OF



		Size, ins.	⅛	¼	⅜	½	¾
A	Centre to Face of Elbows, Tees, and Crosses	GAS ins.	¾	⅞	1 5/16	1 5/8	1 7/8
		STEAM „	⅞	1 5/16	1	1¼	1½
B	Outside Diam. of Elbows, Tees, Crosses, and Sockets	GAS „	⅝	¾	⅞	1 1/16	1 5/16
		STEAM „	11/16	1 3/16	1 5/16	1⅜	1⅝
C	Length of Nipples	GAS & STEAM „	½	⅝	¾	⅞	1
D	Length of Barrel Nipples	GAS & STEAM „	1¼	1⅜	1½	1¾	2
E	Length of Sockets	GAS & STEAM „	⅞	1	1⅛	1⅛	1 5/16
F	Length of Main Cocks	GAS „	—	1 5/16	2⅝	3	3½
G	Diameter of Flanges	GAS & STEAM „	2¼	2½	3	3	4
H	Thickness of Flanges	GAS „	1/16	⅛	5/32	3/16	3/16
		STEAM „	—	7/32	⅛	¼	¼
Drilling	Pitch Circle	GAS & STEAM „	1⅝	1⅜	2⅛	2⅝	2 7/8
	Number and Size of Bolts.	GAS „	4 · 5/16	4 · 5/16	4 · ⅜	4 · ½	4 · ½
	Number and Size of Bolts.	STEAM „	—	4 · 5/16	4 · ⅜	4 · ½	4 · ½
J	Centre to Face of Bends	GAS & STEAM „	2⅛	2½	2 7/8	3¼	4
K	Radii of Bends	GAS & STEAM „	1½	1⅝	1 7/8	2¼	2 7/8
L	Outside Diam. of Bends and Springs	GAS & STEAM „	1 3/32	1 7/32	1 11/16	2 7/32	1 13/16
Nos. 6, 7, 8, 9	Length of tube in Bends and Springs	GAS & STEAM „	3¾	4¼	4 7/8	5⅝	6⅝
M	Centre to Centre of W.I. Double Bends	STEAM „	1⅞	2	2⅛	3¼	3½
N	Back to Face of W.I. Double Bends	STEAM „	2	2½	2⅞	3½	4
O	Centre to Centre of Malleable Double Bends	STEAM „	—	—	—	1¼	1½

TEAM AND GAS FITTINGS.



1	1¼	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½	5	5½	6	
1⅝ 1⅝ 1⅝	1 13/16 1 13/16 1 13/16	2 1/16 2 1/16 2 1/16	2 3/16 2 5/16 2 5/16	2 1/2 2 5/8 3	2 7/8 3 3 1/8	3 1/8 3 1/4 3 1/2	3 3/8 3 1/2 3 5/8	3 5/8 4 4 1/8	4 4 1/2 4 3/4	4 1/2 4 3/4 5 1/4	5 1/4 5 1/4 5 3/4	5 3/4 5 3/4 6	6 6 6 1/2	6 1/2 6 1/2 6 1/2	A
1 9/16 1 9/16 1 9/16	1 31/32 2 1/32 2 1/32	2 1/4 2 5/16 2 7/16	2 3/8 2 7/16 2 7/16	2 3/4 2 13/16 3 1/8	3 1/16 3 1/8 3 1/8	3 3/8 3 7/16 3 3/4	3 11/16 3 11/16 4	3 15/16 4 4 1/2	4 7/16 5 5 1/16	5 5 5/8 5 5/8	5 5/8 6 1/8 6 1/8	6 1/8 6 5/8 6 5/8	6 5/8 7 1/8 7 1/8	7 1/8 7 1/8 7 1/8	B
1/8	1 1/2	1 5/8	1 3/4	1 7/8	2 1/8	2 1/4	2 3/8	2 3/8	2 1/2	2 3/4	2 7/8	3	3 1/8	3 1/4	C
1/4	2 3/8	2 1/2	2 3/4	2 3/4	3	3 1/4	3 1/2	3 1/2	3 3/4	4 1/4	4 1/4	4 1/2	4 1/2	5 1/2	D
7/8	2 1/8	2 3/8	2 1/2	2 5/8	2 5/8	2 7/8	2 7/8	3 1/4	3 1/4	3 1/4	3 1/2	4	4	4 1/2	E
1/8	4 7/8	5 1/4	6 1/4	6 1/2	7	7 1/2	8 1/4	8 3/4	10 3/8	11 1/2	—	—	—	—	F
1/2	4 3/4	5 1/4	5 1/2	6	—	6 1/2	—	7 1/4	8	8 1/2	9	10	—	11	G
3/16 9/32	1/4 5/16	1/4 11/32	1/4 11/32	5/16 3/8	— —	5/16 13/32	— —	3/8 7/16	3/8 15/32	3/8 1/2	7/16 17/32	1/2 9/16	— —	1/2 11/16	H
1/2 •1/2 •1/2	3 7/16 4·1/2 4·1/2	3 7/8 4·1/2 4·1/2	4 1/8 4·1/2 4·1/2	4 1/2 4·5/8 4·5/8	— — —	5 4·5/8 4·5/8	— — —	5 3/4 4·5/8 8·5/8	6 1/2 4·5/8 8·5/8	7 4·5/8 8·5/8	7 1/2 8·5/8 8·5/8	8 1/4 8·5/8 8·3/4	— — —	9 1/4 8·5/8 8·3/4	Drilling
3/4	6	6 3/4	7 1/8	8	8 1/8	9 3/4	10 5/8	11 1/2	13 1/4	15	16 1/2	18	20	22	J
1/2	4 1/4	5	5 1/4	6 1/2	7	7 3/4	8 1/2	9 1/8	10 5/8	12 1/8	14	15	16 1/2	18	K
11/32	1 11/16	1 23/32	2 1/32	2 3/8	2 5/8	3	3 1/4	3 1/2	4	4 1/2	5	5 1/2	6	6 1/2	L
7/8	10 1/8	11 1/8	11 3/4	13	14 1/2	15 7/8	17 1/4	18 1/2	22	24 3/4	28	30	33	36	Nos. 6, 7, 8, 9
1/4	4 1/2	5 1/2	5 3/4	6	8 1/2	9 1/4	10	12	13	15	—	—	—	—	M
3/4	5 1/8	6	6 1/4	7	8 1/2	9	9 1/2	11	11	12 1/4	—	—	—	—	N
3/8	3 3/4	4 1/8	4 1/8	4 1/8	4 3/8	4 3/8	5	5 3/8	7	9 1/2	—	—	—	—	O

(*Stewarts & Lloyds, Ltd.*)

APPROXIMATE WEIGHT OF SOCKET PIPES AND FITTINGS.

Socket Pipes.

Inside Diam.	Length ex. Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.	Inside Diam.	Length ex. Socket.	Depth of Socket.	Diam. of Socket.	Weight per Length.
ins.	ft. ins.	ins.	ins.	c. q. lbs.	ins.	ft. ins.	ins.	ins.	c. q. lbs.
$1\frac{1}{2}$	6 0	$2\frac{3}{4}$	$2\frac{3}{4}$	1 0 to 1 10	6	9 0	$4\frac{1}{2}$	$7\frac{1}{2}$	2 1 14 to 2 1 21
2	6 0	3	$3\frac{1}{4}$	1 14 to 1 21	7	9 0	5	$8\frac{3}{4}$	2 2 0 to 2 3 14
$2\frac{1}{2}$	6 0	$3\frac{1}{2}$	$3\frac{3}{4}$	2 0 to 2 14	8	9 0	5	$9\frac{3}{4}$	3 0 0 to 3 1 14
3	9 0	$3\frac{1}{2}$	$4\frac{1}{4}$	3 14 to 3 21	9	9 0	5	$10\frac{3}{4}$	3 3 0 to 3 3 14
$3\frac{1}{2}$	9 0	4	$4\frac{3}{4}$	1 0 0 to 1 1 0	10	9 0	5	$11\frac{3}{4}$	4 2 0 to 4 2 0
4	9 0	4	$5\frac{1}{4}$	1 1 14 to 1 2 0	12	9 0	5	$13\frac{3}{4}$	5 3 0 to 6 2 0
5	9 0	$4\frac{1}{2}$	$6\frac{1}{2}$	1 3 14 to 2 0 0	12	12 0	5	$13\frac{3}{4}$	8 3 0

Connections.

Description.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	12 in.
	q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.	c.q. lbs.
Elbow	10	19	26	1 6	1 16	2 0	3 0	3 18	1 1 24	1 2 14	2 0 10	2 3 0	—
¼ bend	18	26	1 6	1 10	1 22	2 8	1 0 0	1 1 14	2 0 20	2 3 21	3 0 14	4 1 12	4 2 0
⅛ ,,	18	24	25	1 7	—	2 0	3 26	1 1 8	1 3 22	2 3 20	3 1 14	3 2 0	3 3 8 0
16 ,,	—	20	25	1 8	—	1 27	2 25	1 1 0	—	—	3 0 0	3 1 7	4 0 14
Tee	1 7	1 18	2 5	2 24	3 6	3 19	1 0 21	1 2 10	2 2 7	3 0 18	4 0 16	4 1 0	5 2 0
Branch	1 9	1 24	2 12	3 0	—	1 0 10	1 1 14	1 2 14	3 0 0	3 1 6	3 3 24	4 2 16	5 2 21
Collar	11	16	20	26	1 2	1 16	1 20	2 10	3 0	3 17	3 10	1 0 14	1 2 0
Syphon bend													
,,													
Plug pipe	—	1 10	1 20	1 25	—	2 12	2 27						
End plug pipe	—	—	—	2 20	—	2 26	3 12						
,, ,, New Style													
Ducksfoot bend	—	1 16	—	2 7	—	3 16							
Syphon and cover	3 26	1 2 0	—	2 0 0	—	2 1 0	2 2 14	3 1 21	5 0 21	5 1 14	6 0 14	7 0 0	8 1 0
,, ,, new style	—	1 1 17	—	1 3 16	—	2 0 25	3 0 15	3 0 21	—	3 2 7	—	—	9 3 0
Cross	—	1 27	—	3 16	—	1 0 16	1 2 12	2 0 4					
Double bend 4½ cen.	—	—	—	1 16	—	2 7							
,, 6 ,,	—	—	—	1 17	—	2 10							
,, 7 ,,													
,, 9 ,,	—	—	—	1 18	—	2 14							
,, 12 ,,	—	—	—	1 23	—	3 0							
,, 13½ ,,	—	—	—	2 0	—	3 0							
,, 15 ,,													
,, 18 ,,													
,, 21 ,,													
Cap	8	8	9	15	18	23	1 1	1 8	1 24	2 10	2 22	3 12	1 1 20
Angle branch	—	1 24	—	3 0	—	3 24	1 1 14	1 3 14					

Reducing Pipes.

Size.	c. q. lb.	Size.	c. q. lb.	Size.	q. lb.	Size.	q. lb.	Size.	lbs.
12 in. to 10 in.	3 0 7	8 in. to 6 in.	1 3 14	5 in. to 4 in.	3 10	2 to 1½ in.	1 6	3 to 2 in., 2 in. socket	25
10 ,, 9	3 0 2	7 ,, 6	1 2 0	5 ,, 3	3 0	6 ,, 5 in., 5 in. socket	2 14		
10 ,, 8	2 2 25	7 ,, 5	1 1 21	4 ,, 3	2 18	6 ,, 4 ,, 4 ,,	1 25		
9 ,, 8	2 1 20	6 ,, 5	1 0 8	4 ,, 2	2 8	5 ,, 4 ,, 4 ,,	1 18		
9 ,, 7	2 0 8	6 ,, 4	1 0 4	3 ,, 2½	2 6	4 ,, 3 3 ,,	1 9		
8 ,, 7	2 0 0	6 ,, 3	1 0 0	3 ,, 2	1 24	4 ,, 2 2 ,,	1 3		

WEIGHT OF SEAMLESS COPPER TUBES.

S.W.G.					Thickness of Copper.															
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inches. F=full. B=bare.	·400	·372	·348	·324	·300	·276	·252	·232	·212	·192	·176	·160	·144	·128	·116	·104	·092	·080	·072	·064	·056	·048	·040	·036
	13/32B	3/8B	11/32F	21/64B	19/64F	9/32B	1/4F	15/64B	7/32B	3/16F	11/64F	5/32F	9/64F	1/8F	7/64F	7/64B	5/32	5/64F	5/64B	1/16F	1/16B	3/64F	3/64B	1/32F
Millimètres.	10·160	9·449	8·889	8·229	7·620	7·010	6·401	5·893	5·385	4·877	4·470	4·064	3·658	3·251	2·946	2·263	2·337	2·032	1·829	1·626	1·422	1·219	1·016	0·914
Internal Diam.	Weight of a Lineal Foot in Pounds.																							
Inches. Mm.																								
⅛ 3	3·2	2·54	2·24	1·99	1·76	1·54	1·34	1·15	1·00	·86	·74	·64	·55	·47	·39	·34	·29	·24	·20	·17	·15	·12	·10	·08	·07
5	6·3	3·14	2·80	2·52	2·25	2·00	1·76	1·53	1·35	1·18	1·05	·91	·79	·69	·58	·51	·44	·38	·32	·28	·24	·21	·17	·14	·12
3/16	9·5	3·75	3·35	3·04	2·74	2·45	2·17	1·91	1·70	1·50	1·32	1·17	1·04	·90	·78	·69	·60	·53	·44	·39	·34	·29	·25	·20	·18
¼	12·7	4·35	3·92	3·57	3·23	2·90	2·59	2·29	2·05	1·83	1·61	1·44	1·28	1·12	·97	·86	·76	·66	·56	·50	·44	·38	·32	·26	·23
5/16 7	15·9	4·96	4·49	4·10	3·72	3·36	3·01	2·67	2·40	2·15	1·90	1·70	1·52	1·34	1·17	1·04	·92	·80	·68	·61	·53	·46	·39	·32	·29
	19·0	5·56	5·05	4·62	4·21	3·81	3·43	3·05	2·76	2·47	2·19	1·97	1·76	1·56	1·36	1·21	1·07	·94	·80	·72	·63	·55	·46	·38	·34
	22·2	6·17	5·61	5·15	4·70	4·26	3·84	3·44	3·11	2·79	2·48	2·24	2·00	1·77	1·55	1·39	1·23	1·08	·92	·82	·73	·63	·54	·44	·40
1	25·4	6·77	6·17	5·67	5·19	4·72	4·26	3·82	3·46	3·11	2·77	2·50	2·24	1·99	1·75	1·57	1·39	1·21	1·04	·93	·82	·71	·61	·50	·45
1⅛	28·6	7·38	6·74	6·20	5·68	5·17	4·68	4·20	3·81	3·43	3·06	2·77	2·49	2·21	1·94	1·74	1·55	1·35	1·17	1·04	·92	·80	·68	·56	·51
1¼	31·7	7·98	7·30	6·73	6·17	5·62	5·09	4·58	4·16	3·75	3·35	3·04	2·73	2·43	2·13	1·92	1·70	1·49	1·29	1·15	1·02	·88	·75	·62	·56
1⅜	34·9	8·59	7·86	7·25	6·66	6·08	5·51	4·96	4·51	4·07	3·64	3·30	2·97	2·65	2·33	2·09	1·86	1·63	1·41	1·26	1·11	·97	·83	·68	·61
1½	38·1	9·19	8·42	7·78	7·15	6·53	5·93	5·34	4·86	4·39	3·93	3·57	3·21	2·86	2·52	2·27	2·02	1·77	1·53	1·37	1·21	1·05	·90	·74	·67
1⅝	41·3	9·80	8·99	8·31	7·64	6·99	6·35	5·72	5·21	4·71	4·22	3·83	3·45	3·08	2·71	2·44	2·17	1·91	1·65	1·48	1·31	1·14	·97	·81	·72
1¾	44·4	10·40	9·55	8·83	8·13	7·44	6·76	6·10	5·56	5·03	4·51	4·10	3·70	3·30	2·91	2·62	2·33	2·05	1·77	1·59	1·40	1·23	1·04	·87	·78
1⅞	47·6	11·01	10·11	9·36	8·62	7·89	7·18	6·48	5·91	5·35	4·80	4·37	3·94	3·52	3·10	2·79	2·49	2·19	1·89	1·70	1·50	1·31	1·12	·93	·83
2	50·8	11·61	10·67	9·88	9·11	8·35	7·60	6·86	6·26	5·67	5·09	4·63	4·18	3·73	3·29	2·97	2·65	2·33	2·01	1·80	1·60	1·39	1·19	·99	·89
2⅛	53·9	12·22	11·24	10·41	9·60	8·80	8·02	7·25	6·61	5·99	5·38	4·90	4·42	3·95	3·49	3·14	2·80	2·47	2·13	1·91	1·69	1·48	1·26	1·05	·94
2¼	57·1	12·83	11·80	10·94	10·09	9·25	8·43	7·63	6·97	6·31	5·67	5·16	4·65	4·17	3·68	3·32	2·96	2·61	2·25	2·02	1·79	1·56	1·33	1·11	1·00
2⅜	60·3	13·43	12·36	11·46	10·58	9·71	8·85	8·01	7·32	6·63	5·96	5·43	4·91	4·39	3·88	3·50	3·12	2·75	2·38	2·13	1·89	1·65	1·41	1·17	1·05
2½	63·5	14·03	12·92	11·99	11·07	10·16	9·27	8·39	7·67	6·95	6·25	5·70	5·15	4·61	4·07	3·67	3·28	2·88	2·50	2·24	1·98	1·73	1·48	1·23	1·10
2⅝	66·7	14·64	13·49	12·52	11·56	10·62	9·69	8·77	8·02	7·28	6·54	5·96	5·39	4·82	4·26	3·85	3·43	3·02	2·62	2·35	2·08	1·82	1·55	1·29	1·16
2¾	69·8	15·24	14·05	13·04	12·05	11·07	10·10	9·15	8·37	7·60	6·83	6·23	5·63	5·04	4·46	4·02	3·59	3·16	2·74	2·46	2·18	1·90	1·62	1·35	1·21
2⅞	73·0	15·85	14·61	13·57	12·54	11·52	10·52	9·53	8·72	7·92	7·12	6·50	5·87	5·26	4·65	4·20	3·75	3·30	2·86	2·57	2·27	1·99	1·70	1·41	1·27
3	76·2	16·45	15·17	14·09	13·08	11·98	10·94	9·91	9·07	8·24	7·41	6·76	6·12	5·48	4·84	4·37	3·90	3·44	2·98	2·68	2·37	2·07	1·77	1·47	1·32
3⅛	79·4	17·06	16·30	15·15	14·01	12·88	11·77	10·68	9·77	8·88	7·99	7·29	6·60	5·91	5·28	4·72	4·23	3·72	3·23	2·89	2·57	2·24	1·91	1·59	1·43
3¼	82·5	17·67	16·87	15·69	14·52	13·34	12·20	11·08	10·12	9·20	8·28	7·55	6·84	6·13	5·47	4·89	4·38	3·85	3·35	2·99	2·66	2·32	1·98	1·64	1·48
3⅜	85·7	18·28	17·42	16·20	14·99	13·79	12·61	11·44	10·47	9·52	8·58	7·82	7·08	6·35	5·67	5·07	4·53	4·00	3·46	3·11	2·76	2·41	2·06	1·71	1·54
3½	88·9	18·87	17·42	16·20	14·99	13·79	12·61	11·44	10·47	9·52	8·58	7·82	7·08	6·35	5·62	5·07	4·53	4·00	3·46	3·11	2·76	2·41	2·06	1·71	1·54
3⅝	92·1	19·48	18·55	17·25	15·97	14·70	13·44	12·20	11·18	10·16	9·16	8·36	7·57	6·78	6·00	5·42	4·85	4·28	3·71	3·33	2·95	2·58	2·20	1·83	1·65
4	95·2	20·08	19·07	17·74	16·45	15·14	13·85	12·57	11·52	10·47	9·44	8·62	7·80	6·99	6·18	5·58	4·99	4·41	3·82	3·43	3·04	2·65	2·26	1·88	1·70
4⅛	98·4	20·69	19·67	18·30	16·95	15·61	14·28	12·96	11·88	10·80	9·74	8·89	8·05	7·22	6·39	5·78	5·16	4·55	3·95	3·55	3·15	2·75	2·35	1·95	1·76
4¼	101·6	21·29	20·27	18·86	17·46	16·08	14·71	13·35	12·24	11·14	10·03	9·16	8·31	7·45	6·59	5·96	5·32	4·69	4·07	3·66	3·25	2·84	2·42	2·01	1·81
4⅜	104·8	21·90	20·87	19·43	17·98	16·56	15·14	13·74	12·60	11·47	10·33	9·43	8·54	7·67	6·78	6·13	5·48	4·83	4·19	3·76	3·34	2·92	2·50	2·08	1·87
4½	107·9	22·50	21·48	19·99	18·49	17·04	15·57	14·13	12·96	11·80	10·62	9·69	8·78	7·89	6·97	6·31	5·64	4·97	4·31	3·87	3·44	3·01	2·58	2·14	1·93
4⅝	111·1	23·11	21·98	20·56	19·01	17·52	16·01	14·52	13·32	12·12	10·92	9·96	9·02	8·11	7·16	6·48	5·79	5·11	4·43	3·98	3·53	3·09	2·64	2·20	1·97
4¾	114·3	23·71	22·59	21·13	19·52	17·99	16·45	14·91	13·68	12·44	11·22	10·23	9·26	8·33	7·35	6·65	5·95	5·25	4·55	4·09	3·63	3·17	2·71	2·25	2·02
4⅞	117·5	24·32	23·09	21·69	20·04	18·47	16·88	15·30	14·04	12·76	11·51	10·50	9·50	8·55	7·54	6·83	6·11	5·39	4·67	4·20	3·73	3·26	2·79	2·32	2·08
5	127·0	26·13	24·18	22·51	20·87	19·23	17·62	16·01	14·68	13·37	12·06	11·02	9·99	8·96	7·94	7·18	6·42	5·67	4·92	4·42	3·92	3·42	2·93	2·44	2·19
5⅛	130·2	27·34	25·30	23·57	21·85	20·14	18·45	16·77	15·39	14·01	12·64	11·55	10·47	9·40	8·30	7·53	6·74	5·95	5·16	4·64	4·11	3·59	3·08	2·56	
5¼	133·4	28·55	26·43	24·62	22·83	21·05	19·29	17·54	16·09	14·65	13·22	12·08	10·96	9·83	8·71	7·88	7·05	6·22	5·40	4·85	4·31	3·76	3·22	2·68	
5⅜	136·5	29·76	27·55	25·67	23·81	21·96	20·12	18·30	16·79	15·29	13·80	12·62	11·44	10·27	9·10	8·23	7·36	6·50	5·64	5·07	4·50	3·93	3·37	2·80	
5½	139·7	30·97	28·68	26·72	24·79	22·86	20·95	19·06	17·49	15·93	14·38	13·15	11·92	10·70	9·49	8·58	7·68	6·78	5·88	5·29	4·69	4·10	3·51	2·92	

Weight of Seamless Copper Tubes—(*continued*).

S.W.G.		Thickness of Copper.																							
		0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inches.		·400	·372	·348	·324	·300	·276	·252	·232	·212	·192	·176	·160	·144	·128	·116	·104	·092	·080	·072	·064	·056	·048	·040	·036
F=full. B=bare.		13/32B	3/8 3	11/32F	21/64B	19/64F	9/32B	1/4F	15/64B	7/32B	3/16F	11/64F	5/32F	9/64F	1/8F	7/64F	7/64B	3/32	5/64F	5/64B	1/16F	1/16B	3/64F	3/64B	1/32F
Millimètres.		10·160	9·449	8·839	8·229	7·620	7·010	6·401	5·893	5·385	4·877	4·470	4·064	3·658	3·251	2·946	2·642	2·337	2·032	1·829	1·626	1·422	1·219	1·016	·914
Internal Diam.		Weight of a Lineal Foot in Pounds.																							
Inches.	Mm.																								
6¼	158·7	32·18	29·80	27·78	25·77	23·77	21·79	19·82	18·19	16·57	14·96	13·68	12·41	11·14	9·88	8·93	7·99	7·06	6·13	5·51	4·89	4·27	3·66		
6½	165·1	33·39	30·93	28·83	26·75	24·68	22·62	20·58	18·89	17·21	15·54	14·21	12·89	11·57	10·26	9·28	8·31	7·34	6·37	5·72	5·08	4·44	3·80		
6¾	171·4	34·60	32·05	29·88	27·73	25·59	23·46	21·35	19·60	17·85	16·12	14·75	13·37	12·01	10·65	9·63	8·62	7·61	6·61	5·94	5·28	4·61	3·95		
7	177·8	35·81	33·18	30·93	28·71	26·49	24·29	22·11	20·30	18·50	16·70	15·28	13·86	12·44	11·04	9·99	8·94	7·89	6·85	6·16	5·47	4·78	4·09		
7¼	184·1	37·02	34·30	31·99	29·69	27·40	25·13	22·87	21·00	19·14	17·29	15·81	14·34	12·88	11·42	10·34	9·25	8·17	7·09	6·38	5·66	4·95			
7½	190·5	38·23	35·43	33·04	30·67	28·31	25·96	23·63	21·70	19·78	17·87	16·34	14·83	13·32	11·81	10·69	9·57	8·45	7·34	6·60	5·86	5·12			
7¾	196·8	39·44	36·55	34·09	31·65	29·22	26·80	24·39	22·40	20·42	18·45	16·88	15·31	13·75	12·20	11·04	9·88	8·73	7·58	6·81	6·05	5·29			
8	203·2	40·65	37·68	35·14	32·65	30·12	27·63	25·16	23·10	21·06	19·03	17·41	15·79	14·19	12·59	11·39	10·20	9·01	7·82	7·03	6·24	5·46			
8¼	209·5	41·86	38·80	36·20	33·61	31·03	28·47	25·92	23·81	21·70	19·61	17·94	16·28	14·62	12·97	11·74	10·51	9·28	8·06	7·25	6·44				
8½	215·9	43·07	39·93	37·25	34·59	31·94	29·30	26·68	24·51	22·34	20·19	18·47	16·76	15·06	13·36	12·09	10·82	9·56	8·30	7·47	6·63				
8¾	222·2	44·28	41·05	38·30	35·57	32·84	30·14	27·44	25·21	22·98	20·77	19·00	17·25	15·49	13·75	12·44	11·14	9·84	8·55	7·68	6·82				
9	228·6	45·49	42·18	39·35	36·55	33·75	30·97	28·21	25·91	23·63	21·35	19·54	17·73	15·93	14·13	12·79	11·45	10·12	8·79	7·90	7·02				
9¼	234·9	46·70	43·30	40·41	37·53	34·66	31·81	28·97	26·61	24·27	21·93	20·07	18·21	16·36	14·52	13·14	11·77	10·40	9·03	8·12					
9½	241·3	47·91	44·43	41·46	38·51	35·57	32·64	29·73	27·31	24·91	22·51	20·60	18·70	16·80	14·91	13·49	12·08	10·68	9·27	8·34					
9¾	247·6	49·12	45·55	42·51	39·49	36·47	33·48	30·49	28·02	25·55	23·09	21·13	19·18	17·24	15·30	13·84	12·40	10·95	9·51	8·55					
10	254·0	50·33	46·68	43·56	40·47	37·38	34·31	31·25	28·72	26·19	23·67	21·67	19·67	17·67	15·68	14·20	12·71	11·23	9·76	8·77					
10¼	260·3	51·54	47·80	44·62	41·45	38·29	35·15	32·02	29·42	26·83	24·25	22·20	20·15	18·11	16·07	14·55	13·03	11·51	10·00						
10½	266·7	52·75	48·93	45·67	42·43	39·20	35·98	32·78	30·12	27·47	24·83	22·73	20·63	18·54	16·46	14·90	13·34	11·79	10·24						
10¾	273·0	53·96	50·05	46·72	43·41	40·10	36·81	33·54	30·82	28·11	25·42	23·26	21·12	18·98	16·84	15·25	13·66	12·07	10·48						
11	279·4	55·16	51·18	47·77	44·39	41·01	37·65	34·30	31·52	28·75	26·00	23·80	21·60	19·41	17·23	15·60	13·97	12·34	10·72						
11¼	285·7	56·37	52·30	48·83	45·37	41·92	38·48	35·06	32·23	29·40	26·58	24·33	22·08	19·85	17·62	15·95	14·28	12·62							
11½	292·1	57·58	53·43	49·88	46·35	42·83	39·32	35·83	32·93	30·04	27·16	24·86	22·57	20·28	18·01	16·30	14·60	12·90							
11¾	298·4	58·79	54·55	50·93	47·33	43·73	40·15	36·60	33·63	30·68	27·74	25·39	23·05	20·72	18·39	16·65	14·91	13·18							
12	304·8	60·00	55·68	51·98	48·31	44·64	40·99	37·35	34·33	31·32	28·32	25·92	23·54	21·16	18·78	17·00	15·23	13·46							
12¼	311·1	61·21	56·80	53·04	49·29	45·55	41·82	38·11	35·03	31·96	28·90	26·46	24·02	21·59	19·17	17·35	15·54								
12½	317·5	62·42	57·93	54·09	50·26	46·45	42·66	38·88	35·73	32·60	29·48	26·99	24·50	22·03	19·55	17·70	15·86								
12¾	323·8	63·63	59·05	55·14	51·24	47·36	43·49	39·64	36·44	33·24	30·06	27·52	24·99	22·46	19·94	18·05	16·17								
13	330·2	64·84	60·18	56·19	52·22	48·27	44·33	40·40	37·14	33·88	30·64	28·05	25·47	22·90	20·33	18·41	16·49								
13¼	336·5	66·05	61·30	57·25	53·20	49·18	45·16	41·16	37·84	34·58	31·22	28·59	25·96	23·33	20·72	18·76									
13½	342·9	67·26	62·43	58·30	54·18	50·08	46·00	41·92	38·54	35·17	31·80	29·12	26·44	23·77	21·10	19·11									
13¾	349·2	68·47	63·55	59·35	55·16	50·99	46·83	42·69	39·24	35·81	32·38	29·65	26·92	24·20	21·49	19·46									
14	355·6	69·68	64·68	60·40	56·14	51·90	47·67	43·45	39·94	36·45	32·96	30·18	27·41	24·64	21·88	19·81									
		3·37	3·25	2·93	2·54	2·18	1·84	1·54	1·30	1·09	·89	·75	·62	·50	·40	·33	·26	·20	·15	·12	·10	·08	·06	·04	·03

If the external diameter is given, subtract figure in black type at bottom of column; for example, the weight per lineal foot of a copper tube 2 inches external diameter, 12 S.W.G., is 2·65 − 0·26 = 2·39 *lbs.* The weights are calculated from 12 samples of tubes made from tough copper (specific gravity at 60° F. 8·8917, or 3299 lb. per cubic inch). Brazed copper tubes weigh more than seamless; but an exact multiple cannot be given. Mandril-drawn brazed tubes weigh the same as seamless tubes. In practice a slight deviation from the above theoretical weights must be expected. To ascertain the weight of a seamless tube of other metal, multiply the weight of a similar copper tube by ·9626 for brass (70 and 30 alloy), by ·86 for wrought iron, by ·81 for cast iron, or by 1·28 for lead. (*The Broughton Copper Co., Ltd.*)

Weight of Seamless Brass Tubes.
(Containing 70 % of copper.)

S.W.G.	Thickness of Brass															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Inches . .	·212	·192	·176	·160	·144	·128	·116	·104	·092	·080	·072	·064	·056	·048	·040	·036
Millimètres	5·385	4·877	4·470	4·064	3·658	3·251	2·946	2·642	2·337	2·032	1·829	1·626	1·422	1·219	1·016	·914
External Diameter.	Weight of a Lineal Foot in Pounds.															
Ins. Mm.																
⅜ 9·5	..	..	..	..	..	..	..	..	..	..	..	..	·21	·18	·16	·14
7/16 11·1	..	..	..	..	..	..	..	..	..	..	..	·28	·25	·22	·18	·17
½ 12·7	..	..	..	..	..	..	..	..	..	..	·36	·32	·29	·25	·21	·19
5/8 15·9	..	..	..	..	..	..	..	..	..	·51	·46	·42	·37	·32	·27	·25
¾ 19·0	..	..	..	..	..	..	..	..	·70	·62	·57	·51	·45	·39	·33	·30
7/8 22·2	..	..	..	..	..	..	..	·93	·84	·74	·67	·60	·53	·46	·39	·35
1 25·4	..	..	..	..	..	1·19	1·08	·97	·86	·78	·70	·62	·53	·45	·40	
1⅛ 28·6	..	..	..	..	..	1·49	1·36	1·24	1·11	·97	·88	·79	·70	·60	·50	
1¼ 31·7	..	..	..	..	..	1·67	1·53	1·39	1·24	1·09	·99	·88	·78	·67	·56	
1⅜ 34·9	..	..	..	..	2·06	1·86	1·70	1·54	1·37	1·21	1·09	·98	·86	·74	·62	
1½ 38·1	..	..	..	..	2·27	2·04	1·87	1·69	1·51	1·32	1·20	1·07	·94	·81	·68	
1⅝ 41·3	..	..	..	2·73	2·48	2·23	2·04	1·84	1·64	1·44	1·30	1·16	1·02	·88		
1¾ 44·4	..	..	..	2·96	2·69	2·42	2·21	1·99	1·78	1·56	1·41	1·26	1·10	·95		
1⅞ 47·6	..	..	3·48	3·19	2·90	2·60	2·38	2·14	1·91	1·67	1·51	1·35	1·19	1·02		
2 50·8	..	..	3·74	3·43	3·11	2·79	2·54	2·30	2·04	1·79	1·62	1·44	1·27	1·09		
2⅛ 54·0	..	4·32	3·99	3·66	3·32	2·98	2·71	2·45	2·18	1·90	1·72	1·54	1·35			
2¼ 57·1	..	4·60	4·25	3·89	3·53	3·16	2·88	2·60	2·31	2·02	1·83	1·63	1·43			
2⅜ 60·3	5·34	4·88	4·51	4·13	3·74	3·35	3·05	2·75	2·45	2·14	1·93	1·72	1·51			
2½ 63·5	5·65	5·16	4·76	4·36	3·95	3·54	3·22	2·90	2·58	2·25	2·04	1·81	1·59			
2⅝ 66·7	5·96	5·44	5·02	4·59	4·16	3·72	3·39	3·05	2·71	2·37	2·14	1·91	1·67			
2¾ 69·8	6·27	5·72	5·28	4·83	4·37	3·91	3·56	3·20	2·85	2·49	2·24	2·00	1·76			
2⅞ 73·0	6·57	6·00	5·53	5·06	4·58	4·09	3·73	3·36	2·98	2·60	2·35	2·09	1·84			
3 76·2	6·88	6·28	5·79	5·29	4·79	4·28	3·90	3·51	3·11	2·72	2·45	2·19	1·92			
3⅛ 79·3	7·19	6·56	6·04	5·52	5·00	4·47	4·06	3·66	3·25	2·84	2·56	2·28				
3¼ 82·5	7·50	6·84	6·30	5·76	5·21	4·65	4·23	3·81	3·38	2·95	2·66	2·37				
3⅜ 85·7	7·81	7·12	6·56	5·99	5·42	4·84	4·40	3·96	3·52	3·07	2·77	2·47				
3½ 88·9	8·12	7·40	6·81	6·22	5·63	5·03	4·57	4·11	3·65	3·19	2·87	2·56				
3⅝ 92·0	8·43	7·68	7·07	6·46	5·84	5·21	4·74	4·26	3·78	3·30	2·98	2·65				
3¾ 95·2	8·73	7·95	7·32	6·69	6·05	5·40	4·91	4·42	3·92	3·42	3·08	2·75				
3⅞ 98·4	9·04	8·23	7·58	6·92	6·26	5·58	5·08	4·57	4·05	3·53	3·19	2·84				
4 101·6	9·35	8·51	7·84	7·15	6·47	5·77	5·25	4·72	4·19	3·65	3·29	2·93				
4⅛ 107·9	9·97	9·07	8·35	7·62	6·88	6·14	5·58	5·02	4·45	3·88	3·50					
4½ 114·3	10·59	9·63	8·86	8·09	7·30	6·52	5·92	5·32	4·72	4·12	3·71					
4½ 120·6	11·20	10·19	9·37	8·55	7·72	6·89	6·26	5·63	4·99	4·35						
5 127·0	11·82	10·75	9·89	9·02	8·14	7·26	6·60	5·93	5·26	4·58						
5⅛ 133·3	12·44	11·31	10·40	9·48	8·56	7·63	6·93	6·23	5·53							
5½ 139·7	13·05	11·87	10·91	9·95	8·98	8·01	7·27	6·53	5·79							
5⅞ 146·0	13·67	12·43	11·42	10 41	9·40	8·38	7·61	6·84								
6 152·4	14·29	12·99	11·94	10·88	9·82	8·75	7·95									
Per cent. .	*103·4*	*105·2*	*102·1*	*102·9*	*102·6*	*104·4*	*103·3*	*104·6*	*103·1*	*103·6*	*100·0*	*101·5*	*103·5*	*102·0*	*104·8*	*97·3*

The figures in italics show the difference in percentage of weight of brass tubes made to the B.W.G. d the S.W.G., the latter being taken at 100.

The above weights, multiplied by ·994, give the weight of a brass tube 2 and 1 alloy.

These weights are calculated from the specific gravity of 16 samples of tubes, from various akers, each of the samples being 1 foot long × 1⅜ inch external diameter × 14 B.W.G., which as found to be 8·558, or ·3089 lb. per cubic inch, for the alloy of 70 and 30, and 8·508 specific avity, or ·3071 lb. per cubic inch, for the alloy of 2 and 1 at a temperature of 60° F.

To ascertain the weight of a seamless tube of copper, multiply the weight of a similar brass be by 1·0388.

S.W.G.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Thickness	ins.	0·300	0·276	0·252	0·232	0·212	0·192	0·176	0·160	0·144	0·128	0·116	0·104	0·092	0·080	0·072	0·064	0·056	0·048	0·040	0·036	0·032	0·028	0·024
	mm.	7·62	7·00	6·40	5·89	5·38	4·87	4·46	4·06	3·66	3·25	2·94	2·64	2·34	2·03	1·83	1·62	1·42	1·22	1·02	0·914	0·812	0·711	0·610

Outside Diameter ins.	mm.	Weight in lbs. per Linear foot.																						
	4·76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·029	0·028	0·025	0·022	0·020	0·018	0·016	0·014
1/16	6·35	—	—	—	—	—	—	—	—	—	—	—	—	—	0·050	0·047	0·044	0·040	0·036	0·031	0·028	0·026	0·023	0·020
1/4	9·52	—	—	—	—	—	—	—	—	—	—	0·110	0·104	0·096	0·087	0·080	0·073	0·066	0·058	0·049	0·045	0·040	0·036	0·031
3/8	12·7	—	—	—	—	—	—	—	—	0·189	0·175	0·164	0·152	0·138	0·124	0·113	0·103	0·091	0·080	0·068	0·061	0·055	0·049	0·042
1/2	15·9	—	—	—	—	—	0·308	0·291	0·274	0·255	0·234	0·217	0·199	0·180	0·160	0·147	0·132	0·117	0·102	0·086	0·078	0·070	0·061	0·053
5/8	19·0	—	—	—	—	0·419	0·394	0·372	0·347	0·321	0·293	0·270	0·247	0·223	0·197	0·180	0·162	0·143	0·124	0·104	0·095	0·085	0·074	0·064
3/4	22·2	—	—	0·578	0·549	0·517	0·483	0·453	0·421	0·387	0·352	0·324	0·295	0·265	0·234	0·213	0·191	0·169	0·146	0·123	0·111	0·099	0·087	0·075
7/8	22·2	—	—	0·578	0·549	0·517	0·483	0·453	0·421	0·387	0·352	0·324	0·295	0·265	0·234	0·213	0·191	0·169	0·146	0·123	0·111	0·099	0·087	0·075
1	25·4	0·773	0·735	0·694	0·656	0·615	0·571	0·533	0·494	0·453	0·411	0·377	0·343	0·308	0·271	0·246	0·220	0·195	0·168	0·141	0·128	0·114	0·100	0·086
1¼	28·6	0·910	0·862	0·809	0·762	0·713	0·659	0·615	0·568	0·520	0·469	0·431	0·391	0·350	0·308	0·279	0·251	0·220	0·190	0·160	0·144	0·129	0·113	0·097
1¼	31·8	1·05	0·989	0·926	0·870	0·810	0·748	0·696	0·642	0·586	0·529	0·484	0·438	0·392	0·345	0·312	0·279	0·246	0·213	0·178	0·161	0·143	0·126	0·108
1⅜	34·9	1·19	1·11	1·04	0·975	0·907	0·836	0·777	0·716	0·653	0·587	0·538	0·487	0·435	0·381	0·345	0·309	0·272	0·235	0·196	0·178	0·158	0·139	0·120
1½	38·1	1·32	1·24	1·16	1·08	1·01	0·924	0·858	0·789	0·719	0·646	0·591	0·534	0·476	0·418	0·378	0·338	0·298	0·257	0·215	0·194	0·173	0·152	0·130
1⅝	41·3	1·46	1·37	1·27	1·19	1·10	1·01	0·939	0·863	0·785	0·705	0·645	0·582	0·519	0·455	0·411	0·368	0·323	0·279	0·234	0·211	0·188	—	—
1¾	44·5	1·60	1·50	1·39	1·30	1·20	1·10	1·02	0·936	0·851	0·764	0·699	0·630	0·560	0·491	0·444	0·397	0·349	0·301	0·252	0·227	0·202	—	—
1⅞	47·6	1·74	1·62	1·50	1·40	1·30	1·19	1·10	1·01	0·917	0·822	0·751	0·678	0·603	0·528	0·478	0·426	0·375	0·323	—	—	—	—	—
2	50·8	1·88	1·75	1·62	1·51	1·39	1·28	1·18	1·08	0·982	0·882	0·805	0·726	0·645	0·565	0·510	0·455	0·400	0·345	—	—	—	—	—
2¼	53·9	2·01	1·88	1·74	1·62	1·49	1·36	1·26	1·16	1·05	0·941	0·858	0·773	0·687	0·602	0·543	0·485	0·426	0·370	—	—	—	—	—
2¼	57·1	2·15	2·00	1·85	1·72	1·59	1·45	1·34	1·23	1·12	1·00	0·910	0·821	0·730	0·639	0·577	0·515	0·452	0·389	—	—	—	—	—
2⅜	60·3	2·29	2·13	1·97	1·83	1·69	1·54	1·42	1·30	1·18	1·06	0·965	0·866	0·775	0·676	0·610	0·544	0·478	0·411	—	—	—	—	—
2½	63·5	2·43	2·26	2·08	1·94	1·78	1·63	1·51	1·38	1·25	1·12	1·02	0·916	0·815	0·712	0·643	0·573	0·504	0·433	—	—	—	—	—
2⅝	66·6	2·57	2·39	2·20	2·04	1·88	1·72	1·59	1·45	1·32	1·18	1·07	0·965	0·857	0·750	0·675	0·603	0·530	0·455	—	—	—	—	—
2¾	69·8	2·70	2·51	2·32	2·15	1·98	1·81	1·67	1·53	1·38	1·24	1·12	1·01	0·899	0·785	0·708	0·632	0·555	0·477	—	—	—	—	—
2⅞	73·0	2·84	2·64	2·43	2·26	2·08	1·90	1·75	1·60	1·44	1·29	1·18	1·06	0·942	0·822	0·743	0·662	0·581	0·500	—	—	—	—	—
3	76·2	2·98	2·77	2·55	2·37	2·17	1·98	1·83	1·67	1·51	1·35	1·23	1·11	0·985	0·860	0·776	0·690	—	—	—	—	—	—	—
3¼	82·6	3·26	3·02	2·78	2·57	2·37	2·16	1·99	1·82	1·65	1·47	1·34	1·20	1·07	0·932	0·842	0·750	—	—	—	—	—	—	—
3½	88·9	3·53	3·27	3·02	2·78	2·57	2·34	2·15	1·97	1·78	1·59	1·45	1·30	1·15	1·01	0·909	0·800	—	—	—	—	—	—	—
3¾	95·2	3·81	3·53	3·24	3·00	2·76	2·51	2·32	2·12	1·91	1·71	1·55	1·40	1·24	1·08	—	—	—	—	—	—	—	—	—
4	102	4·08	3·78	3·48	3·22	2·96	2·69	2·48	2·26	2·04	1·82	—	—	—	—	—	—	—	—	—	—	—	—	—
4¼	108	4·36	4·03	3·70	3·43	3 15	2·87	2·64	2·41	2·18	1·94	—	—	—	—	—	—	—	—	—	—	—	—	—
4½	114	4·63	4·28	3·93	3·64	3·34	3·04	2·80	2·56	2·31	2·06	—	—											
4¾	121	4·91	4·54	4·17	3·85	3·54	3·22	2·96	2·71	2·44	2·18	—	—											
5	127	5·19	4 79	4·40	4·06	3·73	3·40	3·12	2·85	2·57	2·30	—	—											
5¼	133	5·46	5·05	4·62	4·27	3·92	3·57	3·29	3·00	2·70	2·41	—	—											
5½	140	5·75	5·30	4·86	4·49	4·12	3·74	3·45	3·15	2·84	2·53	—	—											
5¾	146	6·01	5·55	5·09	4·71	4·32	3·92	—	—	—	—	—	—											
6	152	6·30	5·81	5·33	—	—	—	—	—	—	—	—	—											

	Aluminium.	Brass.	Copper.	Steel.
Specific Gravity ...	2·71	8·45	8·89	7·80
Ratio of Weight ...	1·00	3·12	3·28	2·88

The above weights are subject to the usual manufacturing

TINPLATES.

Principal Denominations and Sizes.

Mark.	Size.	Sheets per Box.	Weight per Box.	Thicknesses of Sheets.		Mark.	Size.	Sheets per Box.	Weight per Box.	Thicknesses of Sheets.	
	Ins.		Lbs.	Mm.	In.		Ins.		Lbs.	Mm.	In.
O	14×10	225	108	0·313	0·0123	IC	28×20	56	108	0·315	0·0123
X	,,	,,	136	0·395	0·0155	IX	,,	,,	136	0·396	0·0155
XX	,,	,,	156	0·453	0·0179	IC	20×10	225	154	0·313	0·0123
XXX	,,	,,	176	0·511	0·0201	IX	,,	,,	194	0·394	0·0155
O	20×14	112	108	0·315	0·0123	IC	14×18¾	124	110	0·309	0·0122
CL	,,	,,	100	0·292	0·0114	IC	14×19¼	120	110	0·311	0·0122
CL	,,	,,	95	0·277	0·0109	IC	30×21	112	243	0·315	0·0124
CL	,,	,,	90	0·262	0·0103	CL	,,	,,	224	0·290	0·0114
CL	,,	,,	85	0·248	0·0997	CLL	,,	,,	190	0·246	0·0097
CL	,,	,,	80	0·233	0·0091	CLLL	,,	,,	176	0·228	0·0090
X	,,	,,	136	0·396	0·0155	CLLLL	,,	,,	160	0·207	0·0081
XX	,,	,,	156	0·455	0·0179	DC	17×12½	100	94	0·404	0·0160
XXX	,,	,,	176	0·513	0·0201	DX	,,	,,	122	0·525	0·0206
XXXX	,,	,,	196	0·571	0·0223	DXX	,,	,,	143	0·615	0·0242
O	28×20	,,	216	0·315	0·0124	DXXX	,,	,,	164	0·706	0·0278
X	,,	,,	272	0·396	0·0156	DXXXX	,,	,,	185	0·796	0·0313

Weights in Lbs. per Foot Super and Equivalent S.W.G.

Mark.	Weight.	S.W.G.	Mark.	Weight.	S.W.G.
IC	0·514	30	DXXX	1·138	22
IX	0·643	27	DXXXX	1·281	21
IXX	0·739	26	SDC	0·733	26
IXXX	0·836	25	SDX	0·825	25
IXXXX	0·932	23	SDXX	0·916	24
DC	0·664	27	SDXXX	1·008	23
DX	0·854	24	SDXXXX	1·100	22
DXX	0·996	23			

Approximate Weight of Single Plates

Mark.	Weight per Plate.	Size of Plate, Ins.	Weight per Plate.	Size of Plate, Ins.	Weight per Plate.	Size of Plate, Ins.
	lb. oz.		lb. oz.		lb. oz.	
IC	0 8		1 0		2 0	
IX	0 10		1 4		2 8	
IXX	0 11½	14 × 10	1 7	14 × 20	2 14	28 × 20
IXXX	0 13		1 10		3 4	
IXXXX	0 14½		1 13		3 10	
DC	0 15½		1 15⅝		3 14½	
DX	1 4½		2 8½		5 0⅝	
DXX	1 7½	17 × 12½	2 15	17 × 25	5 14	34 × 25
DXXX	1 10⅞		3 5¾		6 11½	
DXXXX	1 14½		3 12½		7 9	
SDC	0 13½		1 10⅞			
SDX	0 15½		1 14½			
SDXX	1 0½	15 × 11	2 1½	15 × 22	—	—
SDXXX	1 2½		2 5			
SDXXXX	1 4½		2 3½			

WEIGHT AND DIMENSIONS OF HOOP-IRON PER FOOT RUN.

S.W. Gauge.	Width.	Weight.	B.W. Gauge.	Width.	Weight.	B.W. Gauge.	Width.	Weight.	B.W. Gauge.	Width.	Weight.
	Ins.	Lbs.		Ins.	Lb.		Ins.	Lb.		Ins.	Lb.
11	2¾	1·1577	13	2	·6332	15	1½	·3637	18	1	·1616
12	2½	·9178	13	1⅞	·5540	15	1⅜	·3334	19	⅞	·1237
12	2	·7342	14	1½	·4715	16	1¼	·2652	20	¾	·0884
13	2¼	·7123	14	1⅛	·4042	17	1⅛	·2084	21	⅝	·0694

Weight of Wire per 100 Feet.

B. W. Gauge.	Diam. in Decimals of an Inch.	Iron.	Steel.	Brass.	Copper.	B. W. Gauge.	Diam. in Decimals of an Inch.	Iron.	Steel.	Brass.	Copper.
		Lbs.	Lbs.	Lbs.	Lbs.			Lbs.	Lbs.	Lbs.	Lbs.
0	·340	30·582	30·919	33·427	35·170	19	·042	·466	·471	·510	·536
1	·312	25·753	26·036	28·148	29·616	20	035	·324	·327	·344	·372
2	·284	21·338	21·573	23·322	24·539	21	·033	·288	·291	·314	·331
3	·261	18·022	18·220	19·698	20·725	22	·029	·222	·224	·243	·255
4	·239	15·112	15·278	16·517	17·378	23	·028	·207	·209	·226	·238
5	·217	12·458	12·595	13·616	14·326	24	·025	·164	·166	·179	·189
6	·208	11·446	11·572	12·510	13·173	25	·021	·116	·118	·127	·134
7	·187	9·251	9·353	10·112	10·639	26	·020	·105	·107	·115	·121
8	·166	7·290	7·370	7·968	8·384	27	·018	·085	·086	·093	·098
9	·158	6·604	6·677	7·219	7·595	28	·015	·059	·060	·065	·068
10	·137	4·965	5·020	5·427	5·710	29	·013	·044	·045	·048	·051
11	·125	4·134	4·179	4·518	4·754	30	·012	·038	·038	·041	·043
12	·109	3·143	3·178	3·435	3·615	31	·010	·026	·026	·028	·030
13	·094	2·338	2·363	2·555	2·688	32	·009	·021	·021	·023	·024
14	·080	1·693	1·712	1·851	1·947	33	·008	·016	·017	·018	·019
15	·072	1·371	1·387	1·499	1·577	34	·007	·013	·013	·014	·014
16	·063	1·050	1·062	1·148	1·208	35	·005	·006	·006	·007	·007
17	·055	·800	·809	·874	·920	36	·004	·004	·004	·004	·005
18	·048	·609	·616	·666	·701						

Table of Weight of Castings in Proportion to the Make of Patterns of Different Materials.

A Pattern weighing 1 lb.	Will Weigh when Cast in				
	Cast Iron.	Zinc.	Copper.	Yellow Brass.	Gun-metal.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Mahogany	8	8	10	9·8	10
White pine	14	14·5	18	17·5	17·8
Yellow pine	13	12·6	16	15·5	16
Cedar	11·5	11·4	14·5	14	14·5
Maple	10	9·8	12·5	12	12·4

Number of Cold Punched Nuts per 100 Pounds.

Size.	Square.	Hexagon.	Size.	Square.	Hexagon.	Size.	Square.	Hexagon.
$\frac{3}{8}$ inch	2,694	2,944	$\frac{3}{4}$ inch	412	496	$1\frac{1}{8}$ inch	126	156
$\frac{1}{2}$,,	1,200	1,440	$\frac{7}{8}$,,	258	314	$1\frac{1}{4}$,,	104	121
$\frac{5}{8}$,,	758	900	1 ,,	171	201	$1\frac{1}{2}$,,	60	68

Weight of Nut and Bolt-heads.

Head and Nut.	Diameter of Bolt in Inches.												
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Hexagon	·017	·057	·128	·267	·43	·73	1·1	2·14	3·77	5·62	8·75	17·2	28·8
Square	·021	·070	·164	·321	·553	·882	1·31	2·56	4·42	7·00	10·5	21·0	36·4

WEIGHT OF WASHERS PER 100.

Size.	Weight.	Size.	Weight.	Size.	Weight.	Size.	Weight.
In.	Lbs.	In.	Lbs.	Ins.	Lbs.	Ins.	Lbs.
$\frac{3}{8}$	$1\frac{3}{4}$	$\frac{3}{4}$	$6\frac{3}{4}$	1	$10\frac{3}{4}$	$1\frac{1}{4}$	24
$\frac{1}{2}$	$2\frac{3}{4}$	$\frac{7}{8}$	$8\frac{1}{2}$	$1\frac{1}{8}$	$18\frac{3}{4}$	$1\frac{1}{2}$	30
$\frac{5}{8}$	$4\frac{1}{2}$						

WEIGHT OF WROUGHT-IRON NAILS PER 1,000.

Name.	Lgth	Weight per 1000.	Name.	Lgth	Weight per 1000.	Name.	Lgth	Weight per 1000.
	Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.
Spike	5	100 0	Clasp, strong	$2\frac{1}{2}$	12 0	Tacks, clout	$\frac{3}{4}$	1 12
"	6	200 0	" "	$2\frac{3}{4}$	14 0	Tacks, cut	$\frac{11}{16}$	14
"	7	300 0	" "	$3\frac{1}{2}$	20 0	" "	$\frac{7}{8}$	12
"	8	450 0	" "	$3\frac{3}{4}$	25 0	" "	1	10
"	9	600 0	" "	$3\frac{7}{8}$	32 0	Trunk	$1\frac{3}{4}$	1 4
"	10	750 0	" "	4	40 0	"	1	1 12
Rose	$\frac{7}{8}$	2 0	Clasp, cut	$1\frac{1}{4}$	3 0	"	$1\frac{1}{4}$	2 12
"	$1\frac{1}{4}$	4 0	" "	$1\frac{1}{2}$	3 8	"	$1\frac{1}{4}$	5 0
"	$1\frac{3}{4}$	7 0	" "	2	8 0	Brads, wrought	$\frac{3}{4}$	8
"	2	10 0	" "	$2\frac{1}{2}$	12 0	" "	$\frac{3}{4}$	12
"	$2\frac{1}{2}$	16 0	Clout	$\frac{3}{4}$	2 8	" "	1	14
"	$2\frac{3}{4}$	20 0	Clout, fine	1	2 0	" "	$1\frac{1}{4}$	1 12
"	$3\frac{1}{4}$	28 0	" "	$1\frac{1}{4}$	3 0	" "	$1\frac{1}{2}$	2 12
"	$3\frac{3}{4}$	36 0	" "	$1\frac{1}{2}$	4 0	" "	2	4 0
"	4	50 0	" "	$1\frac{3}{4}$	5 0	Brads, flooring	$2\frac{1}{4}$	10 0
"	$4\frac{1}{2}$	70 0	Clout, strong	$1\frac{3}{4}$	5 0	" "	$2\frac{1}{2}$	15 0
"	5	90 0	" "	$1\frac{3}{4}$	9 0	" "	$3\frac{1}{4}$	20 0
Rose, fine drawn	4	40 0	" "	$1\frac{1}{2}$	16 0	Brads, cut	$\frac{1}{2}$	5
" " "	$5\frac{1}{4}$	80 0	" "	2	23 0	" "	$\frac{3}{4}$	12
Rose, stamped	$1\frac{1}{4}$	4 0	" "	$2\frac{1}{4}$	32 0	" "	1	1 0
" "	$1\frac{1}{2}$	5 0	" "	$2\frac{1}{2}$	40 0	" "	$1\frac{1}{4}$	1 4
" "	2	7 0	" "	3	50 0	Glaziers' sprigs	$\frac{1}{2}$	4
" "	$2\frac{1}{2}$	11 0	" "	$3\frac{1}{4}$	60 0	" "	$\frac{3}{4}$	14
" "	3	25 0	" "	$3\frac{1}{2}$	80 0	Horseshoe	2	5 8
Clasp, fine	1	1 12	Clout, tinned	$1\frac{1}{2}$	4 0	"	$2\frac{1}{8}$	7 0
" "	$1\frac{1}{4}$	2 8	" "	$1\frac{3}{4}$	7 0	"	$2\frac{1}{4}$	8 8
" "	$1\frac{1}{2}$	4 0	Tacks, Flemish	$\frac{1}{4}$	4	"	$2\frac{3}{8}$	10 0
" "	2	6 0	" "	$\frac{3}{8}$	6	"	$2\frac{1}{2}$	11 0
" "	$2\frac{1}{2}$	10 0	" "	$\frac{1}{2}$	8	"	$2\frac{3}{4}$	13 8
" "	$3\frac{1}{4}$	18 0	" "	$\frac{9}{16}$	14	Cart-tyre	$3\frac{1}{2}$	187 8
Clasp, strong	$1\frac{1}{2}$	7 0	Tacks, clout	$1\frac{1}{8}$	3 8	" "	4	218 12
" "	$2\frac{1}{4}$	10 0	" "	$\frac{15}{16}$	2 12	Mop	$5\frac{1}{2}$	58 0

WEIGHT OF WROUGHT COPPER NAILS PER 1,000.

Name.	Length.	Weight per 1000.	Name.	Length.	Weight per 1000.	Name.	Length.	Weight per 1000.
	Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.
Diehead	5	80 6	Rose, strong	1	3 4	Rose, fine	$2\frac{3}{4}$	18 11
"	5	116 4	Rose, fine	$\frac{7}{8}$	1 12	" "	3	30 1
"	4	80 1	" "	1	2 5	" "	4	50 6
"	3	40 0	" "	$1\frac{1}{4}$	4 7	Jagged	$1\frac{3}{4}$	8 4
"	$2\frac{1}{2}$	29 4	" "	$1\frac{1}{2}$	5 5	Brads	2	6 5
"	$2\frac{1}{4}$	14 12	" "	$1\frac{3}{4}$	6 3	"	$1\frac{1}{2}$	3 0
Rose, strong	2	11 4	" "	2	10 2	Tacks	$\frac{3}{4}$	1 15
" "	$1\frac{1}{2}$	9 9	" "	$2\frac{1}{2}$	10 3	"	$\frac{1}{2}$	13
" "	$1\frac{1}{4}$	5 3	" "	$2\frac{1}{2}$	14 6	"	$\frac{3}{8}$	10

Weight of Screws per 1,000.

Name.	Length.	Weight per 1000.	Name.	Length.	Weight per 1000.	Name.	Length.	Weight per 1000.
	Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.		Ins.	Lbs. Ozs.
Strong .	3¾	28 0	Middling .	2¾	16 0	Fine . .	2¾	14 0
,, .	3	24 0	,, .	2½	16 0	,, . .	2½	14 0
,, .	2¾	24 0	,, .	2	14 0	,, . .	2¼	13 0
,, .	2½	22 0	,, .	1¾	14 0	,, . .	2	13 0
,, .	2	22 0	,, .	1½	13 0	,, . .	1¾	12 0
,, .	1½	20 0	,, .	1¼	13 0	,, . .	1½	11 0
,, .	1¼	18 0	,, .	1	12 0	,, . .	1¼	10 0
,, .	1	16 0	,, .	⅞	11 0	,, . .	1	8 0
,, .	⅞	14 0	,, .	¾	10 0	,, . .	⅞	8 0
,, .	¾	13 0	,, .	⅝	9 0	,, . .	¾	7 0
,, .	⅝	13 0	,, .	½	9 0	,, . .	⅝	6 0
Middling .	5	24 0	,, .	⅜	7 0	,, . .	½	6 0
,, .	4	20 0	Fine . .	3½	18 0	,, . .	⅜	3 0
,, .	3½	20 0	,, . .	3¼	16 0	,, . .	¼	3 0
,, .	3	16 0	,, . .	3	16 0			

Composition Nails.

Gauge	Thick.	Length.	In 1 lb.	Gauge	Thick.	Length.	In 1 lb.	Gauge	Thick.	Length.	In 1 lb.
No.	In.	Ins.	Num.	No.	In.	Ins.	Num.	No.	In.	Ins.	Num.
1	·04	⅜	290	7	·1	1⅛	184	12	·12	2	64
2	·05	⅜	260	8	·1	1¼	168	13	·13	2¼	59
3	·06	1	212	9	·11	1½	110	14	·14	2½	51
4	·07	1⅛	201	10	·11	1⅝	101	15	·15	2¾	43
5	·08	1¼	199	11	·12	1¾	74	16	·16	3	35
6	·09	1	190								

Brazers' Copper Rivets.

Gauge	Diameter.	Length.	In 10 lbs.	Gauge	Diameter.	Length.	In 10 lbs.	Gauge	Diameter.	Length.	In 10 lbs.
No.	In.	In.	Num.	No.	In.	Ins.	Num.	No.	In.	Ins.	Num.
1	3/16	½	2,384	7	⅜	15/16	334	12	11/16	1 9/16	53·8
2	¼	½	1,018	8	7/16	1	210	13	¾	1⅝	41·6
3	¼	9/16	983	9	½	1 3/16	141	14	13/16	1 13/16	32·8
4	5/16	9/16	573	10	9/16	1 5/16	99·5	15	⅞	2 1/16	26·3
5	5/16	⅝	516	11	⅝	1 7/16	71·9	16	1	2⅜	16·7
6	⅜	⅞	357								

Iron Rivets.

Gauge	Diameter.	Length.	In 10 lbs.	Gauge	Diameter.	Length.	In 10 lbs.	Gauge	Diameter.	Length.	In 10 lbs.
No.	In.	In.	Num.	No.	In.	Ins.	Num.	No.	In.	Ins.	Num.
0	3/16	½	3280	6	⅜	15/16	380	11	11/16	1 9/16	61·3
1	¼	½	1276	7	7/16	1	239	12	¾	1½	47·3
2	¼	9/16	1130	8	½	1 3/16	160	13	13/16	1 13/16	37·3
3	5/16	9/16	654	9	9/16	1 5/16	112	14	⅞	2 1/16	30
4	5/16	⅝	589	10	⅝	1 7/16	81·7	15	1	2⅜	19
5	⅜	⅞	407								

APPROXIMATE WEIGHT OF PIPE JOINTING MATERIALS PER JOINT.

Spigot and Faucet Pipes.			Flanged Pipes.						
			India Rubber.			Bolts and Nuts.			
Inside Diam.*	Lead	Rope Yarn.	Inside Diam.*	Faced all over.	Faced on Strips.	No.	Diam.	Length.	Weight.
Ins.	Lbs.	Ozs.	Ins.	Ozs.	Ozs.		Ins.	Ins.	Lbs.
¾	½	¾	2	1⅝	⅞	4	½	2⅜	1¼
1	¾	1	2½	1¾	1⅛	4	9/16	2½	1½
1¼	1	1	2½	2	1⅜	4	9/16	2⅝	1½
1½	1¼	1	3	2	2	4	9/16	2⅝	1½
1½	1¼	1	3	2	2	4	9/16	2⅝	1½
2	1½	1¼	3	2	2	4	9/16	2⅝	1¾
2	1¾	1¼	3	2	2	4	9/16	2⅝	1¾
2	1¾	1¼	3½	2½	2⅛	4	9/16	2⅝	1¾
2½	2	1½	3½	2½	2⅜	4	9/16	2⅝	1¾
2½	2	1½	4	2⅞	3¼	4	9/16	2¾	1¾
2½	2	1½	4	2⅞	3¼	4	9/16	2¾	1¾
3	2½	2	4	2⅞	3¼	4	9/16	2¾	1¾
3	2½	2	4	2⅞	3¼	4	9/16	2¾	1¾
3	2½	2	4½	3½	4	4	⅝	3	2¼
3½	2¾	2½	4½	3½	4	4	⅝	3	2¼
4	3⅛	2½	5	3½	5	6	⅝	3	3½
4	3⅛	2¾	5	3½	5	6	⅝	3	3½
4½	3½	3½	5½	3¾	5½	6	⅝	3	3½
5	6	4	6	4½	6	6	⅝	3	3½
5	6	4	6	4½	6	6	⅝	3	3½
5½	7	4½	6	4½	6	6	⅝	3	3½
6	8	5½	7	5¼	8	6	⅝	3⅛	3½
6	8	5½							
7	8½	6¼							
7	8½	6¼							

(*Macfarlane, Strang & Co., Ltd.*)

* For thickness of metal, see columns (A) and (B), page 261.

THICKNESSES OF PIPES.

1. Iron Water Piping.			2. Hydraulic Piping. Wrought Iron. To Stand 4,000 lbs. per Square Inch Pressure.			3. Hydraulic Piping. Cast Iron. To stand 200 lbs. per Square Inch Pressure.	
Internal Diameter of Pipe, in Inches.	External Diameter of Pipe, in Inches.	Number of Threads per Inch Whitworth Standard.	Internal Diameter of Pipe, in Inches.	External Diameter of Pipe, in Inches.	Number of Threads per Inch.	Internal Diameter of Pipe, in Inches.	Thickness of Pipe, in Inches.
⅜	·665	19	⅜	¾	14	1½	7/16
½	·822	14	½	1	14	1¾	7/16
¾	1·034	14	⅝	1⅛	14	2	½
1	1·302	11	¾	1¼	11	2¼	9/16
1⅛	1·492	11	⅞	1⅜	11	2½	9/16
1¼	1·650	11	1	1½	11	3	⅝
1⅜	1·745	11	1⅛	1⅝	11	3½	⅝
1½	1·882	11	1¼	1¾	11	4	¾
1⅝	2·021	11	1⅜	1⅞	11	5	⅞
1¾	2·047	11	1½	2	11	6	1
1⅞	2·245	11	1⅝	2⅛	11		
2	2·347	11					
2⅛	2·467	11					
2¼	2·587	11					
2⅜	2·794	11					
2½	3·001	11					

BRITISH STANDARD SPECIFICATION FOR CAST-IRON PIPES AND SPECIAL CASTINGS FOR WATER, GAS, AND SEWAGE.*

(No. 78—1917.)

(*Abstract.*)

2. The metal used for casting the pipes shall be pig iron alone, or pig iron and scrap, and shall be remelted in the cupola or air furnace. The pig iron shall be best tough grey foundry pig iron, and the scrap shall be clean, unburnt, and of good quality. There shall be no admixture of cinder iron or any material calculated to render the metal inferior in quality, and the resulting casting shall not be white or vitreous on fracture.

7. The tensile breaking strength of the metal shall be not less than 9½ tons per square inch.

11. The straight pipes shall be cast vertically, in dry sand moulds formed from turned iron patterns and in accurately faced and truly jointed boxes, and without the use of core nails, chaplets, or thickness pieces, or any substitute therefor. They shall be cast with a sufficient head of metal to ensure soundness, which head shall be afterwards cut off in a lathe and the finished pipe left the length and shape required. All straight spigot and socket pipes shall be cast socket downwards.

22. The straight pipes shall, before being coated, respectively withstand the following hydraulic test pressures without showing any leakage, sweating, or other defect of any kind :—

	Gas.	Water.		
	Class A.	Class B.	Class C.	Class D.
Test pressure in feet head . .	200	400	600	800

While under the test pressure each pipe shall be smartly struck with a suitable hand hammer weighing not less than one and a half pounds.

BRITISH STANDARD CAST-IRON PIPES FOR WATER, GAS, AND SEWAGE.

Standard Thicknesses and External Diameters for Spigot and Socket and Flange Straight Pipes.

Nominal Internal Diameter of Pipe (ins.)	Gas. Class A. Test Pressure 200 ft. hd.		Water and Sewage. Class B. Test Pressure 400 ft. hd.		Class C. Test Pressure 600 ft. hd.		Class D. Test Pressure 800 ft. hd.		Nominal Internal Diameter of Pipe (ins.)
	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	
3	·38	3·76	·38	3·76	·38	3·76	·40	3·76	3
4	·39	4·80	·39	4·80	·40	4·80	·46	4·80	4
5	·41	5·90	·41	5·90	·45	5·90	·52	5·90	5
6	·43	6·98	·43	6·98	·49	6·98	·57	6·98	6
7	·45	8·06	·45	8·06	·53	8·06	·61	8·06	7
8	·47	9·14	·47	9·14	·57	9·14	·65	9·14	8
9	·49	10·20	·49	10·20	·60	10·20	·69	10·20	9
10	·52	11·26	·52	11·26	·63	11·26	·73	11·26	10
12	·55	13·14	·57	13·14	·69	13·60	·80	13·60	12
14	·57	15·22	·61	15·22	·75	15·72	·86	15·72	14
15	·59	16·26	·63	16·26	·77	16·78	·89	16·78	15
16	·60	17·30	·65	17·30	·80	17·84	·92	17·84	16
18	·63	19·38	·69	19·38	·85	19·96	·98	19·96	18
20	·65	21·46	·73	21·46	·89	22·06	1·03	22·06	20
21	·67	22·50	·75	22·50	·92	23·12	1·06	23·12	21

* By permission of the British Engineering Standards Association.

BRITISH STANDARD CAST-IRON PIPES FOR WATER, GAS AND SEWAGE—(*contd.*).

Nominal Internal Diameter of Pipe (ins.)	Gas. Class A. Test Pressure 200 ft. hd.		Water and Sewage. Class B. Test Pressure 400 ft. hd.		Class C. Test Pressure 600 ft. hd.		Class D. Test Pressure 800 ft. hd.		Nominal Internal Diameter of Pipe (ins.)
	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	Thickness. (ins.)	External Diameter. (ins.)	
22	·68	23·54	·77	23·54	·94	24·16	1·08	24·16	22
24	·71	25·60	·80	25·60	·98	26·26	1·13	26·26	24
26	·74	27·66	·83	27·66	1·02	28·36	1·18	28·36	26
27	·75	28·70	·85	28·70	1·04	29·40	1·20	29·40	27
28	·76	29·72	·86	29·72	1·06	30·44	1·22	30·44	28
30	·79	31·78	·89	31·78	1·09	32·52	1·26	32·52	30
32	·82	33·84	·92	33·84	1·13	34·62	1·31	34·62	32
33	·83	34·88	·94	34·88	1·15	35·66	1·33	35·66	33
36	·87	37·96	·98	37·96	1·20	38·76	1·38	38·76	36
38	·90	40·02	1·01	40·02	1·23	40·84	1·42	40·84	38
40	·92	42·06	1·03	42·06	1·26	42·92	1·46	42·92	40
42	·95	44·12	1·06	44·12	1·30	45·00	1·50	45·00	42
44	·98	46·16	1·08	46·16	1·33	47·06	1·53	47·06	44
46	1·00	48·22	1·11	48·22	1·36	49·14	1·57	49·14	46
48	1·03	50·26	1·13	50·26	1·38	51·20	1·60	51·20	48

NOTE.—It is suggested that the working pressures should not exceed one-half of the respective test pressures.

Weight of Steel Wire Ropes.

The weight per fathom (6ft.) in lbs. of the usual engineering wire rope is approximately the square of the circumference, *i.e.*, for example, a 3 in. rope would weigh 9 lbs. per fathom, approximately.

Sorting out Mixed Steel Bars.

In the majority of large engineering works who carry a fairly large stock of different kinds of steel bar, it frequently happens that the material inadvertently becomes mixed up so that no one can vouch for any particular bar being of a certain composition. This mixing up invariably leads to trouble, and so it becomes imperative that the material be correctly sorted out into its correct categories again.

Classes of steel may be broadly divided into two distinct classes, which are 'straight carbon steels' and 'alloy steels.' These two classes may be again subdivided into low, medium, and high carbon steels, and nickel, nickel-chrome, and high-speed alloy steels.

To ascertain if the steel is of the 'straight carbon' variety or of the 'alloy steel' variety, dissolve a few drillings or chippings from the bar in dilute nitric acid; then all straight carbon steels will produce a brownish coloured solution—the brown colour varying in intensity with the amount of carbon in the steel—whilst nickel steels will produce a light green coloured solution, and nickel-chrome steels a dark green solution of a characteristic hue.

To determine what class of carbon steel any particular bar consists of, supposing it has been found to be a straight carbon steel, grind a piece of the steel on any ordinary grinding wheel and carefully note the type of spark produced. The higher the carbon content of the steel the more brilliant and lively are the sparks produced and, therefore, file steel produces brilliant, lively, and forked sparks, whilst case-hardening steel produces dull and dead-looking sparks. With repeated practice it is easily possible to discriminate between low, medium, and high carbon steels by this method. This test is one of the best for high-speed steel, this steel producing very characteristic sparks of a dull reddish colour.

To ascertain the carbon content of a steel very accurately, dissolve 0·20 gram of the steel in 2 c.c. of dilute nitric acid, and at the same time dissolve (in a separate vessel) the same quantity

of steel of known carbon content. Place the two solutions in graduated tubes and dilute the unknown sample with water until it is exactly the same colour as the standard steel which has previously been diluted to any convenient degree. From this reading of the graduated tube the carbon content of the unknown steel may be immediately found. For example, supposing the standard steel contains 0·49 per cent. carbon: this may be diluted to 9·8 c.c., when, if the unknown sample of stee' requires being diluted to 6·8 c.c. before it is the same colour as the standard, then it will contain 0·34 per cent. carbon. The method is accurate to about 0·02 per cent., and twenty or more tests may be carried out in about half an hour.

Should the steel prove to be an alloy steel the colour test will ascertain whether it is a nickel or nickel-chrome alloy steel, and to discover if it is an oil or air-hardening nickel-chrome steel, take a small piece of the steel and heat it to 1,550° F., and allow it to cool freely in air, then test the hardness of the steel by means of a Brinell or scleroscope hardness tester.

(*Met.*, '*Machinery*,' *July* 5, 1923.)

Identification of Nickel-Steel Bars.

Place one drop of nitric acid having a specific gravity of 1·20 on a spot on the bar from which the scale has been removed, and allow it to work for ten seconds. Press a piece of white blotting paper lightly on the spot to soak up the nitrates of iron and nickel (if present). Put two drops of dimethyl-glyoxime solution on the nitrates on the blotting paper.

If the colour appears red, the steel contains nickel, but if it is brown then the steel contains no nickel. This method is sensitive to 0·17 per cent. nickel. The time required to make the test is about three minutes. (*Machinery.*)

Identification of Steel Pipes.

Steel pipe may be distinguished from wrought-iron pipe by testing the material in the pipe for manganese, which is present in the steel pipe, but not in the wrought iron.

The test is as follows:—Place a clean, bright chip or filing of the metal to be tested, about the size of a pin-head, in a porcelain crucible; add six drops of pure nitric acid, and heat; add two drops of silver nitrate solution, then one crystal of ammonium persulphate not greater than $\frac{1}{8}$ in. in diameter; warm the solution, but do not let it boil. If the metal is steel, a pink colour will begin to develop, and at this point the crucible should be removed from the source of heat when a very decided red coloration will result. If no colour develops, but a small amount of dark residue remains in the dish, the metal is wrought iron.

SECTION V

PART II

TENSILE STRENGTH OF MATERIALS — STRENGTH OF WIRE, CHAINS, AND ROPES—LATERAL STRENGTH OF MATERIALS—TRANSVERSE STRENGTH OF MATERIALS—BRITISH STANDARD SPECIFICATIONS FOR STRUCTURAL STEEL—ADMIRALTY TESTS FOR STEEL AND IRON—STRENGTH OF TUBES, RINGS, CHAINS, SLINGS, AND ROPES.

STRENGTH OF MATERIALS.

This Table shows the weight a column can bear with *safety* when the weight presses through the length of the column. The tabular number is the weight in pounds or tons per square inch of the transverse section of a column of a length less than twelve times its smallest thickness.

Resistance to Compression.

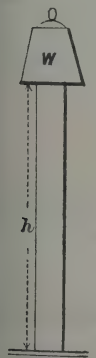


FIG. 1.

Kind of Material.	Lbs.	Tons.
Oak of good quality	432	·1885
„ common	280	·125
Spruce, red (Sapin rouge)	540	·241
„ white (Sapin blanc)	140	·6256
Iron, wrought	14,400	6·43
„ cast	28,750	12·85
Basalt	2,875	1·285
Granite, hard	1,000	·446
„ common	575	·256
Marble, hard	1,435	·640
„ common	431	·192
Sandstone, hard	1,295	·577
„ loose	5·6	·0025
Brick, good quality	175	·078
„ common	58	·0259
Limestone of hardest kind	720	·321
„ common	432	·193
Plaster of Paris	86	·0384
Mortar, good quality, and 18 months old	58	·0259
„ common	36	·016

When the length or height of the column is more than twelve times its smallest thickness, divide the tabular weight by the corresponding number in the following Table :

Length ÷ thickness	12	18	24	30	36	42	48	54	60
Divide by	1·2	1·6	2	2·8	4	5	6	8	12

T,

TENSILE STRENGTH OF MATERIALS.

Weight or Power required to tear Asunder One Square Inch.

TENSILE STRENGTH OF WOODS.

Woods.	Lbs.	Woods.	Lbs.	Woods.	Lbs.
Ash	14000	Lignum-vitæ	11800	Pear	9800
Bay	14000	Locust	20500	Pine, pitch	12000
Beech	11500	Mahogany	21000	„ larch	9500
Box	20000	„ Spanish	12000	„ American, white	11800
Cedar	11400	„ „	8000	Poplar	7000
Chestnut, sweet	10500	Maple	10500	Spruce, white	10290
Cypress	6000	Oak, American, white	11500	Sycamore	13000
Deal, Christiania	12400	„ English	10000	Teak	14000
Elm	13400	„ seasoned	13600	Walnut	7800
Lance	23000	„ African	14500	Willow	13000

TENSILE STRENGTH OF RUBBER.

Plantation rubber of good average quality should have a tensile strength of from 2,300 lbs. to 2,400 lbs. per square inch.

TENSILE STRENGTH OF METALS.

Metals.	Lbs.	Metals.	Lbs.	Metals.	Lbs.
Copper, wrought	34000	Iron, English bar	56000	Lead, milled	332
„ rolled	36000	„ rivets, American	53300	„ wire	258
„ cast, American	24250	„ „ English	65000	Platinum wire	5300
„ wire	61200	„ bolts	52250	Silver, cast	4000
„ bolt	36800	„ hammered	53913	Steel, cast, maximum	14200
Iron, cast, Low Moor No. 2	14076	„ „ mean of English	53900	„ „ mean	8865
„ „ Clyde No. 1	16125	„ crank-shaft	44750	„ blistered, soft	13300
„ „ „ No. 3	23468	„ turnings	55800		10400
„ „ Calder No. 1	13735	„ plates, boiler, American	48000	„ shear	12400
„ „ Stirling, mean	25764	„ plates, mean of English	62000	„ chrome, mean	17098
„ „ mean of American	31829	„ plates, lengthwise	51000	„ puddled, extreme	17381
„ „ mean of English	19484	„ „ crosswise	53800	„ plates, lengthwise	9630
„ wrought wire	103000	„ inferior, bar	48800	„ „ crosswise	9370
„ best Swedish bar	72000	„ wire, American	30000	„ razor	15000
„ Russian bar	59500	„ scrap	73600	Tin, cast, block	500
		Lead, cast	53400	„ Banca	212
			1800	Zinc	350
				„ sheet	1600

Lake Superior and Iron Mountain charcoal bloom iron has resisted 90,000 lbs. per square inch

TENSILE STRENGTH OF ALLOYS.*

Alloys.	Lbs.	Alloys.	Lbs.
Gold 5, copper 1	50000	Copper 10, tin 1	32000
Brass	42000	„ 8, „ 1 (gun-metal)	30000
„ yellow	18000	„ 8, „ 1 (gun-metal, small bars)	50000
Bronze, least	17698	Tin 10, antimony 1	11000
„ greatest	56788	Delta bronze, No. I alloy	11160

* See also METALLURGY, Section XL.

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BRONZE, BRASS, YELLOW METAL, NAVAL BRASS, COPPER, &c.,

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Acid-proof and other Corrosion-resisting Alloys;
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in Brass, Bronze, Copper, etc.

High Conductivity Copper Rods, Bars, Sections, Wire, etc

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Bolts, Rods, Forgings and Stampings.

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[SEE OTHER SIDE

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TENSILE TEST OF DELTA BRONZE No. I, EXTRUDED.

Made by Mr. R. H. Harry Stanger, Broadway Testing Works, Westminster.

Description.	Diameter. Inches.	Area. Square Inches.	Ultimate Strength. Tons per Sq. In.	Elongation per Cent. on 2 inches.	Reduct on of Area Per Cent.
Extruded bar. Delta bronze No. 1	0·502	0·1979	49 82	26·0	24·9

TENSILE TESTS OF DELTA BRONZE No. I, CAST.

Made by Mr. W. H. Stanger, M.I.C.E., F.C.S., Broadway Testing Works, Westminster.

Diameter. Inches.	Area. Square Inches.	Ultimate Strength. Tons per Square Inch	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.
0·500	0·1963	40·75	18·6	23·9
0·500	0·1963	40·75	19·4	20·1
0·500	0·1963	40·80	23·0	22·2
0·500	0·1963	41·30	20·0	20·4
0·501	0·1971	41·40	—	—
0·501	0·1971	41 50	20·5	19·3
0·500	0·1963	40·50	20·5	20·8
0·491	0·1893	40·46	18·0	17·9

Tensile strength, mean of 8 tests 40·93 tons per square inch.

Tensile Strength of Metals at Different Temperatures.

TENSILE STRENGTH OF IRON, STEEL, AND CAST IRON AT HIGH AND LOW TEMPERATURES.

The tensile strength of wrought iron or steel appears to be a minimum at about 70° F., and increases as the temperature is changed, becoming 20 per cent. greater at about 500° F. There are indications of a brittle region at the temperature of steam at 5 to 10 lbs. pressure. Iron at low temperatures, while increasing in strength, retains its ductility.

The tensile strength of cast iron begins to decrease at as low a temperature as 200° F., and at a dull red heat, say about 1,000° F., its strength is reduced by one-third; at 1,240° F. it is reduced to zero.

Effect of Superheated Steam Temperatures on Steel.

Based upon the experiments made in the Brown-Firth Research Laboratories, Sheffield.

(*Contributed by W. H. Hadfield, D.Met.*)

Steam at 100 lbs. per sq. in. pressure and 350° of superheat probably represents the highest temperature at which steam is likely to be used. This corresponds to about 845° F. or 452° C. As the testing temperature increases from atmospheric to about 500° C. most types of steel show first an increase of strength, then a decrease. A mild carbon steel which at ordinary temperatures gave 27·2 tons per sq. in. maximum stress with 38 per cent. elongation gave at 200° C. 30 tons per sq. in. and 27 per cent. elongation, at 300° C. 32·3 tons per sq. in. with 23 per cent. elongation, but at 400° C. fell to 25·1 tons per sq. in. maximum stress with 37·6 per cent. elongation. At 550° C. the maximum stress was only 16·8 tons per sq. in. Carbon steel of higher carbon content shows a similar order of changes, but there is in some cases a slight decrease in strength at about 100° C. before the increase takes place. The temperatures at which

the steel has its maximum strength varies with the steel, a higher carbon generally bringing the maximum at a lower temperature. A 52-ton carbon steel gave 50 tons per sq. in. at 100° C., 53 tons per sq. in. at 200° C., 58 tons at 310° C., 48·5 tons per sq. in. at 420° C., and so on. A nickel chrome steel, which gave 37 tons per sq. in. and 30 per cent. elongation at ordinary temperatures, gave only 32·4 tons per sq. in. at 200° C.; 29 per cent. elongation followed by an increase of strength to 34·2 tons per sq. in., with 33 per cent. elongation at 410° C. Beyond this temperature the strength fell off rapidly.

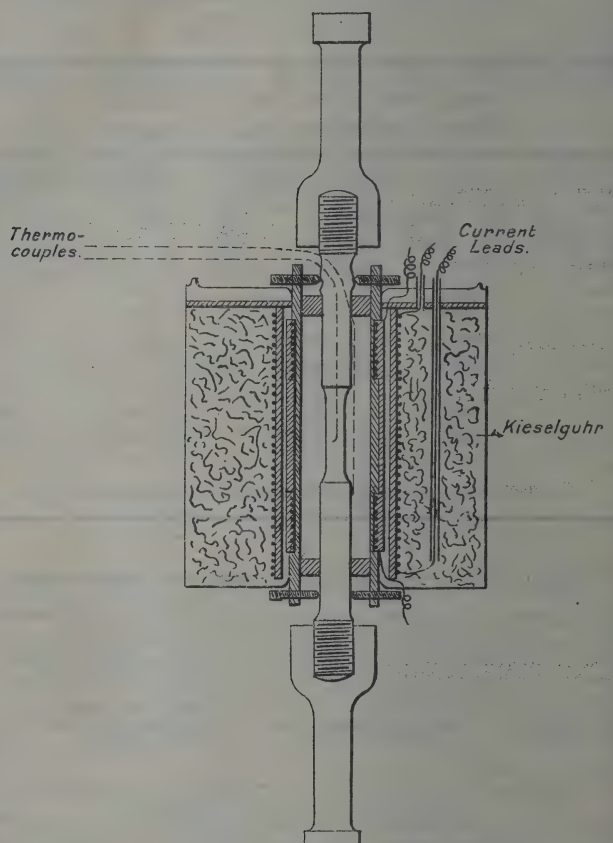

FIG. 2.

Tests in Firth's stainless steel, which had a strength of 55·0 tons per sq. in. and 21 per cent. elongation at ordinary temperature, retained a strength of 45·0 tons per sq. in. with 22 per cent. elongation at 410° C., after falling slightly below this strength at 300° C. A specimen of high speed tool steel in an annealed condition showed a gradual reduction in strength as the temperature increased. The values were 50 tons per sq. in., and 21·6 per cent. elongation at ordinary temperature, and 36·4 tons per sq. in., 19·2 per cent. elongation at 460° C. This stainless steel and high speed steel retain their strength to a considerable degree up to 600° C.

A further test on nickel steel showed a decrease of strength from 48·6 tons per sq. in. to 39·2 tons per sq. in. at 250° C., followed by an increase to 43 tons per sq. in. at 350° C., and a further decrease to 32·7 tons per sq. in. at 500° C. The elongations per cent. at these temperatures were, ordinary 23·2 per cent.; 250° C., 21 per cent.: 350° C., 19 per cent.; 500° C., 24 per cent.

For use in steam turbines, the above properties require careful consideration, since, of course, the design and strength of the parts should be based on the properties of the material at the actual working temperature.

For making the above determinations, a special small electric furnace (fig. 2) was constructed and used for heating the specimens. An iron tube about 7¼ ins. long and 1½ ins. internal diameter and $\frac{3}{16}$ in. thick was turned down, except about 1½ in. length at each end, to about $\frac{3}{8}$ in. thickness. The main heating coil was a spiral of nichrome wire wrapped on a silica tube of 2¼ ins. diameter and fixed concentrically with the iron tube. Auxiliary heating coils were added at each end of the turned portion of the central tube, being separated from the latter by a layer of mica, and covered with a coating of refractory cement. A cylindrical metal box surrounded the whole, the space being filled with refractory material (kieselguhr). The object of the metal tube was to equalise the temperatures over the central portion of the furnace, and the end heating coils were added to compensate for the heat lost by radiation at the ends of the furnace. The tests were carried out in the Olsen testing machine. The test piece was 10 ins. long, having the test portion 1½ in. parallel, by 357 mils diameter (i.e. $\frac{1}{10}$ sq. in. cross section). This was located axially in the furnace by three set screws carried at each end of the iron tube. The screwed ends of the test piece were connected to the shackles of the machine by special gluts of 25 per cent. nickel steel, which has fairly low heat-conducting properties. This was found to be necessary in order to prevent the shackles and attachments of the machine from heating up unduly. The weight of the furnace was carried by the test piece itself from its upper end, a groove being turned on the test piece so that the upper set screws could be screwed tightly on it. The lower set screws were turned so as to only bear lightly on the test piece, thus permitting the lower portion of the latter to pass through easily, when elongation and fracture took place during the test. The heating coils, in series with a suitable resistance, were connecting across the 200-volt. A.C. supply mains. The temperature was measured by means of two thermo-electric couples which had been previously calibrated. One was placed with the junction at the centre of the parallel portion of the test piece, and the other just above the end of the 'radius' so as to detect any variation in the temperature. The couples were tied in position on the test piece by fine wire previous to inserting in the furnace. To prevent any air current passing through the furnace the ends of the tube were packed with asbestos packing.

Strength of Steel at very High Temperatures.

(W. H. Hatfield.)

It frequently happens that engine parts have to work at still higher temperatures than those corresponding to superheated steam. Valves, pistons, and other parts of internal combustion engines, boiler flues, etc., are examples of such parts.

It is generally found that as the temperature rises above 500° C. the mechanical strength falls off fairly rapidly, whatever the composition of the steel. A mild steel of ·14 per cent. carbon content showed a strength of 9 tons per sq. in. at 640° C. and a strength of only 2·5 tons per sq. in. at 850° C. Under such conditions, however, the strength exhibited depends largely on the speed of deformation. A relatively small load will frequently cause a gradual breakdown of the material if the load is maintained. The order of strengths exhibited at 850° C. is somewhat as follows:—Mild carbon steel, higher carbon steel, nickel chrome steel, Firth's stainless steel, tungsten high-speed steel. A sample of the latter gave a strength of 11 tons per sq. in. when tested at 850° C. when suitably hardened and tempered.

It might be of interest to note that a quality of high speed steel having the condition of hardness in which it is employed as a tool (and in which it retains its cutting properties while working at a red-heat) had a strength of 78 tons per sq. in. at a temperature of 625° C.

TENSILE STRENGTH OF COPPER AT DIFFERENT TEMPERATURES.

Temperature, °F . . .	122°	212°	302°	482°	545°	602°	801°	912°	1010°
Lbs. per square inch . .	33,100	32,200	30,900	27,000	25,400	22,300	18,900	14,800	11,700

Copper may suffer considerable loss in strength when exposed for a long period to variable temperatures, even if as low as 400° F. Le Chatelier found that at this temperature the ultimate tenacity of good copper thoroughly annealed is not more than 10 tons per square inch, while this figure cannot be depended on in the case of brazed pipes, as the metal is often seriously injured in the neighbourhood of the joint. Hard copper suffers more than soft annealed copper

from the effects of heat. Le Chatelier's test showed that with a hard copper having a tenacity of 31·5 tons per sq. in., at 60° F. the strength was reduced to 11·4 tons after being exposed to a temperature of 482° F. for 30 minutes. Under the same conditions the tenacity of soft copper was reduced from 15·9 to 10·4 tons per sq. in. Prof. Roberts-Austen showed that minute quantities of impurities in copper seriously affect its tenacity. The presence of one-tenth of 1 per cent. of bismuth reduced the breaking load of a sample from 8 tons per sq. in. at 64° F. to 1·7 tons at 390° F. (*Philip Dawson, M.I.C.E.*)

TENSILE STRENGTH OF DELTA BRONZE NO. IV. AT DIFFERENT TEMPERATURES.

Delta Bronze, No. IV. Cast, tested at increased temperatures by Professor W. C. Unwin had lost :—

At 410° F.	. . . .	5·9	per cent. of its original strength
„ 506° F.	. . . .	17·6	„ „ „
„ 590° F.	. . . .	33·0	„ „ „

that is to say, at a temperature as high as 590° F. it still retained two-thirds of its original strength.

TENSILE STRENGTH OF GUN-METAL AT DIFFERENT TEMPERATURES.

Gun-metal (9 of copper and 1 of tin) becomes perceptibly softer at 400° F., and at 550° F. its tenacity is reduced one-half ; at 1380° F. (750° C.) it almost reaches zero. This is no doubt due to a large extent to the tin element, the melting-point of which is 446° F. But it is not altogether the melting-point of the individual constituents which appear to influence the matter. Copper, for instance (see p. 283), has a high melting-point (1929° F.), but its strength is seriously affected by prolonged exposure to a temperature as low as 400° F. Superheated steam will affect gun-metal (and other alloys) by chemical action, apart from the question of temperature.

REINFORCED SHEET LEAD.

A reinforcement of lead with perforated iron sheet has been found to increase the elastic limit four- to five-fold, and the tensile strength from two- to three-fold, the variations being due to differences in gauge of wire and mesh used. Lateral extensions of 20 per cent. and elongation of 20 per cent. have been obtained. Sheets 4 ft. 6 ins. by 5 ft. 6 ins. have been made. These reinforced sheets may be bent or shaped almost at will, as the lead does not fracture when bent. The sheets may be cut and joints burned together as in ordinary sheet lead. A pipe, 8 ins. in diameter, made up of reinforced lead 0·2 in. thick, when tested for strength, resisted pressures up to 85 lbs. per sq. in.

Stress due to Temperature.

A change of temperature = 16° C. (29° F.) for cast iron, and of 6½° C. (11·7° F.) for wrought iron, will produce 1 ton stress per square inch of section. For 45° C. (81° F.) wrought iron varies $\frac{1}{8000}$ of its length ; this will produce 7 tons stress per square inch of section.

Corrosion of Metals.*

RELATIVE CORROSION OF SOFT STEEL, WROUGHT IRON, AND NICKEL STEEL, TAKING WROUGHT IRON AS A STANDARD.

Metal.	Sea Water.	Fresh Water.	Weather.	Average.
Wrought iron . . .	100	100	100	100
Soft steel	114	94	103	103
3 per cent. nickel steel .	83	80	67	77
26 per cent. nickel steel .	32	32	30	31

(*H. M. Howe.*)

COMPARATIVE TESTS WITH WROUGHT IRON, STEEL, AND DELTA BRONZE NO. IV., IMMERSED DURING A PERIOD OF 6½ MONTHS IN ACID MINE WATER.

Details.	Wrought Iron.	Steel.	DELTA BRONZE No. IV.
Weight of bar when put in . . .	1·1805	1·2125	1·2787
Weight of bar after 6½ months . . .	0·6393	0·6614	1·2633
Loss in 6½ months	46·3 per cent.	45·45 per cent.	1·2 per cent.

* See also METALLURGY Section.

Strength of Brickwork.

(Royal Institute of British Architects' Experiments.)

Nature of Brickwork.	Crushing Strength. Tons per Sq. Ft.
London stocks in lime mortar (average workmanship)	12
" " (specially good workmanship)	18½
" cement mortar (average workmanship)	17
" " (specially good workmanship)	39
Gault bricks in lime mortar (average workmanship)	21
" " (specially good workmanship)	31
" cement mortar (average workmanship)	24
" " (specially good workmanship)	50½
Leicester reds in lime mortar (average workmanship)	32
" " (specially good workmanship)	45½
" cement mortar (average workmanship)	54½
" " (specially good workmanship)	84
Staffordshire blues in lime mortar (average workmanship)	74
" " (specially good workmanship)	114
" cement mortar (average workmanship)	77½
" " (specially good workmanship)	119
Fletton bricks in lime mortar (specially good workmanship)	30½
" cement mortar (specially good workmanship)	56

The following table gives the strength of these bricks when tested separately :—

Strength of Bricks.

Description.	London Stocks.	Burham Gaults.	Leicester Reds.	Stafford-shire Blues.	Fletton.
	Tons per Sq. Ft.	Tons per Sq. Ft.	Tons per Sq. Ft.	Tons per Sq. Ft.	Tons per Sq. Ft.
Cracked at	76·2	102·3	248·1	471·6	—
Crushed at	84·3	182·2	382·1	701	220·8

Strength of Masonry.

Masonry will carry safely 2 to 10 tons per square foot, and carefully-built masses of cut and ressed granite may carry 4 times the higher figure.

Adhesive Strength of Mortars.

Nature of Substance.	Tensile Strength, in Pounds per Square Inch.	After Mixture.
		Months.
Common mortar to compact limestone	15	6
" " brick	33	6
Good hydraulic lime	170	12
Ordinary " "	140 to 100	12
Fat lime	40	12
Good hydraulic mortar	140	12
Ordinary " "	85	12
Good common mortar	50	12
Bad " "	20	12
Cement from chalk lime and blue clay a few days after mixture	125	
Portland cement from compact limestone and clay 30 to 50 days after mixture	1,200 to 1,500	

Holding Power of Glue.

Wood.	Pounds per Square Inch across the Grain End to End.	Pounds per Square Inch with the Grain.
Beech	2,133	1,095
Elm	1,436	1,124
Oak	1,735	568
White wood	3,149	341
Maple	1,422	896

Some elaborate tests carried out in Germany proved that joints made with ordinary joiners' glue are strongest when the glue is dissolved in 150 per cent. of water and applied to wood heated to 104° Fah. The joint was dried under a pressure of 284 lbs. per square inch for twenty-four hours, and had a breaking strength of 984 lbs. per square inch. Increases in the proportion of water or the temperature reduced the strength of the joint.

Strength of Soldered Joints.

It is generally recognised that the strength of soft-soldered joints is increased if the film of solder between the surfaces of the join is kept as thin as possible. Some experiments carried out by T. B. Crow and described in *The Journal of the Society of Chemical Industry*, No. 13, vol. xliii, showed that by keeping the film as thin as possible a tensile strength 2½ times as strong as the original solder is obtainable in a joint between copper pieces, although in no case was the strength up to the yield point of the copper. It was demonstrated that the tin of the solder diffuses into the copper. With solder films 0·1 to 0·15 mm. in thickness the strongest joints, in tension, were those made at 265° C., while those made at a temperature above 280° C. were noticeably weak and brittle.

Breaking Stresses of Wire and Wire Ropes.

SIZES, WEIGHTS, LENGTHS, AND BREAKING STRESSES OF ANNEALED AND BRIGHT IRON WIRE (*Rylands'*).

Standard Wire Gauge.	Diameter.		Sectional Area.	Weight of		Length of 1 Cwt.	Breaking Stresses.		Standard Wire Gauge.
				100 Yards.	Mile.		Annealed.	Bright.	
	In.	Mm.	Sq. In.	Lbs.	Lbs.	Yards.	Lbs.	Lbs.	
7/0	·500	12·7	·1963	193·4	3,404	58	10,470	15,700	7/0
6/0	·464	11·8	·1691	166·5	2,930	67	9,017	13,525	6/0
5/0	·432	11·0	·1466	144·4	2,541	78	7,814	11,725	5/0
4/0	·400	10·2	·1257	123·8	2,179	91	6,702	10,052	4/0
3/0	·372	9·4	·1087	107·1	1,885	105	5,796	8,694	3/0
2/0	·348	8·8	·0951	93·7	1,649	120	5,072	7,608	2/0
1/0	·324	8·2	·0824	81·2	1,429	138	4,397	6,595	1/0
1	·300	7·6	·0707	69·6	1,225	161	3,770	5,655	1
2	·276	7·0	·0598	58·9	1,037	190	3,190	4,785	2
3	·252	6·4	·0499	49·1	864	228	2,660	3,990	3
4	·232	5·9	·0423	41·6	732	269	2,254	3,381	4
5	·212	5·4	·0353	34·8	612	322	1,883	2,824	5
6	·192	4·9	·0290	28·5	502	393	1,544	2,316	6
7	·176	4·5	·0243	24·0	422	467	1,298	1,946	7
8	·160	4·1	·0201	19·8	348	566	1,072	1,608	8
9	·144	3·7	·0163	16·0	282	700	869	1,303	9
10	·128	3·3	·0129	12·7	223	882	687	1,030	10
11	·116	3·0	·0106	10·4	183	1,077	564	845	11
12	·104	2·6	·0085	8·4	148	1,333	454	680	12
13	·092	2·3	·0066	6·5	114	1,723	355	532	13
14	·080	2·0	·0050	5·0	88	2,240	268	402	14
15	·072	1·8	·0041	4·0	70	2,800	218	326	15
16	·064	1·6	·0032	3·2	56	3,500	172	257	16
17	·056	1·4	·0025	2·4	42	4,667	131	197	17
18	·048	1·2	·0018	1·8	32	6,222	97	145	18
19	·040	1·0	·0013	1·2	21	9,333	67	100	19
20	·036	0·9	·0010	1·0	18	11,200	55	82	20

BREAKING STRESSES OF STEEL WIRE (*Rylands'*).

S.W.G.	Annealed.	Bright.	S.W.G.	Annealed.	Bright.	S.W.G.	Annealed.	Bright.
	Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.
7/0	13,611	20,310	3	3,458	5,187	12	590	884
6/0	11,722	17,583	4	2,930	4,395	13	461	691
5/0	10,159	15,243	5	2,447	3,672	14	349	523
4/0	8,712	13,067	6	2,007	3,011	15	284	424
3/0	7,534	11,302	7	1,668	2,530	16	223	334
2/0	6,593	9,891	8	1,393	2,091	17	170	256
1/0	5,726	8,573	9	1,130	1,694	18	128	188
1	4,901	7,351	10	893	1,339	19	87	130
2	4,127	6,221	11	734	1,099	20	72	106

BREAKING STRESSES OF GALVANISED HIGH-PURITY IRON LINE WIRE
(*British Engineering Standards Association Specification No.* 182—1927.)*

Weight per Statute Mile.			Diameter.			Minimum Breaking Load of Wire of Standard Weight.	Minimum Number of Twists.		Weight of each piece (or coil).	
Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.				Minimum.	Maximum.
lbs.	lbs.	lbs.	inch.	inch.	inch.	lbs.			lbs.	lbs.
800	780	820	0·240	0·236	0·242	2,400	12		90	120
600	585	615	0·207	0·205	0·210	1,800	15		90	120
400	380	420	0·170	0·165	0·174	1,200	22	In 6 ins.	90	120
300	285	315	0·147	0·143	0·150	900	24		70	120
200	190	210	0·120	0·117	0·123	600	26		50	120
100	95	105	0·085	0·083	0·087	300	18	In 3 ins.	50	120
60	57	63	0·066	0·064	0·067	220	15		15	30

BREAKING STRESSES OF HARD-DRAWN COPPER WIRE.
(*British Engineering Standards Association Specification No.* 174—1927.)*

Weight per Statute Mile.			Diameter.			Minimum Breaking Load of Wire of Standard Weight.	Minimum Number of Twists.		Weight of each piece (or coil).	
Standard.	Minimum.	Maximum.	Standard.	Minimum.	Maximum.				Minimum.	Maximum.
lbs.	lbs.	lbs.	inch.	inch.	inch.	lbs.			lbs.	lbs.
800	784	816	0·2237	0·2215	0·2259	2,400	15			
600	588	612	0·1937	0·1918	0·1956	1,800	20	In 6 ins.		
400	392	408	0·1582	0·1566	0·1598	1,250	25		100	140
300	294	306	0·1370	0·1356	0·1384	945	30			
200	196	204	0·1119	0·1108	0·1130	640	20		75	140
150	147	153	0·0969	0·0959	0·0979	490	25	In 3 ins.	75	140
100	98	102	0·0791	0·0783	0·0799	330	30			
70	68·5	71·5	0·0662	0·0655	0·0669	230	35		50	140

* By permission of the British Engineering Standards Association.

TABLE OF ROUND STEEL WIRE ROPES FOR MINING, HAULING, WINDING AND SIMILAR PURPOSES.

Size Circumference.	Approximate Diameter.	Approximate Weight per 100 Feet.	Actual Breaking Stress.			
			Best Patent Steel.	Special Improved Patent Steel.	Best Plough Steel.	Special Improved Plough Steel.
Ins.	Ins.	Lbs.	Tons.	Tons.	Tons.	Tons.
1¼	3/8	27	4·5	4·9	5·4	6·0
1½	7/16	40	6·5	7·1	7·9	8·6
1¾	9/16	54	8·7	9·8	10·8	11·9
2	5/8	72	11·5	12·8	14·2	15·6
2¼	11/16	87	14·2	16·9	17·6	19·3
2½	13/16	107	17·7	19·8	21·8	23·9
2¾	7/8	132	21·9	24·5	27·1	29·6
3	15/16	154	25·6	28·7	31·7	34·7
3¼	1 3/32	184	30·2	33·7	37·3	48·8
3½	1 1/8	217	35·1	39·2	43·3	47·5
3¾	1 3/16	247	40·4	45·1	49·9	54·6
4	1¼	275	45·4	50·7	56·0	61·4
4¼	1 5/16	308	51·4	57·5	63·5	69·5
4½	1 7/16	350	57·8	64·5	71·3	78·1
4¾	1½	392	64·4	72·0	79·6	87·2
5	1 9/16	420	70·7	79·0	87·4	97·7

BRITISH STANDARD SPECIFICATION FOR GALVANISED STEEL WIRE STRAND FOR SIGNALLING PURPOSES.*

(No. 163—1924.) (*Abstract.*)

7. British Standard Galvanised Steel Wire Strand for Signalling Purposes shall consist of 7 wires of No. 17 Standard Wire Gauge (S.W.G.) stranded together.

8. The wire shall be of a homogeneous steel of one of the four grades specified in the table (col. 1), and shall be galvanised with virgin spelter of good ordinary brands, containing not less than 97·75 per cent. pure zinc.

9. The wire shall be drawn in continuous pieces and shall be, after galvanising, 56 mils (1·42 mm.) in diameter, with a tolerance above or below of 3 mils (0·076 mm.).

11. The lay shall be right-handed and 2¾ inches in length.

The wires shall be so stranded together that when an evenly distributed pull is applied at the ends of the completed strand, each wire will take an equal share of the pull.

12. Each piece shall be warranted to contain no weld, splice or joint whatever, either in the rod before it is drawn or in the finished wire.

18. (*a*) The quality of the galvanising will be tested by immersing samples of the wire before stranding in a freshly made neutral solution of sulphate of copper saturated at 60° F. (15·6° C.) and allowing them to remain in the solution for one minute, when they will be withdrawn and wiped clean. The galvanising shall admit of this process being performed twice with each sample without there being any sign of a reddish deposit of metallic copper on the wire.

(*b*) The galvanised wire before stranding shall also stand being coiled round a bar having a diameter ten times the diameter of the wire without the galvanised surface cracking.

* By permission of the British Engineering Standards Association.

TABLE OF WIRE STRAND FOR SIGNALLING PURPOSES.

1	2	3	4	5	6	7	8
	Single 17 S.W.G. Wire.						
Designation.	Tensile Strength.		Percentage Elongation in 10 in.		Minimum Breaking Load.	Minimum Number of Twists in 5·6 in. (142 mm.)	7/17 Wire Strand. Minimum Breaking Load.
	Tons per sq. in.	lb. per sq. in.	Before Stranding.	After Stranding.	lb.		lb.
W.S. 1	25–30	56,000– 67,200	10	8	138	30	966
W.S. 2	40–50	89,600–112,000	7	5	220	25	1540
W.S. 3	60–70	134,400–156,800	5	4	330	25	2310
W.S. 4	80–90	179,200–201,600	5	4	440	25	3080

Col. 7. 5·6 in. (142 mm.) is equal to one hundred times the diameter of No. 17 S.W.G. wire.
Col 8. A tolerance of 5 per cent. below the figures shown in the column will be al owed.

Resistance to Torsional Rupture.

RELATIVE POWER OF RESISTANCE TO TORSIONAL RUPTURE BY SHOCK OF VARIOUS WOODS.

White pine	1·00	Yellow pine	3·87
Spruce	1·50	Black walnut	3·95
Red cedar	1·61	Locust	5·80
Spanish mahogany	1·65	Oak	6·60
Ash	2·25	Hickory	6·90
Chestnut	2·40		

In a report issued by the Forest Service of the United States Department of Agriculture, it is stated that a wooden beam can take twice as much deflection under impact as under ordinary rates of loading without showing loss of elasticity. Increased rate of loading is accompanied by an increase in strength.

Stiffness of Woods.

(Ratio of twisting moment to total angle of torsion.)

White pine	1·00	Red cedar	4·00
Yellow pine, sap	2·25	Spanish mahogany	3·00
" " heart	2·25	Oak	2·53
Spruce	0·67	Hickory	4·1
Ash	1·87	Locust	5·50
Black walnut	2·63	Chestnut	1·60

Lateral Strength of Materials.

l = length of beam, in feet.
h = height, b = breadth or thickness in inches, of the beam where the load is acting.
k = coefficient for the different materials and sections of beams.*
x = coefficient of elasticity of materials (table, page 292) = modulus of elasticity† ÷ 7,000.
f = elastic deflection, in inches.
W = weight, in lbs., which the beam can bear with safety, being about one-quarter of the ultimate load at which the beam would break.

* The value of k varies according to the shape of the beam section (see pages 291–292). For rectangular beams the values are those given in the table, page 292. † See page 294.

EXAMPLE 1 (fig. 382).—A rectangular beam of English oak fastened in a wall projects out $l = 6$ feet 4 inches; $h = 8$ inches, and $b = 5$ inches. Required, what weight, W, it can bear with safety on the end. For English oak, coefficient $k = 25$.

$$W = \frac{25 \times 5 \times 8^2}{6{\cdot}333} = 1{,}263 \text{ lbs.}$$

EXAMPLE 2 (fig. 383).—A cast-iron beam of section fig. 393, with thickness $b = 1{\cdot}25$ inches, height $h = 22{\cdot}5$ inches. supported at the two ends in a length $l = 25$ feet. Required, what weight, W, it can bear with safety in the middle. For cast iron, coefficient $k = 266$.

$$W = \frac{4 \times 266 \times 1{\cdot}25 \times 22{\cdot}5^2}{25} = 26{,}930 \text{ lbs.} = 12{\cdot}03 \text{ tons.}$$

EXAMPLE 3.—Required the elastic deflection for the same beam and condition as in the last example. Modulus of elasticity $x = 2{,}285$ for cast iron.

$$f = \frac{26325 \times 25^3}{16 \times 2285 \times 1{\cdot}25 \times 22{\cdot}5^3} = {\cdot}79 \text{ inches.}$$

EXAMPLE 4 (fig. 386).—A wrought-iron girder of section fig. 399, consisting of four angle irons of $a = 3{\cdot}5 \times 0{\cdot}5 \times 2 \times 4 = 14$ square inches, the plate being $0{\cdot}5 : 1{\cdot}35 = 0{\cdot}37$ inches thick, and $h = 18$ inches deep by $l = 22$ feet. Required, how much weight, W, evenly distributed, the girder can bear with safety. For wrought iron, coefficient $k = 1040$.

$$W = \frac{8 \times 1040 \times 14 \times 18}{22} = 95{,}302 \text{ lbs.} = 42{\cdot}55 \text{ tons.}$$

If plates are riveted to the angle iron at top and bottom, add that area to a.

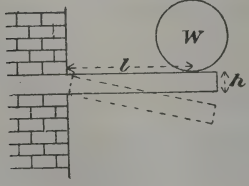

FIG. 382.

$$W = \frac{kbh^2}{l}, \qquad f = \frac{Wl^3}{xbh^3}.$$

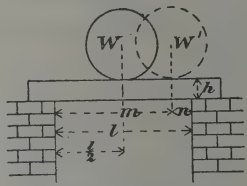

FIG. 383.

$$W = \frac{4kbh^2}{l}, \qquad W' = \frac{Wl^2}{4mn}, \qquad f = \frac{Wl^3}{16xbh^3}.$$

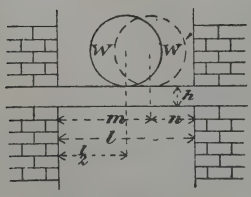

FIG. 384.

$$W = \frac{8kbh^2}{l} \qquad W' = \frac{Wl^2}{4mn}, \qquad f = \frac{Wl^3}{32xbh^3}.$$

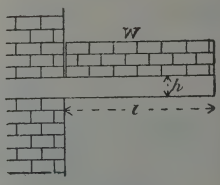

FIG. 385.

$$W = \frac{2kbh^2}{l}, \qquad f = \frac{5Wl^3}{2xbh^3}.$$

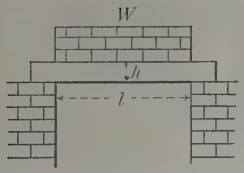

FIG. 386.

$$W = \frac{8kbh^2}{l}, \qquad f = \frac{5Wl^3}{32xbh^3}.$$

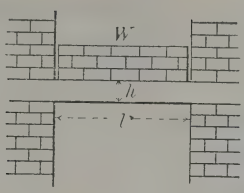

FIG. 387.

$$W = \frac{16kbh^2}{l}, \qquad f = \frac{5Wl^3}{64xbh^3}.$$

VALUES OF COEFFICIENT k FOR BEAMS OF VARIOUS SECTIONS.
(Factor of safety = 4.)

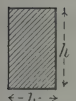

FIG. 388.

Material.	Coefficient k.
Steel	233
Wrought iron	156
Cast iron	154
English oak	25

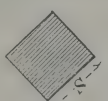

FIG. 389.

Material.	Coefficient k.
Steel	233
Wrought iron	156
Cast iron	154
English oak	25

$bh^2 = S^3$.

FIG. 390.

Material.	Coefficient k.
Steel	137
Wrought iron	92
Cast iron	91
English oak	15

$bh^2 = D^3$.

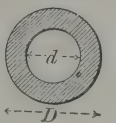

FIG. 391.

Material.	Coefficient k.
Steel	137
Wrought iron	92
Cast iron	91
English oak	15

$bh^2 = D^3 - d^3$.

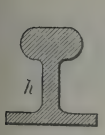

FIG. 392.

Material.	Coefficient k.
Steel	1360
Wrought iron	910

$bh^2 = ah$.
h = height. a = sectional area in square inches.

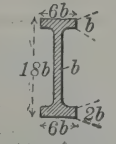

FIG. 393.

Material.	Coefficient k.
Steel	403
Wrought iron	270
Cast iron	266

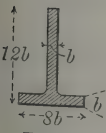

FIG. 494.

Material.	Coefficient k.
Steel	367
Wrought iron	246
Cast iron	243

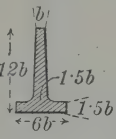

FIG. 395.

Material.	Coefficient k.
Steel	388
Wrought iron	260
Cast iron	236

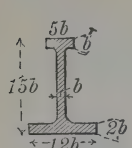

FIG. 396

Material.	Coefficient k.
Steel	1090
Wrought iron	728
Cast iron	720

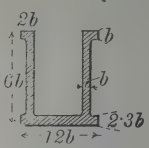

FIG. 397.

Material.	Coefficient k.
Cast iron	923

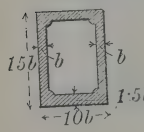

FIG. 398.

Material.	Coefficient k.
Cast iron	821

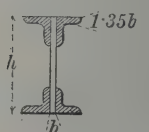

FIG. 399.

Material.	Coefficient k.
Steel	1550
Wrought iron	1040

$bh^2 = ah.$

a = area of all the four angle irons in square inches.

ABSOLUTE AND ULTIMATE STRENGTH OF MATERIALS.

Kind of Material.	Coefficient k (for Rectangular Beams).				Elasticity.
	Safety.	Short Intervals.	Pressing Circumstances.	Ultimate.	x
Wrought iron	120	162	240	488	4,110
Cast iron	150	200	300	600	2,285
Cast steel, soft	385	519	170	1,540	4,300
„ „ hardened	1,050	1,400	2,100	4,200	6,000
Blistered steel, soft	175	233	350	700	4,200
Brass	58	75	113	226	1,280
Copper	53	71	106	212	2,160
Zinc	15	20	30	61	2,360
Tin	17	23	34	69	
Lead	4	6	9	18	100
Ash	45	56	85	170	221
Hickory	67	90	135	270	
Chestnut, sweet	42	56	85	170	
Oak, white	50	66	100	200	300
„ English	25	33	50	100	248
„ Canadian	37	49	73	147	283
Pine, white	34	45	67	135	
„ yellow	38	50	75	150	268
Teak	51	68	102	205	316

The absolute safety weight is here taken as one-quarter of the ultimate breaking weight, but when the weight is acting at short intervals one-third might be relied upon, or in pressing circumstances one-half, when the materials in the beams are known to be of good quality; but the latter value should never be exceeded.

Crushing Strength of Timber.

Approximately the crushing strength (in direction of grain) of timber in lbs. per sq. in. = weight of wood in lbs. per cu. ft. × 165.
(*Percy W. Smith*, exps. made at Northampton Poly. Inst.—*Engineer*, April 10, 1914.)

Safe Limit of Loading.

Wood, $\frac{1}{10}$: Wrought Iron, $\frac{1}{5}$ to $\frac{1}{3}$: Cast Iron, $\frac{1}{4}$ to $\frac{1}{6}$: of the load which would produce rupture.

Wrought iron will resist about two-thirds as much to crushing as to tension.

A triangular beam which has the same area and depth as a rectangular one is only half as strong as the rectangular one.

A beam of cast iron supported at both ends is six times as strong with the apex up as down; if fixed at one end and loaded at free end it is six times as strong with apex down as with it up.

The strength of a cylindrical beam to that of a square one of the same area is as

$$1 : \tfrac{2}{3}\sqrt{\pi}; \text{ or } 1 : 1{\cdot}18 \text{ nearly.}$$

Transverse Strength of Materials.

TABLE SHOWING TRANSVERSE STRENGTH OF MATERIALS.

(Reduced to the uniform measure of one inch square and one foot in length; weight suspended from one end.)

Material.	Breaking Weight.	Value for General Use.
Metals.	Lbs.	
Cast iron, American — means of four divisions of grades	507	125–160
	632	155–210
	733	180–240
	772	192–250
„ mean by Major Wade	681	170–225
„ West Point Foundry, extreme	980	250–325
„ English, Low Moor, cold blast	472	110–140
„ Ponkey, cold	581	145–190
„ hot blast, mean	500	125–165
„ cold „ „	516	130–170
„ Ystalyfera, cold blast	770	195–255
„ mean of 65 kinds	500	125–165
„ mean of 15 kinds, direct from the pig, cold blast	641	160–215
„ planed bar	518	130–170
„ rough bar	534	133–175
Steel, greatest	1,918	350–450
„ puddled (permanent bend)	800	170–225
Woods.		
Ash	168	55
Beech	130	32
Birch	160	40
Chestnut	160	53
Deal, Christiania	137	45
Elm	125	30
Hickory	250	55
Locust	295	80
Maple	202	65
Norway pine	123	40
Oak, African	208	50
„ American white	230	50
„ „ live	245	55
„ Canadian	146	36
„ Dantzic	122	30
„ English	140	35
„ „ superior	188	45
Pitch pine	136	45
„ American	160	50
Riga fir	94	30
Teak	206	60
White pine	92	30
„ American	130	45
Whitewood	116	38
Wrought Iron.		
American	700	160–200
	650	
	600	

Material.	Breaking Weight.	Value for General Use.
Wrought Iron (continued).	Lbs.	
English	400	100–130
„	550	135–180
Swedish *	665	165–210
Mixture of Cast and Wrought Iron, &c.		
Cast iron, Blaenavon	..	145
„ „ 10 per cent. of wrought	..	175
„ „ 30 per cent. of wrought	..	230
„ „ 50 per cent. of wrought	..	185
„ „ and 2½ per cent. of nickel, mean	..	180
„ „ Stirling, second quality	..	154
„ „ Stirling, third quality	..	125
Copper	..	55
Brass	..	58
Stones (American).		
Flagging, blue	31	10
Freestone, Conn.	13	4
„ Dorchester	10·8	3½
„ New Jersey	20·1	6½
	17·8	6
„ New York	24	8
Granite, blue, coarse	18	6
„ Quincy, Mass.	26	8½
Stones (English).		
Adelaide marble	4·5	1½
Arbroath	17	5½
Bangor slate	90	30
Bath	5·2	1¾
Caithness paving, Scotland	68	22
Cornish granite	22	7
Craigleith sandstone	10·7	3½
Darley sandstone, Victoria	1·3	4
Kentish rag	35·8	12
Limestone	11	3½
Llangollen slate	43	14
Park Spring sandstone	4·3	1·4
Portland oolite	21·2	7
Valentia paving, Ireland	68·5	23
Welsh „ „	157	55
Yorkshire, blue	26	8½
„ landing	22·5	7½
„ paving	10·4	3½

* With 840 lbs. the deflection was one inch, and the elasticity of the metal destroyed.

TRANSVERSE STRENGTH OF MATERIALS (*continued*).

Material.	Breaking Weight.	Material.	Breaking Weight.
Concretes.	Lbs.	*Bricks.*	Lbs.
Fire-brick beam, Portland cement	3·1	Best stock	11·8
„ sand 3 parts, lime 1 part	·7	Fire-brick	14
Cements.		New brick	10·7
Blue clay and chalk	5·4	Old brick	9·1
Portland	37·5 to 10·2	Stock-brick, well burned	5·8
Sheppey	5	„ inferior, burned	2·5

(*Haswell.*)

Increase in Strength of Woods by Seasoning.

Wood.	Increase in Strength.	Wood.	Increase in Strength.	Wood.	Increase in Strength.
Ash	44·7 per cent.	Elm	12·3 per cent.	White pine	9 per cent.
Beech	61·9 „	Oak	26·1 „		

Spike-Gripping Power of Wood.

Experiments have shown that generally twice as much force is required to extract spikes from oak as from white or yellow pine. The spikes in the experiments were driven across the grain of the wood; when driven with the grain, the holding power is reduced at least one-half. The condition of the wood affects the gripping power; experiments have shown that the force required to draw spikes $\frac{9}{32}$ by $\frac{9}{16}$-in., driven $4\frac{1}{2}$ ins. into seasoned oak, is about 4,280 lbs.; the same spikes driven into unseasoned oak require 6,500 lbs. to draw.

Elongation Produced by Stress. Young's Modulus of Elasticity (e)

If length, L, in feet, of a bar of section A square inches, increases to L + l by stress of P lbs., then $l = \text{LP} \div \text{A}e$.

(1.)

Woods	e.	Woods	e.	Metals.	e.
Ash	1,600,000	Teak, African	2,300,000	Manganese bronze, cast	14,000,000
Beech	1,350,000	Willow	1,400,000	Monel metal	23,000,000
Birch, common	1,562,000			Nickel aluminium, forged	21,150,000
„ American	1,258,000	*Metals.*		„ (98·5%), cast	28,900,000
Box	1,856,000	Aluminium (99·3%), cast	9,810,000	„ hard drawn	34,100,000
Cedar	488,000	Antimony, hard drawn	11,320,000	„ silver	16,300,000 to 18,900,000
Chestnut	1,140,000	Brass, cast	13,000,000 to 15,500,000	Palladium	13,800,000
Elm	700,000	Bronze, cast	10,000,000 to 15,500,000	Platinum	22,800,000 to 24,900,000
Fir, Christiania	1,856,000	Copper, electrolytic	17,400,000		8,530,000 to 11,370,000
„ Riga	1,328,000	„ cast	11,000,000	Silver	30,000,000
„ New England	2,191,000	„ hard drawn	17,600,000	Steel	13,600,000
„ spruce	1,800,000	Delta metal	16,600,000	„ semi	27,000,000
„ larch	900,000	Duralumin	10,000,000	Tantalum	5,950,000
Kawrie or Cowdie	2,357,000	Gun metal	8,800,000	Tellurium	3,500,000
Mahogany, Honduras	1,255,000	Iron, cast	15,000,000	Tin, cast	514,000
Oak, English and Russian	1,451,000	„ „ malleable	25,000,000	Tungsten, drawn wire	13,400,000
„ Dantzic	1,191,000	„ electrolytic	25,000,000	Zinc	8,000,000
„ American, red	2,150,000	Iron, wrought	25,000,000	Glass	
„ African	2,283,000	Lead, sheet	720,000		
Pine, pitch	1,225,000				
Pine, Canada, red	1,840,000				
„ American yellow	1,600,000				
Teak, Indian	2,400,000				

See also Bureau of Standards, Report No. 101.

(2.)

The following were obtained from the flexure of thin strips:—

Material.	e.	Material.	e.	Material.	e.
Celluloid (1) . .	347,500	Drawing - paper (across direction of rolling) .	581,500	Box-wood . .	174,000
„ (2) . .	547,000			Whalebone . .	503,000
Drawing paper (in direction of rolling)	394,000	Thick stiff paper .	852,000		

(*F. H. Humme.*)

Breaking Weight of Wooden Beams.

BREAKING WEIGHT (w) IN CWTS. (DEAD LOAD) OF A RECTANGULAR BEAM OF YELLOW PINE 1 IN. BROAD, SUPPORTED AT BOTH ENDS AND LOADED IN THE CENTRE.

Span in Feet (s).	Depth in Inches (d).											
	3	4	5	6	7	8	9	10	11	12	13	14
4	7·50	13·33	20·83	30·00	40·83	53·33	67·50	83·33	100·84	120·00	140·84	163·33
6	5·00	8·89	13·89	20·00	27·16	35·56	45·00	55·56	67·22	80·15	93·89	108·90
8	3·75	6·67	10·43	15·00	20·42	26·67	33·75	41·67	50·42	60·00	70·42	81·67
10	3·00	5·33	8·33	12·00	16·33	21·33	27·00	33·33	40·33	48·00	56·33	65·33
12	2·50	4·44	6·94	10·00	13·61	17·78	22·50	27·78	33·61	40·00	46·94	54·44
14	2·14	3·81	5·95	8·57	11·67	15·24	19·29	23·81	28·81	34·25	40·24	46·67
16	1·88	3·33	5·21	7·50	10·20	13·33	16·88	20·83	25·21	30·00	35·21	40·83
18	1·67	2·96	4·63	6·67	8·95	11·85	15·00	18·52	22·41	26·67	31·30	36·30
20	1·50	2·67	4·17	6·00	8·17	10·67	13·50	16·67	20·17	24·00	28·17	32·67
22	1·36	2·42	3·79	5·46	7·42	9·70	12·27	15·15	18·33	21·82	25·61	29·70
24	1·25	2·22	3·47	5·00	6·81	8·90	11·25	13·89	16·81	20·00	23·47	27·22
26	1·15	2·05	3·21	4·62	6·28	8·21	10·38	12·82	15·51	18·46	21·67	25·13
28	1·07	1·99	2·98	4·29	5·83	7·62	9·64	11·90	14·40	17·14	20·12	23·33
30	1·00	1·78	2·78	4·00	5·44	7·11	9·00	11·11	13·44	16·00	18·78	21·78

(Formula : $w = \frac{d^2}{s} \times \frac{20}{6}$; see (10), p. 324.)

EXAMPLE.—To find the breaking weight of a beam of Yellow Pine 18 ft. span, 6 ins. broad, and 12 ins. deep. From table, breaking weight for 1 in. broad and 12 ins. deep is 26·67 cwts. : therefore,

Breaking weight of beam 6 ins. broad = 26·67 × 6 = 160 cwts.

(*H. R. Kempe.*)

BRITISH STANDARD SPECIFICATION FOR STRUCTURAL STEEL FOR BRIDGES AND GENERAL BUILDING CONSTRUCTION.*

(No. 15—1912.) (*Abstract.*)

A steel shall be made by the Open Hearth Process (Acid or Basic) unless either process is required or specified, and must not show on analysis more than ·06 per cent. of sulphur or phosphorus.

B steel (which is not intended for bridges, nor for plates ¼ in. in thickness or over, or rivet bars) may be made either by the Open Hearth Process (Acid or Basic) unless any one of the four processes is required or specified, and must not show on analysis more than ·08 per cent. of phosphorus, and not more than ·06 per cent. of sulphur.

Plates, sections, and flat bars must show a tensile breaking strength of 28 to 33 tons per sq. in., with an elongation of not less than 20 per cent. for steel of ·375 in. thickness and upwards, and not less than 16 per cent. for steel below ·375 in. thickness.

* By permission of the British Engineering Standards Association.

Round and square bars (other than rivet bars) must show a tensile breaking strength of 28 to 33 tons per sq. in.; the elongation must be not less than 20 or 24 per cent. (according to the form standard test piece used for making the test).

Rivet Bars, 25 to 30 tons per sq. in. breaking strength, and not less than 25 or 30 per cent. elongation (according to the test piece used).

ADMIRALTY TESTS FOR STEEL AND IRON.

(1925.)

TESTS FOR STEEL.

Tests for Steel Angles, Angle Bulbs, Tees, Tee Bulbs, Zed Bars, Ship Plates, and Ship Sheets.

(*Abstract.*)

Strips cut lengthwise or crosswise to have an ultimate tensile strength of not less than 26 and not more than 30 tons per sq. in. of section, with an elongation of 20 per cent. in a length of 8 ins. For plates of 10 lbs. and sheets elongation may be not less than 18 per cent.

One bar, plate, or sheet is to be selected from every charge, provided the number of bars, plates, or sheets does not exceed 50. If above that number, one for every additional 50 or portion of 50. A sample may be selected from every section of bar, or every thickness of plate or sheet, from each charge, but bars may be received or rejected without a trial of every section, and plates or sheets without a trial of every thickness, on the invoice.

Strips cut crosswise or lengthwise $1\frac{1}{2}$ in. wide must stand bending cold in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested.

The steel shall stand such forge tests (hot and cold for bars and hot for plates and sheets), and other general usage tests as may be considered necessary to prove the soundness of the material and its fitness to stand such treatment and bending as it may be subjected to in the shipyard.

The strips may all be cut in a planing machine, and have the sharp edges taken off.

The ductility of every bar or plate is to be ascertained by the application of such of the above tests as may be considered necessary.

The steel to be free from lamination and injurious surface defects.

Tests for Steel Rivets.

One tensile test shall be taken from each charge, but when the weight of the bars, as rolled from one charge exceeds 5 tons, an additional test shall be made for each further 5 tons or portion thereof.

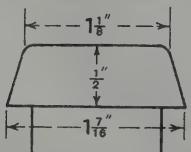

FIG. 400.—Pan Heads, Straight Necks.

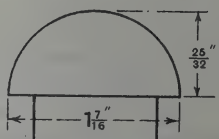

FIG. 401.—Snap Heads, Straight Necks.

The rivets are to be made from British 'acid open-hearth' steel bars having an ultimate tensile strength, for 'boiler' rivets, of not less than 24 and not more than 27 tons per square inch, with a minimum elongation of 25 per cent. in a length of 8 inches; for 'ordinary and screw' rivets, the bars to have an ultimate tensile strength of not less than 26 and not more than 30 tons per square inch, with a minimum elongation of 25 per cent. in a length of 8 diameters of the test piece.

Rivets selected as considered necessary to stand the following tests:—

(*a*) Bending double when cold, and hammered till the two parts of the shank touch, in the manner shown in fig. 405, without fracture.

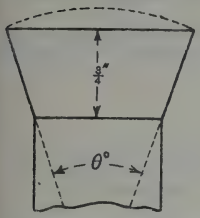

FIG. 402.—Countersunk Heads.

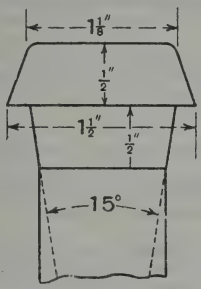

FIG. 403.—Pan Heads, Conical Necks.

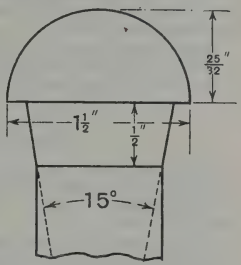

FIG. 404.—Snap Heads, Conical Necks.

FIG. 405.

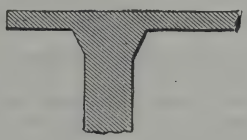

FIG. 406.

(*b*) Flattening of the rivet head, while hot, in the manner shown in fig. 406, without cracking at the edges. The head to be flattened until its diameter is 2½ times the diameter of the shank.

(*c*) The shank of the rivet to be nicked on one side, and bent cold to show the quality of the material.

SCHEDULE OF DIMENSIONS.

Diameter of Rivet.	With Pan or Snap Head and Straight Necks. Fig. 400 or fig. 401.		With Countersunk Heads. Fig. 402.		With Pan or Snap Heads and Conical Necks. Fig. 403 or fig. 404.		
	Diam. of Head.	Depth of Head.	Angle of countersink.	Depth of Head.	Diam. of Head.	Depth of Head.	Depth of Cone.
Inch.	Inches.	Inch.	Degrees.	Inch.	Inches.	Inch.	Inch
1 1/8	2	1 1/8	—	—	2	1 1/8	
1 1/4	1 3/4	1	40	1 1/16	1 3/4	1	5/8
1 1/8	1 5/8	29/32	40	1 1/16	1 5/8	29/32	9/16
1	1 7/16	25/32	40	5/8	1 1/2	25/32	1/2
7/8	1 9/32	11/16	45	9/16	1 5/16	11/16	7/16
3/4	1 1/8	5/8	45	3/8	1 3/16	5/8	3/8
5/8	15/16	1/2	45	1/4	1	1/2	5/16
1/2	1 3/16	3/8	45	3/16	7/8	3/8	1/4
7/16	11/16	5/16	—	—	—	—	—
3/8	5/8	1/4	60	3/16	—	—	—
5/16	1/2	7/32	—	—	—	—	—
1/4	7/16	3/16	60	3/32	—	—	—
3/16	3/8	1/8	—	—	—	—	—

Tests for Steel Bars, Flat, Segmental, Round, Square, and Hexagonal.

Test pieces are to have an ultimate strength of not less than 28 and not exceeding 32 tons per square inch of section, with an elongation of 20 per cent. in a length of 8 ins. The steel to stand such forge tests, both hot and cold, as may be sufficient to prove soundness of material and fitness for service.

Strips not less than 1 in. square or of the full thickness of section of the bar as rolled, must stand bending double in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested. To be tested cold.

Instructions for Treatment of Mild Steel.

All plates or bars which can be bent *cold* are to be so treated, and if the whole length cannot be bent cold, the portion to be bent hot must be of a uniform temperature throughout; the varying temperature from hot to cold portion is to be extended so as to avoid an abrupt termination of the heat.

In cases where plates or bars have to be heated, the greatest care should be taken to prevent any work being done upon the material after it has fallen to the dangerous limit of temperature known as a 'blue heat'—say from 600° to 400° F. Should this limit be reached during working, the plates or bars should be reheated.

Where plates or bars have been heated throughout for bending, flanging, &c., and the work has been completed at one heat, subsequent normalising is unnecessary.

Where simple forge-work has been done, such as the formation of joggles, corners, and easy curves or bends, on portions of plates or bars, and the material has not been much distressed, subsequent normalising may be dispensed with.

Plates or bars which have had a large amount of work put upon them while hot, and have had to be reheated, should be subsequently normalised. It is preferred that this normalising should be done simultaneously over the whole of each plate or bar when this can be done conveniently. If it is inconvenient to perform the operation of normalising at one time for the whole of a plate or bar, portions may be normalised separately, proper care being taken to prevent an abrupt termination of the line of heat. If the severe working has been limited to a comparatively small part of a plate or bar, normalising may be limited to the parts which have been heated, the same care being taken to prevent an abrupt termination of the line of heat.

In important cases where any bar or plate shows signs of failure or fracture in working, the details should be forwarded to the Admiralty, in order that instructions may be given as to the disposal of the bar or plate. Failure need not be reported in every case.

It is not generally necessary to anneal plates or bars after punching as a means of making good damage done in punching. For mild steel plating which forms an important feature in the general structural strength, such as the inner and outer bottom plating, deck plating, deck stringers, &c., the butt straps should have the holes drilled or punched $\frac{1}{16}$-in. small and rimed. In such plating the countersunk holes should be punched about $\frac{1}{8}$ in. less in diameter than the rivets which are used, the enlargement of the holes being made in the countersinking. All countersinking to be carefully done.

All steel and iron work is to be carefully scaled, scraped, and cleaned before being painted, and each portion of it as it is turned out of hand is to have a coat of linseed oil, thin red lead, or other substance, as may be required, as soon as it is sufficiently completed to receive it, in order to prevent as far as possible the work from becoming in any degree injuriously oxidised during the building of the ship. The plates of outer and inner bottom and sides, vertical keel and longitudinals, the lower plates and bulkheads, including those above the inner bottom, all the plates of oil fuel, water ballast and fresh water compartments, and the lower plates of frames, are to be treated as follows, with a view to removing the black oxide or scale:—The plates previous to their being taken in hand for working are to stand a few hours in a liquid consisting of 19 parts of water and one of hydrochloric acid. The plates should be pickled on edge and not laid flat. When plates are removed from the dilute acid bath both the surfaces are to be well brushed and washed to remove any scale which may still adhere to them. They should then be placed in another similar bath filled and kept well supplied with fresh water, or be thoroughly washed with a hose, as may be found necessary; the plates on removal from the fresh water should be placed on edge to dry.

TESTS FOR IRON.

Tests for Bar Iron.

The whole of the samples of every description of iron when tested with the grain are to realise a tensile strength of 22 tons to the square inch.

Forge Test, Hot.

Bars are to be punched with a punch one-third the diameter of the bar, at distances of one and a half and three diameters from the end of the bar, the holes being at right angles to one

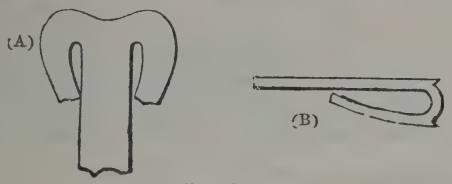

FIG. 407.

another. The holes are then to be drifted out to one and a quarter times the diameter of the bar. The sides of the holes are then to be split, and the ends must admit of turning back without fracture, as shown by (A).

Broad thick flats may be flattened on the edge to admit of being punched.

Thin flats $\frac{5}{8}$ in. thick and below are to be bent to a radius of two and a half times their thickness with the grain, without fracture.

Forge Tests, Cold.

Samples should be notched and bent, as shown by (B), to show the quality of the iron.

Fire Bars. Forge Test, Hot.

The bars are to be subjected to such bending and other usage tests as may be considered necessary.

The standard weight of the bar iron is to be taken at 40 lbs. per sq. ft. for bars of 1 in. thick, and in proportion for bars of all other thicknesses. No bar iron should exceed this prescribed weight, but a latitude of 5 per cent. below this weight will be allowed for thicknesses of $\frac{1}{2}$ an inch and upwards, and of 10 per cent. for less thicknesses. The weight of the iron ordered will be ascertained by weighing the parcel when its weight does not exceed 5 tons, and in lots of 5 tons when its weight exceeds 5 tons.

BRITISH STANDARD SPECIFICATION FOR STRUCTURAL STEEL FOR SHIPBUILDING.*

(No. 13—1910.) (*Abstract.*)

Plates.—The tensile breaking strength of steel plates, determined from Standard test pieces, shall be between the limits of 28 and 32 tons per sq. in. For plates specially intended for cold flanging and marked for identification the tensile breaking strength shall be between the limits of 26 and 30 tons per sq. in. The elongation, measured on a Standard test piece having a gauge length of 8 ins., shall be not less than 20 per cent. for material of ·375 in. in thickness and upwards, and not less than 16 per cent. for material below ·375 in. in thickness.

Angles, Bulb Angles, Channels, etc.—The tensile breaking strength of sectional material, such as angles, bulb angles, channels, etc., shall be between the limits of 28 and 33 tons per sq. in. The elongation, measured on a Standard test piece having a gauge length of 8 ins., shall be not less than 20 per cent. for material of ·375 in. in thickness and upwards, and not less than 16 per cent. for material below ·375 in. in thickness.

Rivet Bars.—The tensile breaking strength of rivet bars shall be between the limits of 25 and 30 tons per sq. in. of section, with an elongation of not less than 25 or 30 per cent. (according to the test piece used).

* By permission of the British Engineering Standards Association.

Bursting Strength of Tubes.

Let,

p = bursting pressure in lbs. per sq. in. inside tube;
D = outside diameter of tube in inches;
d = inside " " "

then,

$$p = \frac{D^2 - d^2}{D^2 + d^2} f.$$

Values of f.

Steel (60° F.) . . . 95,000	Wrought iron (60° F.). 50,000	Copper (rolled) (60° F.) . 35,000
" (800° F.)* . . 28,800	Cast iron (60° F.) . . 20,000	" " (640° F.)* 14,700
Brass (rolled) (60° F.) 30,000		

If

t = thickness of tube, and $n = \frac{d}{t}$,

then,

$$p = \frac{2}{n+1+\frac{1}{n+1}} f = \kappa f.$$

TABLE SHOWING VALUES OF κ FOR VARIOUS VALUES OF n.

n	·1	·2	·3	·4	·5	·6	·7	·8	·9	1
κ	·995	·984	·967	·946	·923	·899	·874	·849	·824	·800
n	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2
κ	·776	·753	·731	·710	·690	·670	·651	·634	·616	·600
n	2·1	2·2	2·3	2·4	2·5	2·6	2·7	2·8	2·9	3
κ	·584	·569	·555	·541	·528	·516	·504	·492	·481	·471
n	3·1	3·2	3·3	3·4	3·5	3·6	3·7	3·8	3·9	4
κ	·461	·451	·441	·432	·424	·415	·407	·399	·392	·385
n	4·1	4·2	4·3	4·4	4·5	4·6	4·7	4·8	4·9	5
κ	·378	·371	·364	·358	·352	·346	·340	·335	·330	·324
n	5·1	5·2	5·3	5·4	5·5	5·6	5·7	5·8	5·9	6
κ	·319	·314	·310	·305	·301	·296	·292	·288	·284	·280
n	6·1	6·2	6·3	6·4	6·5	6·6	6·7	6·8	6·9	7
κ	·276	·273	·269	·265	·262	·259	·256	·252	·249	·246
n	7·1	7·2	7·3	7·4	7·5	7·6	7·7	7·8	7·9	8
κ	·243	·240	·238	·235	·232	·229	·227	·224	·222	·220
n	8·1	8·2	8·3	8·4	8·5	8·6	8·7	8·8	8·9	9
κ	·217	·215	·213	·210	·208	·206	·204	·202	·200	·198
n	9·1	9·2	9·3	9·4	9·5	9·6	9·7	9·8	9·9	10
κ	·196	·194	·192	·191	·189	·187	·185	·184	·182	·180
n	11	12	13	14	15	16	17	18	19	20
κ	·166	·153	·142	·133	·125	·117	·111	·105	·0998	·0950
n	21	22	23	24	25	26	27	28	29	30
κ	·0907	·0868	·0832	·0799	·0768	·0740	·0713	·0689	·0666	·0645
n	31	32	33	34	35	36	37	38	39	40
κ	·0625	·0606	·0588	·0571	·0555	·0540	·0526	·0513	·0500	·0488
n	41	42	43	44	45	46	47	48	49	50
κ	·0476	·0465	·0454	·0444	·0435	·0425	·0417	·0408	·0400	·0392
n	51	52	53	54	55	56	57	58	59	60
κ	·0384	·0377	·0370	·0364	·0357	·0351	·0345	·0339	·0333	·0328

* *Durston.* *(H. R. Kempe.)*

EXAMPLE (1).—What is the bursting strength of a wrought-iron tube whose bore is 2 ins. (d), and thickness ·1 inch (t)?

$$n = \frac{d}{t} = \frac{2}{\cdot 1} = 20.$$

κ corresponding to 20 is ·095; therefore

$$p = \cdot 095 \times 50{,}000 = 4{,}750 \text{ lbs per sq. in.}$$

If the value of n is not a number whose exact value can be found in the table, then multiply the excess which n has above the next lower value in the table by the difference between the value of κ corresponding to this lower value and the next higher value; then add the result to the lower value of κ, thus:

EXAMPLE (2).—What is the bursting strength of a wrought-iron tube whose bore is 2 ins. (D.), and thickness 1·2 ins. (t)?

$$n = \frac{D}{t} = \frac{2}{1 \cdot 2} = 1 \cdot 67;$$

next lower value of n in the table is 1·6, and

Excess of 1·67 over 1·6 = ·07. Value of κ corresponding to 1·6 = ·670.

Next higher value of κ = ·651;

then

·670 − ·651 = ·019; ·019 × ·07 = ·00133; ·00133 + ·651 = ·65233, the required value of κ;

therefore bursting strength p is

$$p = \cdot 652 \times 50{,}000 = 32{,}600 \text{ lbs. per sq. in.}$$

Values of p for values of $\frac{d}{t}$ exceeding 60 may be calculated very approximately by the formula

$$p = \frac{2}{n+1}, \text{ or } \frac{2t}{d+t}.$$

EXAMPLE (3).—What is the bursting strength of a steel tube 3 ins. in bore and ·045 inch thick?

$$p = \frac{2 \times \cdot 045}{3 + \cdot 045} \times 95{,}000 = \cdot 0296 \times 95{,}000 = 2{,}810 \text{ lbs. per sq. in.}$$

If t is *very* small compared with d, then

$$p = \frac{2t}{d}.$$

Strength of Steel Tubes.

1. The length of tube, between transverse joints tending to hold it to a circular form, has no practical influence upon the collapsing pressure of a commercial lap-welded steel tube so long as this length is not less than about six diameters of tube.

2. The formulæ, as based upon the present research, for the collapsing pressure of modern lap-welded Bessemer steel tubes are as follows:—

$$P = 1{,}000\left(1 - \sqrt{1 - 1{,}600\,\frac{t^2}{d^2}}\right) \quad \text{(A)} \qquad P = 86{,}670\,\frac{t}{d} - 1{,}386 \quad \text{(B)}$$

where,

P = collapsing pressure, in pounds per square inch; d = outside diameter of tube in inches; t = thickness of wall in inches.

Formula (A) is for values of P less than 580 lbs., or for values of $\frac{t}{d}$ less than 0·023, while formula (B) is for values greater than these.

These formulæ, while strictly correct for tubes that are 20 ft. in length between transverse joints tending to hold them to a circular form, are at the same time substantially correct for all lengths greater than about six diameters. They have been tested for seven diameters, ranging from 3 ins. to 10 ins., in all obtainable commercial thicknesses of wall, and are known to be correct for this range.

3. For the most favourable practical conditions—viz. when the tube is subjected only to stress due to fluid pressure, and only the most trivial loss could result from its failure—a factor of safety of 3 would appear sufficient.

4. When only a moderate amount of loss could result from failure, use a factor of 4.

5. When considerable damage to property and loss of life might result from a failure of the tube, then use a factor of safety of 6.

6. When the conditions of service are such as to cause the tube to become less capable of resisting collapsing pressure, such as the thinning of wall due to corrosion, the weakening of the material due to overheating, the creating of internal stress in the wall of the tube due to unequal heating, vibration, etc., the above factors of safety should be increased in proportion to the severity of these actions. (*R. T. Stewart.*)

Strength of Lead Pipes.

Internal diameter in ins.	⅛	¼	¾	1	1¼	1½	2
Thickness in ins.	·2	·2	·22	·2	·21	·24	·21
Weight per ft.	2·3	2·6	3·8	4·1	5·3	7·1	9·2
Bursting pressure in lbs. per sq. in.	1,579	1,349	1,191	911	683	734	498

(*Kirkaldy.*)

Allowable Pressure in Thick Hollow Cylinders.

If

P = allowable pressure in lbs. per sq. in.; S_t = allowable working stress of the material in lbs. per sq. in.; K = ratio of the external diameter to the internal diameter; then

$$\frac{P}{S_t} = 0{\cdot}6\,\frac{K^2 - 1}{K^2}.$$

(*Gilbert Cook and Andrew Robertson,* '*Engineering,*' Dec. 15, 1911.)

Chart for Computing Allowable Pressure in Thick Hollow Cylinders.

The chart, fig. 408, prepared by Herman Steiger from the foregoing formula, may be used to determine the allowable pressure for a given cylinder, or to determine the dimensions of a cylinder for a given internal pressure.

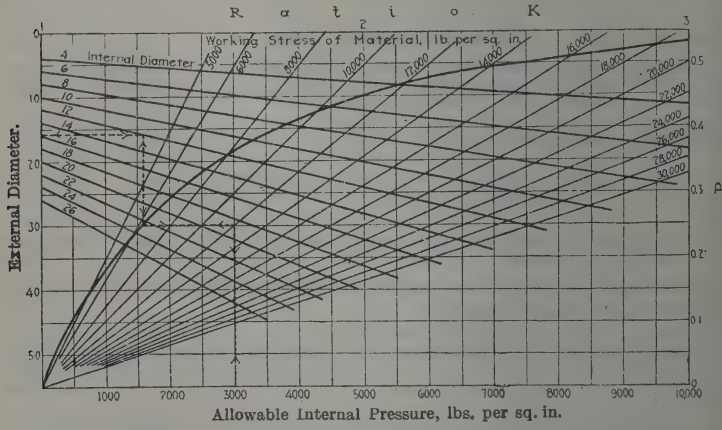

Fig. 408.

Example 1.—Suppose a steel cylinder is 16 ins. outside diameter and 12 ins. inside diameter, and the metal is good for 12,000 lbs. per sq. in. working stress. It is desired to find the allowable

internal pressure.—From the given external diameter, 16 ins., on the vertical scale move horizontally, as shown by the dotted line, to the line marked 12 ins. internal diameter. From this point move vertically to the heavy curved line and then horizontally to the line marked 12,000 lbs. working stress. Directly below this point read off the allowable pressure on the horizontal scale, 3,000 lbs. per sq. in.

Example 2.—Suppose it is desired to know the thickness of a cylinder to stand 3,000 lbs. per sq. in. pressure when the internal diameter is 12 ins. and the allowable stress is 12,000 lbs. per sq. in.—From the 3,000-lb. point on the horizontal scale move upward to the 12,000-lb. stress line and then horizontally to the curved line. From here move vertically to the 12-in. internal diameter line and read off the external diameter, 16 ins., on the left-side scale. (' *Power.*')

Strength of Iron Chains.

(*Abstract, Safety Pamphlet No.* 3 ; ' *The use of Chains and other Lifting Gear.*' *Issued by the Home Office.*) *

Ordinary short-link or close-link chains usually have links (fig. 1) with an overall length of four and a half times, and a breadth of three and a quarter times the diameter of the bar. For chains designed to stand severe shocks, links with slightly oval sides, as in fig. 2, instead of with straight sides, as in fig. 1, should be adopted ; they give the chain greater elasticity.

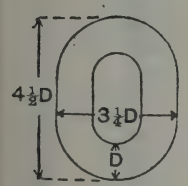

FIG. 1.—Straight-Sided Link.

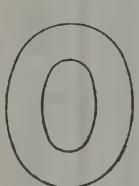

FIG. 2.—Oval Link.

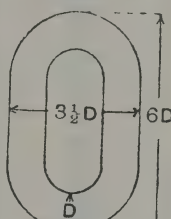

FIG. 3.—Long Link.

A cheaper but weaker form of link (fig. 3) is sometimes used for packing chains and for light foundry chains in cases where it is required to hitch a hook in any link. The links of such chains have an outside length of six times and an outside breadth of three and a half times the diameter of the bar.

The Ultimate Strength of Chain Iron.

The ultimate strength of chain iron varies from 21 to 25 tons per sq. in., but a reduction in strength results from welding and bending action in a link, so that the breaking stress in actual tests is about 15·5 tons per sq. in. for close-link crane chain. Based on this, the breaking strength of this class of chain is obtained by the formula $W = \frac{15 \cdot 5}{2} \pi d^2 = 24d^2$ tons (approximately).

This corresponds very closely with the standard adopted by the Admiralty, War Office, railway and dock companies, and with that specified in the Anchors and Chain Cables Act, 1899, for short-link chain cables, but most authorities agree that *short-link or close-link lifting chains of good quality should have a minimum strength of approximately* $27d^2$ *tons*, for chains up to 1½ in. diameter, but slightly less for chains exceeding this diameter (*see* Table A, p. 304).

Safe Working Loads for Chains.

The tensile test loads, generally known as the Admiralty Proof Loads, are approximately equal to $12d^2$ tons for short-link cable where, d is the diameter in inches of the iron of the chain.

The safe working load generally adopted for close-link welded chains is one-half the proof load, i.e. *the safe working load S.L.* $= 6d^2$ *tons*. With chain having a breaking strength of $27d^2$

* His Majesty's Stationery Office, Imperial House, Kingsway, London, W.C. 2.

tons this allows a factor of safety * of 4·5, which may be regarded as satisfactory if the chain is not subjected to shock or any abnormal use.

TABLE A.

BREAKING, PROOF, AND MAXIMUM WORKING LOADS FOR SHORT-LINK CHAINS.

Size of Chain. Diameter of Iron in ins. (1)	Minimum Breaking Load. Tons. (2)	Proof Load. Tons. (3)	Maximum Working Load. Tons. (4)	Size of Chain. Diameter of Iron in ins. (1)	Minimum Breaking Load. Tons. (2)	Proof Load. Tons. (3)	Maximum Working Load. Tons. (4)
$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{10}$	$1\frac{3}{8}$	51	$22\frac{5}{8}$	$11\frac{3}{10}$
$\frac{5}{16}$	1	$\frac{2}{5}$	$\frac{1}{5}$	$1\frac{7}{16}$	$55\frac{1}{2}$	$24\frac{3}{4}$	$12\frac{1}{4}$
$\frac{3}{8}$	$1\frac{7}{10}$	$\frac{3}{5}$	$\frac{2}{5}$	$1\frac{1}{2}$	$60\frac{1}{2}$	27	$13\frac{1}{2}$
$\frac{7}{16}$	$2\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{5}$	$1\frac{9}{16}$	$63\frac{1}{2}$	$29\frac{1}{2}$	$14\frac{2}{5}$
$\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{5}$	$1\frac{5}{8}$	$68\frac{1}{2}$	$31\frac{5}{8}$	$15\frac{1}{5}$
$\frac{9}{16}$	$5\frac{1}{8}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{11}{16}$	$73\frac{3}{4}$	$34\frac{1}{10}$	17
$\frac{5}{8}$	$6\frac{3}{4}$	3	$1\frac{1}{2}$	$1\frac{3}{4}$	$79\frac{1}{2}$	$36\frac{3}{4}$	$18\frac{3}{5}$
$\frac{11}{16}$	$8\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{13}{16}$	$85\frac{3}{4}$	$39\frac{2}{3}$	$19\frac{7}{10}$
$\frac{3}{4}$	$10\frac{1}{2}$	$4\frac{5}{8}$	$2\frac{3}{10}$	$1\frac{7}{8}$	$91\frac{3}{4}$	$42\frac{1}{2}$	21
$\frac{13}{16}$	$12\frac{7}{10}$	$5\frac{5}{8}$	$2\frac{1}{5}$	$1\frac{15}{16}$	$97\frac{5}{8}$	45	$22\frac{1}{2}$
$\frac{7}{8}$	15	$6\frac{3}{4}$	$3\frac{3}{8}$	2	100	48	24
$\frac{15}{16}$	$17\frac{3}{4}$	$7\frac{9}{10}$	$3\frac{9}{10}$	$2\frac{1}{16}$	106	51	$25\frac{1}{2}$
1	$20\frac{3}{5}$	$9\frac{1}{8}$	$4\frac{3}{8}$	$2\frac{1}{8}$	$112\frac{3}{4}$	54	27
$1\frac{1}{16}$	$23\frac{3}{4}$	$10\frac{1}{2}$	$5\frac{1}{4}$	$2\frac{3}{16}$	$119\frac{1}{2}$	$57\frac{1}{2}$	$28\frac{5}{8}$
$1\frac{1}{8}$	27	12	6	$2\frac{1}{4}$	$126\frac{1}{4}$	$60\frac{3}{4}$	$30\frac{3}{8}$
$1\frac{3}{16}$	$30\frac{1}{5}$	$13\frac{1}{2}$	$6\frac{3}{4}$	$2\frac{5}{16}$	$133\frac{1}{2}$	64	32
$1\frac{1}{4}$	$34\frac{1}{10}$	$15\frac{1}{8}$	$7\frac{3}{5}$	$2\frac{3}{8}$	$140\frac{3}{4}$	$67\frac{1}{2}$	$33\frac{3}{4}$
$1\frac{5}{16}$	38	$19\frac{9}{10}$	$8\frac{2}{5}$	$2\frac{7}{16}$	$149\frac{1}{2}$	$71\frac{1}{4}$	$35\frac{5}{8}$
$1\frac{3}{8}$	$42\frac{1}{2}$	$18\frac{3}{4}$	$9\frac{3}{8}$	$2\frac{1}{2}$	156	75	$37\frac{1}{2}$
$1\frac{5}{16}$	$47\frac{7}{10}$	$20\frac{5}{8}$	$10\frac{3}{10}$				

Where there is any special risk to life or limb a maximum safe working load of $5d^2$ tons should be adopted, and where chains are subjected to shock or heavy wear, or work over pulleys, or are used for lifting vessels containing molten metal or heated liquids, the safe working load should not exceed $3 \cdot 5d^2$ tons.

The maximum safe working load for a long-link chain (fig. 3) *should not exceed two-thirds of that for a short-link chain of the same diameter.*

RINGS.

(1.)

The opening of a ring is determined, to some extent, by the size of the hook or shackle upon which it is to be placed, as this should be sufficient to allow the ring to hang freely and without jamming the end links of any attached chains.

Rings attached to sling chains are usually made with a mean diameter of four to five times the diameter of the iron forming the ring.

A ring must be sufficiently strong to carry safely a load equal to the sum of the safe loads of all the attached chains, and, moreover, must be capable of standing the total proof loads of these chains without deformation. When a proof load is applied to a chain, it causes a slight elonga-

* As a result of experiments on chains carried out at Illinois University, the National Safety Council of the United States of America has recommended that the safe working load for chains should not exceed $0 \cdot 4fd^2$ where f is the safe tensile stress of the material; for good wrought iron this may be taken as 7 tons per sq. in., hence the safe working load would be $2 \cdot 8d^2$ tons, which allows a factor of safety of over 9, i.e. about twice the factor of safety generally adopted in this country.

tion, but this is not objectionable, because in use the load on the links is always applied in the same direction, but a ring is liable to be turned round, and hence deformation must be avoided.

If the safe working load for a ring (fig. 4) is regarded as one-half the proof load; then if D = mean diameter of ring and d_1 = diameter of the iron of the ring, the *maximum safe load can be calculated* by the formula S.L. = $10\ \frac{d_1^3}{D}$ tons. This should also be equal to the maximum safe load of the attached chain, i.e. $6d^2$ where d is the diameter of iron in the chain links.

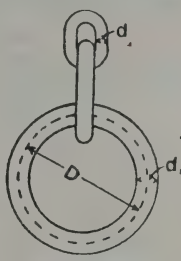

FIG. 4.—Ring.

(2.)

(Engineering Experiment Station of the University of Illinois, U.S.A.)

The connecting ring must be designed to resist the same safe load as the chain. The following formula is recommended :—

where $$P = \frac{0{\cdot}617Fd^3}{D}$$

P = safe load; d = diameter of stock in rung;
F = fibre stress of material used; D = main diameter of ring.

SWIVELS.

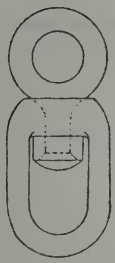
FIG. 5.—Swivel.

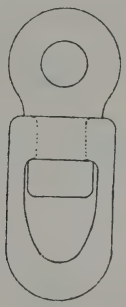
FIG. 6.—Weldless Swivel.

The Board of Trade Regulations * for testing chain cables, etc., require that the various parts of a swivel shall be of the following proportions: 'The diameter of the iron in the common link being regarded as unity, the diameter of the iron in the eye of the swivel must be at least $1\frac{1}{4}$; the diameter of the iron in the pin at the bottom of the thread must be $1\frac{1}{8}$; the diameter of the iron in the crown of the bow piece must be $1\frac{1}{2}$; the depth of the bow piece where bearing on the swivel nut must be $1\frac{1}{8}$; the diameter of the nut of the swivel pin must be $1\frac{1}{8}$. The swivel pin should be screwed to the Whitworth standard and the nut secured thereto by welding it to the end of the pin or by fitting a tapered locking pin.'

The nut or collar on the shank of a swivel must be rigidly secured so that it cannot work loose; and if the shank is riveted at the end an ample countersink must be allowed in the collar so that the metal cannot be sheared and the shank pulled through.

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* The Anchors and Chain Cables Act, 1899, with Regulations as to Testing, Scale of Maximum Charges, etc., issued by Board of Trade—to be obtained from H.M. Stationery Office, Imperial House, Kingsway, London, W.C.2.

SLINGS

The values of T for different values of W from $\frac{1}{4}$ to 20 tons, calculated for different angles between the legs, and the size of chain necessary to lift these loads safely, without the tension exceeding a safe working load of $6d^2$ tons, is given in Table B. Table C shows the actual loads, calculated from the formula $W = 12d^2 \times \frac{AO}{AB}$ which can be safely lifted by slings of different sizes when used with two legs at various angles.

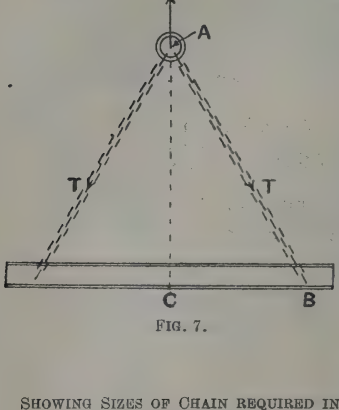
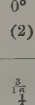
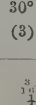
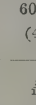
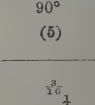
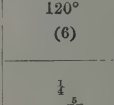
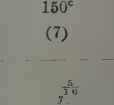


FIG. 7.

Thus it will be seen from Table B that a load of 5 tons can be safely lifted with a two-legged sling of $\frac{11}{16}$ in. chain if the angle between the legs does not exceed 30°, but when the angle is increased to 90° a $\frac{13}{16}$ in. chain is required, whilst with an angle of 150°, i.e. the sling nearly flat, a $1\frac{5}{16}$ in. chain is required if the tension in the chain is not to exceed the safe load $6d^2$ tons. Again, Table C shows that, whereas a two-legged sling made from good quality 1 in. chain can safely lift a load of 12 tons if the sling legs are vertical, the load should not exceed 10·35 tons if the legs are at an angle of 60° nor more than 6 tons with an angle of 120°.

TABLE B.

SHOWING SIZES OF CHAIN REQUIRED IN TWO-LEGGED SLINGS WHEN TENSION DOES NOT EXCEED SAFE LOADS.

Total Load. Tons.	Diameter of Chains in Ins. for given Angles between Legs.					
						
	0°	30°	60°	90°	120°	150°
(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$
$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
$\frac{3}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$
1	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{5}{8}$
$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{3}{4}$
2	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{13}{16}$
$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$		$\frac{9}{16}$	$\frac{5}{8}$	$\frac{15}{16}$
3	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	1
4	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$1\frac{3}{16}$
5	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$1\frac{5}{16}$
6	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{13}{16}$	$1\frac{7}{16}$
8	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{15}{16}$	1	1	$1\frac{9}{16}$
10	$\frac{15}{16}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{13}{16}$
12	1	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{5}{16}$	2
14	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{7}{16}$	$2\frac{1}{8}$
16	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{9}{16}$	$2\frac{5}{16}$
18	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{11}{16}$	$2\frac{7}{16}$
20	$1\frac{5}{16}$	$1\frac{5}{16}$	$1\frac{7}{16}$	$1\frac{9}{16}$	$1\frac{7}{8}$	$2\frac{5}{8}$

Many large users of chains issue to their employees printed rules containing instructions as to the use of multiple slings and the loads which can safely be lifted at various angles of the legs. In some cases a rule is adopted that the horizontal distance between the points of attachment of the load shall not exceed the length of sling leg; this means, in effect, that the angle between the legs must not exceed 60°.

This is a simple rule which can be readily followed by the slinger, but it makes it necessary always to provide chains which can safely lift any particular load at this opening of the sling legs. Thus, to lift a load of 12 tons, $1\frac{1}{8}$ in. chains should be used.

TABLE C.

SAFE WORKING LOADS FOR TWO-LEGGED SLINGS.

Chain Diameter. Ins.	Safe Working Loads in Tons and Cwts. for given Angles between Legs.					
	0°	30°	60°	90°	120°	150°
(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\frac{3}{16}$	0–8	0–8	0–7	0–5	0–4	0–2
$\frac{1}{4}$	0–15	0–14	0–13	0–10	0–7	0–3
$\frac{5}{16}$	1–3	1–2	1–0	0–16	0–11	0–5
$\frac{3}{8}$	1–13	1–12	1–9	1–3	0–16	0–8
$\frac{1}{2}$	3–0	2–17	2–12	2–2	1–10	0–15
$\frac{5}{8}$	4–13	4–10	4–0	3–6	2–6	1–4
$\frac{3}{4}$	6–15	6–10	5–17	4–15	3–7	1–14
$\frac{7}{8}$	9–3	8–17	7–18	6–9	4–11	2–7
1	12–0	11–11	10–7	8–9	6–0	3–1
$1\frac{1}{8}$	15–3	14–12	13–2	10–14	7–11	3–18
$1\frac{1}{4}$	18–15	18–2	16–5	13–5	9–7	4–16
$1\frac{3}{8}$	22–13	21–17	19–12	16–0	11–7	5–17
$1\frac{1}{2}$	27–0	26–1	23–8	19–1	13–0	6–19
$1\frac{5}{8}$	31–12	30–12	27–8	22–8	15–16	8–3
$1\frac{3}{4}$	36–15	35–9	31–16	25–19	18–7	9–9
$1\frac{7}{8}$	42–3	40–14	36–10	29–16	21–1	10–17
2	48–0	46–8	41–11	33–18	24–0	12–7
$2\frac{1}{4}$	54–2	52–6	46–18	38–5	27–1	13–19
$2\frac{1}{2}$	60–15	58–12	52–12	42–19	30–7	15–13
$2\frac{3}{4}$	67–12	65–6	58–12	47–16	33–16	17–8
$2\frac{1}{2}$	75–0	72–9	65–0	53–0	37–10	19–7

A few firms allow double slings to be used for the normal working load, provided the angle between the legs does not exceed 90°. This is an unsafe practice, as at this angle the tension in each leg is 0·7 times the total load, and unless the normal working load for the sling is taken with a very ample factor of safety the chains may be overstrained.

Shortening Slings.—Chain slings should never be shortened by tying the chain into a knot, a method frequently adopted, but one which causes excessive bending stresses in some of the links, and may result in permanent injury or fracture. If it is necessary to shorten a chain a suitable adjuster should be used, and the links bearing the load will then be subjected only to their normal stresses.

TESTING.

TABLE D.
ORDER BY THE BOARD OF TRADE.

Tests for Short-Link Chain Cables.

Order of the Board of Trade dated June 26, 1900, *under s.* 8 *of the Anchors and Chain Cables Act*, 1899.
Short-Link Chain Cables.

Breaking and Tensile Strains.

Diameter of Iron Common Links. (1)	Breaking strain which 3 links in each 15 fathoms must withstand previous to the tensile strain being applied. (2)	Tensile strain to be applied to every 15 fathoms separately. (3)	Diameter of Iron Common Links. (1)	Breaking strain which 3 links in each 15 fathoms must withstand previous to the tensile strain being applied. (2)	Tensile strain to be applied to every 15 fathoms separately. (3)
Ins.	Tons.	Tons.	Ins.	Tons.	Tons.
2	96	48	$1\frac{3}{32}$	$28\frac{6}{10}$	$14\frac{3}{10}$
$1\frac{31}{32}$	93	$46\frac{1}{2}$	$1\frac{1}{16}$	27	$13\frac{1}{2}$
$1\frac{15}{16}$	90	45	$1\frac{1}{32}$	$25\frac{1}{2}$	$12\frac{3}{4}$
$1\frac{29}{32}$	$87\frac{9}{10}$	$43\frac{9}{10}$	1	24	12
$1\frac{7}{8}$	$84\frac{1}{2}$	$42\frac{1}{2}$	$\frac{31}{32}$	$22\frac{1}{2}$	$11\frac{1}{4}$
$1\frac{27}{32}$	$81\frac{1}{2}$	$40\frac{3}{4}$	$\frac{15}{16}$	21	$10\frac{1}{2}$
$1\frac{13}{16}$	$78\frac{8}{10}$	$39\frac{4}{10}$	$\frac{29}{32}$	$19\frac{6}{10}$	$9\frac{8}{10}$
$1\frac{25}{32}$	76	38	$\frac{7}{8}$	$18\frac{1}{2}$	$9\frac{1}{4}$
$1\frac{3}{4}$	$73\frac{1}{2}$	$36\frac{1}{2}$	$\frac{27}{32}$	17	$8\frac{1}{2}$
$1\frac{23}{32}$	$70\frac{8}{10}$	$35\frac{4}{10}$	$\frac{13}{16}$	$15\frac{8}{10}$	$7\frac{9}{10}$
$1\frac{11}{16}$	$68\frac{1}{2}$	$34\frac{1}{2}$	$\frac{25}{32}$	$14\frac{6}{10}$	$7\frac{3}{10}$
$1\frac{21}{32}$	$65\frac{9}{10}$	$32\frac{9}{10}$	$\frac{3}{4}$	$13\frac{1}{2}$	$6\frac{3}{4}$
$1\frac{5}{8}$	$63\frac{1}{2}$	$31\frac{5}{8}$	$\frac{23}{32}$	$12\frac{1}{2}$	$6\frac{1}{4}$
$1\frac{19}{32}$	$60\frac{8}{10}$	$30\frac{4}{10}$	$\frac{11}{16}$	$11\frac{1}{2}$	$5\frac{5}{8}$
$1\frac{9}{16}$	$58\frac{1}{2}$	$29\frac{1}{2}$	$\frac{21}{32}$	$10\frac{1}{2}$	$5\frac{1}{4}$
$1\frac{17}{32}$	$56\frac{1}{2}$	$28\frac{1}{2}$	$\frac{5}{8}$	$9\frac{1}{2}$	$4\frac{5}{8}$
$1\frac{1}{2}$	54	27	$\frac{19}{32}$	$8\frac{4}{10}$	$4\frac{2}{10}$
$1\frac{15}{32}$	$51\frac{3}{4}$	$25\frac{7}{8}$	$\frac{9}{16}$	$7\frac{1}{2}$	$3\frac{3}{4}$
$1\frac{7}{16}$	$49\frac{1}{2}$	$24\frac{3}{4}$	$\frac{17}{32}$	$6\frac{3}{4}$	$3\frac{3}{8}$
$1\frac{13}{32}$	$47\frac{4}{10}$	$23\frac{7}{10}$	$\frac{1}{2}$	6	3
$1\frac{3}{8}$	$45\frac{1}{2}$	$22\frac{5}{8}$	$\frac{15}{32}$	$5\frac{1}{2}$	$2\frac{5}{8}$
$1\frac{11}{32}$	$43\frac{1}{2}$	$21\frac{5}{8}$	$\frac{7}{16}$	$4\frac{1}{2}$	$2\frac{1}{4}$
$1\frac{5}{16}$	$41\frac{1}{2}$	$20\frac{5}{8}$	$\frac{13}{32}$	$3\frac{8}{10}$	$1\frac{9}{10}$
$1\frac{9}{32}$	$39\frac{1}{4}$	$19\frac{5}{8}$	$\frac{3}{8}$	$3\frac{1}{4}$	$1\frac{5}{8}$
$1\frac{1}{4}$	$37\frac{1}{2}$	$18\frac{3}{4}$	$\frac{11}{32}$	$2\frac{6}{10}$	$1\frac{4}{10}$
$1\frac{7}{32}$	$35\frac{6}{10}$	$17\frac{8}{10}$	$\frac{5}{16}$	$2\frac{1}{4}$	$1\frac{1}{8}$
$1\frac{3}{16}$	$33\frac{3}{10}$	$16\frac{9}{10}$	$\frac{9}{32}$	$1\frac{8}{10}$	$\frac{9}{10}$
$1\frac{5}{32}$	32	16	$\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{4}$
$1\frac{1}{8}$	$30\frac{1}{4}$	$15\frac{1}{8}$			

NOTES.

(4) The maximum working load for any short or close-link chain should not exceed $6d^2$ tons, when used under normal conditions without hook; $5d^2$ tons where there is any special danger to life or limb, or $3{\cdot}5d^2$ tons where the chain is subjected to shock or heavy wear, or is used for lifts of molten metal or heated liquid; d being the diameter in inches of the iron of the chain. The maximum working load for a long-link chain should not exceed two-thirds of that for a short-link chain of the same diameter.

(5) When chain slings with two or more legs are used with the legs inclined, care should be taken to ensure that the maximum load in each leg does not exceed that given in recommendation (4) above—see also table.

(8) Slings or other chains should never be shortened by tying knots in them; and wood or other suitable packing should be provided to prevent the links coming in contact with corners of loads of hard material.

(11) All chains and other lifting appliances should—(*a*) If used for lifting in connection with molten metal or molten slag, be examined at least once in every month and be annealed at least once in every six months; or (*b*) if used in connection with lifting machinery or plant operated mechanically or electrically, or used for lifting in metal foundries other than that mentioned in paragraph (*a*) above, be examined at least once in every three months and be annealed at least once in every twelve months; or (*c*) if used for classes of lifts other than those mentioned in (*a*) and (*b*) above, e.g., in connection with hand cranes, be examined at least once in every six months and be annealed at least once in every two years; or (*d*) if used for holding down any crane or other lifting machinery upon a stage or platform should be examined as far as reasonably practicable, *in situ*, at least once in every three months, and be fully examined and annealed at least once in every twelve months, unless the nature of the operations preclude such examinations and annealing.

(12) A chain or other appliance should not be used for lifting its maximum working load if the wear at any part exceeds 10 per cent. of the nominal dimension of that part, or for lifting any load if it has been subjected to a severe shock or is deformed or otherwise injured.

(13) A chain or other appliance which has been altered or repaired should be re-tested before use.

Annealing Wrought Iron Chains.*

Surface hardening, caused by repeated small blows due to inter-link action, chafing, rattling, etc., is the principal cause of brittleness, and low-temperature annealing is the most practical method of correction.

The chain should be placed in a muffle furnace and uniformly heated to a temperature of 650° C. A lower temperature is unsuitable and may be detrimental. The chain should then be cooled slowly either in the furnace or under a layer of non-conducting material. Slow cooling is most important.

After annealing, the chain should be cleaned by brushing, and each link examined for faulty welds, cracks, etc.

Strength of Ropes.†

The following rules are useful for roughly estimating the safe working loads for ropes:

Steel Ropes.

C = Circumference of rope in inches; S = Safe working load in tons.

$$S = C^2 \div 2.$$

Hemp Ropes.

C = Circumference of rope in inches; S = Safe working load in cwts.

$$S = C^2.$$

From a series of 368 tests of Manila rope in sizes from $\frac{1}{2}$ in. to $4\frac{1}{2}$ in. diameter carried out at the United States Bureau of Standards during the past three or four years it has been found that the average breaking strength of a three-strand regular lay rope is very closely represented by the formula

$$L = 5000\, d\,(d + 1).$$

Testing Manila Rope.

This test has been adopted by the United States Bureau of Standards: Free the rope from oil, soak it for 20 seconds in a solution of bleaching powder acidulated with acetic acid, rinse in water and then in alcohol, and finally expose the fibres of the rope for a minute to the fumes of ammonia. Manila fibre turns russet brown, while all other rope fibres turn a cherry red.

Preservation of Manila and Wire Ropes.

Manila ropes and slings and wire cables through neglect do not last as long as they should, because they are allowed to decay and rust, and apart from the waste of not preserving them they are a source of accidents. Ordinary ropes should be painted over with beeswax and resin,

* 'Notes on the Annealing and Use of Wrought-Iron Chains,' H.M. Stationery Office, Adastral House, Kingsway, W.C. 2, price 1*d.* net.

† See paper read by Mr. Daniel Adamson, M.I.Mech.E., before the Inst. of Mech. Engrs. 1912.

about equal parts of each, melted together, and applied with a paint brush. The rusting of wire cables and ropes is arrested by treating them with a mixture of tallow and oil, seven or eight pounds of melted tallow to a gallon of oil, lime being added, when the mixture is cold, until it is thick. The composition is then applied with a brush.

Hemp ropes may be preserved by dipping them when dry into a solution of 1 oz. of sulphate of copper dissolved in 2½ pints of water, and kept in this solution for four days, afterwards being dried; the rope should then be soaked in a solution of 5 ozs. of soap dissolved in 2½ pints of water, and again dried.

Corrosion of Iron Ropes.

Experience has shown that wire ropes of compound construction, subjected to corrosion influences, are likely to deceive engineers as to the strength remaining in them. Where reduction of diameter or circumference of the rope has taken place, not accounted for by the evidence of wear, the part of the rope under examination should first be fully loaded and then relieved of the load. Any noticeable difference in circumference in these circumstances, and the slackening of the outside wires when the load is off, will indicate that internal corrosion has taken place. The extent of corrosion inside the strand can only be estimated by the slackness of the outside wires. The corrosion between the strands can be further examined by untwisting the rope or displaying the strands sufficiently with a marlin-spike.

SECTION VI

BEAMS — GIRDERS — STRESSES — BENDING MOMENTS — INFLUENCE VALUES — MOMENT OF INERTIA — DEFLECTION — COLUMNS — STANCHIONS — RIVETING — STEEL ROOF FRAMING AND COVERINGS — BRITISH STANDARD SECTIONS

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STRESSES ON BEAMS AND GIRDERS.

When designing framed structures, the external forces (or those acting *on* the structure, are always known or assumed, and from these, and the configuration or design of the structure, the internal stresses set up in the several portions of the structure can be determined.

The external forces may be assumed as acting transversely, i.e., at right angles to the beam, or girder, the supporting forces or reactions necessarily acting parallel to and in the opposite direction to the applied forces. Where any force acts other than transversely, it should be resolved into two component forces, one acting in the direction of the length of the beam (and causing compression or tension throughout the complete cross-section), and the other acting transversely; to obtain the total stress at any section of the beam, the tension or compression due to the former component must be added algebraically to the stress from the transverse component.

The beam or girder, whatever its form may be, will tend to shear transversely, and to bend under any system of loading, and the values of these tendencies at any section are termed the 'shearing stress' and the 'bending moment' values at that particular section.

At any vertical section throughout a beam the shearing stress to be resisted is the algebraic sum of all the vertical forces acting to the right or the left of the section chosen; the forces being reckoned, say, as positive or negative as they act in an upward or downward direction.

For any series of transverse forces W_1, W_2, W_3, etc., acting to one side of the chosen vertical section, the general formula for the shearing stress is :—

$$S = \Sigma W = \pm W_1 \pm W_2 \pm W_3, \text{ etc.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

At any vertical section throughout a beam, the bending moment to be resisted is the algebraic sum of the moments of the several vertical forces acting to the right or left of the chosen section, these moments being reckoned, say, as positive or negative as they tend to turn the beam about the section line in a clock-way or anti-clock way.

Thus, for any series of transverse forces W_1, W_2, W_3, etc., acting at the several horizontal distances l_1, l_2, l_3, etc., from the chosen vertical section, the general formula for the bending moment is :—

$$M = \Sigma(Wl) = \pm W_1 l_1 \pm W_2 l_2 \pm W_3 l_3, \text{ etc.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(In the case of uniformly distributed loads the value W is that for the total load under consideration, the horizontal distance being then measured from the chosen section to the centre of the load.)

Where the supports to a beam are not more than two in number, and the ends of the beam are free, the reactions or supporting loads can readily be found by the law of the lever. These values are then added to the list of external forces, and the shearing forces and bending moment values calculated from formulæ (1) and (2).

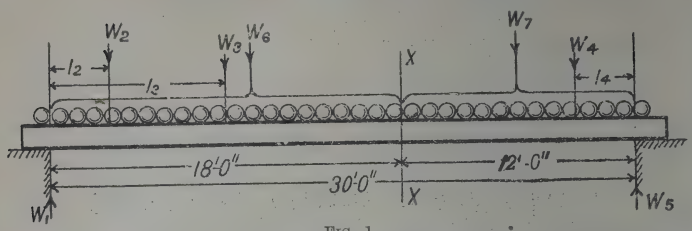


FIG. 1.

EXAMPLE :—A beam 30 ft. clear span between reactions carries three concentrated loads of 150 lbs. each, spaced as shown (fig. 1); weight of beam 60 lbs. per linear foot. l_2, $l_4 = 3'\text{-}0''$, $l_3 = 9'\text{-}0''$.

Reaction, left $= W_1$.		Reaction, right $= W_5$.	
Beam	$= 30 \times 60 \times \frac{1}{2} = 900$ lbs.	$= 30 \times 60 \times \frac{1}{2} = 900$ lbs.	
Load W_2	$= 150 \times \frac{30-3}{30} = 135$,,	$= 150 \times \frac{3}{30} = 15$	,,
,, W_3	$= 150 \times \frac{30-9}{30} = 105$,,	$= 150 \times \frac{9}{30} = 45$	,,
,, W_4	$= 150 \times \frac{30-27}{30} = 15$,,	$= 150 \times \frac{30-3}{30} = 135$	,,
Total $= 1{,}155$ lbs.		Total $= 1{,}095$ lbs.	

Shearing stress at Section XX, fig. 1, calculated from left :—

Formula (1) $S = W_1 - (W_2 + W_3 + W_6)$
$= 1{,}155 - [150 + 150 + (60 \times 18)] = 224$ lbs.

Calculated from right $S = W_5 - (W_4 + W_7)$
$= 1{,}095 - [150 + (60 \times 12)] = 224$ lbs.

Bending moment at Section XX, fig. 1, calculated from left :—

Formula (2) $M = W_1 l_1 - (W_2 l_2 + W_3 l_3 + W_6 l_6)$
$= 1{,}155 \times 18 - [(150 \times 15) + (150 \times 9) + (18 \times 60 \times 9)] = +7{,}470$ ft. lbs.

and from right, $M = -W_5 l_5 + (W_4 l_4 + W_7 l_7)$
$= -1{,}095 \times 12 + [(150 \times 9) + (60 \times 12 \times 6)] = -7{,}470$ ft. lbs.

Graphic diagrams for shear and bending moment values can be drawn so as to represent these values at all points throughout the length of a beam or girder, and such diagrams can always be used when setting out some preliminary or trial design, or checking a design ; when carefully and accurately drawn they can be utilised directly in designing all ordinary structures, thus saving a large amount of time and labour which would be necessary if all required values were calculated arithmetically. Since these diagrams show the variations in stress throughout the beam, they can be further utilised to set out the sections or scantlings of the web and flange members, such as the thickness of the web or shear resisting members, and the cut-off in the flange plates or bending resisting members.

The tables of bending moments and shearing stresses given on pages 318 and 319 embrace all simple conditions for concentrated or uniformly distributed loads. Any complex loading occurring in practice can always be resolved into a series of simple loadings; so that diagrams for each simple loading can be drawn on one base line, and these diagrams combined to produce the required diagram for the complex loading, by adding together the several ordinates at any desired section. An example of this is given in fig. 2.

It should be noted that for any series of concentrated loads the bending moment line will form a polygon, the line changing its direction over each of the loaded points ; at each of these points the shearing stress is suddenly changed in value, and the shearing stress diagram takes a stepped outline. For a uniformly distributed load, the bending moment line is always a parabolic curve, while the shearing stress changes by a regular gradation.

When beams or girders are of varying depth, the diagrams on pages 318 and 319, which are based on the condition of uniform depth, must be adjusted, for the following reason :—By formula (3) it will be obvious that the flange stresses are dependent on the depth, and, in fact, *vary inversely as this depth* ; it is, therefore, necessary to alter the bending moment heights in the *inverse ratio to the alteration in depth of the beam.* Reducing the depth of a beam increases the bending moment value, and necessitates the increasing of the height of the bending moment diagram. Fig. 3 and brief explanation accompanying same will indicate how this adjustment can be readily carried out.

Where the shearing stress diagram is intended to be used in setting out the varying thickness of the web plate of a beam, the shear stress diagram must similarly be adjusted by altering its heights in *inverse ratio to the alteration in depth of the beam*; a shallower girder necessitates a thicker web, when the shear value remains unaltered (see fig. 3).

When these graphic diagrams on pages 318 and 319 are used in connection with panel or lattice girders, a modification is necessary, since the flange stress remains constant between the points of connection of flange to lattice bars; the diagram becomes stepped in outline, and may not be the same in both flanges (see fig. 4).

For the majority of the simple panel or lattice girders met with in practice, the various stresses can be most readily obtained by the reciprocal diagram method or by the method of moments.

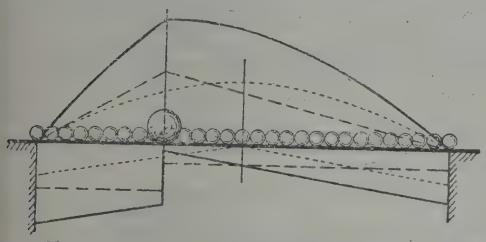


FIG. 2.

This example shows a free-ended beam supporting a uniformly distributed load (see Table 1, type (d)), the bending moment and shearing stress diagrams being indicated by dotted lines; and a single concentrated load (see Table 1, type (e)), the two diagrams being here indicated by broken lines. The combined diagrams for these two loads are shown by full lines, and are got by adding together the two heights at any section, to obtain the new height there.

In some cases, as for girders with fixed ends, negative moments may occur, and these must obviously be added algebraically to the positive moments to obtain the required new combined height.

This figure shows the effect on the bending moment and shearing stress diagrams due to a change in the depth of the girder, and a simple graphic method of indicating this effect on change. The left half of fig. 3 shows diagrams for a free-ended girder of uniform depth carrying a uniformly distributed load (Table 1, type (d)); in the right half of the figure the depth of the girder is reduced as indicated.

From the centre to the first section line the depth is uniform, so that the bending moment line remains unaltered, but beyond this section the *height of diagram must be increased in proportion to the reduction in depth of the girder*. This increase can be obtained graphically thus: — Take the vertical section line at point *a*, and draw any line *ab*; on this line mark off *ab* equal to the centre depth of the girder, and *ac* equal to the reduced depth at this section; join *cd* (*d* being at the point of intersection of original diagram line and section line), and draw *be* parallel to *cd* and cutting the section line at *e*. It is obvious that the new vertical heights *ae* and *ad* are proportionate to the original depth and the reduced depth of the girder, or to the lengths *ab* and *ac*, and consequently the adjusted bending moment diagram must pass through the new point *e*. Repeating this operation at a number of other sections will give a series of new points through which the complete adjusted diagram can be drawn.

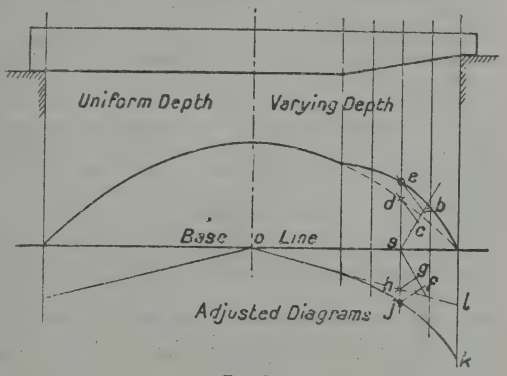


FIG. 3.

Similarly if the shear diagram is to be used for determining the thickness of web plate required, *its depth must first be increased in proportion to the reduction in depth of the girder*, since the sectional area of the web plate is directly proportionate to its depth. Graphically the same operation as above explained can be followed, marking off on the line *af* the lengths *aj* and *ag* equal to the centre and reduced depths of the girder, drawing the lines *gh* and *fj* parallel to one another, and deepening the diagram at this section line to the point *j*. The complete adjusted diagram would take the form of the curved line *oik*.

In determining the stresses on the several members of a lattice girder such as that outlined

in fig. 4, it is assumed that at the junctions between the several members the connections will allow of free movement, as if pin jointed: thus the flanges are assumed as hinged at each junction with the lattices, and no allowance is made for the stiffness due to their being actually formed in one piece.

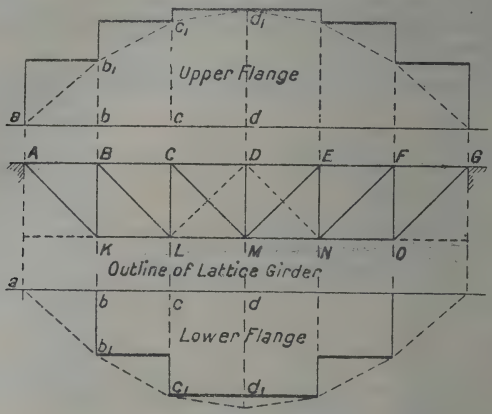


FIG. 4.

This girder rests on abutments at its ends AG, and is loaded at the points BCDEF, say by means of cross girders resting on and fixed to the top flange.

Considering first the load at centre point D, the upper flange does not support it, but the load passes downwards through the vertical strut DM, and is carried by the two inclined ties MC, ME. At the upper ends of these ties the tension due to load at D becomes resolved into compression stress between CE in top flange and compression stress in CL and EN, to which latter stresses must be added a further compression due to loads at points C and E. This transfer of stress is continued to the ends of the girder A and G, the final compression stresses at each end being equal to half the total load, and acting on the bearings at the abutments.

The dotted lines on upper and lower diagrams indicate the bending moment diagrams, and the full lines touching the same show the adjustments necessary owing to the breakage up of flanges and web into a series of members jointed together. The above referred to adjustment is made as follows:—The bending moment diagrams are divided up into sections to correspond with the number of bays in the girder, and as the stress in any section of top or bottom flange must be uniform from joint to joint, the several lines in the diagrams representing the stresses must be parallel to the base line of the diagram throughout the lengths between the joints or junctions between flanges and lattices, all variations in stress taking place suddenly, and being represented by vertical lines in diagram. The stress is the portion AB of upper flange is determined from the moment at point B, and is equal to *bb*; at BC it is equal to *cc*; and at centre portion CDE it is equal to *dd*. Similarly in the lower flange, since the girder is complete without any members extending from K or O to the abutments (as dotted lines), the first stressed bar in lower flange is KL, the amount of stress being determined from height *bb*; the centre portion LMN having its stress determined by the height *cc*; the stress in the two inclined members CM and EM being equal—on the assumption of equal loads at all upper flange joints—must balance one another, and consequently do not affect the lower flange stress at centre.

Influence Value Tables.

It has already been pointed out on page 314 that the several bending moment diagrams given on pages 318 and 319 may be combined to produce one diagram for a series of different loadings.

The same result may be readily obtained, particularly where the value at one particular section is desired, by calculating the bending moment value at that section for each loading and adding the several values together. This process can be much simplified by the use of the tables on pages 320–322, where the value is given of the effect or influence at a series of other points or sections throughout the length of the beam, of a concentrated load applied at certain points. These values are for a load of unit value for a beam of unit length, and for a beam with free ends, with one end fixed, and with both ends fixed: and reactions and inflection points are also noted. The brief notes accompanying the tables will explain their application.

INTERNAL STRESSES.

The tendency of a beam to shear, or to deflect, under any system of loading, is opposed by the resistance of the material of which the beam is composed to shearing, or to tension or compression.

It is the general practice to consider the flanges as resisting the bending moment stresses, the web providing the required shear resistance only.

Considering in the first instance the flange stresses, it is evident, if failure is not to occur, that the moment of resistance at all points in every beam or girder must oppose and balance the bending moment there; this resistance moment is the sum of the moments of all the fibre resistances reckoned about the neutral axis. In a beam of ordinary section the resisting fibres lie at various distances from the neutral axis (owing to the thickness of the flanges); but the simplest case is that of a girder with flanges whose thickness is small in comparison to the depth of the girder, so that without material error all the fibres of one flange may be considered to be practically at one distance from the neutral axis. Thus if d = vertical depth of girder between centres of gravity of the two flanges, M = bending moment due to the external loads, we have the general formula,

$$\pm F = \frac{M}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

F being the horizontal stress in either of the two flanges, being compressive stress in the one and tensile stress in the other.

Where the flanges of a girder are of considerable thickness, in comparison with the depth of the girder, or the beam is of a non-symmetrical or irregular cross-section, the fibres of either flange cannot be considered as practically at one distance from the neutral axis, and it is necessary to take into account the varying distances of the fibres from the neutral axis, in the following manner:—

Under the action of any transverse bending, the intensity of the tensile and compressive stresses varies in different fibres of the beam, being greatest in the extreme fibres at the top and the bottom of the cross-section, while the fibre-stress will be zero at the 'neutral axis.'

Whatever may be the figure of the beam's cross-section, the neutral axis will be a horizontal line drawn through its centre of gravity; and the intensity of the stress in any fibre will be proportional to the vertical distance y of the fibre above or below the neutral axis.

If a denotes the sectional area of any thin layer of fibres lying at the height y above the axis, the total stress in that layer will be proportional to ay, and its moment about the neutral axis will be proportional to $ay \times y = ay^2$. The summation of the quantities ay^2 for the different layers is the so-called 'moment of inertia' of the beam, or

$$I = \Sigma (ay^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

When the bending moment, M, due to the external forces has been found in the manner already described, the problem will often be to find the maximum stress per square inch, f, in the extreme layer of fibres; and if y denotes the vertical distance of that layer from the neutral axis, we have

$$f = \frac{My}{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Where the section of the beam is symmetrical about the neutral axis, as in rolled joists, y = half the vertical depth of the beam between centres of gravity of the two flanges, or $\frac{1}{2}d$, and for such sections the above formula may be written,

$$= \frac{Md}{2I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In the case of cast iron, whose strength in compression is much greater than in tension, the tension flange should be made considerably larger than the compression flange. In rolled steel joists the two flanges are made of equal area, and an approximate value for the moment of resistance may be readily found by adding to the actual area of each flange $\frac{1}{6}$th of the area of the web, and then reckoning the depth d as the depth between the centres of gravity of the two flanges; then with A = area of one flange and $\frac{1}{6}$th web, and F = max. safe stress on steel,

$$\text{Approx. resistance moment} = A \times F \times d \quad . \quad . \quad . \quad . \quad (7)$$

When the thickness of the web is small in comparison with the width of the flanges, the extreme tensile stress, f, under the breaking load, as determined by formula (5), corresponds nearly with the ultimate tensile strength of the material; but should the girder have a very substantial web, or should the section be that of a solid rectangle, the calculated breaking load will generally be found to be lower than the actual breaking load. For such cases see formula on page 324.

TABLE I.—BENDING MOMENTS, SHEARING STRESSES, AND DEFLECTION OF STEEL GIRDERS. Graphic Diagrams and Formulæ.

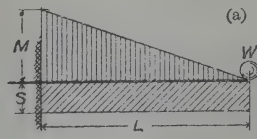
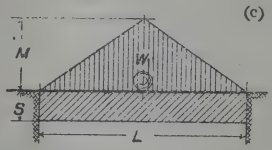
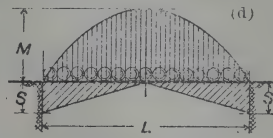
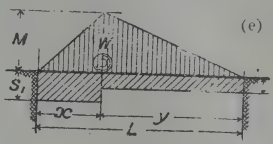
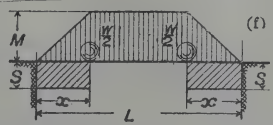
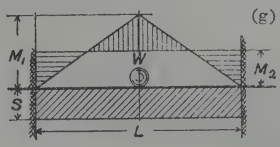
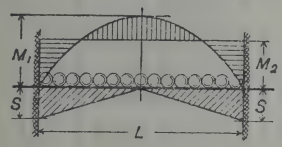
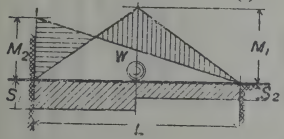
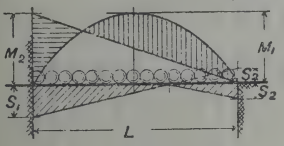
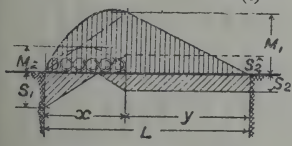
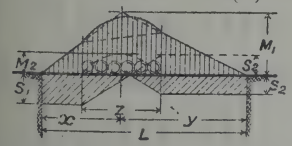
Type.	Formulæ. Bending Moment.	Shearing Stress.	Maximum Deflection.
	$M = WL$	$S = W$	$\frac{WL^3}{3EI}$
	$M = \frac{WL}{2}$	$S = W$	$\frac{WL^3}{8EI}$
	$M = \frac{WL}{4}$	$S = \frac{W}{2}$	$\frac{WL^3}{48EI}$
	$M = \frac{WL}{8}$	$S = \frac{W}{2}$	$\frac{WL^3}{76{\cdot}8EI}$
	$M = \frac{Wxy}{L}$	$S_1 = \frac{Wy}{L}$ $S_2 = \frac{Wx}{L}$	$\frac{Wxy(2L-x)}{27EIL} \times \sqrt{3x(2L-x)}$
	$M = \frac{Wx}{2}$	$S = \frac{W}{2}$	$\frac{Wx(3L^2-4x^2)}{48EI}$
	$M_1 = \frac{WL}{4}$ $M_2 = \frac{WL}{8}$	$S = \frac{W}{2}$	$\frac{WL^3}{192EI}$

TABLE II.—BENDING MOMENTS, SHEARING STRESSES, AND DEFLECTIONS—*contd.*

Type.	Formulæ. Bending Moment.	Shearing Stress.	Maximum Deflection.
(h) 	$M_1 = \frac{WL}{8}$ $M_2 = \frac{WM}{12}$	$S = \frac{W}{2}$	$\frac{WL^3}{384\,EI}$
(i) 	$M_1 = \frac{WL}{4}$ $M_2 = \frac{3}{16}\frac{W}{L}$	$S_1 = \frac{11}{16}W$ $S_2 = \frac{5}{16}W$	$\frac{WL^3}{107{\cdot}3\,EI}$ at a point ·5528 L from Fixed End
(k) 	$M_1 = \frac{WL}{8}$ $M_2 = \frac{WL}{8}$	$S_1 = \frac{5}{8}W$ $S_2 = \frac{3}{8}W$	$\frac{WL^3}{184{\cdot}6\,EI}$ at a point 5785 L from Fixed End
(l) 	$M_1 = \frac{Wxy}{2L}$ $M_2 = \frac{Wx}{8}$	$S_1 = \frac{W\left(y+\frac{x}{2}\right)}{L}$ $S_2 = \frac{Wx}{2L}$	—
(m) 	$M_1 = \frac{Wxy}{L}$ $M_2 = \frac{Wz}{8}$	$S_1 = \frac{Wy}{L}$ $S_2 = \frac{Wx}{L}$	—

NOTE.— *All curves in these tables are parabolic curves.*

For an example of the combination of bending moments and shearing stress diagrams, and adjustment of same, see page 315.

Table III.—Influence Values.

Beam Free at Both Ends.

Load at Section.	Bending Moment Coefficient at Section noted.																		Left end reaction.	Right end reaction.
	·05	·10	·15	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95	
·05	·047	·045	·042	·040	·037	·035	·032	·030	·027	·025	·022	·020	·017	·015	·013	·010	·007	·005	·002	·95	·05
·10	·045	·090	·085	·080	·075	·070	·065	·060	·055	·050	·045	·040	·035	·030	·025	·020	·015	·010	·005	·90	·10
·15	·042	·085	·127	·120	·112	·105	·097	·090	·082	·075	·067	·060	·052	·045	·037	·030	·022	·015	·007	·85	·15
·20	·040	·080	·120	·160	·150	·140	·130	·120	·110	·100	·090	·080	·070	·060	·050	·040	·030	·020	·010	·80	·20
·25	·037	·075	·112	·150	·187	·175	·162	·150	·137	·125	·112	·100	·087	·075	·062	·050	·037	·025	·112	·75	·25
·30	·035	·070	·105	·140	·175	·210	·195	·180	·165	·150	·135	·120	·105	·090	·075	·060	·045	·030	·015	·70	·30
·35	·032	·065	·097	·130	·162	·195	·227	·210	·192	·175	·157	·140	·122	·105	·087	·070	·052	·035	·017	·65	·35
·40	·030	·060	·090	·120	·150	·180	·210	·240	·220	·200	·180	·160	·140	·120	·100	·080	·060	·040	·020	·60	·40
·45	·027	·055	·087	·110	·137	·165	·192	·220	·247	·225	·202	·180	·157	·135	·112	·090	·067	·045	·022	·55	·45
·50	·025	·050	·075	·100	·125	·150	·175	·200	·225	·250	·225	·200	·175	·150	·125	·100	·075	·050	·025	·50	·50
·55	·022	·045	·067	·090	·112	·135	·157	·180	·202	·225	·247	·220	·192	·165	·137	·110	·082	·055	·027	·45	·55
·60	·020	·040	·060	·080	·100	·120	·140	·160	·180	·200	·220	·240	·210	·180	·150	·120	·090	·060	·030	·40	·60
·65	·017	·035	·052	·070	·087	·105	·122	·140	·157	·175	·192	·210	·227	·195	·162	·130	·097	·065	·032	·35	·65
·70	·015	·030	·045	·060	·075	·090	·105	·120	·135	·150	·165	·180	·195	·210	·175	·140	·105	·070	·035	·30	·70
·75	·012	·025	·037	·050	·062	·075	·087	·100	·112	·125	·137	·150	·162	·175	·187	·150	·112	·075	·037	·25	·75
·80	·010	·020	·030	·040	·050	·060	·070	·080	·090	·100	·110	·120	·130	·140	·150	·160	·120	·080	·040	·20	·80
·85	·007	·015	·022	·030	·037	·045	·052	·060	·067	·075	·082	·090	·097	·105	·112	·120	·127	·085	·042	·15	·85
·90	·005	·010	·015	·020	·025	·030	·035	·040	·045	·050	·055	·060	·065	·070	·075	·080	·085	·090	·045	·10	·90
·95	·002	·005	·007	·010	·013	·015	·017	·020	·022	·025	·027	·030	·032	·035	·037	·040	·042	·045	·047	·05	·95

These tables are calculated for a unit load, and for a girder of unit length ; the length of the girder is divided into 20 equal sections and the bending moment values are given at each section point for unit load placed on each section line in turn. For any weight and any length of span it is necessary only to multiply the proper tabular coefficient by the number of units in the load and in the span to obtain the actual

(*Continued on p.* 321).

TABLE IV.—INFLUENCE VALUES.

BEAM FIXED AT RIGHT END.

Load at Section.	Bending Moment Coefficient at Sections noted—(To left of heavy broken line—positive moments; to right—negative).																			Left end reaction.	Right end reaction.	Inflection point.
	·05	·10	·15	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95	1·00			
·05	·046	·042	·039	·035	·031	·027	·024	·020	·016	·012	·009	·005	·001	·002	·006	·010	·014	·017	·021	·025	·925	·075	·333
·10	·042	·085	·078	·070	·063	·055	·048	·040	·033	·025	·018	·010	·003	·005	·012	·020	·027	·034	·042	·049	·851	·149	·331
·15	·039	·078	·116	·105	·094	·083	·072	·061	·050	·038	·027	·016	·005	·007	·018	·030	·041	·054	·066	·073	·777	·223	·328
·20	·035	·070	·106	·141	·126	·111	·096	·082	·067	·052	·037	·023	·008	·007	·022	·037	·051	·066	·081	·096	·704	·296	·324
·25	·032	·063	·095	·127	·158	·140	·122	·103	·085	·066	·048	·030	·011	·007	·025	·044	·062	·081	·099	·117	·633	·367	·319
·30	·028	·056	·085	·113	·141	·169	·147	·125	·103	·082	·060	·038	·016	·006	·027	·049	·071	·093	·114	·136	·564	·436	·313
·35	·025	·050	·075	·099	·124	·149	·174	·148	·123	·098	·073	·048	·025	·002	·028	·053	·078	·103	·128	·153	·497	·503	·305
·40	·022	·043	·065	·086	·108	·129	·151	·173	·144	·116	·087	·059	·031	·002	·026	·054	·083	·111	·140	·168	·432	·568	·296
·45	·018	·037	·055	·074	·092	·111	·129	·148	·167	·135	·104	·072	·041	·009	·020	·053	·085	·116	·148	·179	·371	·629	·285
·50	·016	·031	·047	·063	·078	·094	·109	·125	·141	·156	·122	·087	·053	·019	·016	·050	·084	·119	·153	·187	·313	·687	·273
·55	·013	·026	·039	·052	·065	·077	·090	·103	·116	·129	·142	·105	·068	·031	·006	·043	·080	·118	·155	·192	·258	·742	·258
·60	·010	·021	·031	·042	·052	·062	·073	·083	·094	·104	·114	·125	·085	·045	·006	·034	·074	·113	·152	·192	·208	·792	·243
·65	·008	·016	·024	·033	·041	·049	·057	·065	·073	·082	·090	·098	·106	·064	·022	·020	·062	·104	·146	·188	·162	·838	·224
·70	·006	·012	·018	·024	·030	·036	·042	·049	·055	·061	·067	·073	·079	·085	·041	·003	·047	·090	·135	·178	·122	·878	·203
·75	·004	·009	·013	·017	·021	·026	·030	·034	·039	·043	·047	·052	·056	·060	·064	·019	·027	·072	·118	·164	·086	·914	·179
·80	·003	·006	·008	·011	·014	·017	·020	·022	·025	·028	·031	·034	·036	·039	·042	·045	·003	·050	·097	·144	·056	·944	·153
·85	·002	·003	·005	·006	·008	·010	·011	·013	·014	·016	·018	·019	·021	·022	·024	·026	·027	·021	·070	·118	·032	·968	·122
·90	·001	·001	·002	·003	·004	·004	·005	·006	·006	·007	·008	·009	·009	·010	·011	·012	·012	·013	·036	·085	·015	·985	·087
·95	·000	·000	·001	·001	·001	·01	·001	·001	·002	·002	·002	·002	·002	·003	·003	·003	·003	·003	·003	·046	·004	·996	·046

bending moment value desired. Thus for a load of 2 tons on a girder of 20 feet span the tabular values multiplied by 2×20 will give the actual values in foot tons.

Taking the above load and span, and a free-ended girders, with load at ¼th span (or line ·25) the bending moment under the load and at centre of span will be respectively (·187×2×20) 7·48 and (·125×2×20) 5 foot-tons respectively. For a girder fixed at one end the corresponding values will be (·158×2×20) 6·32 and (·066×2×20) 2·64 foot-tons respectively.

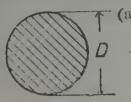
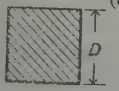
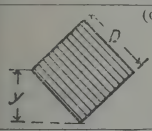
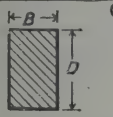
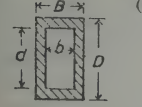
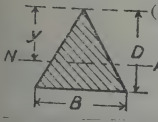
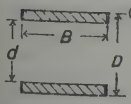
TABLE V.—INFLUENCE VALUES.

BEAM FIXED AT BOTH ENDS.

Load at Section.	Bending Moment Coefficient at Sections noted (outside heavy broken lines—negative moment; inside—positive).																					Left end reaction.	Right end reaction.	Left Infl. pt.	Right Infl. pt.
	0	·05	·10	·15	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95	1·00				
·05	·045	·004	·004	·004	·003	·003	·003	·002	·002	·002	·001	·001	·000	·000	·000	·001	·001	·001	·002	·002	·002	·993	·007	·045	·333
·10	·081	·032	·016	·015	·013	·012	·011	·009	·008	·006	·005	·004	·002	·001	·001	·002	·003	·005	·006	·007	·009	·972	·028	·083	·321
·15	·108	·061	·014	·032	·029	·026	·023	·020	·017	·014	·011	·008	·005	·002	·001	·004	·007	·010	·013	·016	·019	·940	·060	·115	·315
·20	·128	·083	·038	·006	·051	·046	·041	·036	·030	·025	·020	·015	·010	·004	·001	·006	·011	·016	·022	·027	·032	·896	·104	·143	·308
·25	·141	·098	·056	·013	·028	·070	·063	·055	·047	·039	·031	·023	·016	·008	·000	·008	·016	·023	·031	·039	·047	·845	·155	·166	·300
·30	·147	·108	·069	·030	·009	·049	·088	·077	·066	·056	·045	·034	·023	·013	·002	·009	·020	·031	·041	·052	·063	·784	·216	·186	·292
·35	·148	·112	·076	·040	·004	·032	·068	·103	·090	·075	·061	·047	·033	·019	·005	·009	·023	·037	·051	·066	·080	·718	·282	·206	·282
·40	·144	·111	·079	·047	·014	·018	·050	·083	·115	·098	·080	·063	·045	·027	·010	·008	·025	·043	·061	·078	·096	·648	·352	·222	·272
·45	·136	·107	·079	·050	·021	·007	·036	·065	·094	·122	·101	·080	·059	·037	·016	·005	·026	·048	·069	·090	·111	·575	·425	·237	·262
·50	·125	·100	·075	·050	·025	·000	·025	·050	·075	·100	·125	·100	·075	·050	·025	·000	·025	·050	·075	·100	·125	·500	·500	·250	·250
·55	·111	·090	·069	·048	·026	·005	·016	·037	·059	·080	·101	·122	·094	·065	·036	·007	·021	·050	·079	·107	·136	·425	·575	·262	·237
·60	·096	·078	·061	·043	·025	·008	·010	·027	·045	·063	·080	·098	·115	·083	·050	·018	·014	·047	·079	·111	·144	·352	·648	·272	·222
·65	·080	·066	·051	·037	·023	·009	·005	·019	·033	·047	·061	·075	·090	·103	·068	·032	·004	·040	·076	·112	·148	·282	·718	·282	·206
·70	·063	·052	·041	·031	·020	·009	·002	·013	·023	·034	·045	·056	·066	·077	·088	·049	·009	·030	·069	·108	·147	·216	·784	·292	·188
·75	·047	·039	·031	·023	·016	·008	·000	·008	·016	·023	·031	·039	·047	·055	·063	·070	·028	·013	·056	·098	·141	·155	·845	·300	·166
·80	·032	·027	·022	·016	·011	·006	·001	·004	·010	·015	·020	·025	·030	·035	·041	·046	·051	·006	·038	·083	·128	·104	·896	·308	·143
·85	·019	·016	·013	·010	·007	·004	·001	·002	·005	·008	·011	·014	·017	·020	·023	·026	·029	·032	·014	·061	·108	·060	·940	·315	·115
·90	·009	·007	·006	·005	·003	·002	·001	·001	·002	·004	·005	·006	·008	·009	·011	·012	·013	·015	·016	·032	·081	·028	·972	·321	·083
·95	·002	·002	·002	·001	·001	·001	·000	·000	·000	·001	·001	·002	·002	·002	·003	·003	·003	·004	·004	·004	·045	·007	·993	·333	·045

In some cases the values are only approximate, since the tabular values give 3 decimal figures only: for example, in the first calculation the full tabular value would be ·1875, and the accurate result 7·5 foot-tons. The values for a load distributed over a part or the whole of the span may be obtained approximately by assuming the total load as formed of a number of equal loads placed at adjoining section points; the result here would generally be near enough to the true value for all practical purposes.

TABLE VI.—MOMENTS OF INERTIA, SECTIONAL AREA, ETC., FOR VARIOUS SIMPLE SECTIONS.

Section.	Area.	Neutral Axis.	Moment of Inertia.
 (a)	$\frac{\pi D^2}{4}$ $\pi = 3{\cdot}1416$	Through centre	$\frac{\pi D^4}{64}$
(b)	$\frac{\pi(D^2 - d^2)}{4}$	Through centre	$\frac{\pi (D^4 - d^4)}{64}$
 (c)	D^2	Through centre	$\frac{D^4}{12}$
 (d)	D^2	Through centre $y = \frac{D}{1{\cdot}4142}$	$\frac{D^4}{12}$
 (e)	BD	Through centre	$\frac{BD^3}{12}$
 (f)	$BD - bd$	Through centre, parallel to B Through centre, parallel to D	$\frac{BD^3 - bd^3}{12}$ $\frac{DB^3 - db^3}{12}$
 (g)	$\frac{BD}{2}$	$y = \frac{2}{3}D$ Through Base Line, through Apex, and parallel to Base	$\frac{BD^3}{36}$ $\frac{BD^3}{4}$ $\frac{BD^3}{12}$
 (h)	$B(D - d)$	Through centre and parallel to B	$\frac{B(D^3 - d^3)}{12}$

The value for the moment of inertia for the standard steel sections of rolled joists, angles, tees, etc., can be got from the section books issued by many of the rolling-mill companies and constructional engineering contracting firms.

The value for the moment of inertia about any other axis parallel to and at a distance y, from the neutral axis = I for neutral axis + (area $\times$ y^2) . . . . . (8)

The value for the radius of gyration (see page 325, etc.) is $R = \sqrt{\frac{I}{\text{Area}}}$. (9)

Solid Rectangular Beams.

Where the strength can be shown to vary directly as the breadth of the beam and as the square of the depth, it is better, for the reason given above, to calculate the strength by means of coefficients derived from direct experiments in cross-breaking; thus

$$\text{Breaking load in tons} = \frac{\text{Breadth in inches} \times \text{depth in inches}^2}{\text{Span in inches}} \times c \times k \quad . \quad . \quad (10)$$

TABLE VII.

Material	Coeff. c.	Ends of Beams	Coeff. k.
Mild Steel	3·50	One fixed, other end loaded	1
Cast Iron	2·50	,, ,, load distributed	2
Fir (Spruce)	0·60	Both supported, load in centre	4
English Oak	0·75	,, ,, ,, distributed	8
Red Pine	0·65	Both fixed, ,, in centre	6
Yellow Pine	0·50	,, ,, ,, distributed	12
Pitch Pine	0·75		

The factor of safety for steel may be $\frac{1}{4}$th to $\frac{1}{5}$th breaking load; for the other materials it may vary between $\frac{1}{5}$th and $\frac{1}{7}$th breaking load. If the beam carries a heavy live load the safe load should be further reduced.

Safe Working Stress.

The safe working stress is usually taken as some fraction of the ultimate strength of the material; it requires careful consideration and much experience to decide on the correct value for this fraction. This consideration is further complicated when any portion of the total load is such that it is applied and removed, since these conditions may produce a considerable dynamic effect. Another point which must be kept in view is that the maximum stress, however produced, must be well within the elastic limit of the material, so as to avoid any permanent distortion or set. For mild steel such as is used in general structural work, the ultimate strength will vary from 27 to 32 tons per square inch, with an elastic limit of 14 tons per square inch and upwards; the maximum stress should therefore not exceed 9 to 10 tons per square inch, or say a factor of safety of 3 with respect to the ultimate strength.

Repeated or fluctuating loads.—These can be classed under two heads, first where the load is such as will produce stresses in the structure varying from zero to a maximum; and second where the load will produce stresses varying from compression to an equal tension.

Wöhler's law of stresses for repeated loading and reversed loading may be briefly indicated thus:—

Class 1.—Static or dead loading	. . . . .	ratio 3
,, 2.—Loads producing stresses varying from zero to maximum	.	,, 2
,, 3.— ,, ,, ,, ,, ,,	comp. to equal tension	,, 1

As the load carried by any structure is always composed partly of dead and partly of live or fluctuating loads, difficulties arise in determining the stresses in the several members of the structure, for the following reasons. The weight of the structure itself provides a necessary dead load, irrespective of any other additional dead load (for example, water flowing into a tank, although actually a live load, is so steadily added to the structure as to be *practically* a dead load), and it is obvious that the dynamic resistance of this dead load must more or less reduce the actual dynamic effect on the structure of any live load. A simple formula has been suggested by Mr. E. H. Stone, M.Inst.C.E., which he calls his 'Range' formula, and which takes into account the *immediate effect* (due to sudden loading, as when a train passes over a bridge), and the *cumulative effect* (that produced in time by repeated loading and unloading). The former effect, as compared with that due to the same amount of dead load, was deduced from experiments, while the second effect was deduced from Wöhler's experiments: these two effects were then combined in a rational manner to give the total effect of the moving load, as compared with that of an equivalent amount of dead load. Starting with a maximum safe stress for *dead loads alone* of 9 tons per square in. for mild steel, Mr. Stone deduced the following formula for obtaining the equivalent dead load stresses for varying percentages of life to dead loads, which would produce all actual maximum stress of 9 tons per sq. in. (p = percentage of live to dead load).

$$\text{Safe working stress} = 9 - (5 \times p) \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The following table is based on this formula :—

TABLE VIII.—DEAD LOAD EQUIVALENTS FOR COMBINED LIVE AND DEAD LOADS.

p	E.D.L.	p	E.D.L.	p	E.D.L.
100	4·00	65	6·89	30	8·55
95	4·49	60	7·20	25	8·69
90	4·95	55	7·49	20	8·80
85	5·39	50	7·75	15	8·89
80	5·80	45	7·99	10	8·95
75	6·19	40	8·20	5	8·99
70	6·55	35	8·39	0	9·00

p = percentage of live load in total load. E.D.L. = equivalent dead load stress.

Deflection of Beams.

Deflection formulæ for various arrangements of loading are given in tables 1 and 2, pages 318 and 319. For structural steel the value of E (the modulus of elasticity) may be taken at 30,000,000 lbs. and the value of W must then be expressed in lbs. also. For the value of E for other materials see *e*, page 294.

COLUMNS AND STRUTS.

The strength of columns or struts depends not only on the cross-sectional area of the member, but also on its height or length, and on the condition of fixture of the ends. As the ratio of the length to the least diameter increases, the column becomes more *slim* or liable to fail by bending under its load : such a ratio might thus be called the *ratio of stiffness or slenderness* of a column, and so that this ratio may be used as a means of comparing the strength or stiffness for columns of varying cross-section, the value for the radius of gyration (see p. 323) of the cross-section should be adopted instead of the diameter, since it is obvious, for example, that the diameters of a square and a round column may be the same, but the stiffness would be quite different.

The ends of columns are divided into three classes or conditions of fixture :—

1. Both ends hinged, or free to move.
2. One end hinged and one end fixed.
3. Both ends fixed.

The limiting values for $\frac{L}{R}$ in the tables on pp. 326, 327 have been taken as 200, and this should very rarely be exceeded, owing to the practical difficulties in producing a perfectly straight long column, and one free from internal stresses ; and also of erecting such a column on rigid foundations, and ensuring a truly central loading.

The formulæ adopted in calculating tables are given under the same.

Eccentric Loads.

Where the load is not applied centrally, as where a beam rests on a bracket attached to a column, considerably increased stresses may arise through the bending tendency introduced.

The equivalent concentric load which would produce the same maximum stress as that due to the actual eccentric load may be found as follows :—

$$\text{EQUIVALENT CONCENTRIC LOAD} = W\left(1 + \frac{xy}{R^2}\right) \quad . \quad . \quad . \quad . \quad (12)$$

where

W = Eccentric load.

x = Distance from neutral axis of stanchion to point of application of load = eccentricity.

y = Distance from neutral axis to edge of stanchion nearest load.

R = Radius of gyration of cross section of stanchion about neutral axis at right angles to line of eccentricity.

TABLE IX.—MILD STEEL STANCHIONS.

Maximum Safe Stresses per sq. in. of Section. (London Building Act Amendment, 1909.)

$\frac{L}{R}$	A	B	C	$\frac{L}{R}$	A	B	C	$\frac{L}{R}$	A	B	C
2	4·50	5·50	6·50	72	2·70	3·70	4·70	142	—	*1·90*	2·95
4	4·40	5·40	6·40	74	2·65	3·65	4·65	144	—	*1·80*	2·90
6	4·35	5·35	6·35	76	2·60	3·60	4·60	146	—	*1·70*	2·85
8	4·30	5·30	6·30	78	2·55	3·55	4·55	148	—	*1·60*	2·80
10	4·25	5·25	6·25	80	2·50	3·50	4·50	150	—	*1·50*	2·75
12	4·20	5·20	6·20	82	2·45	3·45	4·45	152	—	*1·40*	2·70
14	4·15	5·15	6·15	84	2·40	3·40	4·40	154	—	*1·30*	2·65
16	4·10	5·10	6·10	86	2·35	3·35	4·35	156	—	*1·20*	2·60
18	4·05	5·05	6·05	88	2·30	3·30	4·30	158	—	*1·10*	2·55
20	4·00	5·00	6·00	90	2·25	3·25	4·25	160	—	*1·00*	2·50
22	3·95	4·95	5·95	92	2·20	3·20	4·20	162	—	*·90*	*2·40*
24	3·90	4·90	5·90	94	2·15	3·15	4·15	164	—	*·80*	*2·30*
26	3·85	4·85	5·85	96	2·10	3·10	4·10	166	—	*·70*	*2·20*
28	3·80	4·80	5·80	98	2·05	3·05	4·05	168	—	*·60*	*2·10*
30	3·75	4·75	5·75	100	2·00	3·00	4·00	170	—	*·50*	*2·00*
32	3·70	4·70	5·70	102	*1·90*	2·95	3·95	172	—	*·40*	*1·90*
34	3·65	4·65	5·65	104	*1·80*	2·90	3·90	174	—	*·30*	*1·80*
36	3·60	4·60	5·60	106	*1·70*	2·85	3·85	176	—	*·20*	*1·70*
38	3·55	4·55	5·55	108	*1·60*	2·80	3·80	178	—	*·10*	*1·60*
40	3·50	4·50	5·50	110	*1·50*	2·75	3·75	180	—	*·00*	*1·50*
42	3·45	4·45	5·45	112	*1·40*	2·70	3·70	182	—	—	*1·40*
44	3·40	4·40	5·40	114	*1·30*	2·65	3·65	184	—	—	*1·30*
46	3·35	4·35	5·35	116	*1·20*	2·60	3·60	186	—	—	*1·20*
48	3·30	4·30	5·30	118	*1·10*	2·55	3·55	188	—	—	*1·10*
50	3·25	4·25	5·25	120	*1·00*	2·50	3·50	190	—	—	*1·00*
52	3·20	4·20	5·20	122	*·90*	2·45	3·45	192	—	—	*·90*
54	3·15	4·15	5·15	124	*·80*	2·40	3·40	194	—	—	*·80*
56	3·10	4·10	5·10	126	*·70*	2·35	3·35	196	—	—	*·70*
58	3·05	4·05	5·05	128	*·60*	2·30	3·30	198	—	—	*·60*
60	3·00	4·00	5·00	130	*·50*	2·25	3·25	200	—	—	*·50*
62	2·95	3·95	4·95	132	*·40*	2·20	3·20				
64	2·90	3·90	4·90	134	*·30*	2·15	3·15				
66	2·85	3·85	4·85	136	*·20*	2·10	3·10				
68	2·80	3·80	4·80	138	*·10*	2·05	3·05				
70	2·75	3·75	4·75	140	*·00*	2·00	3·00				

A = Both ends hinged.
B = One end hinged, one end fixed.
C = Both ends fixed.

The above table gives an extension of the empirical working or safe stress values adopted by the London County Council, and embodied in their (General Powers) Act 1909. This table should be used for all districts where the L.C.C. Building Regulations are enforced.

The limit of height of a stanchion should, as a rule, not exceed the lesser of the two following values :—

1. 160 times the least radius of gyration.

2. 40 times the least overall or breadth of the section.

The economical ratio of slenderness for the three types of stanchions, namely the point beyond which the section increases at a greater rate than below this point, occurs at 100, 140, and 160. Below these values the rate varies one ton per sq. in. for each variation of 40 in the $\frac{L}{R}$ values; above these values the rate of change is two tons, being double.

TABLE X.—MILD STEEL STANCHIONS

Maximum Safe Stresses per sq. in. of Section. (Prof. Claxton Fidler's Formulæ.)

$\frac{L}{R}$	A	B	C	$\frac{L}{R}$	A	B	C	$\frac{L}{R}$	A	B	C
2	6·50	6·50	6·50	72	3·72	4·55	5·39	142	1·33	2·17	3·02
4	6·49	6·49	6·50	74	3·61	4·47	5·33	144	1·30	2·13	2·97
6	6·48	6·48	6·49	76	3·50	4·38	5·26	146	1·26	2·08	2·91
8	6·47	6·48	6·49	78	3·39	4·30	5·20	148	1·23	2·04	2·86
10	6·44	6·46	6·48	80	3·28	4·20	5·13	150	1·20	2·00	2·80
12	6·41	6·44	6·47	82	3·18	4·12	5·07	152	1·17	1·96	2·75
14	6·39	6·42	6·46	84	3·08	4·04	5·00	154	1·15	1·92	2·70
16	6·35	6·40	6·45	86	2·99	3·91	4·93	156	1·12	1·88	2·65
18	6·31	6·37	6·43	88	2·89	3·87	4·86	158	1·10	1·85	2·60
20	6·27	6·35	6·42	90	2·80	3·79	4·79	160	1·07	1·81	2·55
22	6·22	6·31	6·40	92	2·72	3·72	4·72	162	1·05	1·77	2·50
24	6·16	6·27	6·38	94	2·63	3·63	4·65	164	1·02	1·74	2·46
26	6·10	6·23	6·36	96	2·55	3·56	4·57	166	1·00	1·70	2·41
28	6·04	6·19	6·34	98	2·47	3·48	4·50	168	·98	1·67	2·37
30	5·97	6·14	6·31	100	2·40	3·42	4·43	170	·96	1·64	2·33
32	5·90	6·09	6·29	102	2·32	3·34	4·36	172	·94	1·61	2·28
34	5·81	6·03	6·26	104	2·26	3·27	4·28	174	·92	1·58	2·24
36	5·73	5·98	6·23	106	2·19	3·20	4·21	176	·90	1·55	2·20
38	5·64	5·92	6·20	108	2·12	3·13	4·14	178	·88	1·52	2·16
40	5·55	5·85	6·16	110	2·06	3·06	4·07	180	·86	1·49	2·12
42	5·45	5·79	6·13	112	2·00	3·00	4·00	182	·84	1·46	2·08
44	5·35	5·72	6·09	114	1·94	2·93	3·93	184	·82	1·43	2·05
46	5·24	5·64	6·05	116	1·89	2·87	3·86	186	·81	1·41	2·01
48	5·13	5·57	6·01	118	1·83	2·80	3·79	188	·79	1·38	1·98
50	5·02	5·50	5·97	120	1·78	2·75	3·72	190	·78	1·36	1·94
52	4·91	5·41	5·92	122	1·73	2·69	3·65	192	·76	1·33	1·91
54	4·79	5·33	5·88	124	1·69	2·63	3·58	194	·75	1·31	1·88
56	4·67	5·25	5·83	126	1·64	2·58	3·52	196	·73	1·28	1·84
58	4·55	5·16	5·78	128	1·60	2·52	3·45	198	·72	1·26	1·81
60	4·43	5·08	5·73	130	1·56	2·47	3·39	200	·70	1·24	1·78
62	4·31	5·00	5·68	132	1·51	2·42	3·32				
64	4·19	4·90	5·62	134	1·47	2·35	3·26				
66	4·07	4·82	5·57	136	1·44	2·32	3·20				
68	3·95	4·73	5·51	138	1·40	2·27	3·14				
70	3·83	4·64	5·45	140	1·36	2·22	3·08				

A = Both ends hinged.
B = One end hinged, one end fixed.
C = Both ends fixed.

The following are the formulæ used in calculating the above table:—

$$\text{Breaking strength in tons per square inch} = \frac{F + f - \sqrt{(F+f)^2 - 2{\cdot}4\,Ff}}{1{\cdot}2} \quad . \quad . \quad (13)$$

= Ultimate compressive strength = 26 tons per square inch in this table.

$$F = \begin{cases} E\pi^2 \times \left(\frac{R}{\cdot 6L}\right)^2 \text{ for both ends fixed.} \\ E\pi^2 \times \left(\frac{R}{\cdot 8L}\right)^2 \text{ for one end hinged, one end fixed.} \\ E\pi^2 \times \left(\frac{R}{L}\right)^2 \text{ for both ends hinged,} \end{cases}$$

E = Modulus of elasticity = 12,000 tons.
π = 3·1416.
R = Minimum radius of gyration of cross section.
L = Height of stanchion in inches.

TABLE XI.—CAST-IRON COLUMNS.

Maximum Safe Stresses per sq. in. of Section. (London Building Act Amendment, 1909.)

$\frac{L}{R}$	Hinged ends.	Hinged and fixed.	Fixed ends.	$\frac{L}{R}$	Hinged ends.	Hinged and fixed.	Fixed ends.	$\frac{L}{R}$	Hinged ends.	Hinged and fixed.	Fixed ends
2	4·4	4·9	5·4	32	2·9	3·4	3·9	62	1·4	1·9	2·4
4	4·3	4·8	5·3	34	2·8	3·3	3·8	64	1·3	1·8	2·3
6	4·2	4·7	5·2	36	2·7	3·2	3·7	66	1·2	1·7	2·2
8	4·1	4·6	5·1	38	2·6	3·1	3·6	68	1·1	1·6	2·1
10	4·0	4·5	5·0	40	2·5	3·0	3·5	70	1·0	1·5	2·0
12	3·9	4·4	4·9	42	2·4	2·9	3·4	72	0·9	1·4	1·9
14	3·8	4·3	4·8	44	2·3	2·8	3·3	74	0·8	1·3	1·8
16	3·7	4·2	4·7	46	2·2	2·7	3·2	76	0·7	1·2	1·7
18	3·6	4·1	4·6	48	2·1	2·6	3·1	78	0·6	1·1	1·6
20	3·5	4·0	4·5	50	2·0	2·5	3·0	80	0·5	1·0	1·5
22	3·4	3·9	4·4	52	1·9	2·4	2·9	82	0·4	0·9	1·4
24	3·3	3·8	4·3	54	1·8	2·3	2·8	84	0·3	0·8	1·3
26	3·2	3·7	4·2	56	1·7	2·2	2·7	86	0·2	0·7	1·2
28	3·1	3·6	4·1	58	1·6	2·1	2·6	88	0·1	0·6	1·1
30	3·0	3·5	4·0	60	1·5	2·0	2·5	90	0·0	0·5	1·0

Riveted Joints in Girderwork.

The riveted joint of a tension-member may fail either by the tearing of the plate, or the shearing of the rivets, or in some special cases by the crippling of the bearing area between plate and shank of rivet.

The tearing of the plates is resisted by the tensile strength of the plate per square inch of area taken over the *net effective section* between rivet holes. When the assumed line of fracture is at right angles to the direction of the pull, the sectional area measured on this line between the rivet-holes is the net effective section. But when the line of fracture may follow a zigzag or inclined direction, the effective sectional area should be taken at about three-fourths of the area measured on such a line. The fraction is not universally applicable, but will generally meet the case of ordinary zigzag riveting.

The shearing of the rivets is resisted by the shearing strength of the rivet-material per square inch of area taken over the effective section of the rivets engaged. Assuming all the rivets to take an equal share in the work, the number of rivets engaged in resisting the total pull upon the tie will be the whole number of rivets in the case of a lap-joint such as that shown in figs. 7 and 8; while in the case of a butt joint, such as No. 2 of fig. 9, it will consist only of the rivets employed on either side of the joint. But in any large assemblage of rivets allowance should be made for unequal distribution of the work when calculating the number of rivets required for a joint.

For rivets in 'single shear,' as in the case of lap joints, and in butt joints covered by a single cover-plate, the effective section of each rivet is simply the area of its cross-section. But wherever practicable double cover-plates should be employed, placing the rivets in 'double shear,' and in this case the effective section of each rivet should be reckoned at $1\frac{3}{4}$ times the sectional area of the rivet.

In wrought-iron work the shearing strength of good rivet iron per square inch is fully equal to the tensile strength of the plates; and the effective rivet section is often made equal to the effective plate section, an allowance of 10 per cent. being sometimes added in the case of large joints.

The shearing strength of steel rivets may be taken at 24 tons per square inch, while the plates have often a tensile strength of 26 to 32 tons; and the rivet section will generally require to be somewhat greater than the plate section.

The 'efficiency' of a riveted joint is the ratio between its strength at the weakest part and the strength of the unperforated plate.

RIVETING.

Rivets.

The heads (fig. 5) are usually either snap or pan. Snap heads are used generally in machine riveting. The points are countersunk, conical, or snap; the former are largely employed in iron shipbuilding, where a flush surface is required, the latter in ordinary boiler and bridge work. Conical, also called *staff* or *hammered*, points are chiefly used where the restricted space only allows of hammering.

The following figures give ordinary proportions of rivet heads in terms of diameter of shank.

Countersunk point. FIG. 5. Conical point.

If d = diameter of shank of rivet,

Length allowed for forming pan head = 2 to $2\frac{1}{2}d$.
" " " snap head = $1\frac{1}{2}d$.
" " " countersunk head = $1d$.
" " " conical head = $1\frac{1}{4}d$.

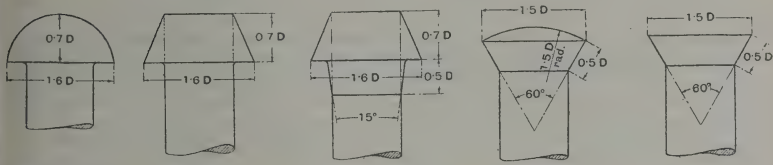
When a conical form is given under the rivet head an additional length of about $\frac{1}{4}''$ is usually allowed in making the rivet.

BRITISH STANDARD SPECIFICATION FOR DIMENSIONS OF RIVETS.*

($\frac{1}{2}$ INCH TO $1\frac{3}{4}$ INCH DIAMETER.)

(No. 275—1927.) (*Abstract.*)

(This Specification does not apply to Boiler Rivets.)



Snap Head. Pan Head. Pan Head with Tapered Neck. Rounded Countersunk Head. Flat Countersunk Head.

FIG. 5A.

d = Nominal diameter of rivet.

Diameter of Rivets or Rivet Holes.

d = diameter of rivet hole; t = thickness of thickest plate.

Fairbairn's Rule, commonly used When t is less than $\frac{1}{2}''$, $d = 2t$.
When t is equal to, or greater than, $\frac{1}{2}''$, $d = 1\frac{1}{2}t$.

With rivets so proportioned the total number in single shear, such as lap, single cover and grouped, joints will, when the resistance to shearing is taken at 4 tons and bearing at 5 tons, depend on the number required for shearing, in $\frac{1}{2}''$ plates and over $\frac{1}{2}''$, and for bearing with plates under $\frac{1}{2}''$ thick.

When more than 2 plates, besides the covers, are riveted together, as in flanges of girders, some engineers add $\frac{1}{16}$ to d for each extra plate.

Unwin's Rule for Rivets: $d = 1{\cdot}2\sqrt{t}$.

Rivets of more than $\frac{1}{8}''$ diameter are rarely used.

The rivet holes are made about $\frac{1}{16}''$ larger than the rivets, to allow for expansion when heated. For ordinary work the proportions of diameter of punch to that of bolster hole in the die varies from 1 : 1·15 to 1 : 1·2; the greater the difference, the less cleanly cut will the burr be, but the metal round the hole will be stronger, being less reduced and more compressed. The hole when punched is slightly conical.

It is hardly practicable to temper a punch so as to punch a great number of holes if it is of less diameter than the thickness of the plate, or even with a diameter of equal thickness. Punched

* By permission of the British Engineering Standards Association.

holes should never be less than $1\frac{1}{2}$ diameter apart or from edge to plate. For drilled holes the limit may be 1 diameter.

Pitch of rivets=distance from centre to centre of rivet. *Longitudinal pitch*=pitch in direction of stress. *Transverse pitch* = pitch at right angles to stress. *Zigzag pitch* = minimum pitch when placed zig-zag: this should slightly exceed the transverse pitch. *A pitch line* is a straight line running through the centres of a longitudinal or transverse row.

Minimum pitch = $2\frac{1}{2}$ diameters for punched or 2 for drilled holes.

Maximum longitudinal pitch in compression plates = 12 times thickness of weakest outside plate.

Strength of Rivets and Plates.

Mean tensile breaking strength of best iron, such as BBB Staffordshire, best Yorkshire or Lowmoor (and the best only should be used), is from 26·33 tons per square inch (Fairbairn) to 25·98 tons per square inch (Kirkaldy); whilst the contraction of fractured area should not be less than 40 per cent.

Forge Tests for Rivets.—When cold they should stand being hammered double, or being upset endways, a $\frac{3}{4}$″ rivet $2\frac{1}{2}$″ long being hammered down to a cylinder 1″ long, without any sign of cracking. A rivet ready heated for use should now and then be taken, allowed to cool, and treated as above, to see if they are being overheated. Much overheating is detected by the burnt, scaly appearance of the surface of shank; $\frac{3}{4}$″ or even 1″ rivets should not be over 20 minutes in the fire. When *hot* the heads should stand hammering down to less than $\frac{1}{8}$″ thick without cracking at edges; and the stalks should stand having a punch, even more than their own diameter, driven through them without cracking round the hole.

The foregoing tests are equally applicable to steel rivets.

Careful punching does not injure soft plates, but weakens hard or steely iron plates from 15 to 30 per cent.

Sharp edges of drilled holes reduce the shearing resistance of rivets, but rounding the edges of the holes increases resistance of rivet.

Drilled rivet holes reduce the strength of a plate by $1\frac{1}{4}$ per cent., and punched holes about 9 per cent. Punching and counter-sinking reduce the strength 4 per cent., but if the holes are punched, reamered, and countersunk, there is little reduction in the strength of the plate. Comparative tests of high tensile plates, connected by iron and by high tensile rivets, show that $\frac{1}{2}$-in. iron rivets worked cold in single shear have a shearing strength of 3·6 tons compared with 6·6 in the case of high-tensile steel worked cold, and 9·6 in case of the same steel worked hot. For double shear the same figures are 6·6, 13·1, and 18·4. Experiments show that the bearing pressure with high tensile steel rivets does not exceed 60 lbs. per square inch.

(*Sir P. Watts.*)

Riveting.

Riveting gangs consist of a holder-up, two riveters, and one or two boys for heating and supplying rivets. Rivets are heated in a portable hearth or a reverberatory furnace. Before inserting the rivet the plates round the hole should be hammered into positive contact, and the holes ascertained to be concentric.

Riveting hammers vary from 2 to 7 lbs., the holding-up hammer or 'dolly' from 10 to 40 lbs. 130 to 150 rivets is a day's work of 13 hours of a riveting gang. 360 to 720 can be put in by a riveting machine.

Riveted Joints.

The loss of strength is ordinarily, for chain-riveted joints (fig. 6), 15 per cent.; for double-riveted, 30 per cent.; for single-riveted joints, 44 per cent., as compared with the strength of the plate unpunched.

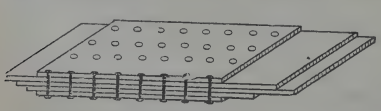


FIG. 6. Grouped Butt Joint. Chain Riveting.

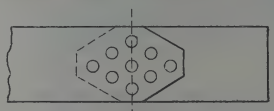


FIG. 7. Lap Joint. Lozenge Riveting.

Zigzag Riveting.—In this (fig. 8) the distance between the transverse pitch lines should be at east two-thirds the transverse pitch of the rivets.

Lozenge Riveting.—Arranging the rivets in this way, as illustrated by the lap-joint of fig. 7, and calculating the plate strength and rivet strength at each of the possible lines of fracture, it is possible to obtain a strength of joint equal to the strength of the whole plate less one rivet

hole. With the same efficiency a still better joint for a plate-tie may be made with two cover-plates of lozenge form, the maximum row of rivets being repeated on each side of the butt joint.

Cover-Plates.—In the special case last mentioned the united thickness of the cover-plates will have to be considerably greater than that of the main tie, and will be determined by the net section of cover taken through the maximum row of rivets. In chain riveting generally it would be theoretically sufficient to make the united cover thickness equal to the plate thickness, but in practice it is often made somewhat greater, both in single and double covers. If there is

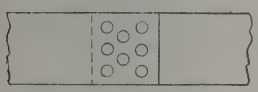


FIG. 8. Lap Joint. Zigzag Riveting.

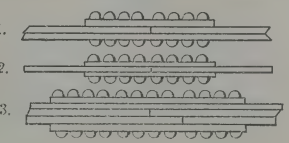


FIG. 9.

a whole plate on one side, as in No. 1, fig. 9, a single cover-plate may be used on the other side equal in thickness to the jointed plate. When the member consists of several thicknesses of plate, as in No. 3, they may with advantage be all jointed between one pair of cover-plates, arranging the several layers to break joint one with another, and leaving between every two joints a space containing a sufficient number of rivets to take up the pull of one layer of plates.

STEEL ROOF FRAMING AND COVERING.

Some points to be considered in designing steel roofing :—

(a) *Nature of Covering.*—If of **corrugated sheeting,** either ridged or curved type may be adopted ; in the latter the joints near crown of roof lie nearly horizontal, and leakage through rain being blown in must not be overlooked. A continuous covering, such as tarred felt or asphalt laid on timber boarding, is applicable to ridged or curved types.

With slates or tiles, the ridged type (except in very large spans) is necessary.

(b) *Rise of Roof.*—Where this is not controlled by architectural requirements, a rise of about $\frac{1}{5}$ span will generally prove most economical. Where water-tightness is essential, $\frac{1}{4}$ rise may be adopted ; a rise of even $\frac{1}{3}$ may be used with slates or tiles. In very exposed positions a low rise of $\frac{1}{4}$ has been provided, but here leakage is likely to prove troublesome.

(c) *Lighting and Ventilation in Roof.*—Skylights can be arranged in any position on the slope of a ridged roof, or set low down on curved roofs. Lights are often combined with ventilators at the centre or ridge of the roof. Ventilation at the ridge may consist merely in slightly raising the ridge cap above the sheets ; by the use of special ridge sheeting (often curved) supported on raised purlins ; or where greater ventilation is desired, the cover may be raised to a considerable height and louvres provided for weather-tightness. See sketch examples.

(d) *Temporary Structures.*—Here the framing and covering can be designed as light as possible, and factor of safety reduced to about 3, since allowance for rusting and general deterioration need not be considered. The self-supporting type of curved roof should be considered in this case.

(e) *Special Headroom* generally requires a special type, as the main tie cannot economically be raised much over $\frac{1}{10}$ rise for ridged or curved trusses of ordinary design. Two suggestions are given in sketch examples to meet this requirement.

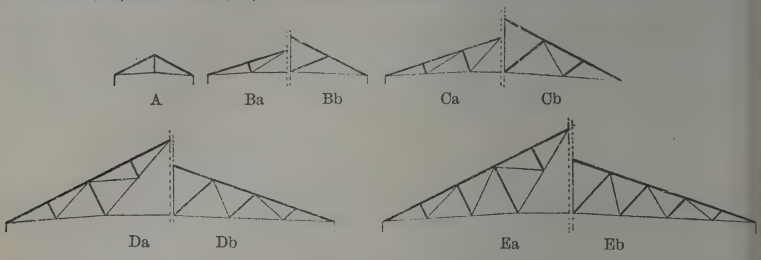
Struts, or members in compression, should be kept as short in length as possible. The strength of *ties* to resist tension is independent of their length, and no consideration on this point is necessary, except that relating to the carrying of their own weight.

The Purlins (or horizontal bearers which carry the weight of the roof covering, and the wind and snow load on the same, and transmit these loads to the roof trussing) should rest, wherever possible, on the rafters close to the points where the struts and ties meet, and stiffen the same ; loads applied between these junction points (usually termed 'joints') may induce considerable *bending stresses* which must be carefully allowed for, generally at considerable expense, owing to the large increase in section which may be necessary.

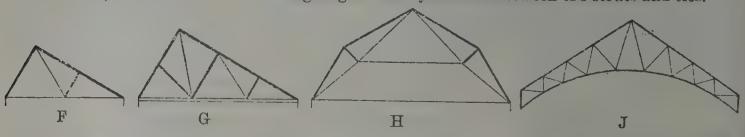
The unsupported length of the Rafter, that is to say the length between the joints, should not exceed 7 to 8 feet where the purlins are fixed close to the joints ; where purlins occur between the joints, this length should be considerably reduced, or the section of the rafter increased to resist the bending stresses.

In the brief notes accompanying the outline types of roofs shown here, the application of some of the preceding hints will be evident.

For ordinary conditions the types shown below are suitable up to the following spans :—A, 14 to 16 feet ; B, 25 to 30 feet ; C, 45 to 50 feet ; D, 55 to 60 feet ; and E, 70 to 80 feet.

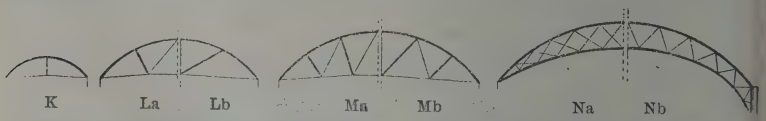


The two rises indicated in B to E are $\frac{1}{4}$ span and $\frac{1}{6}$ span. Where special conditions do not arise, the form of bracing should be decided by considerations of length and inclination of the several struts, and convenience for designing efficient junctions between the struts and ties.



Types of ridged roofs designed to provide special lighting, such as is required in spinning and weaving factories, are shown in F and G ; the long slope is covered with sheets or slates, and the short, upright slope glazed and turned towards the north, thereby ensuring efficient light free from direct sunshine. These types are frequently called 'Saw Tooth' or 'Northern Light' roofs, and are suitable for spans of 18 to 20 ft., and 25 to 30 ft. respectively.

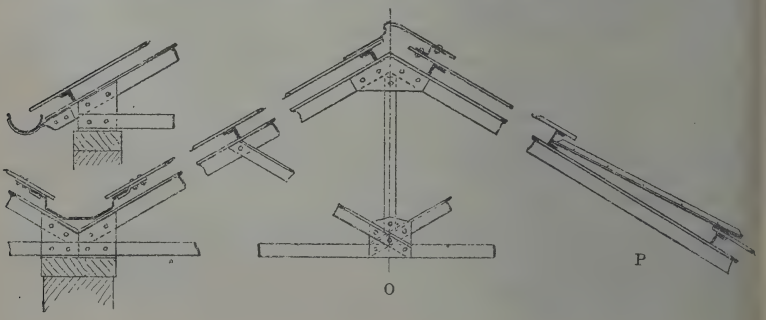
Types H and J show a high rise, with main tie raised to give increased headroom ; the former may frequently be adopted for factories, the lower slopes being glazed and the upper slopes sheeted or slated.



The curved types K, L, and M, are similar to A, B, and C, but arranged for a curved sheet covering, and may be adopted for similar spans.

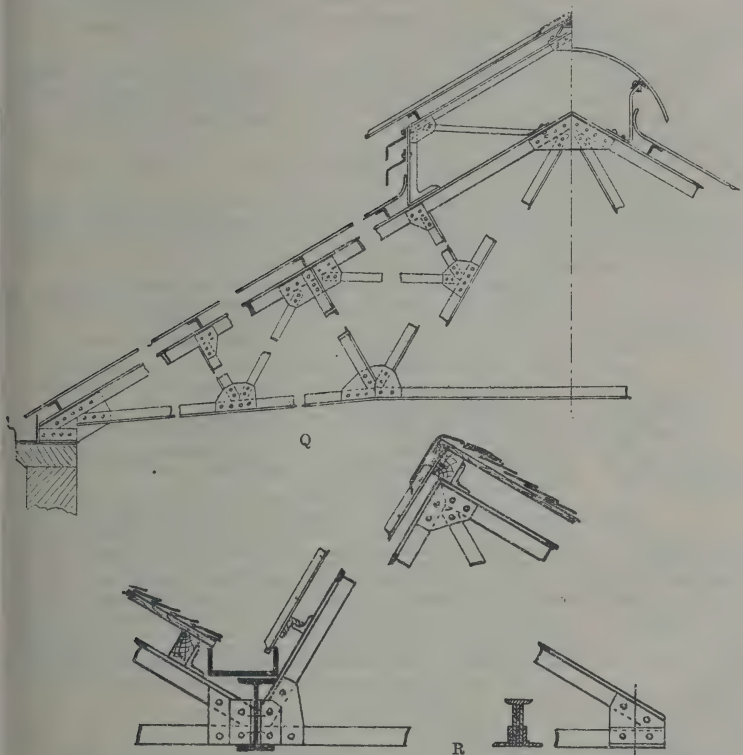
Types N are in reality curved lattice girders, and may be designed for large spans such as are required for markets, railway stations, public halls, or the like.

Sketch Details.—Sketch O suggests details for a ridged roof, type Bb ; on left two spans meet and a valley gutter is provided, and above this a sketch of an eaves gutter. At the apex, or



ridge, an ordinary ridge cap is shown on the left, and on the right a plain ridge cap is slightly raised on light brackets to provide a small amount of ventilation.

Sketch P indicates a skylight in the slope of a roof. Sketch Q gives suggestions for type Da. At apex a simple ventilator is shown on the right, and a larger louvred ventilator on the left. In the latter arrangement the straight cover may be glazed, thus forming a combined skylight and ventilator.



Q

R

Sketch R is that for a 'Northern Light' roof, types F or G. A valley detail (showing this part supported on a rolled steel beam) with valley gutter is given, also an eaves shoe detail. The long slope is covered with timber and slates, and the short slope is glazed.

Corrugated Sheets and Fixings.

Sheets can be procured in lengths from 5 to 10 feet, and in thicknesses from No. 16 to No. 26 B.W.G.; for special or very temporary purposes, No. 28 B.W.G. might be adopted.

Corrugations from 2 inches width in light sheets to 6 inches in heavy sheets may be got but for usual conditions the following sizes will meet all requirements :—

5–5	inch	corrugated	sheets	(depth of	corrugations	1¼	in.)
6–5	"	"	"	("	"	"	) See Sketch S.
8–3	"	"	"	("	"	⅝	")
10–3	"	"	"	("	"	¾	")

For ordinary conditions, a side lap of one corrugation (see right-hand of Sketch S) would be adopted, but for special water-tightness or stiffness, two corrugations lap could be given (see left

hand of Sketch S). The effective width of the above sheets would be 25 inches or 30 inches, for single lap, and 20 inches or 25 inches for double lap.

S

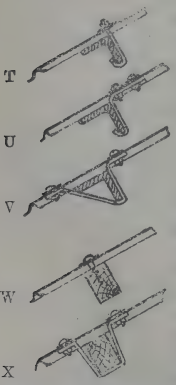
In the 3-inch corrugated sheets, the corresponding widths would be 24 and 30 inches for single lap, and 21 and 27 inches for double lap.

The end lap is generally given at 6 inches.

Sheets should be connected together by means of galvanised rivets or bolts and washers: these would be placed about 9 inches apart along the side laps, and at every second corrugation in the end laps, being in all cases placed on *top* of the corrugations to check leakage. For *double* corrugation side lap, place rivets or bolts in edge of outer sheets 6 inches apart, and 12 inches apart in inner corrugation.

Five-inch corrugations should always be adopted for No. 16 B.W.G. sheets, and may be used for No. 18 or 20 B.W.G.; 3-inch corrugations may be used for 18 or 20 B.W.G., and always for No. 22 B.W.G. and upwards.

In very exposed positions, and particularly with light gauge sheets, Wind Ties of flat or light angle section are sometimes carried along the length of the roof, and held in position by means of the purlin bolts. A line of these wind ties near each eaves level will considerably strengthen the roofing; and it is sometimes also desirable to add ties over some of the intermediate horizontal joints in the roof sheets, to further resist excessive winds.



T

U

V

W

X

In addition to connecting the roof sheets together, they must be securely fixed to the roof purlins, and suggestions for doing this are here indicated :—

Sketch T, simple hook bolt, with nut and washer outside, connecting sheets to steel angle purlin.

Sketch U, similar to above, but formed of flat clip bolted to sheets.

Sketch V, a more secure form of flat clip carried round purlin and connected to sheets by bolts and washers at ends.

Sketch W, galvanised nail or wood screw and washer, for simple connection to timber purlin.

Sketch X, flat stirrup carried round timber purlin; generally made with slight clearance in width, to admit of adjustment due to change of temperature in the sheet covering.

The washers used with the bolts are sometimes formed of lead, or of some special form, to check leakage at the bolt holes. Red lead putty, or rope yarn soaked in red lead paint, is sometimes specified to be placed under the nut or washer, but such special treatment is seldom justifiable, or really necessary.

Corrugated Sheets are generally galvanised, but in localities near the sea, or in manufacturing districts near chemical works where acid fumes are likely to be given off, the galvanising quickly disappears, and the sheets become eaten through and spoiled. In such conditions the galvanised sheets should receive two good coats of metallic oxide paint shortly after erection, or plain corrugated sheets used, these being well tarred and sanded after erection, and at such intervals as may be necessary to efficiently protect the sheets from corrosion.

Self-Supporting Roofing.

This term is generally applied to a type of curved roofing in which the curved rafters of the trussing are dispensed with, their place being supplied by the corrugated sheets themselves.

In the smaller spans, say up to 15 to 20 feet, the roof sheets are connected to timber or steel eaves beams, and the bracing (generally as types K or L) bolted direct to the curved roof sheets.

In the larger spans angle purlins are securely clipped to the curved sheets and extend for the whole length of the roof, and the bracing is bolted to these purlins.

By this method of construction, and the use of corrugated roof sheets of sufficient strength to serve the double purpose of acting as a curved rafter, and as a weather protection, spans over 55 feet have been erected. It will not, however, as a rule be found economical to exceed about 35 feet span with this type of roofing; and as the life of this structure depends on the strength of the covering, it is seldom justifiable to provide self-supporting roofs for permanent use, as this would entail great watchfulness and cost in protecting the sheeting against corrosion or decay.

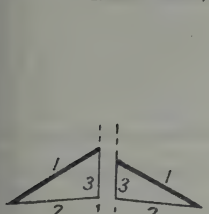
The curved form of covering must be used for this type of roof, and for the larger spans the sheets may be arranged to *break joint* in the longitudinal joints; greater stiffness may be obtained in the complete sheeting by this arrangement of joints. The lower sheets of the roof, which have to resist a much greater strain than the upper ones, are sometimes made of a heavier gauge. Special attention is also necessary to ensure sufficient strength when bolting or riveting the several sheets together.

Ridged Roof Truss Multipliers.

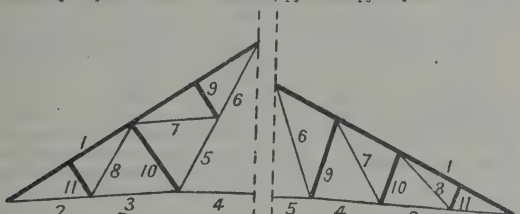
The determination of the stresses in the several members of any roof truss is usually a comparatively simple matter, although a considerable amount of time may sometimes be required to carry out this operation. Where any of the following types of trusses can be adopted, the above calculations can be much simplified and shortened.

For special water-tightness with slate or tile covering, one-third rise (shown by capital letters) should be adopted; one-fourth rise is usual for corrugated sheet covering.

Rise of rafters, $\frac{1}{3}$rd and $\frac{1}{4}$th span. Rise of main ties, $\frac{1}{14}$th and $\frac{1}{15}$th span.

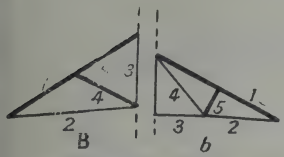


Spans to 15 ft.

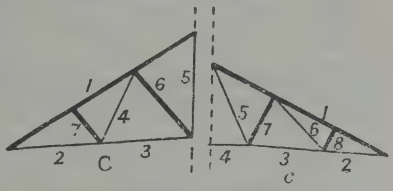


Spans, 46 to 60 ft.

Compression shown by heavy lines. Tension shown by light lines.



Spans, 16 to 30 ft.



Spans, 31 to 45 ft.

In spans up to 60 feet the rafter is usually kept the same section throughout the full length; the table gives only the max. stress multiplier for rafters.

The max. practical span for any type of truss is indicated by multiplying the numbers of sections formed in the rafters by the joints in the same by $7\frac{1}{2}$ feet. Thus Type B gives $4 \times 7\frac{1}{2} = 30$ feet max. span, and Type D $= 8 \times 7\frac{1}{2} = 60$ feet max. span.

Purlins are assumed to be set at the joints; if not, allowance must be made for the extra stress due to the bending tendency produced.

It is also assumed that the trusses are fixed at both ends; if this is not so, the stress in some members may be increased by about 10 per cent.

The multipliers in the following table are calculated as for *unit load and unit span*. Thus for dead-load stress the actual dead load of truss covering, etc., is multiplied by the particular dead-load multiplier for the required member; for live-load stress, the live load from the actual normal wind pressure on one side of the truss is used along with the particular live-load multiplier. Both stresses added together give the max. stress on the member.

Member.	Type A.		Type *a*.		Type B.		Type *b*.		Type C.		Type *c*.		Type D.		Type *d*.	
	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.	D.L.	L.L.
1	·51	·58	·63	·69	·76	·70	·97	1·04	·86	·85	1·08	1·25	·90	93	1·13	1·37
2	·42	·29	·57	·48	·63	·81	·87	1·12	·72	·98	·96	1·35	·76	1·06	1·12	1·46
3	·07	·05	·07	·06	·31	·34	·55	·45	·58	·63	·77	·92	·65	·81	·87	1·12
4	—	—	—	—	·24	·58	·33	·69	·12	·30	·56	·46	·42	·27	·72	·81
5	—	—	—	—	—	—	·22	·50	·41	·45	·28	·56	·26	·54	·57	·47
6	—	—	—	—	—	—	—	—	·21	·50	·19	·43	·36	·81	·27	·56
7	—	—	—	—	—	—	—	—	·14	·34	·22	·50	·10	·26	·19	42
8	—	—	—	—	—	—	—	—	—	—	·15	·31	·10	·26	·18	·36
9	—	—	—	—	—	—	—	—	—	—	—	—	·10	·25	·22	·50
10	—	—	—	—	—	—	—	—	—	—	—	—	·21	·50	·17	·37
11	—	—	—	—	—	—	—	—	—	—	—	—	·10	·25	·11	·25

D.L. = Dead Load. L.L. = Live Load.

GALVANISED CORRUGATED IRON SHEETS. Approximate Weight.

(Sheets 26 inches in width; 8-3 inch corrugations.)

Length of Sheet in Feet.						
5	6	7	8	9	10	B. W. G.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
33½	40	46½	53½	60	66½	16
26⅝	32	37⅛	42⅝	48	53⅛	18
21½	25½	29¾	34	38½	42½	20
16⅝	20	23⅛	26½	30	33⅛	22
13¼	16	18⅝	21¼	24	26⅝	24
10¼	12⅓	14⅜	16½	18⅝	20⅝	26
9½	11¼	13	15	16¾	18¾	28

Approximate Number of Sheets per Ton.

Length of Sheet in Feet.						
5	6	7	8	9	10	B. W. G.
67	56	48	42	37	34	16
84	70	60	52	46	42	18
105	88	75	66	58	53	20
134	112	96	84	74	67	22
168	140	120	105	93	84	24
216	180	154	135	120	108	26
240	200	171	150	133	120	28

Approximate weight per 100 superficial feet of Galvanised Corrugated Straight Iron Sheets when fixed on roof.

18	20	22	24	26 W.G.
cwts. qr. lbs.	cwt. qrs. lbs.	cwt. qrs. lbs.	cwt. qr. lbs.	cwt. qr. lbs.
2 1 21	1 3 21	1 2 7	1 1 7	1 0 7

One ton of Galvanised Corrugated Iron Sheets will cover when fixed, and after allowing for laps, the undermentioned areas :—

16	18	20	22	24	26	28	B.W.G.
600	800	1020	1280	1530	2100	2250	Square Feet.

It is a bad practice to fasten zinc-iron sheets together with iron or steel rivets. These soon rust if not painted, and the rust penetrates through the edges of the iron encircling the rivets, and thus proves disastrous. Only zinc, or zinc-covered rivets, should be so used.

The great objection to iron as a roofing material is the drip from the moisture which condenses on the underneath side of it.

PAINTING FOR GALVANISED IRON ROOFS.

Paint adheres badly to new galvanised iron, but after a few years it will do so readily and will add greatly to its life. In order to make paint adhere to new galvanised iron, brush it over with the following mixture : Chloride of Copper, 1 part ; Nitrate of Copper, 1 part ; Salammoniac, 1 part ; Water, 64 parts, to which is added 1 part of Hydrochloric Acid. This mixture turns the galvanised iron black ; it should be left for at least 12 hours before being painted.

It is stated that paint will adhere to galvanised iron if the surface is washed with vinegar before painting.

(See also ' Painting,' Section XLII.)

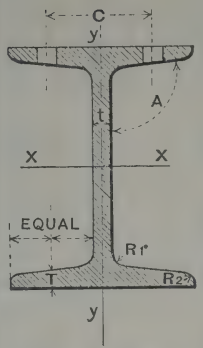
VARNISH FOR GALVANISED IRON ROOFS.

Heat 100 gallons of tar to a low boiling point, and add 100 lbs. of fresh slaked lime, sifted over the top and then worked down. Boil this mixture until it becomes pasty. Let it settle for a few minutes and then add 20 lbs. of tallow and 5 lbs. of powdered resin. Stir until thoroughly mixed and all ingredients dissolved ; then allow to cool. The mixture should not be raised to a higher temperature than 100 degs. F. If too thick, it can be thinned down with paraffin or naphtha.

TRANSVERSE STRENGTH OF CORRUGATED IRON.

If W = breaking weight in tons (distributed) ; L = unsupported length of sheet in inches ; t = thickness of sheet in inches ; b = breadth of sheet in inches ; d = depth of corrugations in inches

$$W = \frac{44{\cdot}6\ t\ b\ d}{L}$$



Reference		Size Ins.	Weight per Foot Lbs.	DIAGRAM. Web t	Flange T	Radius R1	Radius R2	Area Sq. Ins.	Moments of Inertia. About X-X	Moments of Inertia. About Y-Y	Radii of Gyration Inches. About X-X	Radii of Gyration Inches. About Y-Y	Section Modulus. About X-X	Centres of Holes. c Ins.	Reference Mark.
B S B	30	24 × 7½	100	·6	1·07	·7	·35	29·4	2654	6·92	9·5	1·5	221·1	4·5	B S B 30
,,	29	20 × 7½	89	·6	1·01	·7	·35	26·17	1670	62·63	7·99	1·54	167·0	4·5	,, 29
A S B	29A	20 × 6½	65	·493	·79	·6	·3	19·12	1178	27·40	7·85	1·20	117·8	3·5	A S B 29A
B S B	28	18 × 7	75	·55	·928	·65	·325	22·06	1149	47·04	7·21	1·46	127·6	4·0	B S B 28
A S B	28A	18 × 6	55	·466	·691	·56	·276	16·18	806·3	20·84	7·06	1·13	89 59	3·5	A S B 28A
B S B	27	16 × 6	62	·55	·847	·65	·325	18·23	725·7	27·08	6·31	1·21	90·71	3·5	B S B 27
,,	26	15 × 6	59	·5	·88	·6	·3	17·35	628·9	28·22	6·02	1·27	83·85	3·5	,, 26
,,	25	15 × 5	42	·42	·647	·52	·26	12·35	428·	11·81	5·88	·978	57·06	2·75	,, 25
,,	24	14 × 6	57	·5	·873	·6	·3	16·76	532·9	27·96	5·63	1·29	76·12	3·5	,, 24
,,	23	14 × 6	46	·4	·698	·5	·25	13·53	440·5	21·6	5·7	1·26	62·92	3·5	,, 23
,,	22	12 × 6	54	·5	·883	·6	·3	15·88	375·5	28·3	4·86	1·33	62·58	3·5	,, 22
,,	21	12 × 6	44	·4	·717	·5	·25	12·94	315·3	22·27	4·93	1·31	52·55	3·5	,, 21
D L B	20A	12 × 5	39	·44	·664	·54	·27	11·47	260·9	12·16	4·77	1·03	43·48	2·75	D L B 20A
B S B		12 × 5	32	·35	·55	·45	·225	9·41	220·	9·753	4·88	1·01	36 66	2·75	B S B 20
,,	19	10 × 8	70	·6	·97	·7	·35	20·6	344·9	71·67	4·09	1·86	68·98	4·75	,, 19
,,	18	10 × 6	42	·4	·736	·5	·25	12·35	211·5	22·95	4·13	1·36	42·3	3·5	,, 18
D L	17A	10 × 5	35	·42	·652	·52	·26	10·29	167·2	11·89	4·03	1·07	33·45	2·75	D L B 17A
B S B	17	10 × 5	30	·36	·552	·46	·23	8·82	145·6	9·79	4·06	1·05	29·12	2·75	B S B 17
A S B	17B	10 × 4·66	25	·3	·491	·41	·19	7·353	122·7	6·778	4·08	·960	24·53	2·5	A S B 17B
B S B	16	9 × 7	58	·55	·924	·65	·325	17·06	229·5	46·3	3·66	1·64	51·0	4·0	B S B 16
D L B	A	9 × 3½	21·5	·34	·453	·44	·22	6·324	83·41	3·446	3·63	·738	18·03	2·0	D L B 15A
B S B	15	9 × 4	21	·3	·46	·4	·2	6·176	81·1	4·2	3·62	·824	18·02	2·25	B S B 15
,,	14	8 × 6	35	·44	·597	·54	·27	10·29	110·5	17·95	3·27	1·32	27·62	3·5	,, 14
,,	13	8 × 5	28	·3	·575	·45	·225	8·24	89·32	10·26	3·29	1·11	22·33	2·75	,, 13
,,	12	8 × 4	18	·28	·402	·38	·19	5·294	55·69	3·578	3·24	·822	13·92	2·25	,, 12
,,	11	7 × 4	16	·25	·387	·35	·175	4·706	39·21	3·414	2·88	·851	11·2	2·25	,, 11
,,	10	6 × 5	25	·41	·52	·51	·255	7·35	43·61	9·116	2·43	1·11	14·53	2·75	,, 10
,,	9	6 × 4½	20	·37	·431	·47	·235	5·88	34·62	5·415	2·42	·959	11·54	2·5	,, 9
,,	8	6 × 3	12	·26	·348	·3	·18	3·53	20·21	1·339	2·39	·616	6·736	1·5	,, 8
,,	7	5 × 4½	18	·29	·448	·39	·195	5·29	32·69	5·664	2·07	1·08	9·076	2·5	,, 7
,,	6	5 × 3	11	·22	·376	·32	·16	3·235	13·61	1·462	2·05	·672	5·444	1·5	,, 6
D L	5A	4½ × 1¾	10	·32	·48	·32	·16	2·941	9·275	·413	1·78	·375	3·905	—	D L B 5A
B S B	5	4½ × 1½	6·5	·18	·325	·28	·14	1·912	6·73	·263	1·87	·37	2·833	—	B S B 5
,,	4	4 × 3	9·5	·22	·336	·32	·16	2·794	7·52	1·281	1·64	·677	3·76	1·5	,, 4
D L B	3A	4 × 1¾	8	·3	·388	·3	·15	2·353	5·328	·324	1·50	·371	2·664	—	D L B 3A
B S B	3	4 × 1½	5	·17	·24	·27	·135	1·47	3·668	·186	1·58	·355	1·834	—	B S B 3
,,	2	3 × 3	8·5	·2	·332	·3	·15	2·5	3·787	1·262	1·23	·71	2·524	1·5	,,
D L B	1A	3½ × 1½	6	·25	·344	·25	·125	1·765	3·086	·183	1·32	·322	1·763	—	D L B 1A
B S B	1	3 × 1½	4	·16	·248	·26	·13	1·176	1·659	·124	1·18	·324	1·106	—	B S B 1

For Angle A

B.S.B.'s 98°

D.L.B.'s 98°

A.S.B.'s 99° 27′ 44″

The properties of British Standard Sections in above table are published by permission of the Engineering Standards Association. (*Dorman, Long & Co. Ltd.*)

Safe Loads in Tons Uniformly Distributed.

Size.	Weight per Foot.	Span in Feet.																	Deflection Coefficient.	Weight per Foot.	Size.
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	36	40			
Ins.	Lbs.																				Lbs.	Ins.
24 ×7½	100					102	92	79	69	61	55	50	46	42	9	36	34	30	27	·00078	100	24 ×7½
20 ×7½	89				94	88	69	59	52	46	41	38	34	32	29	27	26	23	20	·000937	89	20 ×7½
20 ×6½	65				69	59	49	42	37	33	29	27	25	23	21	20	18	16	15	·000937	65	20 ×6½
18 ×7	75				78	64	53	45	40	35	32	29	26	24	22	21	20	17		·00104	75	18 ×7
18 ×6	55				56	45	37	32	28	25	22	20	19	17	16	15	14	12·5	11	·00104	55	18 ×6
16 ×6	62			73	56	45	38	32	28	25	22	20	19	17	16	15	14	12		·00117	62	16 ×6
15 ×6	59			62	52	42	35	30	26		21	19	17	16	15	14	13	11		·00125	59	15 ×6
15 ×5	42			47	35	28	24	20	18	16	14	13	12	11	10	9·5	9			·00125	42	15 ×5
14 ×6	57			59	47	38	31	27	24	21	19	17	16	14	13	12				·00133	57	14 ×6
14 ×6	46			43	39	31	26	22	19	17	15	14	13	12	11	10				·00133	46	14 ×6
12 ×6	54		53	52	39	31	26	22	19	17	15	14	13	12	11	10				·00156	54	12 ×6
12 ×6	44			40	33	26	22	19	16	14	13	12	11	10	9					·00156	44	12 ×6
12 ×5	39		45	36	27	22	18	15	13	12	11	9·9	9·0	8·3	7·7	7·2				·001562	39	12 ×5
12 ×5	32		32	30	28	18	15	13	11	10		8·3	7·6	7	6·5					·00156	32	12 ×5
10 ×8	70			58	43	34	28	24	21	19	17	15	14	13						·001875	70	10 ×8
10 ×6	42			35	26	21	17	15	13	11	10	9·6	8·8	8						·001875	42	10 ×6
10 ×5	35		37	28	21	17	14	12	10	9·3	8·4	7·6	7·0	6·4						·001875	35	10 ×5
10 ×5	30		30	24	18	14	12	10	9	8	7·2	6·6	6	5·6						·001875	30	10 ×5
10 ×4·66	25		24	20	15	12	10	9	8	6·8	6·1	5·6	5·1	4·7	4·4	4·1				·001875	25	10 ×4·66
9 ×7	58		44	42	32	25	21	18	16	14	12	11	10	9·8						·00208	58	9 ×7
9½×3½	21·5	26	22	15	11	9·0	7·5	6·4	5·6	5·0	4·5	4·1	3·7	3·5						·002027	21·5	9½×3½
9 ×4	21		22	15	11		7·5	4	5·6	5	4·5	4	3·7							·00208	21	9 ×4
8 ×6	35		31	23	17	14	11	9·8	8·6	7·7	7	6·3								·00234	35	8 ×6
8 ×5	28		25	18	14	11	9	8	7	6·2	5·5	5								·00234	28	8 ×5
8 ×4	18	19	17	11	8·7		5·8	5	4·3	3·8	3·5	3·2								·00234	18	8 ×4
7 ×4	16	15	14	9·4	7	5·6	4·7	4	3·5	3·1	·8	2·5								·00268	16	7 ×4
6 ×5	25	22	18	12		7·3	6	5·2	4·5	4										·003125	25	6 ×5
6 ×4½	20	20	14	9·6	7·2	5·8	4·8	4·1	3·6	3·2										·003125	20	6 ×4½
6 ×3	12	14	8·4	5·6	4·2	3·4	2·8	2·4	2·1	1·9										·003125	12	6 ×3
5 ×4½	18	13	11·3	7·6	5·6	4·5	3·8	3·2	2·8											·00375	18	5 ×4½
5 ×3	11	9·8	6·8	4·5	3·4	2·7	2·3	1·9	1·7											·00375	11	5 ×3
4½×1½	10		4·9	3·3	2·4	2·0	1·6	1·4												·00395	10	4½×1½
4½×1¼	6·5	7	3·5	2·4	1·8	1·4	1·2	1												·00395	6·5	4½×1¼
4 ×3	9·5	7·8	4·7	3·1	2·3	1·9	1·6	1·3												·00469	9·5	4 ×3
4 ×1¾	8	6·6	3·3	2·2	1·6	1·3	1·1	·95												·00469	8	4 ×1¾
4 ×1¼	5	4·6	2·3	1·5	1·1	·91	·76	·65												·00469	5	4 ×1¼
3 ×3	8·5	5·3	3·2	2	1·6	1·2		·9												·00625	8·5	3 ×3
3½×1½	6	4·4	2·2	1·5	1·1	·88	·73	·63												·005357	6	3½×1½
3 ×1½	4	2·8	1·4	·92	·6	·55	·46	·39												·00625	4	3 ×1½

BROAD FLANGE BEAMS AS STANCHIONS. Safe Loads in Tons on Stanchions for Heights of 8 to 32 Feet. (L.C.C. Formula. Ends Fixed.)										SECTION.		BROAD FLANGE BEAMS AS GIRDERS. Safe distributed Loads in Tons for Spans of 8 to 64 Feet.														
8′	10	12′	14′	16′	18′	20′	24′	28′	32′	Approx. Size. Ins.	Wt. per Foot. Lbs.	8′	10′	12′	14′	16′	18′	20′	24′	28′	32′	36′	40′	44′	48′	56′	64′
33	30	27	24	21	18	13	—	—	—	5½ × 5½	23	8	7	5	5	4	—	—	—	—	—	—	—	—	—	—	—
36	33	30	27	24	21	18	—	—	—	6 × 6	25	10	8	6	5	5	—	—	—	—	—	—	—	—	—	—	—
45	42	38	35	32	28	25	14	—	—	6½ × 6½	31	12	10	8	7	6	6	—	—	—	—	—	—	—	—	—	—
53	49	46	42	39	35	32	25	11	—	7 × 7	35	16	13	11	9	8	7	6	—	—	—	—	—	—	—	—	—
68	64	60	56	53	49	45	37	27	12	8 × 8	44	22	18	15	13	11	10	9	—	—	—	—	*Figures in italics produce a deflection greater than span ÷ 360.*				
76	73	69	65	61	57	53	46	38	25	8½ × 8½	48	—	22	18	16	14	12	11	9	—	—	—					
81	77	73	69	65	61	58	50	42	32	9 × 9	50	—	24	20	17	15	13	12	10	—	—	—					
95	91	86	82	78	73	69	60	52	43	9½ × 9½	59	—	29	25	21	18	16	15	12	—	—	—					
100	95	91	87	82	78	74	65	56	48	10 × 10	61	—	32	27	23	20	18	16	13	11	—	—	—	—	—	—	—
104	100	96	91	87	83	78	70	61	53	10½ × 10½	64	—	—	29	25	22	19	17	14	12	—	—	—	—	—	—	—
126	121	116	111	107	102	97	88	78	69	11 × 11	76	—	—	37	32	28	25	22	19	16	14	—	—	—	—	—	—
136	131	127	122	117	112	108	98	89	79	12 × 12	80	—	—	43	37	32	29	26	22	18	16	14	—	—	—	—	—
151	146	141	135	130	125	119	109	98	87	12½ × 12	90	—	—	51	44	38	34	31	25	22	19	17	15	—	—	—	—
153	148	143	137	132	126	121	110	99	88	13½ × 12	92	—	—	—	47	41	37	33	27	23	20	18	16	15	—	—	—
169	163	157	151	145	139	133	121	109	97	14 × 12	101	—	—	—	54	48	42	38	32	27	24	21	19	17	—	—	—
171	165	159	153	147	140	134	122	110	97	15 × 12	102	—	—	—	58	51	45	41	34	29	25	22	20	18	17	—	—
184	177	171	164	157	151	144	131	118	105	16 × 12	110	—	—	—	66	58	51	46	38	33	29	25	23	21	19	—	—
187	180	173	166	160	153	146	133	119	106	17 × 12	112	—	—	—	71	62	55	50	41	35	31	27	25	22	21	18	—
204	196	189	182	174	167	159	145	130	115	18 × 12	122	—	—	—	81	71	63	57	47	41	35	31	28	26	24	20	—
207	199	192	184	176	169	161	146	131	116	19 × 12	124	—	—	—	87	76	68	61	51	43	38	34	30	28	25	22	19
224	216	208	199	191	183	175	158	141	125	20 × 12	135	—	—	—	98	86	76	69	57	49	43	38	34	31	29	24	21
231	222	213	205	196	187	178	161	144	126	22 × 12	139	—	—	—	—	97	86	78	65	55	48	43	39	35	32	28	24
252	243	233	223	214	204	194	175	156	136	24 × 12	152	—	—	—	—	115	102	92	76	65	57	51	46	42	38	33	28
259	249	239	229	219	209	199	179	158	138	26 × 12	157	—	—	—	—	127	113	102	85	72	63	56	51	46	42	36	32
282	271	260	249	237	226	215	193	171	149	28 × 12	171	—	—	—	—	147	131	118	98	84	73	65	59	53	49	42	37
289	278	266	254	243	231	220	196	173	150	30 × 12	176	—	—	—	—	161	143	129	107	92	80	71	64	58	53	46	40
296	284	272	260	248	236	224	200	176	152	32 × 12	180	—	—	—	—	175	155	140	116	100	87	77	70	63	58	50	43
321	308	295	282	268	255	242	215	189	163	34 × 12	195	—	—	—	—	199	177	159	133	114	99	88	79	72	66	57	50
329	315	301	287	274	260	246	218	191	163	36 × 12	200	—	—	—	—	—	191	172	143	123	107	95	86	78	71	61	53
336	322	308	293	279	265	250	222	193	165	38 × 12	205	—	—	—	—	—	204	184	153	131	115	102	92	83	76	65	57
344	329	314	299	284	270	255	225	196	166	40 × 12	210	—	—	—	—	—	219	197	164	141	123	109	98	89	82	70	61

The above tables are as published by Messrs R. A. Skelton & Co., Steel & Engineering, Ltd.

TABLE SHOWING THE WEIGHTS AND DIMENSIONS OF, AND ESTIMATED SAFE PERMANENT DISTRIBUTED LOADS, IN TONS, FOR, VARIOUS COMPOUNDED ROLLED STEEL GIRDERS SUPPORTED AT BOTH ENDS.

No of. Section.	Weight per Ft. in Lbs.	Size in Inches.	Compounded of	Distributed Load, in Tons that 1 Ft. will carry, being 1-4th of the Breaking Strain.	Distributed Load, in Tons that 1 Ft. will carry, being 1-5th of the Breaking Strain.
G1 C1	144	21¼ × 12	1 G 1 and 2 ⅝-in. plates	1,533	1,226
G1 C2	260	21¼ × 18	2 G 1 „ 2 ⅝ „	2,654	2,123
G1 C3	377	21¼ × 24	3 G 1 „ 2 ⅝ „	3,775	3,020
G1 C4	195	22½ × 12	1 G 1 „ 4 ⅝ „	2,335	1,868
G1 C5	335	22½ × 18	2 G 1 „ 4 ⅝ „	3,821	3,056
G1 C6	480	22½ × 24	3 G 1 „ 4 ⅝ „	5,306	4,245
G1 C7	248	23¾ × 12	1 G 1 „ 6 ⅝ „	3,183	2,546
G1 C8	414	23¾ × 18	2 G 1 „ 6 ⅝ „	5,054	4,043
G1 C9	582	23¾ × 24	3 G 1 „ 6 ⅝ „	6,925	5,540
G2 C1	130	19½ × 12	1 G 2 „ 2 ⅝ „	1,279	1,023
G2 C2	227	19½ × 16	2 G 2 „ 2 ⅝ „	2,061	1,649
G2 C3	340	19½ × 24	3 G 2 „ 2 ⅝ „	3,092	2,474
G2 C4	180	20½ × 12	1 G 2 „ 4 ⅝ „	2,007	1,606
G2 C5	294	20½ × 16	2 G 2 „ 4 ⅝ „	2,989	2,391
G2 C6	440	20½ × 24	3 G 2 „ 4 ⅝ „	4,483	3,587
G2 C7	360	21¾ × 16	2 G 2 „ 6 ⅝ „	3,975	3,180
G2 C8	540	21¾ × 24	3 G 2 „ 6 ⅝ „	5,962	4,770
G3 C1	98	17 × 10	1 G 3 „ 2 ½ „	808	647
G3 C2	178·5	17 × 14	2 G 3 „ 2 ½ „	1,353	1,083
G3 C3	266	17 × 20	3 G 3 „ 2 ½ „	1,986	1,589
G3 C4	132	18 × 10	1 G 3 „ 4 ½ „	1,228	983
G3 C5	271	19 × 14	2 G 3 „ 6 ½ „	2,505	2,004
G3 C6	394	19 × 20	3 G 3 „ 6 ½ „	3,618	2,894
G5 C1	77	16 × 10	1 G 5 „ 2 ½ „	618	495
G5 C2	127	16 × 12	2 G 5 „ 2 ½ „	907	725
G5 C3	191	16 × 18	3 G 5 „ 2 ½ „	1,360	1,088
G5 C4	111·25	17 × 10	1 G 5 „ 4 ½ „	1,014	811
G5 C5	210	18 × 12	2 G 5 „ 6 ½ „	1,813	1,450
G5 C6	315	18 × 18	3 G 5 „ 6 ½ „	2,720	2,176
G6 C1	142	14½ × 15	2 G 6 „ 1 ½ „	898	718
G6 C2	93	15 × 10	1 G 6 „ 2 ½ „	684	547
G6 C3	164	15 × 14	2 G 6 „ 2 ½ „	1,137	910
G6 C4	245	15 × 20	3 G 6 „ 2 ½ „	1,667	1,334
G6 C5	127	16 × 10	1 G 6 „ 4 ½ „	1,056	845
G6 C6	212	16 × 14	2 G 6 „ 4 ½ „	1,633	1,306
G6 C7	326	16 × 20	3 G 6 „ 4 ½ „	2,370	1,896

LIMITING DIMENSIONS OF ROLLED STEEL.

Dimensions. O, Ordinary. M, Maximum.	Flat.		Round.		Square.		Angle.		Tee.		Joists.		Channel.	
	O	M	O	M	O	M	O	M	O	M	O	M	O	M
Length in feet	40	60	24	60	24	60	50	60	50	60	36	50	36	60
Width in inches	18	18	4	4	4	4	6×6	8×8	5×3	6×3	24×7½	24×7½	15×4	15×4
Thickness in ins.	1	1	—	—	—	—	⅝	1	⅜	½	½	⅝	⅝	⅝

BRITISH STANDARD SECTIONS.*

(No. 6—1924.) ***(Abstract.)***

The British Engineering Standards Association list of Rolled Steel Sections for structural purposes comprises seven different sections, viz. (1) Equal Angles, (2) Unequal Angles, (3) Bulb Angles, (4) Bulb Plates, (5) Channels, (6) Beams, and (7) T Bars.

The following are abbreviated tables showing some of the standard dimensions recommended.

Attention is directed to the footnotes on pp. 343, 344.

*By permission of the British Engineering Standards Association.

BRITISH STANDARD SECTIONS.

EQUAL ANGLES.

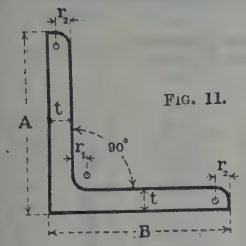


FIG. 11.

BULB PLATES.

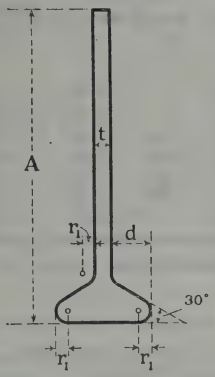


FIG. 15.

BULB ANGLES.

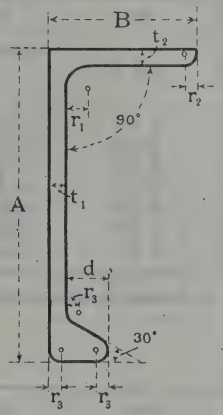


FIG. 14.

UNEQUAL ANGLES

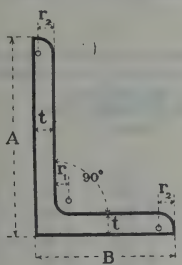


FIG. 12.

T BARS.

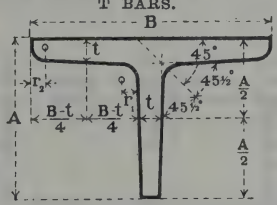


FIG. 13.

BEAMS.

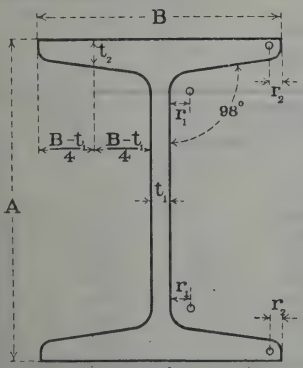


FIG. 17.

CHANNELS.

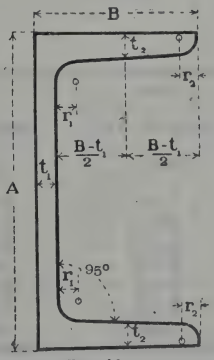


FIG. 16.

EQUAL ANGLES (Fig. 11).

Size. A × B	Standard Thickness. Minimum. t	Mean. t	Maximum t	Maximum Thickness rolled.	Minimum Thickness rolled.	Radii. Root. r_1	Toe. r_2
1 × 1	0·125	—	0·250	0·300	0·125	0·18	0·13
1½ × 1½	0·125	—	0·250	0·350	0·125	0·21	0·15
2 × 2	0·175	—	0·300	0·400	0·175	0·24	0·17
2½ × 2½	0·250	0·375	0·500	0·500	0·200	0·27	0·19
3 × 3	0·250	0·375	0·500	0·525	0·250	0·30	0·21
3½ × 3½	0·300	0·425	0·500	0·575	0·275	0·33	0·23
4 × 4	0·300	0·425	0·500	0·625	0·300	0·36	0·25
6 × 6	0·450	—	0·625	0·775	0·425	0·48	0·34
8 × 8	0·550	—	0·750	0·950	0·550	0·60	0·42

In the complete table sixteen sizes are given. All sizes are in inches.

UNEQUAL ANGLES (Fig. 12).

Size. A × B	Standard Thickness. Minimum. t	Mean. t	Maximum t	Maximum Thickness rolled.	Minimum Thickness rolled.	Radii. Root. r_1	Toe. r_2
2 × 1½	0·175	—	0·300	0·375	0·150	0·23	0·16
3 × 2	0·250	0·375	0·500	0·500	0·200	0·27	0·19
3½ × 2½	0·250	0·375	0·500	0·525	0·250	0·30	0·21
4 × 3	0·300	0·425	0·500	0·575	0·275	0·33	0·23
5 × 4	0·375	—	0·500	0·650	0·325	0·39	0·27
6 × 4	0·375	—	0·500	0·700	0·350	0·42	0·29
8 × 4	—	—	0·625	0·775	0·425	0·48	0·34
9 × 4	—	—	0·650	0·825	0·450	0·51	0·36
10 × 4	—	—	0·675	0·850	0·475	0·54	0·38

In the complete table twenty sizes are given. All sizes are in inches.

T BARS (Fig. 13).

Size. Flange × Web. B × A	Standard Thickness. Minimum. t	Mean t	Maximum. t	Radii. Root. r_1	Toe. r_2
1 × 1	0·125	0·187	—	0·18	0·13
1½ × 1½	0·187	0·250	—	0·21	0·15
2 × 2	0·250	0·312	0·375	0·24	0·17
2½ × 2½	0·250	0·312	0·375	0·27	0·19
3 × 3	0·312	0·375	0·437	0·30	0·21
4 × 3	0·375	0·500	—	0·30	0·21
5 × 4	0·500	0·625	—	0·39	0·27
6 × 4	0·500	0·625	—	0·42	0·29
6 × 6	0·500	0·625	—	0·48	0·34

In the complete table ten sizes are given. All sizes are in inches.

BULB ANGLES (Fig. 14).

Size.	Standard Thickness.		Max. Web Thickness rolled.	Min. Web Thickness rolled.	Radii.			Bulb.
	Web.	Flange						
A × B	t_1	t_2	t_1	t_1	r_1	r_2	r_3	d
4×2½	0·26		0·46	0·21	0·42	0·21	0·16	0·52
5×2½	0·30		0·50	0·25	0·42	0·21	0·20	0·65
6×3	0·33		0·54	0·28	0·48	0·24	0·24	0·78
7×3	0·38		0·59	0·33	0·48	0·24	0·28	0·91
8×3	0·40		0·61	0·35	0·48	0·24	0·32	1·04
9×3½	0·43		0·65	0·38	0·54	0·27	0·36	1·17
10×3½	0·45		0·67	0·40	0·54	0·27	0·40	1·30
11×3½	0·48		0·70	0·43	0·54	0·27	0·44	1·43
12×4	0·50		0·73	0·45	0·60	0·30	0·48	1·56
15×4	0·57		0·82	0·52	0·60	0·30	0·60	1·95

In the complete table eighteen sizes are given. All sizes are in inches.

BULB PLATES (Fig. 15).

Size.	Standard Thickness.	Maximum Thickness rolled.	Minimum Thickness rolled.	Radius	Bulb.
A	t			r_1	d
7	0·35	0·450	0·275	0·28	0·91
10	0·50	0·625	0·375	0·40	1·30

The above table is complete. All sizes are in inches.

CHANNELS (Fig. 16).

Size.		Calculated Weight per Foot in Lbs.	Standard Minimum Thickness.		Radii.	
			Web.	Flange.	Root.	Toe.
A	B		t_1	t_2	r_1	r_2
3	1½	4·60	0·20	0·28	0·30	0·15
4	2	7·09	0·24	0·31	0·36	0·18
5	2½	10·22	0·25	0·38	0·42	0·21
6	3	12·41	0·25	0·38	0·48	0·24
7	3	14·22	0·26	0·42	0·48	0·24
8	3½	20·21	0·32	0·52	0·54	0·27
9	3½	22·27	0·34	0·54	0·54	0·27
10	3½	24·46	0·36	0·56	0·54	0·27
12	3½	25·25	0·35	0·50	0·54	0·27
12	4	31·33	0·40	0·60	0·60	0·30
15	4	36·37	0·41	0·62	0·60	0·30
17	4	44·34	0·48	0·68	0·60	0·30

In the complete table eighteen sizes are given. All sizes are in inches.

The alterations from the original to the revised sections given in this and the preceding page will take place, particularly in the larger sizes, only as the rolls wear out, or break, and thus require replacing. For some time, therefore, it will be necessary to enquire as to sections available.

A. GIRDER SECTIONS (Fig. 17).

Reference Number.	Size.		Approx. Weight per Foot in Lbs.	Standard Thickness.		Radii.	
				Web.	Flange.	Root.	Toe.
	A	B		t_1	t_2	r_1	r_2
NBSB 1	3	1½	4	0·16	0·249	0·25	0·12
„ 2	4	1¾	5	0·17	0·239	0·27	0·13
„ 3	4½	2	7	0·19	0·322	0·29	0·14
„ 4	5	2½	9	0·20	0·347	0·33	0·16
„ 5	6	3	12	0·23	0·377	0·37	0·18
„ 6	7	3½	15	0·25	0·398	0·41	0·20
„ 7	8	4	18	0·28	0·398	0·45	0·22
„ 8	9	4	21	0·30	0·457	0·45	0·22
„ 9	10	4½	25	0·30	0·505	0·49	0·24
„ 10	12	5	30	0·33	0·507	0·53	0·26
„ 11	13	5	35	0·35	0·604	0·53	0·26
„ 12	14	5½	40	0·37	0·627	0·57	0·28
„ 13	15	6	45	0·38	0·655	0·61	0·30
„ 14	16	6	50	0·40	0·726	0·61	0·30
„ 15	18	6	55	0·42	0·757	0·61	0·30
„ 16	20	6½	65	0·45	0·820	0·65	0·32
„ 17	22	7	75	0·50	0·834	0·69	0·34
„ 18	24	7½	90	0·52	0·984	0·73	0·36

B. HEAVY BEAMS AND PILLARS (Fig. 17).

NBSHB 1	4	3	10	0·24	0·347	0·37	0·18
„ 2	5	4½	20	0·29	0·513	0·49	0·24
„ 3	6	5	25	0·33	0·561	0·53	0·26
„ 4	8	6	35	0·35	0·648	0·61	0·30
„ 5	9	7	50	0·40	0·825	0·69	0·34
„ 6	10	6	40	0·36	0·709	0·61	0·30
„ 7	10	8	55	0·40	0·783	0·77	0·38
„ 8	12	8	65	0·43	0·904	0·77	0·38
„ 9	14	8	70	0·46	0·920	0·77	0·38
„ 10	16	8	75	0·48	0·938	0·77	0·38
„ 11	18	8	80	0·50	0·950	0·77	0·38

The above tables are complete. All sizes are in inches.

For a considerable time the majority of the above sections will not be available, owing to the cost of providing the sets of rolls required for each size, and it will be necessary to utilise the present sections. For particulars of these present available sections of beams, a reference should be made to the table on p. 337, where all present British Standard Beams are marked BSB 1 to 30.

Strengths of Different Sections as Beams and as Struts.

The tables given on pp. 345 and 346 are calculated by Fidler's formula for struts with fixed ends, assuming an ultimate strength of 60,000 lbs. per sq. in. and allowing a factor of safety of 5.

BRITISH STANDARD EQUAL-SIZED ANGLES.

SAFE LOADS AS STRUTS; FIXED ENDS.

Size in Inches.	Thickness in Inches.	Weight per Foot in Pounds.	Area of Cross-Section. Sq. Ins.	Safe Loads in Tons (Struts) for least axis of Gyration. Length. 4 ft.	6 ft.	8 ft.	10 ft.	12 ft.	14 ft.
2 × 2	·300	3·77	1·11	3·0	1·6	—	—	—	—
2¼ × 2¼	·300	4·28	1·26	3·9	2·2	1·5	—	—	—
2½ × 2½	⅜	5·89	1·73	6·0	3·5	2·3	1·6	—	—
2½ × 2½	½	7·65	2·25	7·7	4·6	3·0	2·1	1·4	—
2¾ × 2¾	⅜	6·53	1·92	7·3	4·6	3·0	2·1	1·5	—
2¾ × 2¾	½	8·50	2·50	9·5	6·0	3·9	2·8	2·0	1·4
3 × 3	⅜	7·18	2·11	8·5	5·7	3·8	2·7	2·0	1·4
3 × 3	½	9·36	2·75	11·1	7·5	4·9	3·6	2·6	1·9
3½ × 3½	·425	9·50	2·80	12	9·0	6·4	4·6	3·5	2·7
3½ × 3½	½	11·1	3·25	15	11	8·0	5·7	4·4	3·4
4 × 4	·425	10·9	3·22	15	12	8·6	6·3	4·7	3·8
4 × 4	½	12·8	3·75	17	14	10	7·3	5·5	4·5
4½ × 4½	½	14·5	4·25	20	17	13	10	7·7	6·2
5 × 5	½	16·2	4·75	23	20	16	13	9·6	7·7
6 × 6	⅝	24·2	7·11	36	32	28	23	19	15

(R. A. Skelton & Co.)

BRITISH STANDARD CHANNELS AS STRUTS.

Size in Inches. Width. Depth.	Weight per Foot run. Lbs.	Area of Cross Section. Sq. Ins.	Safe Loads in Tons (Struts). If liable to failure in either direction. Lengths. 6 ft.	8 ft.	10 ft.	12 ft.	If braced against failure in weaker direction. Lengths. 6 ft.	8 ft.	10 ft.	12 ft.	14 ft.	16 ft.
3 × 1½	5·27	1·55	—	—	—	—	7·02	6·14	5·01	4·08	—	—
3½ × 2	6·75	1·99	5·55	—	—	—	9·43	8·62	7·66	6·43	—	—
4 × 2	7·96	2·34	6·53	4·33	—	—	11·4	10·7	9·69	8·73	7·35	—
5 × 2½	11·0	3·23	11·3	8·14	—	—	16·4	15·6	14·7	13·6	12·5	—
6 × 2½	12·0	3·54	12·1	8·74	6·23	—	18·2	17·7	16·9	16·0	15.0	—
6 × 3	14·0	4·26	17·5	13·6	10·5	—	22·0	21·4	20·4	19·6	18·3	—
6 × 3	16·3	4·79	19·4	15·0	11·5	8·77	24·7	24·1	22·8	21·8	20·5	19·3
6 × 3½	17·9	5·27	23·1	19·8	15·7	12·4	27·3	26·5	25·2	24·2	22·7	21·3
7 × 3½	20·2	5·95	25·9	22·4	17·5	13·9	31·0	30·4	29·4	28·2	27·3	25·8
8 × 3½	22·7	6·68	28·9	24·7	19·1	15·2	35·0	34·4	33·8	32·5	31·5	30·5
8 × 4	25·7	7·59	34·7	30·7	25·4	21·0	39·7	39·0	38·5	37·0	35·5	34·7
9 × 4	28·6	8·40	38·8	34·0	27·9	23·0	44·2	43·6	43·0	42·2	40·7	39·5
10 × 4	30·2	8·87	—	35·4	28·9	23·8	46·7	46·3	45·7	45·1	43·8	42·6
11 × 4	33·2	9·77	—	39·0	31·9	25·9	51·5	51·2	50·6	50·0	49·3	47·8
12 × 4	36·5	10·7	—	42·1	34·2	27·6	56·4	56·3	55·6	55·0	54·5	53·2

(R. A. Skelton & Co.)

The assumed ultimate strength of 60,000 lbs. per sq. in. is approximately 26·8 tons per sq. in. For an assumed ultimate strength of 70,000 lbs. per sq. in., or nearly 31·2 tons per sq. in., the values in the tables multiplied by $\frac{7}{8}$ would be approximately correct. Similarly, for a factor of safety of 4, multiply the values by $\frac{4}{5}$.

British Standard Tees.

Safe Loads as Struts; fixed ends.

Size in Ins. Breadth. Height.	Thickness in Ins.	Weight per Ft. run.	Area of Cross Section.	Safe Loads in Tons (Struts.) Lengths.					
		Lbs.	Sq. Ins.	4 ft.	6 ft.	8 ft.	10 ft.	12 ft.	14 ft.
2½ × 2½	5/16	5·00	1·47	5·2	3·2	2·1	1·5	—	—
2½ × 2½	3/8	5·92	1·74	6·2	3·8	2·5	1·7	—	—
3 × 2	3/8	5·93	1·74	7·5	5·5	3·8	2·8	2·1	—
3 × 2½	3/8	6·56	1·93	8·1	5·7	3·9	2·8	2·1	—
3 × 3	3/8	7·21	2·12	8·7	6·0	4·1	2·9	2·2	—
3 × 3	7/16	8·30	2·44	10	6·9	4·7	3·4	2·5	—
3½ × 3½	3/8	8·49	2·50	11	8·5	6·0	4·3	3·3	—
3½ × 3½	7/16	9·78	2·88	13	9·8	6·9	5·0	3·8	3·0
3½ × 3½	½	11·1	3·26	14	11	7 9	5·6	4·3	3·4
4 × 3	½	11·1	3·26	15	13	10	7·6	5·7	4·6
4 × 4	½	12·8	3·76	17	14	11	7·9	6·0	4·9
5 × 3	½	12·8	3·76	19	17	15	12	9·8	7·8
5½ × 3½	½	13·7	4·02	20	18	16	13	10	8·2
5 × 4	½	14·5	4·27	21	19	16	13	10	8·3

British Standard Joists as Struts.

Size in Inches.	Weight per Foot run.	Area of Cross Section.	Safe Load in Tons. Lengths.			
	Lbs.	Sq. Ins.	6 ft.	8 ft.	10 ft.	12 ft.
3 × 3	8½	2·50	8·4	6·0	4·3	—
4 × 3	9½	2·80	9·0	6·2	4·8	—
5 × 3	11	3·24	10·0	7·1	5·1	—
7 × 4	16	4·7	18	14	11	8·1
9 × 4	21	6·18	24	18	13	10
6 × 5	25	7·35	33	29	23	19
10 × 5	30	8·82	39	33	26	21
12 × 5	32	9·41	40	34	27	21
15 × 5	42	12·4	52	42	34	26
12 × 6	44	12·9	61	55	48	40
15·6	59	17·3	81	73	63	52

British Standard Unequal Angles as Beams.

Safe Distributed Loads: Long Side Vertical.

Maximum working stress 7½ tons per square inch.

Size in Ins.	Thickness.	Weight per Ft. run.	Distributed Load in Tons. Maximum Stress 7½ tons per square inch.					
	Ins.	Lbs.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.
2 × 1½	·300	3·27	·34	·27	·22	—	—	—
2½ × 2	·300	4·28	·54	·44	·36	—	—	—
3 × 2	¼	4·04	·65	·52	·44	—	—	—
3 × 2	3/8	5·89	·95	·76	·63	·54	—	—
3½ × 2½	3/8	7·18	1·4	1·1	·91	·78	·68	—
3½ × 2½	½	9·36	1·8	1·4	1·2	1·0	·89	·79
4 × 2½	3/8	7·81	1·7	1·4	1·1	·99	·86	·77
4 × 2½	½	10·2	2·2	1·8	1·5	1·3	1·1	1·0
4 × 3	½	11·1	2·3	1·9	1·6	1·3	1·2	1·0
4½ × 3	½	11·9	2·9	2·3	1·9	1·7	1·5	1·3

(R. A. Skelton & Co.)

SECTION VII

BRIDGES AND BRIDGEWORK
(METAL)

(Contributed by Henry F. Cornick, M.C., A.M.Inst.C.E. (Chartered Civil Engineer), late Major, Royal Engineers

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STEEL BRIDGEWORK
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PLATE GIRDER BRIDGES
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PART III
LATTICE GIRDER BRIDGES
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SWING AND BASCULE BRIDGES
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ARCH BRIDGES
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SUSPENSION BRIDGES
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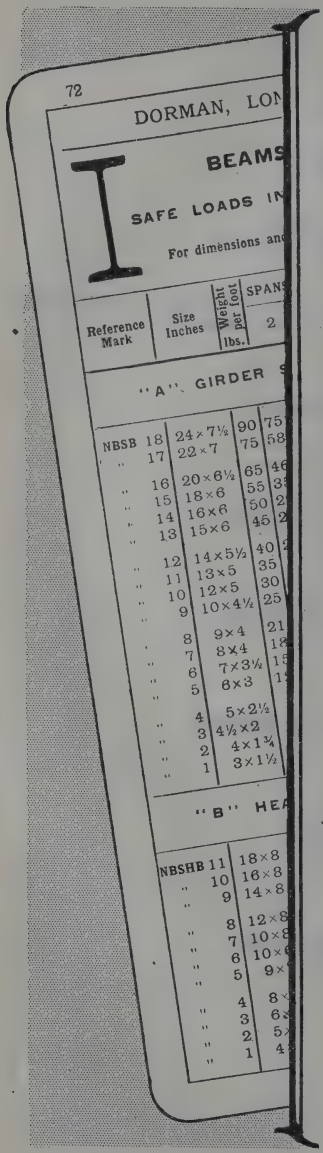
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I BEAMS

SAFE LOADS IN

For dimensions and

Reference Mark	Size Inches	Weight per foot lbs.	SPANS 2
"A" GIRDER S			
NBSB 18	24×7½	90	75
" 17	22×7	75	58
" 16	20×6½	65	46
" 15	18×6	55	3
" 14	16×6	50	2
" 13	15×6	45	2
" 12	14×5½	40	
" 11	13×5	35	
" 10	12×5	30	
" 9	10×4½	25	
" 8	9×4	21	
" 7	8×4	18	
" 6	7×3½	15	
" 5	6×3	1	
" 4	5×2½		
" 3	4½×2		
" 2	4×1¾		
" 1	3×1½		
"B" HEA			
NBSHB 11	18×8		
" 10	16×8		
" 9	14×8		
" 8	12×8		
" 7	10×8		
" 6	10×		
" 5	9×		
" 4	8×		
" 3	6×		
" 2	5×		
" 1	4×		

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SECTION VII

PART I

STEEL BRIDGEWORK

TYPES — ECONOMICAL SPAN — PROPORTIONS — STANDARD CLEARANCES — LIVE LOADS — BRIDGE FOUNDATIONS — PERMISSIBLE STRESSES — WIND PRESSURE — CENTRIFUGAL FORCE—MOMENTUM — IMPACT—TEMPERATURE—BEARINGS—FLOORING—CAMBER, RIVETING, ETC.

TYPES.

Bridges consist of two parts:

(*a*) The substructure, comprising abutments, piers, caissons, and other forms of foundations.

(*b*) The superstructure, which comprises the bridge structure itself.

There are three known methods of carrying weight over space—*i.e.* by means of:

(1) The beam; (2) the arch; (3) the rope.

All bridges can be reduced to one, or a combination, of these types.

(1) THE BEAM.—The strength of the beam depends on transverse bending. The theoretic stress in the extreme fibres is inconsistent with experiments, but the so-called discrepancy diminishes with the thickness of the web and the ratio of depth to span of the beam.

The principal groups of girder bridges are:

(A) Girders of uniform depth; (B) girders of uniform horizontal stress.

Group A: Parallel Girders.—In this case the shearing force is resisted by the web, and the diagram of moments forms the stress diagram.

Group B: Parabolic Girders—In this case, for uniform loading the shearing force is resisted by the flanges and the diagram of moments forms a diagram of depth.

All these types can be used in their inverted form, and it is from these forms that the Arch and Rope are evolved.

(2) THE ARCH.—For any given system of loading a theoretical arch can be designed so as to be in compression only, the neutral axis of the arch coinciding with the line of pressure; but unless it can resist bending, the arch will be in a state of unstable equilibrium. The horizontal stress varies with the rise.

(3) THE ROPE.—The shape which the loaded cable takes up is the same as the link polygon for the given load system drawn from one support to the other with a polar distance equal to the horizontal component of the pull in the cable. Stable equilibrium is obtained under changes of load. The horizontal stress varies with the dip.

Economical Span.

In bridging a large opening by a number of small spans, the economical span may be approximated in the following manner:—

Let

P = cost of one pier; G = cost of main girders for one span erected; n = number of small spans; l = length of small spans; L = total span;

then,

$$n = \frac{L}{l}.$$

Cost of piers = $(n-1)$ P

Cost of main girders $= nG$, and G may be taken as proportional to the square of the span, so that,

$$G = al^2,$$

therefore

$$\text{Total cost} = C = (n-1)\,P + nal^2,$$

where a is a constant.

To get the minimum value of C, differentiate with respect to l and put it equal to zero. Therefore

$$\frac{dC}{dl} = 0.$$

But

$$C = \left(\frac{L-l}{l}\right)P + \frac{Lal^2}{l}.$$

$$= \frac{LP}{l} - P + Lal,$$

therefore

$$\frac{dC}{dl} = \frac{-LP}{l^2} + La = 0,$$

therefore

$$\frac{P}{l^2} = a,$$

or

$$P = al^2 = G.$$

From this it follows that the most economical condition is when the cost of one pier equals the cost of one main girder for one span.

If G equals cost of 100 ft. span, the result may be expressed:

$$\text{Economical span} = \frac{100\sqrt{P}}{\sqrt{G}}. \qquad (\textit{Ency. Brit.})$$

Another formula is as follows:—

Let

H = total height of each pier measured from bottom of foundation; L = total length of bridge;

$$r = \begin{cases} \text{price per cubic yard of masonry} \\ \text{(or) price per ton of steel} \end{cases}; \quad n = \text{number of piers};$$

then for a double line

$$n = 0{\cdot}063L\sqrt{\frac{L-10rH}{rHL}} - 1;$$

for a single line

$$n = 0{\cdot}04L\sqrt{\frac{L-10rH}{rHL}} - 1.$$

These formulæ do not apply when H is more than 98 ft.

Economical Proportions of Girders.

Plate Girders.

Let

x = depth of girder in ins.; W = weight of girder in lbs.; f = allowable working stress on gross area; t = thickness of web; L = extreme length of girder; M = total bending moment at centre (inch-pounds).

Then the weight of the web is $\frac{10}{3}Ltx$, and that of the flanges, assuming the flange plates are the required theoretical lengths, $= \frac{10}{3}\left(1{\cdot}6\frac{ML}{fx}\right)$,

therefore

$$W = \frac{10}{3}Ltx - \frac{10}{3}\left(1{\cdot}6\frac{ML}{fx}\right),$$

and W is a minimum when $x = 1{\cdot}27\sqrt{\frac{M}{ft}}$.

This formula is based upon the assumption that no portion of the web is included in flange area.

If the resistance of web is considered, then

$$x = 1{\cdot}46 \sqrt{\frac{M}{ft}}.$$

If the flanges are of constant section throughout, the foregoing formulæ become

$$x = 1{\cdot}41 \sqrt{\frac{M}{ft}} \text{ (web neglected)}; \quad x = 1{\cdot}63 \sqrt{\frac{M}{ft}} \text{ (web considered)}.$$

Lattice Girders.

In trusses of the N type the maximum stiffness or minimum deflection is obtained when

$$x = \frac{d}{2} \sqrt{\frac{y+2}{y-2}} \times y,$$

where

d = length in feet between verticals; y = number of bays.

(Sir Wm. Arrol & Co.)

For plate girders, the economic depth may be taken roughly as from $\frac{1}{10}$ to $\frac{1}{15}$ of the span, $\frac{1}{12}$ often being adopted; and for lattice girders should be not less than $\frac{1}{10}$ of the span, preferably $\frac{1}{8}$.

If shallower girders are necessary, the sections must be increased, so that the maximum deflection will not be greater than if the limiting ratio had not been exceeded.

Breadth of Flanges.

For plate girders this may be taken as about $\frac{1}{3}$ of the depth, or $\frac{1}{30}$ to $\frac{1}{40}$ of the span.

The width of booms in lattice girders should not be less than $\frac{1}{12}$ of the unsupported distance.

Cross Girders.—Depth should not be less than $\frac{1}{10}$ of the span, preferably $\frac{1}{8}$.

Rail Bearers should have a depth of not less than $\frac{1}{12}$ of the span.

Spans, Standard Clearances, etc.

Over-bridges carrying roads over railways are usually of the following spans:

Over single line, 16 to 18 ft. Over double line, 28 to 30 ft.

Widths of over-bridges, between inside of parapets, are regulated by Act of Parliament, as follows, the roads being of the widths given for 50 yards each way:

Turnpike roads, 35 ft. Other public carriage roads, 25 ft. Private roads, 12 ft.

Under-bridges carrying roads under railway, span and headroom fixed by Act of Parliament.

Turnpike road, clear headroom, 12 ft. at springing, 16 ft. for centre 12 ft. of arch. Where tramways cross the bridge a minimum headroom of 18 ft. should be provided.

Other public and carriage roads, clear headroom 12 ft. at springing, 15 ft. for centre, 13 ft. of arch.

Private roads, clear headroom 14 ft. for centre breadth of 9 ft. of arch.

In all cases, under-bridges must have a parapet at least 4 ft. 6 ins. above rail level.

Live Loads on Railway Bridges.

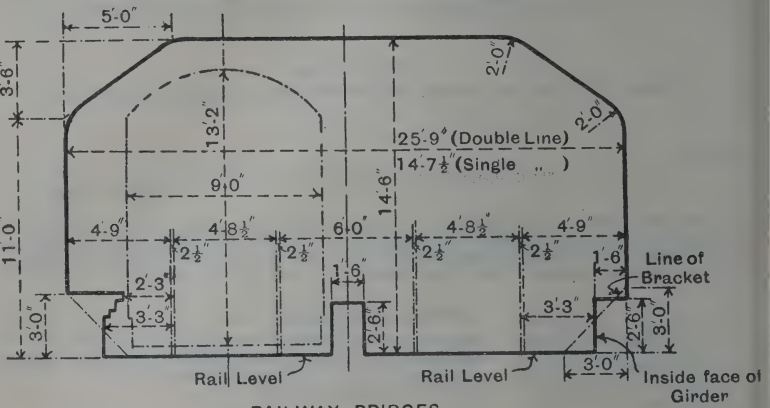
Rolling Load on Railway Bridges.

(1)

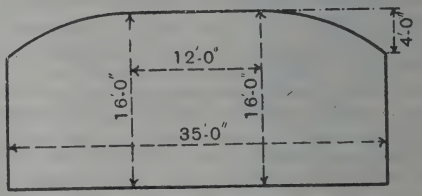
The effective weight of the rolling load, per foot lineal of each line of way, will depend upon the width of span. The heaviest train would consist of locomotives coupled closely together, but while a bridge of short span might frequently be covered by such a train, or by the two engines that often head the train, a bridge of very long span would never be subjected to such a load per foot lineal over its entire length. But for spans shorter than the length of one engine, the load may be very much greater than the weight of the engine per foot of its extreme length. Taking the worst position of the wheel-loads, and the heaviest class of engines now in use upon English lines of railway, the equivalent distributed load per foot lineal may be estimated as follows:—

For spans of 10 feet, a load of 4·40 tons per foot.			For spans of 100 feet, a load of 2·07 tons per foot.		
" 20 " "	3·25 " "	"	150 " "	2·00 "	"
" 30 " "	2·88 " "	"	200 " "	1·90 "	"
" 60 " "	2·30 " "	"	300 " "	1·75 "	"

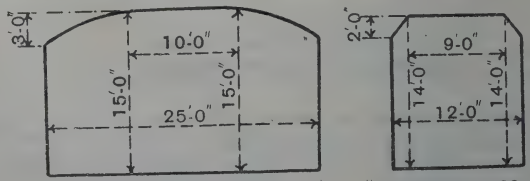
STANDARD CLEARANCES FOR BRIDGES.



RAILWAY BRIDGES



TURNPIKE ROADS



PUBLIC CARRIAGE ROADS PRIVATE ROADS

ROAD BRIDGES

FIG. 1.

In designing cross girders the maximum axle load is taken at 22 tons.

These loads are exclusive of any allowance for impact which may be allowed for by varying the unit stress per sq. in. to suit the application of the load :—From 4·5 tons per sq. in. for cross girders to 6·5 tons per sq. in. for main girders 100 feet span and over. The better plan, however, is to calculate the impact allowance from one of the impact formulæ given on p. 366.

The loads given above are considered to be the maximum that can be obtained from the present loading gauge of British railways.

(2)

Bridge to be designed for a moving load of two engines coupled and a uniformly loaded train for each track. Greatest stresses in any possible circumstances to be taken.

Where not specified take the following :—

For Main Girders.—Distributed rolling load per track = 1·5 tons per foot run, and an excess rolling load to occupy any position on the bridge at the same time equal to $15 \text{ tons} + \left(\frac{\text{span in feet} - 10}{10}\right)$ but not greater than 25 tons.

For Cross Girders.—The load on each cross girder from each track :

For all girders up to 7 ft. centres = 19 tons,
,, ,, beyond 7 ft. ,, = 1·5 tons per ft. run of track plus an excess load of

$$10 \text{ tons} - \left(\frac{10 - \text{centres of cross girders in ft.}}{5}\right),$$

but not greater than 10 tons. *(Sir Wm. Arrol & Co.)*

LOCOMOTIVE WEIGHT DISTRIBUTION ON BRIDGES.

In the case of the new four-cylinder 'Baltic' tank engines—London Midland and Scottish Railway—these engines are of the 4–6–4 type, 40 ft. 4 ins. total wheel base, 49 ft. 10½ ins. long over buffers. The total weight in working order is 99 tons 17 cwt., the adhesion weight being 55 tons 15 cwt.

The general weight distribution is :

	T.	C.	Q.	lbs.
Weight per ft. on coupled wheels	4	2	0	12
,, ,, engine wheel base	2	9	2	2
,, ,, over buffers	2	0	0	5

For further details of locomotives refer to 'Weights of Locomotives and Rolling Stock,' Section XIII. Part II, pp. 668, 720.

In the case of the Sao Paulo Railway, 1912, fig. 2 shows the maximum axle loads to serve as a basis for the design of new bridges, and is repeated in long spans so that the whole bridge is covered by a train of engines.

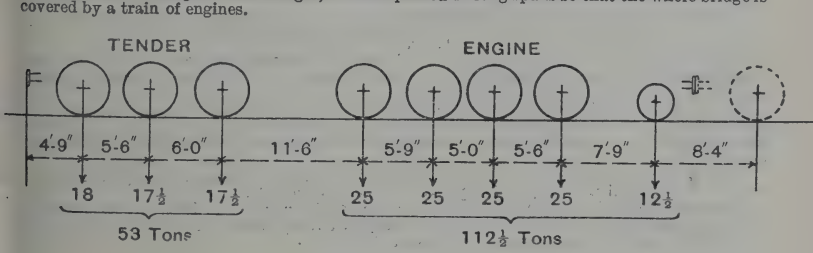


FIG. 2.—SAO PAULO RAILWAY CO. LOADING.

Loads on Highway Bridges.*

The following three classes of bridge loading should give suitable provision for all forms of traffic and loading.

CLASS 1.—Bridges on main thoroughfares in great industrial centres, and within a radius of 25 miles thereof. Will take ordinary boiler trollies and heavy guns.

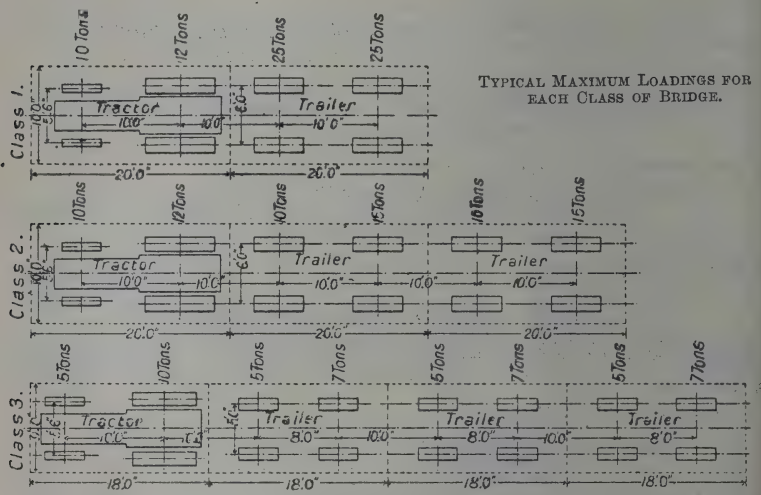
CLASS 2.—Bridges on secondary roads in great industrial centres, and on main roads outside a

* For further particulars see Joint Committee's Report on Loads on Highway Bridges, published by the Institution of Structural Engineers.

radius of 25 miles. Will take 20-ton rollers, large traction engines, large ploughing engines, L.C.C. tramcars, etc.

Class 3.—Bridges on provincial roads other than main roads. Will take 15-ton rollers, ordinary traction engines, ploughing engines, brick trucks, and siege guns.

Note.—For certain localities, as Leeds, Sheffield, West Bromwich, Salford, etc., a maximum axle load of 35 tons, or a gross load of 70 tons on two axles, with a wheel base of 10 × 6 feet should be provided for.



Typical Maximum Loadings for each Class of Bridge.

Fig. 3.

Only one of the above loads to be on the bridge at one time.

All loads are axle loads, i.e. on two wheels.

In addition to the above passing loads, 1 cwt. per foot super should be provided for over the part of the bridge not occupied by these loads.

In designing bridges with cross girders, the latter must be sufficient to carry the maximum axle load travelling across the centre of their spans at the given wheel base, in addition to the dead load, and distributed load of 1 cwt. per foot.

In designing arched bridges, the curve of thrust should be drawn when the heaviest axle has reached the centre of the nearest haunch, and again when it has reached the centre of the further haunch; a further condition, when it has reached the centre of the bridge, should also be taken.

The distribution of point loads through the thickness of the road material may be taken as equal to the depth (i.e. the angle of dispersion can be taken as 45°).

To allow for the virtual increase in the value or intensity of a rolling load by vibration due to irregularities in the road surface, etc., it is suggested that a factor of safety of 4 for spans over 50 feet, and 5 for smaller spans be adopted.

Ministry of Transport Standard Load for Highway Bridges.

In its 'Report on the Road Fund for 1921–22,' the Ministry of Transport states: 'It is obviously desirable for a uniform standard of strength to be applied to bridges on all the principal highways, and with this end in view a standardised loading for highway bridges has been prepared (see diagram). The aim has been to ensure that any bridge, towards the cost of which a grant is made or a loan recommended, shall be so designed as to carry any traffic which may come on the road, so that no restriction need be imposed on the use of the bridge. In deciding upon this standard loading, it had to be borne in mind that a bridge is the most important link in the highway chain, and that a life of at least one hundred years should be anticipated. It was therefore essential that a margin should be allowed to cover the more

onerous loading which may be expected in coming years. This standard loading is only applicable to bridges required to carry normal traffic, and in certain industrial districts, such as Liverpool, where heavy indivisible loads in excess of 16 tons have to be dealt with, the bridges must be designed of greater strength accordingly. These exceptional cases fall to be considered, in the first instance, by the highway authorities concerned. The load specified, namely, one traction engine and three trailers, is the heaviest dead load that is permitted for a train of vehicles having steel tyres, and to this dead load 50 per cent. has been added for impact. It must be admitted that 50 per cent. can only be regarded as an empirical figure, for which it is hoped to substitute an appropriate formula as the result of experiments which are now proceeding. The principal difficulty encountered by highway authorities in the matter of bridges arises in the case of those structures which are maintainable by undertakings such as canal companies, railway companies, etc., whose liability is limited to the maintenance of a structure adapted to the loads and traffic conditions of the period in which the bridge was erected. In these days it is evident that the

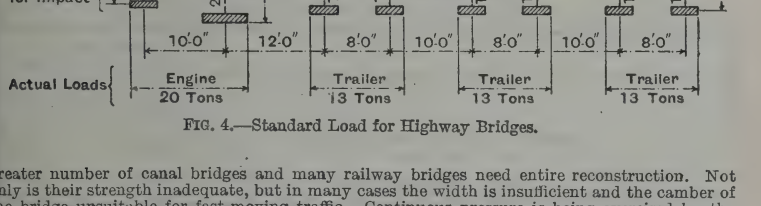


FIG. 4.—Standard Load for Highway Bridges.

greater number of canal bridges and many railway bridges need entire reconstruction. Not only is their strength inadequate, but in many cases the width is insufficient and the camber of the bridge unsuitable for fast-moving traffic. Continuous pressure is being exercised by the Department, and many conferences have been held with a view to drawing up schemes for the apportionment of the cost of reconstruction between the undertaking, the highway authority, and the Road Fund. In view of the magnitude of the problem, some years must necessarily elapse before the highways of the country, especially in regions traversed by canals, can in this respect be brought up to a standard likely to give complete satisfaction to road users. In connection with the standardisation of bridge design, with regard to carriage-ways generally, a standard width is now recommended, based on a unit of 10 ft. per line of traffic. This dimension applies equally to the carriage-way of highways and of bridges, and its adoption has been generally welcomed by local authorities. The introduction of such a standard will serve a useful purpose in discouraging the creation of carriage-ways of unnecessary width, as it is clearly undesirable that intermediate dimensions should be adopted which give an excessive width for (say) two streams of traffic, and an inadequate width for three.'

In using the diagram (fig. 4) of loading, the bridge is to be assumed to be carrying such standard loads or parts of standard loads as will produce the maximum stress in any bridge member or material under consideration, provided that in any train of loads there shall not be more than one engine per 70 ft. of the span of the bridge, and that the distance between the centre lines of two adjacent trains of loads shall be taken as 10 ft. in normal cases where the width of the carriage-way is a multiple of 10 ft. Where a smaller multiple is adopted (but not less in any case than 8 ft.) it shall be assumed that the distance between the centre lines of two adjacent trains of loads is reduced to the dimensions of the lesser multiple so adopted. The overall width of 9 ft. shown on the diagram must then be assumed to be reduced so as to leave 1 ft. clearance between the wheels of two adjacent trains.

It will be seen by this that all new bridges must now be designed to support the same rolling load. The only thing the designer has to choose is the particular type of bridge which he will adopt.

Bridge Foundations.

LOADS ON BRIDGE FOUNDATIONS.

CYLINDER BRIDGE PIERS. APPROXIMATE SAFE LOADS PER SQUARE FOOT (*J. Newman*).

	Tons per Sq. Ft.
Firm sand in estuaries and bays	5·0 to 5·6
Considered safe on firm sand (in Holland)	6·0
Very firm, compact sand, foundations at depths not less than 20 ft.	6·7 to 7·8
Firm shale and clean gravel	6·7 to 8·9
Compact gravel	7·8 to 10·0

Calculated loadings (neglecting friction), tons per square foot: Benares bridge, 11·19; Jubilee bridge, 9; Goral bridge, 8·5 (all deep foundations); Blackfriars bridge, 4·75; Rupnarayan bridge, 6·7 (or, assuming skin friction as 5 cwts. per square foot, the loading on the base of the pier is about 4·5 tons per square foot).

Clyde Bridge, Caledonian Railway.

Caissons 48 to 89 ft. long and 20 to 23 ft. wide:

Land Piers.—Distances from river-bed about 50 and 60 ft.; depths below level of river-bed about 20 and 30 ft. Depths below quay level and loadings, 50 ft., 4·12 tons per sq. ft.; 61 ft., 4·73 tons; 57 ft., 4·75 tons.

River Piers.—Depths below river bed and loadings: 44 ft., 5·66 tons per sq. ft.; 44 ft., 5·96 tons; 48 ft., 6·04 tons; 44 ft., 6·12 tons.

Skin Friction on Bridge Foundations.

(Caissons and 'Wells' or 'Cylinders.')

Foundations of the Empress Bridge over the Sutlej.

Brick Cylinders, 19 Ft. in diameter, sunk on an average 110 Ft.	Skin Friction. Cwts. per Sq. Ft.		
	Mean.	Max.	Min.
Average of 36 cylinders sunk to depths varying from 10 to 27 ft., average 19 ft., under their own weight only, 25½ to 33 tons, average 31 tons.	0·85	1·33	0·63
Average of 100 observations in sinking 36 cylinders, at depths from 17 to 64 ft., loads 31 to 249 tons, average 132 tons besides the weight of the cylinders.	2·13	4·08	1·29
Average of 9 observations in sinking 3 cylinders by pneumatic process at depths varying from 44 ft. to 63 ft.	2·71	3·52	2·32

Papaghni Bridge.—Cast-iron cylinders 12 ft. in diameter and brick cylinders of the same diameter. The following frictional resistances were noted when sinking the piers; cwts. per sq. ft. In the upper sand 2·08 to 2·20; in black clay, 3·50 to 5·60; in silt below the clay, 2·72 to 4·28; in the lower sand, 2·58 to 3·16.

Chittravati Bridge.—Friction through 33 ft. of sand, 10 ft. of clay, and 7 ft. of clay, sand, and boulders—2·32 to 3·77 cwts. per sq. ft. Friction through 33 ft. of sand, 10 ft. of clay, and 3 ft. of sand and clay—2·93 to 3·62 cwts. per sq. ft.

Tavy and Laira Bridges, Devonshire.—2·0 to 2·8 cwts. in mud.

Concrete Cylinders at Haulbowline Dockyard (H. E. Oakley).—Twenty-three cylinders, 8 ft. in diameter, were sunk through silt. The average skin friction for a cylinder varied from 4·2 to 8·6, the mean being 5·9. In only three cases was the average for a cylinder less than 5·2 cwt. per sq. ft. In seven cases the maximum resistance recorded exceeded 9 cwts. per sq. ft.

Caissons of Barnes Railway Bridge.—The caissons are 28 ft. by 18 ft. The skin friction in London clay was 2·03 cwts. for one, and 2·95 cwts. for the other, per sq. ft.

A Shaft sunk at Oxford Circus, London.—Skin friction only 1·0 cwt. per sq. ft. The low value being attributed to (1) the cylinder keeping its shape very well; (2) being kept very upright; and (3) a pocket being formed below the cutting edge and pugged clay inserted.

A Shaft sunk at Greenwich.—In sand and ballast, skin friction 4 to 4½ cwts.; in shelly clay, 6 cwts. per sq. ft.

Unit Loads on Bridge Materials.

Clyde Bridge, Caledonian Railway (D. A. Matheson).—Loads adopted as standards, tons per sq. ft.; concrete in foundations, 7; concrete in walls, 8; red brickwork in cement, 10; blue brickwork in cement, 15; freestone square rubble masonry in cement, 8; freestone ashlar masonry in cement, 15; granite ashlar masonry in cement, 25; freestone ashlar bearing blocks, 12; granolithic bearing blocks, 12; granite ashlar bearing blocks, 20.

Waterway of Bridges.

The simplest cases of waterway calculation are those in which the conditions are such that the amount of heading up is not restricted. In these cases the limiting velocities which may be allowed decide the area of waterway which is necessary. Above the bridge the mean velocity of the stream will be reduced by the heading up.

It may be assumed that the water surface will fall to the original water level before it passes the piers, unless the channel of the river below the bridge has been altered. Taking the water level as the same, the new depth will be the same as the original depth, *plus* any lowering of the bed of the stream at the bridge site. The new width may be taken as the length of waterway. These two dimensions give the new area from which the new velocity can be calculated directly from the discharge, or by

$$V_2 = V_1 \times \frac{d_1 l_1}{d_2 l_2},$$

where

d_1 = original depth, d_2 = new depth; l_1 = mean width of stream cross-section; l_2 = length of waterway.

The new mean velocity is that to which the piers of the bridge are subjected, as well as the bed of the stream for a short distance below the bridge. This distance depends on the velocity and depth of the current. The limiting velocities can best be decided by a study of records of the behaviour of local strata and local masonry under similar conditions.

The following figures provide a rough guide to the velocities usually allowed.

Limiting Velocities in Feet per Second.

On clay, 0·70 to 1·0; on sand which must not be disturbed (shallow foundations) 1·2 to 1·5; on firm, pebbly beds, 3·0 to 3·5; on stony or shingly beds, 4·0; on stratified rock, 6·0; on hard rock, 10·0.

For inferior brickwork, with better masonry in the cutwaters, and on the floor of the waterway at the feet of the cutwaters, about 5·0; better masonry, up to about 8 ft. per second. For ordinary pitching (floor) about 5·0. For very well-shaped bridge openings with thick piers allowing of easy curves, higher values may be allowed, and very high values may be permitted when the masonry is exceptionally strong, such as ashlar of hard stone with fine joints.

Waterway Calculations.

In the case of a bridge or culvert intended for the passage of flood waters which pool up on the upstream side, the discharge may usually be calculated without velocity of approach, especially when the water level on the downstream side is not much lower. This is an ordinary case where a railway embankment crosses land liable to flooding. The head is the difference between the water level below the opening and that above it, when the latter has reached its maximum. This may be a natural maximum, or one fixed by the discharge capacities of the bridges and culverts through the embankment. The amount of headway above this level, under the bridge floor, will depend upon what flotsam is carried by the water in floods.

The formula for discharge is:—

$$D = c\,A\,\sqrt{2gh},$$

where

D = discharge in cubic feet per second (cusecs); A = area of opening in square feet up to the lower water level; h = head, or difference of water levels (in ft.); g = 32·2 approx.; c is a coefficient depending partly upon the size of the opening, and partly upon its form, especially the curves of the cutwaters and wing walls.

Ordinary values for c are in many cases 0·90; for large and well-designed openings, 0·92 to 0·95; for smaller openings, 0·85 to 0·90.

In the case of culverts through an embankment, or for bridges, for the maximum discharge before the embankment is overtopped, it may be necessary to know the discharge when the opening is drowned. If it is drowned on both sides the discharge is:—

$$D = c\,A\,\sqrt{2gh},$$

where

h = difference of water levels, and c = about 0·75 to 0·85, according to the form and size of the opening.

Where the floor of the bridge presents a sharp edge a fairly low value of c should be taken and a fairly high value for well-shaped culverts.

In British measure, $\sqrt{2g} = 8·02$; in metric measure, $\sqrt{2g} = 4·419$.

When the upstream end is drowned and the downstream end is not drowned, the discharge is found by:—

$$D = cl\sqrt{2g}\left[\frac{2}{3}\left(h^{\frac{3}{2}} - h_2^{\frac{3}{2}}\right) + \left(h_1 - h\right)^{\frac{1}{2}}\right],$$

where

l = the width of the opening; h = the difference in water levels; h_1 = the head above the bottom of the opening; h_2 = the head above the top of the opening; c may be taken as 0·75 to 0·85.

When the span is a long one and the waterway deep, a fairly high value may be given to c, but for a culvert the value may be taken as lower than that for the same culvert when wholly drowned.

In a considerable number of cases the waterway of the bridge is nearly as great as that of the stream, or quite as great when a single span clears the flood channel. Even with a considerable number of spans the bridge may obstruct the waterway very little if the piers are thin and are provided with good cutwaters and joinwaters. The velocity of approach may then be taken as v, the mean velocity of the stream, and the following relation will serve for preliminary calculations :

$$D = c\,A\,\sqrt{2g\,(h + h_a)};$$

where

$h_a = \frac{v^2}{2g}$; $A = dl$, l being the waterway of the bridge, and d the depth to the floor under the bridge.

For sluggish streams h may be neglected, and for a stream with a sharp fall it may be taken as the fall in a length measured about $\frac{2}{3}$ that of the piers. The equation, so used, may be useful in preliminary calculations ; where, for instance, the mean velocity of the stream is measured, but not its cross-sectional area, or where the discharge has been separately found. In the case of a sluggish stream it may be possible to fix the value of d, approximately.

Calculations involving Afflux.

Where the actual fall is small, as in most large rivers, and where the bridge considerably impedes the river, the total head driving the water through the opening is usually calculated as : $(x + h_a)$, where x = the afflux and h_a = head equivalent to the velocity of approach. The discharge is then :

$$D = c\,A\,\sqrt{2g\,(x + h_a)},$$

where

A = the smallest cross-sectional area of the waterway under the bridge, usually taken as that given by a water surface at the original water level.

$$x = \frac{v^2}{2g}\left(\frac{l^2}{c^2 l_1^2} - \frac{d^2}{(d + x)^2}\right),$$

where

l = the mean width of the stream ; d = mean depth of the stream below the bridge ; l_1 = the total width of waterway in the bridge openings ; c = coefficient of contraction, say 0·9 to 0·95 for large bridge openings and about 0·85 for small openings with only moderately good cutwaters and wing walls.

First insert the following provisional value of x in the right-hand side of the above equation.

$$x \text{ (provisional)} = \frac{v^2}{2g}\left(\frac{1{\cdot}1\,l^2}{l_1^2} - 1\right).$$

This gives a new value of x.

Repeat the solution of the longer equation with the new value of x on the right-hand side.

Next, to find h_a.

The head is calculated as that at one place, due to afflux and velocity of approach, and the velocity of approach is, therefore, the new reduced velocity of the deepened stream above the bridges, thus :

$$v_a = \frac{d}{d + x}\,v, \text{ and } h_a = \frac{v_a^2}{2g};$$

we can then use the equation :

$$D = c\,A\,\sqrt{2\,g\,(x + h_a)}.$$

If the length of the waterway is only estimated at first, within limits, take a probable value, and having found x, find l_1 by the equation :

$$l_1 = c\,\frac{vl\,(d + x)}{\sqrt{[2gx\,(d + x)^2 + v^2 d^2]}}.$$

In some cases x will be decided by the maximum water level which may be allowed, and the value so found will be used in the equations.

Discharge through Long Culverts.

The foregoing formulæ for discharge are suitable for short culverts, and for fairly long culverts when the velocities are low. For long culverts and for high velocities the head necessary to carry the water through the barrel regarded as a pipe must be added. The heads may be found by a pipe discharge formula, or, for small diameter culverts, may be taken from the tables (see 'Waterworks,' Section XXVI., Part III.).

(Reginald Ryves, M.Cons.E., A.M.I.C.E.)

Weights of Bridgework.

Dead Loads.—The following are weights of various types of bridge floors, etc. :—

Jack arch flooring .	250 lbs. per sq. ft.	Jarrah wood-block paving 2½ ins. thick, including mastic, pegs, and screws	13½ lbs. per sq. ft.
Steel trough flooring .	13–56 ,,	Tar macadam . .	120 lbs. per cub ft.
Roadway setts in cement	120 ,,	Concrete filling over buckled plates . .	140 lbs. per cu. ft.
Timber sleepers . .	125 lbs. each.	Fish plates . . .	40 lbs. per pair.
Ballast (average depth 12 ins.) . . .	120 lbs. per sq. ft. of floor.	,, bolts . . .	5½ lbs. per set (4).
Sleepers and ballast .	112 lbs. per cu. ft.	Oak keys . . .	2½ lbs. per pair.
95-lb. rails, chairs, cross sleepers and all fastenings	1½ cwt. per lin. ft. of single track.	Chairs	42½ lbs. each.

Weights of Girders, etc.

Unwin's Formula.

W_1 = weight of girder per ft. run, exclusive of cross-girders or flooring

$$= \frac{Wr}{cs - lr}$$

where

W = load to be carried in tons; l = span in ft.; r = ratio of span to depth; s = working stress in tons, sq. ins.; c = a constant, which may be taken from 1,200 to 1,400 for small plate girders, and 1,700 to 1,900 for truss bridges.

Johnson, Bryan & Turneaure Formula.

Deck plate girders	$w = 9l + 120$
,, lattice girders	$w = 7l + 200$
Through pin bridge	$w = 5l + 350$

(These figures are for single tracks)

where

l = span in ft.; w = weight of each girder in lbs. per ft. run.

American Formulæ.

(1)

The following empirical formulæ, although roughly approximate, are useful as guides in assuming dead loads of ordinary truss road bridges (exclusive of flooring, cross-girders, and joints):—

For a capacity of 100 lbs. per sq. ft.,

$$W = s + 5b + \frac{(b-6)l}{8} + \frac{l^2}{300} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

For a capacity of 80 lbs. per sq. ft.

$$N = s + 5b + \frac{bl}{16} + \frac{l^2}{300} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

For any other capacity of live load s_1, find W by formula (1), remembering $s = 100$; call required dead load W_1, then $W_1 = W - \left[1 + \frac{(b-12)l}{320}\right](100 - s_1)$,

where

W = dead load per lin. ft. exclusive of floor and joists (lbs.); s = live load per sq. ft. (lbs.) b = clear width of roadway (ft.); l = length of span (ft.).

(2)

For weight of plate and angle girders,

$$P = \frac{Wl}{20d}$$

where

P = weight of beam (lbs.); W = total live load supported (lbs.); l = distance in feet between supports; d = total depth of beam in inches.

Working Stresses.

Railway Bridges.—These vary considerably with the type and degree of accuracy with which the stresses are computed. The unit stresses allowed by the South American railways for their bridges, composed of material to conform to the British Engineering Standards, are as follows:—

Tension—8 tons sq. in.

Compression—8 tons sq. in. and corrected by the following formula to suit the design of member.

$$\text{Unit stress} = 8 - 0{\cdot}04\,\frac{L}{R},$$

where

L = length of compression member centre to centre of connection; R = least radius of gyration.

No compression member to have a length exceeding 100 times its least radius of gyration except wind struts, which may have a length of 120 times their least radius of gyration.

Shear on plates net area (not including web plates), 6 tons sq. in.

Shear on web plates to be determined by following formula. Shear not to exceed 5 tons sq. in.

$$\text{Unit stress} = \frac{7}{1 + \frac{1}{3000}\left(\frac{D}{T}\right)^2}.$$

where

D = unsupported distance between stiffeners or main angles; T = thickness of web.

It must be remembered, however, that where such working stresses are used, all the effects of impact or alternating stresses, centrifugal force, momentum, and wind must be carefully considered and taken into account. That is to say, in the design of the bridge the stress calculations must bear a very close relation to the working stresses adopted.

The majority of engineers prefer to adopt reliable formulæ based on the latest information on the above effects and use an allowable working stress for pure tension and compression of about half the elastic limit of the material used. The point being that the effects of wind, momentum, &c., do not all occur in all bridges, or, if they occur, may vary considerably with the type and situation of the bridges, so that in most cases it is best to treat each bridge on its own particular merits.

The following figures are those of a leading structural engineering company, in which a reduced working stress is used.

Permissible Maximum Stresses.

(A) *Railway Bridges.*

The working stresses shown below have been proportioned to allow for dynamic action of the live load on lightly loaded girders or members of girders.

(B) *Road Bridges.*

To provide for the effects of the dynamic action of the live load on lightly loaded girders or members of girders, the live load stresses to be increased by 25 per cent. in the case of main girders and 33⅓ per cent. in the case of floor girders.

(C) *Railway and Road Bridges.*

(1) The combined stresses resulting from the rolling load, dead load, wind, momentum, and centrifugal force, shall not produce a greater tensile stress than half of the elastic limit, or equal to $\frac{3}{10}$ of the minimum ultimate tensile strength of the material, nor more than the corresponding compressive shearing, bearing, and bending stresses as hereinafter set forth, but

(2) The combined stresses resulting from the rolling load and dead load alone, exclusive of wind, momentum, and centrifugal force, shall not produce greater tensile stresses than those given below.

Tensile Stresses.

Railway Bridges.

For main girders, cross-girders, and rail bearers of plate construction:

Under 20ft. span	4½ tons per sq. in.
20 ft. to 25 ft.	4⅝ ,, ,,
25 ft. to 30 ft.	5 ,, ,,
30 ft. to 50 ft.	5¼ ,, ,,
50 ft. to 80 ft.	5½ ,, ,,

For trusses and lattice girders:

80 ft. and under 160 ft. span—	
Bottom chords	5½ tons per sq. in.
Diagonals	4½ to 5½ tons per sq. in.
160 ft. and under 200 ft. span—	
Bottom chords	5¾ tons per sq. in.
Diagonals	4½ to 5¾ tons per sq. in.
200 ft. to 400 ft. span—	
Bottom chords	6 to 7 tons per sq. in.
Diagonals	4½ to 7 tons per sq. in.
All spans—for wind bracing	8½ tons per sq. in.
Floor suspenders	2½ ,, ,,

Road Bridges.

For main girders, cross-girders, and stringers:

Bottom chords	7 tons per sq. in.
Diagonals	5–7 tons per. sq. in.
Wind bracing	8½ ,, ,,
Floor suspenders	3½ ,, ,,

Note.—The 4½ tons stress on diagonals of railway bridges, and the 5 tons stress on road bridges, will apply to those at the centre portion of the span and to the counterbracing at the same point. The higher stresses will apply at the end portions where variations of stress are not so great. Intermediate diagonals will be subject to stresses lying between these limits.

Compression Stresses.

Railway and Road Bridges.

For plate girders, the gross area of the compression flange shall not be less than that of the tensile flange, nor shall the compression stresses per sq. in. be more than 85 per cent. of the corresponding tensile stresses.

For truss and lattice girders the compression stress per sq. in. shall, in the case of riveted members, not exceed the fraction '0·95—0·003R' of the corresponding specified tensile stress nor in the case of pin joints the fraction '0·95—0·0045R,' where R = the ratio of the length of the unbraced portion of the member to its least radius of gyration; nor in any case shall it exceed 85 per cent. of the said tensile stress.

No compression member in railway bridges shall have a greater length than 100 times its least radius of gyration, or 45 times its least width, except for wind bracing, which may have a length not exceeding 120 times its least radius of gyration.

In the case of road bridges no compression member shall have a length exceeding 120 times its least radius of gyration, except wind bracing, which may have a length not exceeding 140 times its least radius of gyration.

Alternating Stresses.

Railway and Road Bridges.

Members subject to alternate tension and compression stresses shall be proportioned as struts to resist the greater stress plus half the lesser, except for wind bracing, which shall be proportioned for the greater stress only. The sum of the stresses to be used for connections.

Shearing, Bending, and Bearing Stresses.

Railway and Road Bridges.

These must not exceed:—

For truss and lattice girders and all web or flange joints in plate girders:

(*a*) For machine-driven rivets and turned bolts or pins of a driving fit—

Shearing stress:	¾ of the permissible maximum tensile stress per sq. in. in the girder or member.		
Bearing stress:	1½	do.	do.	do.
Bending stress:	1½	do.	do.	do.

(*b*) For hand riveting, rivets having a length of 4 diameters and over, increase the number found for (*a*) by 10 per cent.

(*c*) For ordinary bolts increase (*a*) by 25 per cent.

For plate girders:—

Shearing stress in rivets:	⅞ of the permissible maximum tensile stress per sq. in. in the girder.		
Shearing in web plate:	¼	do.	do.	do.
Bearing stress on rivets:	1½	do.	do.	do.

Bending stresses on members subject to direct tensile or compression stress:—

In this case members to be made to suit the algebraic sum of direct stress and ⅔ of the bending stress, and the stress per sq. in. shall not exceed that permitted for direct stress.

Permissible Unit Stresses in Swing Bridges.

The unit working stresses in main girders shall be 10 per cent. less than those for simply supported spans.

(Sir W. Arrol & Co.)

Permissible Unit Stresses, in Pounds per Square Inch.

Kind of Strain, and Loading.		Structural Steel.	Axle Steel.	Steel Castings.	Cast Iron.	Rolled Copper.	Brass.
Tension	(*A*)	16,000	18,000	12,000	3,000	6,000	3,000
	(*B*)	10,600	12,000	8,000	2,000	4,000	2,000
	(*C*)	5,300	6,000	4,000	1,000	2,000	1,000
Compression	(*A*)	16,000	18,000	16,000	12,000	6,000	3,000
	(*B*)	10,000	12,000	10,000	8,000	4,000	2,000
Bending	(*A*)	16,000	18,000	15,000	6,000	—	—
	(*B*)	10,600	12,000	10,000	4,000	—	—
	(*C*)	5,300	6,000	5,000	3,000	—	—
Shear	(*A*)	12,000	14,000	9,000	3,000	3,600	—
	(*B*)	8,000	9,600	6,000	2,000	2,400	—
	(*C*)	4,000	4,800	3,000	1,000	1,200	—
Torsion	(*A*)	10,000	12,000	7,500	3,000	—	—
	(*B*)	6,600	8,000	5,000	2,000	—	—
	(*C*)	3,300	4,000	2,500	1,000	—	—

A. For a static load; *B*. For a varying load producing stresses of tension or compression only; *C*. For a varying load producing equal maximum strains in opposite directions, accompanied by shocks and vibrations.

The permissible unit stresses for bending (given opposite *B*)—10,000 for cast steel and 4,000 for cast iron—should be used for determining the strength of toothed gearing. The teeth in cut gearing should conform to the following proportions :—

$$P = s\,p\,f\,y.$$

where,

P = pressure on tooth in pounds ; s = permissible unit stress ; p = pitch, in inches ; f = face of tooth, in inches ; y = a factor.

For wheels moving at slow speed (up to about 100 ft. per minute), where strength only is to be considered, $y = 0{\cdot}05$.

The strength of uncut teeth should be computed for a face of one and one-half times the pitch, or

$$P = \frac{3\,s\,p^2\,y}{2};$$

which conforms approximately with the assumption that the pressure is carried on one corner of the tooth.

For higher velocities, which tend to increase the shock and wear, this value should not exceed :—

$$y = 0{\cdot}05\,\frac{10}{\sqrt{v}} = \frac{0{\cdot}5}{\sqrt{v}}$$

where

v = velocity in pitch circle, in feet per minute.

For bronze wheels, the same values should be used as for cast iron.

Fixed Bearings.

For the permissible unit pressures for fixed bearings of different metals, those for compression in the table, should be used.

FIRST-CLASS BRITISH PRACTICE IN BRIDGEWORK.

Brief Specification.

1. Materials to conform to the British Standard Specifications.

2. All steel to be by open-hearth acid or basic process.

3. No material to be used until tested and passed.

4. Steel castings to be Grade 'C.'

5. Bolts and nuts, coach screws, clips, etc., to be Grade 'C' wrought iron.

6. All oak to be English or Scotch.

7. Edges of all flange, end, and web plates and ends of all bars to be planed, or where planing not possible, to be dressed fair and true by hand.

8. Wherever shearing is adopted a $\frac{1}{8}$ in. strip to be left for planing, plates and bars showing less than $\frac{1}{8}$ in. rejected.

9. All plates, bars, angles, tees, etc., carefully levelled, straightened, joggled, or upset by pressure and not by hammering, both before and after they are drilled.

10. Templates and gauges to be made to correspond exactly with each other in order that all holes may be straight through and through. Steel gauge $\frac{1}{16}$ in. less in diameter than hole shall pass through easily irrespective of thickness of plates or bars.

11. Holes for turned bolts to be a driving fit.

12. All holes to be drilled and burrs carefully removed. Holes for rivets to be $\frac{1}{16}$ in. larger than nominal size of rivet.

13. Wherever practicable, all riveting to be done by machine. All loose rivets and such as may be cracked or have burnt or badly formed heads or with heads eccentric with the shaft or where the shaft does not fully fill the hole, cut out and replaced by others.

14. No edge of rivet or bolt hole to be nearer edge of plate or bar, etc., than a distance equal to one and a half times the diameter of rivet.

15. All work riveted or bolted together to be absolutely in contact over whole surface. Immediately before being assembled together whole of surfaces to be thoroughly cleaned and painted with a thick coat of genuine red lead paint.

16. All bolts to be forged and not welded. Screwed to Whitworth's thread. Those taking a shear stress to be so screwed that no part of the thread is in contact with bearing surface.

17. The barrel of all turned bolts to be $\frac{1}{16}$ in. larger in diameter than the screwed portion. Machined washers to be provided.

18. All bolts to be dipped in hot boiled linseed oil.

19. Cover plates connecting different thicknesses of plates to be planed off, the step to be sloped off.

20. All work to be temporarily erected and put together with service bolts.

21. All steelwork to be scraped and cleaned of all rust, mill-scale, and dirt and brushed with wire brushes.

22. All steelwork not to be galvanised to be given two coats of Dixon's Silica Graphite Paint No. 2, or natural colour, and a further two coats after erection, the last a finishing coat of approved colour. No oils or thinners to be used.

Girder Bridge Specification.

A new specification issued by the British Engineering Standards Association (No. 153—1922) deals with railway and highway bridges. The first part is concerned with materials of construction (structural and rivet steel, cast steel, steel for pins and rollers, wrought iron and cast iron); these are required to be in accordance with existing B.S. specifications, and the latter are printed as appendices, making the present document complete in itself. The second part gives requirements as regards workmanship, and includes clauses on straightening, planing and shearing, drilling, punching and reaming, rivets and riveting, smithed work, bolts and nuts, temporary erection at contractors' works, painting, measurement, and packing and marking for export.

WIND PRESSURE.

During a period of fourteen years, from 1890 to 1904, observations were made at fourteen different stations in the United Kingdom, and it was found that the maximum mean wind velocity only reached the following values:—

77–80 miles per hour on one occasion.
73–77 " " "
70–73 " " five occasions.
65–69 " " "

The records of many stations in the British Isles from 1906 to 1913 show that the maximum gusts recorded were:—

99 miles per hour, once.
90 ,, ,, twice.
85–90 ,, ,, nine times.

Velocities very much in excess of these values have been officially recorded by the Robinson anemometer, the velocity of the cups being multiplied by 3, to give the actual velocity of the wind. This figure is now recognised to be too high, and a value of 2·2 is substituted as a multiplier.

The velocity of wind, and therefore the pressure, increases with the height above ground.

The following observations are due to Mr. Adam Hunter, M.I.C.E., and were taken on the Forth Bridge by means of small gauges 1·5 sq. ft. in area placed at different heights.

Year.	Date.	Pressure in Pounds per sq. ft. at Various Heights.				
		50 ft.	163 ft.	214 ft.	214 ft.	378 ft.
1901	Jan. 26	—	15	25	—	65
,,	Nov. 23	—	50	55	55	60
1902	Dec. 13	—	27·5	31	34	18
1903	Jan. 10	15	20	25	27·5	60
,,	,, 31	—	19·5	29	26	65
,,	Mar. 18	20	20	25	29	31
,,	,, 21	10	20	20	22·5	54
1904	,, 26	—	20	32	27	52
,,	Dec. 29	—	22·5	22·5	32·5	—
1905	Jan. 21	—	21	30	23	—
,,	Mar. 18	—	32·5	32·5	42	60
,,	Feb. 28	10	22	20	20	38
1906	Jan. 26	15	—	—	—	59
,,	,, 11	10	20	23·5	25	30
,,	Feb. 8	10	15	25	25	55
Average . . .		13·0	23·0	28·0	30·0	50·0

The two readings at 214 ft. are at opposite ends of the bridge.

Relation between Velocity and Pressure.

(See pp. 677, 1247.)

Notes on Wind Pressure on Bridges.

There is considerable shielding effect of the leeward members of a framed structure by those on the windward side, dependent mainly upon their distance apart.

The determination of effective wind pressure on bridges presents many difficulties, arising chiefly out of the irregular shape and construction of those other than plate girder spans.

Plate girders are not, strictly speaking, flat plates, and up to 10 per cent. increase in area is often allowed for the effect of their cup-shape form.

Common practice, following the Board of Trade recommendations as to maximum pressure, is as follows:—

The wind to be assumed to act at a slight angle to axis of bridge so as to take effect on the exposed areas of floor and of both windward and leeward girders except when they are screened by a passing train. One half of the exposed surface of the leeward girder shall be included in the total area acted upon by the full wind pressure, except when the distance between the main girders is more than twice their depth, when the whole exposed area of leeward girder is to be taken.

With no train on bridge, wind-pressure = 56 lbs. per sq. ft. With a train on the bridge 30 lbs. on both train and bridge. The train to be taken at 10 sq. ft. per lin. ft. and centre of pressure at 7 ft. 6 ins. above rail level. Pressure on train taken as a moving load and the maximum stresses resulting from either condition to be taken in determining the necessary sectional areas of the parts.

In providing the necessary anchorage for the bridge a train of empty passenger carriages to be assumed to be on the bridge, weighing 10 cwt. per lin. ft., and in the case of a double track, the leeward track only to be loaded.

It is customary to specify a reduced wind pressure for a loaded span for the following reasons :—

(*a*) Because the total area exposed to the wind is increased, and hence the allowance necessary for the rise in pressure due to gusts above that corresponding with the maximum mean wind velocity is not so great as is necessary with a smaller area.

(*b*) Because the resistance offered by a body like a train is not so high as that offered by a surface like a bridge.

During a storm of great intensity the speed of trains crossing bridges will probably be reduced, owing to a feeling of insecurity on the part of drivers, but it cannot be assumed that the impact of trains, except for spans less than 150 ft., will be reduced ; for this depends more upon critical speeds than upon their maximum velocities.

It is therefore necessary, in such cases, where a reduced wind pressure is assumed for calculation, to carefully consider the effects of wind in all its aspects, treating it particularly as a moving load on the train.

The shielding effect of double bars will be to a large extent eliminated if the wind is treated as acting at a slight angle as mentioned.

In bridges of large dimensions it is necessary to make a somewhat different and more exact computation of wind pressures, and, where the spaces are large, separate calculations for each individual member based upon their size, shape, and form, may be essential.

Centrifugal Force.

South American Railway Practice.

Centrifugal force on bridges on curves taken at 0·02 of the live load for each degree of curvature up to 5°, and reduced by 0·001 for every degree of curvature above 5°—the force considered as acting at a height of 5 ft. above rail level. In short spans where impact is high, a percentage for impact is added.

British Practice.

Centrifugal force for each degree of curvature, assumed to be 1 per cent. of the maximum rolling load on all tracks for a speed of 30 miles and under, and 1 per cent. added for each increase in speed of 10 miles per hour. Considered as acting at 5 ft. above rail level.

The radius in feet (R) is reduced to degrees of curvature (D) by means of the following formula:—

$$D = \frac{5730}{R}.$$

Theoretically, centrifugal force varies *directly* as the weight of the train, and as the square of the velocity at which it travels, and *inversely* as the radius of the curve, or

$$P = \frac{W}{g} \frac{V^2}{r},$$

where

W = weight of train in tons ; V = its velocity in ft. per sec. ; r = radius of curvature of rails in ft. ; g = 32, the force of gravity ; P = centrifugal force in tons.

The whole of the centrifugal force is not usually neutralised by the superelevation of the rails, hence the allowances are made as above.

Momentum of Trains.

Tractive Force and Braking Stresses.

In bridges of large dimensions special attention should be given to the details of the structure, to provide for the longitudinal stresses resulting from sudden application of continuous brakes to the train while on the bridge. The horizontal force resulting from such action can be taken as one-fifth of the weight of the train.

The adhesion weight of locomotives is usually about 450 lbs. per ton of load on the coupled axles.

(Refer also to Power, Tractive Force, and Adhesion of Locomotives, Train Acceleration, etc., Section XIV., 'Railways,' p. 682.)

Impact.

If a load is applied suddenly to a structure, vibration will ensue and the strain—and thus the stress—will reach twice the value which would occur if the load were gradually applied. There is a great similarity between the results of experiments on variation of stress and sudden loading. The French Government obtain working stresses by means of the Launhardt-Weyrauch formula, but in America and this country various impact formulæ have been devised, but which are by no means final.

Theory prescribes that the following circumstances at least should be taken into account in any impact formula:—

(1) The length of the bridge;
(2) The ratio of live to dead load;
(3) The natural frequency of the bridge;
(4) The fluctuation in rail pressure due to balance weights, hammering, etc.;
(5) The size of the driving wheels.

To supply the necessary information required under (3), a systematic research is required dealing with bridges of various sizes and types.

Waddel's Formula.

$$I = \frac{400}{L + 500},$$

where

L = length of that portion of the span which is covered by the live load when the maximum stress under consideration is produced, and I is the percentage by which the maximum static stress is to be increased.

Pencoyd Ironworks Formula.

$$I = S\left(\frac{300}{300 + L}\right),$$

where

L = impact to be added to live load stresses; S = calculated maximum live load stress; L = length in ft. of the loaded distance which produces the maximum stress in each member.

This formula is used by most of the South American Railways.

Allowance for Impact in Bridges.

If

S = span in ft.; V = velocity in ft. per sec.; T = time in secs. required by a train travelling at velocity V to travel from the point where a given member commences to receive the stress to the point where the stress is a maximum (i.e. in a plain girder, T is the time taken to pass half the span); D = maximum allowable deflection; t = time taken for a free falling body to fall through a height D, then

$$t^2 = \frac{D}{16}, \text{ or } t = \tfrac{1}{4}\sqrt{D}.$$

If

P = percentage allowance for impact, then

$$P = \frac{50V\sqrt{D}}{S}.$$

As the formula is correct for a single concentrated load only, it gives excessive allowances for long spans, and P may be reduced $\frac{1}{300}$th of its found value for each 25 ft. span in spans of over 25 ft.

In all cases where V is such that the load traverses the half span in less time than t, the percentage for impact must be 100, the maximum V being fixed at 100 ft. per sec.

For a deflection of $\frac{1}{3500}$ of the span, $P = \frac{V}{\sqrt{S}}$, less the allowance for spans above 25 ft.

These formulæ are based on the idea that impact must vary with the time of application of the load. On a long bridge even a high speed train only reaches its position of maximum bending moment after several seconds, so that the bridge deflects slowly to its maximum deflection and goes very little beyond what the train at rest would produce. This applies to main members. Floor beams and their attachment, however, receive maximum stress very rapidly, for the train advances to full effect in the brief space of one panel length. On floor stringer end-connections

the first end is loaded absolutely instantaneously; the stringer itself takes its maximum load in about half a panel length, and so on; each member is to be allowed for impact according to the time required from its first feeling the load to the time of maximum moment. No simple load can produce an impactive stress more than double its static stress, but a swaying locomotive may have more than half its load on the wheels of one side, so that a wheel which may cause a maximum load on, say, the first end of a floor stringer, may happen to be loaded at the moment perhaps 30 per cent. more than its half share of the load on its axle, and at the same time it may happen that the balance weight is just delivering its downward hammer blow. Thus care is needed to give ample strength to details even of larger bridges, but the main members of a large bridge are but little affected by the trivial details of locomotive swaying, hammer blow, &c.

(*W. H. Booth.*)

Allowances for Impact in Road Bridges.

For highway bridges an increase of from 20–30 per cent. on the live load stresses in the main girders is often allowed to meet modern traffic conditions, and from 30–40 per cent. for cross or floor girders.

The Ministry of Transport have added 50 per cent. to their standard load for highway bridges (consisting of one traction engine and three trailers), but this can only be regarded as an empirical figure for which an appropriate formula will be substituted as a result of experiments now proceeding.

Temperature Variation and Stresses.

Variation of Temperature and Expansion.

Records which have been made at Greenwich show the average range for twenty years to be 11° below and 13° above the mean temperature. The maximum annual range of temperature in the shade may be 85°, and in the sun as much as 137°. The theoretical expansion which these temperatures would cause in steel would be $\frac{5}{8}$ in. and 1 in. respectively in a length of 100 ft.

The observed movement in the Forth Bridge is $\frac{7}{16}$ in. per 100 ft., while the rise in the crown of one of the cast-iron arched ribs of the Old Southwark Bridge was $1\frac{1}{4}$ ins., the length of the chord of the intrados of which was 246 ft. and the versed sine, 23 ft. 1 in.

In tropical and sub-tropical countries the variation between the highest day temperature and the lowest night temperature may be as much as 150° F. or more.

Provision for Expansion.

For spans less than 40 ft. it is not customary to provide bearings with means of expansion, but for spans in excess of this, provision for expansion to the extent of 1 in. in every 100 ft. should be allowed. No allowance is usually made for expansion and contraction in the direction of the width of the structure, but in large and wide bridges it will be necessary to consider this.

Temperature Stresses.

The forces due to unequal temperatures on different parts of a lattice girder bridge act very slowly and, due to the slow yielding property of ductile metals such as steel, cause the parts of the frame to adjust themselves to the gradual stresses to which they are subjected. Nevertheless temperature stresses in large bridges must be carefully considered.

If the ends of a bar or portion of a bridge are rigidly fixed, a difference of temperature of 100° F. will cause a stress of 8·54 tons per sq. in.

Let

l = length of a bar at 0° F. (in feet); l_1 = its length at t° F. (in ft.); ϕ = coefficient of linear expansion for 1° F.; E = Young's modulus,

then

Elongation for $t° = \phi.t.l$; $l_1 = l(1 + \phi t)$;

Stress per ° F. = $\phi \times$ E tons per sq. in.

Bedplates and Bearings.

Types of Bearings.

Bridges of spans below 100 ft. are not usually fitted with any special means for allowing free expansion, but are simply fitted with a sole plate resting on a bearing block, the holes in the sole plate at one end of the bridge being slotted to allow of movement. The bearing block should rest upon hair-felt or sheet lead.

Bridges over 100 ft. span should rest at one end on roller bearings of not less than 3 ins. diameter, or some other form of expansion bearing.

The average type of roller bearing is usually very liable to rust up and become filled with

dirt, etc., that falls from the bridge, and so becomes practically useless, unless very carefully designed with a view to eliminating this source of trouble.

For bearings of large span bridges to be really satisfactory, they should have some means of providing for the deflection of the bridge under load. This is now arranged for by having some sort of knuckle at both ends of the bridge; a bearing of this type is shown in fig. 5, which, however, is not to be regarded as satisfactory as regards the roller portion, which should be protected from rust and dirt.

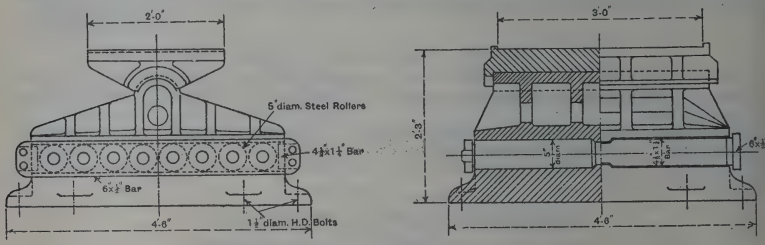


FIG. 5.—Combined Knuckle and Roller Bearing.

The pressure in pounds per lineal in. on rollers of mild steel should not exceed 300 d, where d equals the diameter of the roller in ins.

The bedplates should be of sufficient area to distribute the load over the masonry abutments the limiting or working pressures being:

Granite	20 tons per sq. ft.
Hard stone	16 ,, ,,
P.C. concrete (1-2-4)	10 ,, ,,

A form of end bearing is shown in fig. 6, which is a combined rocker and expansion bearing for the free end of the bridge. The pin in this case takes the place of the knuckle in providing for deflection.

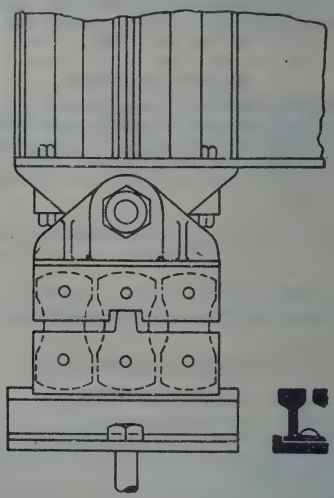


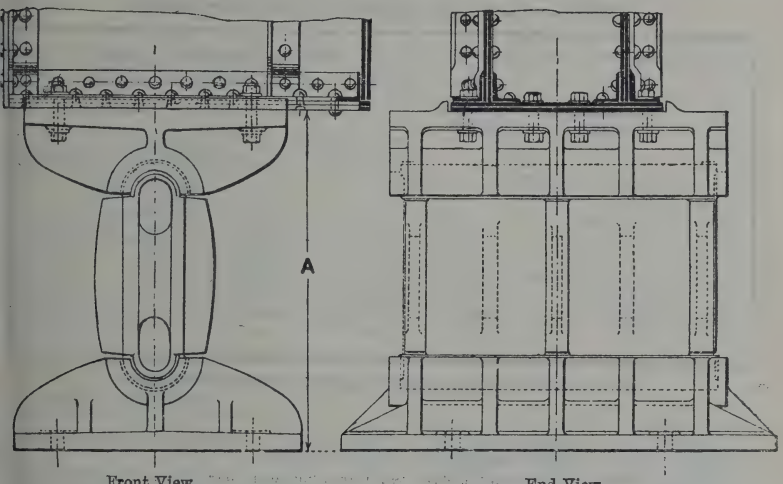
FIG. 6.—Combined Rocker and Roller Bearing.

Rigby's Patent Expansion Rocker Bearing.

A very excellent bridge bearing for spans of 100 ft. and over, is the one designed and patented by the late Mr. H. Rigby, M.Inst.C.E.

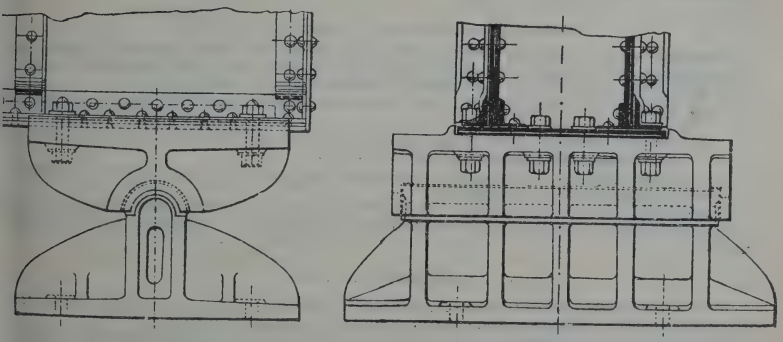
The bearing for both fixed and free ends is shown in figs. 7 and 8.

In this type the knuckles provide for deflection and the rocker for expansion. These bearings are considerably cheaper than most other forms, much simpler in construction, and are quite immune from the effects of rust and dirt in operation.



Front View. End View.

FIG. 7.—Rigby's Patent Expansion Rocker Bearing.



Front View. End View.

FIG. 8.—Rigby's Patent Bearing for Fixed End.

Flooring.

Buckled Plate Flooring.

The resistance of square buckled plates, bolted or riveted down all round, is double the resistance of the same plate merely supported all round, and if the two opposite sides be wholly unsupported, its resistance is reduced in the proportion of 8 to 5.

The stiffness of buckled plates is as the square of the thickness, and inversely as the curvature.

Two inches curvature suffices for 4 ft. square and $\frac{1}{4}$ in. thick.

Ordinary plates are made 3 ft. and 4 ft. square.

Weight and Safe Load of Buckled Plates, 3 ft. square.

No.	Thickness of Metal.	Weight in lbs.	Safe Load distributed in Tons.			
			Passive.		Impulsive.	
			Per Plate.	Per Sq. Ft.	Per Plate.	Per Sq. Ft.
1	18 B.W.G.	17·3	0·27	0·03	0·20	0·022
2	16 ,,	23·6	0·43	0·048	0·32	0·036
3	12 ,,	38·7	0·64	0·071	0·48	0·053
4	$\frac{1}{8}$ in.	45·0	1·00	0·112	0·75	0·083
5	$\frac{3}{16}$ in.	67·5	2·5	0·278	1·7	0·180
6	$\frac{1}{4}$ in.	90·0	4·5	0·5	3·0	0·333
7	$\frac{5}{16}$ in.	112·5	6·2	0·689	4·7	0·522
8	$\frac{3}{8}$ in.	135·0	9·0	1·0	1·8	0·755

The safe loads may be doubled for buckled plates of puddled steel.

(*The Practical Engineer.*)

Buckled plates are usually made 3 ft. to 6 ft. square and $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick. They can also be obtained in long lengths having several buckles to the plate.

To calculate the load uniformly distributed over a buckled plate, which will crush it—the plate being square and fastened all round the edges—multiply the depth to which the plate is buckled by the square of the thickness, both in inches, and by 165; the product will be the crushing load in tons (nearly). Central load which will crush a buckled plate, about one-third of uniformly distributed load. (*Rankine.*)

Westwood's Corrugated Plates and Troughs.

These plates and troughs are made of ordinary steel plate and can be obtained in sizes from $2\frac{1}{2}$ ins. deep to 16 ins. deep, and in lengths up to 30 ft., without joint in the smaller sizes and up to 40 ft. in the larger sizes and thicknesses. The advantages claimed are:—

(1) Ordinary plate is used and pressed in moulds in such manner that no deformation of the plate occurs.

(2) The sections can be made of any thickness to suit requirements and are therefore very economical from the point of view of weight.

The smaller sizes are manufactured with several corrugations in one plate and the larger sizes with only one trough or corrugation.

The makers publish a catalogue in which all the sizes manufactured are given, with the moments of resistance, weight, thickness, and safe load per sq. ft. of area covered for various spans.

Distribution of Load.

It may be assumed that the wheel loads are distributed over 5 ft. run of the floor if the sleepers are parallel with the troughs and 10 ft. if at right angles to the troughs.

The strength and stiffness of trough or corrugated flooring, when riveted up, is considerable.

Each trough may be treated as a girder, but then each girder is connected to its fellow; thus when the load is applied to, say, one trough it cannot deflect without dragging down its adjoining troughs for some distance on each side.

Floor Troughing.

Lindsay's troughs, fig. 9, are composed of special rolled sections of the form of splayed channels and can be obtained in many sizes. The advantages claimed are that the webs are thin and the bottoms and tops thick, and so approach what is required from the girder point of view, also that the riveting is situated at the neutral axis, where the bending stresses are a minimum.

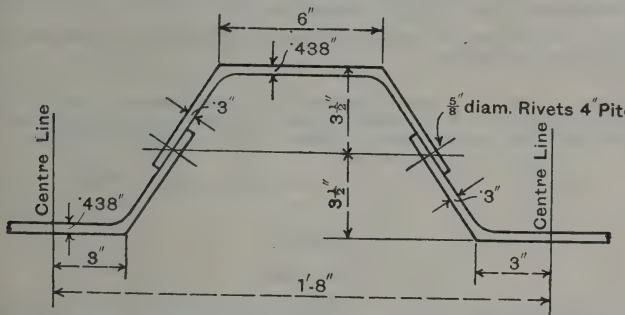
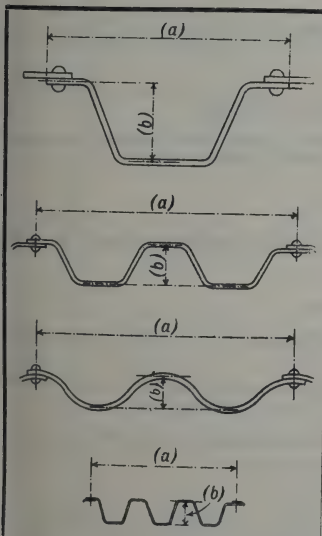


Fig. 9.—Lindsay's Steel Trough C Minimum.

Weight over sq. ft. of area covered = 24·52 lbs. Section Modulus = 21·62.

Westwood's Steel Troughing.



Section.	Depth Centres. (a)	Normal Width Centres. (b)	Thicknesses.	Max. Length Pressed.
	Ins.	Ft. Ins.	Ins.	Ft. Ins.
A	15	2 8	⅜–¾	40 0
B	12	2 8	⅜–¾	40 0
C	10	2 6	⅜–¾	40 0
D	9	2 0	⅜–¾	40 0
F	7½	2 0	5/16–11/16	40 0
G	6½	1 8	¼–⅝	35 0
H	6	1 8	¼–⅝	35 0
I	5	2 8	3/16–7/16	30 0
K	4	2 8	3/16–7/16	30 0
L	3	2 0	3/16–⅜	30 0
O	4	2 8	3/16–7/16	20 0
P	3	2 0	3/16–7/16	20 0
M	3	1 6	⅛–3/16	10 0
N	2½	1 0	⅛–3/16	10 0

Camber.

The provision of an upward camber in bridge girders gives a better appearance to the bridge, and, moreover, obviates the additional stress, due to the centrifugal force of the train running round the curve, which would otherwise occur due to deflection.

Bridges of 100 ft. span and upwards are usually given a camber of 1 in. for every 40 ft. in length. Plate girders of small dimensions are not usually cambered.

For parallel or bow-topped lattice girders the increase in the length of the top boom and bays therein can be found as follows:—

If

c = camber in ins.; N = number of bays; D = depth between centres of flanges; l = length of one bay in ft.; L = horizontal length of bottom boom in feet; x = increase in length of one bay in top boom in inches; y = total increase in length of top boom,

then $x = \frac{8cD}{N^2 l}$, $y = \frac{8cD}{Nl}$ when $c = 1$ in. in 40 ft.; $x = \frac{LD}{5N^2 l}$, $y = \frac{LD}{Nl}$.

Riveting.

Rivet Pitches.

The pitch of rivets in the direction of the stress should not exceed 6 ins., or 16 times the thickness of the thinnest outside plate or bar, nor less than 3 times the diameter of the rivet.

At the ends of compression members the pitch should not exceed 4 times the diameter of the rivets for a distance equal to twice the width of the member.

In the flanges of girders the pitch should not exceed 4 ins. In webs composed of two or more plates, the rivets, used solely for causing the several thicknesses to act as one plate, should not be spaced more than 12 ins. apart in any direction.

The distance from the centre of the rivet (or bolt hole) to the edge of a plate or bar should not be less than $1\frac{1}{2}$ times the diameter of the rivets in the case of planed or rolled edges. When practicable, the distance should be at least 2 diameters of the rivet, but not to exceed 8 times the thickness of the plate.

In chain riveting the distance between centre lines of adjacent rows should preferably not be less than 3 diameters of rivet, and in no case less than $2\frac{1}{2}$ diameters.

In zig-zag or staggered riveting the distance between centre lines of adjacent rows should preferably be not less than $2\frac{1}{2}$ diameters, and never less than 2 diameters.

Forms of Rivet Heads.

The most common forms of rivet heads and their usual proportions are shown on p. 329, Section VI.

Diameters of Rivets.

There are various rules for obtaining the most suitable diameter of rivets, but they are not often used in structural steelwork.

In practice, a $\frac{3}{4}$ in. or $\frac{7}{8}$ in. diameter rivet is adopted whenever possible, and it is best not to use any formula to obtain the diameter in terms of the thickness of the plate.

The following is an exceedingly good rule and is almost universally followed:—

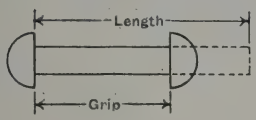
$\frac{3}{4}$ in. rivets for $\frac{3}{8}$ in. plates.
$\frac{7}{8}$ in. ,, ,, $\frac{1}{2}$ in. ,,
1 in. ,, ,, $\frac{5}{8}$ in. ,, and over.

It is difficult to get rivets of larger diameter than 1 in. closed by hand.

Machine Riveting.

Lengths of Rivets for Various Grips.

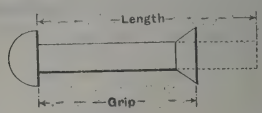
Snapped at both ends.



Grip in ins.	Diameter in ins. $\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
	Length in ins.			
$\frac{3}{4}$	$1\frac{1}{4}$	2	—	—
$\frac{7}{8}$	$1\frac{1}{8}$	$2\frac{1}{8}$	—	—
1	2	$2\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$
$1\frac{1}{8}$	$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{3}{4}$	$2\frac{5}{8}$
$1\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{3}{4}$
$1\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{5}{8}$	$2\frac{1}{4}$	$2\frac{7}{8}$
$1\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$
$1\frac{5}{8}$	$2\frac{3}{4}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$
$1\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$
$1\frac{7}{8}$	3	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$
2	$3\frac{1}{8}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$
$2\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$
$2\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$
$2\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4
$2\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{7}{8}$	4	$4\frac{1}{8}$
$2\frac{5}{8}$	$3\frac{1}{4}$	4	$4\frac{1}{8}$	$4\frac{1}{4}$
$2\frac{1}{4}$	$3\frac{7}{8}$	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{1}{2}$
$2\frac{7}{8}$	4	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{5}{8}$
3	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{5}{8}$	$4\frac{3}{4}$
$3\frac{1}{8}$	—	$4\frac{5}{8}$	$4\frac{1}{8}$	$4\frac{7}{8}$
$3\frac{1}{4}$	—	$4\frac{3}{4}$	$4\frac{7}{8}$	5
$3\frac{3}{8}$	—	$4\frac{7}{8}$	5	$5\frac{1}{8}$
$3\frac{1}{2}$	—	5	$5\frac{1}{8}$	$5\frac{1}{4}$
$3\frac{5}{8}$	—	$5\frac{1}{8}$	$5\frac{1}{4}$	$5\frac{3}{8}$
$3\frac{3}{4}$	—	$5\frac{1}{4}$	$5\frac{3}{8}$	$5\frac{1}{2}$
$3\frac{7}{8}$	—	$5\frac{3}{8}$	$5\frac{1}{2}$	$5\frac{5}{8}$
4	—	—	$5\frac{5}{8}$	$5\frac{3}{4}$
$4\frac{1}{8}$	—	—	$5\frac{3}{4}$	$5\frac{7}{8}$
$4\frac{1}{4}$	—	—	$5\frac{7}{8}$	6
$4\frac{3}{8}$	—	—	6	6
$4\frac{1}{2}$	—	—	$6\frac{1}{4}$	$6\frac{3}{8}$
$4\frac{5}{8}$	—	—	$6\frac{3}{8}$	$6\frac{1}{2}$
$4\frac{3}{4}$	—	—	$6\frac{1}{2}$	$6\frac{5}{8}$
$4\frac{7}{8}$	—	—	$6\frac{5}{8}$	$6\frac{3}{4}$
5	—	—	$6\frac{3}{4}$	$6\frac{7}{8}$

For hand riveting deduct $\frac{1}{4}$ in. from above lengths.

Snapped on one end, countersunk at other.



Grip in ins.	Diameter in ins.			
	½	⅝	¾	⅞
	Length in ins.			
¾	1⅜	1½	—	—
⅞	1½	1⅝	—	—
1	1⅝	1⅞	1⅞	1⅞
1⅛	1¾	1⅞	1⅞	2
1¼	1⅞	2	2	2⅛
1⅜	2	2⅛	2⅛	2¼
1½	2⅛	2¼	2⅜	2⅜
1⅝	2¼	2⅜	2½	2½
1¾	2⅜	2½	2⅝	2⅝
1⅞	2½	2⅝	2¾	2¾
2	2⅝	2¾	2⅞	2⅞
2⅛	2¾	2⅞	3	3
2¼	2⅞	3	3⅛	3⅛
2⅜	3	3⅛	3¼	3¼
2½	3⅛	3¼	3⅜	3⅜
2⅝	3¼	3⅜	3½	3½
2¾	3⅜	3½	3⅝	3⅝
2⅞	3½	3⅝	3¾	3¾
3	3¾	3⅞	3⅞	4
3⅛	—	4	4	4⅛
3¼	—	4⅛	4⅛	4¼
3⅜	—	4¼	4¼	4⅜
3½	—	4⅜	4⅜	4½
3⅝	—	4½	4½	4⅝
3¾	—	4⅝	4⅝	4¾
3⅞	—	4¾	4¾	4⅞
4	—	—	4⅞	5
4⅛	—	—	5	5⅛
4¼	—	—	5⅛	5¼
4⅜	—	—	5¼	5⅜
4½	—	—	5⅜	5½
4⅝	—	—	5⅝	5⅝
4¾	—	—	5¾	5¾
4⅞	—	—	5⅞	5⅞
5	—	—	6	6

For hand riveting deduct ¼ in. from above lengths.

See also p. 329, Section VI.

(*Redpath, Brown & Co., Ltd.*)

Service Bolts and Drifts, Etc.

For field work the number of service bolts should be 50 per cent. of the number of rivets to be closed at site, to suit lengths of grips $\frac{3}{4}$ in. to $1\frac{1}{4}$ in., $1\frac{1}{4}$ in. to $1\frac{3}{4}$ in., $1\frac{3}{4}$ in. to $2\frac{1}{4}$ ins., or every $\frac{1}{2}$ in.

Washers to the number of half the quantity of service bolts of each size should be included, and of the following sizes :—

For $\frac{3}{4}$ in. bolts . . . $1\frac{3}{4}$ in. sq., $\frac{15}{16}$ in. hole, $\frac{1}{8}$ in. thick
$\frac{7}{8}$ in. bolts . . . 2 in. sq., $\frac{15}{16}$ hole, $\frac{1}{8}$ in. thick
1 in. bolts . . . $2\frac{1}{4}$ ins. sq., $1\frac{3}{16}$ in. hole, $\frac{1}{4}$ in. thick

Steel drifts, double-ended spanners, and podger-ended spanners should be sent in the proportion of 1 to every 10 shipment rivets.

SECTION VII.

PART II.

PLATE GIRDER BRIDGES.

LIVE LOAD — WEBS AND STIFFENERS — JOINTS — CROSS GIRDERS—RAIL AND ROAD BEARERS—CURTAILMENT OF FLANGE PLATES—DEFLECTION.

LIVE LOAD.

Criterion for Maximum Bending Moment.

For a maximum bending moment under any load in a system of wheel loads on a girder, the load considered must be as far from one end of the girder as is the centre of gravity of all the wheel loads from the other end of the girder. Or, in other words, the load considered and the centre of gravity of all the loads in the girder must be equidistant from the ends of the girder. It is often possible to determine by inspection which load will produce the absolute maxixmum bending moment due to the passage of the live load.

Criterion for Maximum Shear.

The maximum end shear for a system of concentrated moving loads will occur when the reaction is a maximum.

The maximum positive shear in any section of a girder occurs when the foremost load is at the section, provided W is not greater than $\frac{P_1 L}{a}$. If W is greater than $\frac{P_1 L}{a}$, the greatest shear will occur when some succeeding load is at the point.

In this case—

W = the sum of the loads; P_1 = the foremost load: L = the length of the span; a = the distance apart of the foremost and next load in succession.

In plate girders with cross girders, to determine the position of wheels to give maximum shear in panel to left of any cross girder, one of the large wheels is always placed over the cross girder; the wheel so placed should satisfy the following conditions:—

(1) The load to left of the cross girder, and including the load over the cross girder, must be equal to or greater than the total load on bridge divided by number of panels.

(2) The load to left of the cross girder, and not including the load over the cross girder, must be less than the total load on bridge divided by number of panels.

It will sometimes be found that more than one arrangement of the loads will satisfy the above conditions. In such cases it is necessary to figure the shear for the different loadings and use the greater. (*American Bridge Co.*)

WEBS AND STIFFENERS

Distance apart of Stiffeners.

The distance apart which stiffeners should be placed can be found by the following formula:—

$$L = \sqrt{\left(\frac{5}{K} - 1\right) 1500 t^2},$$

where

L = distance apart in ins.; t = thickness of web in ins.; K = stress per sq. in. to be provided for—*i.e.* $\frac{\text{total shear at a section}}{\text{net area of web}}$.

Another formula used by the South American Railways is given on p. 360, under 'Working Stresses.'

The position of stiffeners should be so arranged as to cause no irregularity in rivet pitches, *i.e.* the pitch should alter if it is necessary at a stiffener. All stiffeners should bear tightly at the top and bottom against the flange angles, and wherever possible, stiffeners should be placed at all web joints.

In British practice, stiffeners are seldom placed at distances wider apart than the depth of the girder, with 6 ft. as a maximum when the thickness of the web is less than $\frac{1}{60}$ of the unsupported distance between the flange angles.

Stiffener angles over the bearings should be designed to carry the entire shear at that point without exceeding the safe stress (packings should not be included in the area); they should be proportioned as struts with fixed ends, having a length equal to $\frac{3}{4}$ of the depth of the girder.

Compound Web Plates.

Web plates composed of two or more plates should not be used where the total thickness is less than 1 in. (For Riveting see p. 328.)

Reduction of Web Thickness.

The following is a graphical method of obtaining the necessary lengths of web plate of given thickness or the thickness of web plates of given length. The thickness of web plate required at the abutments must first be calculated in each case.

Distances such as '*a*' measured to $\frac{3}{4}$ in. scale in fig. 10, give the reduction in thickness permissible.

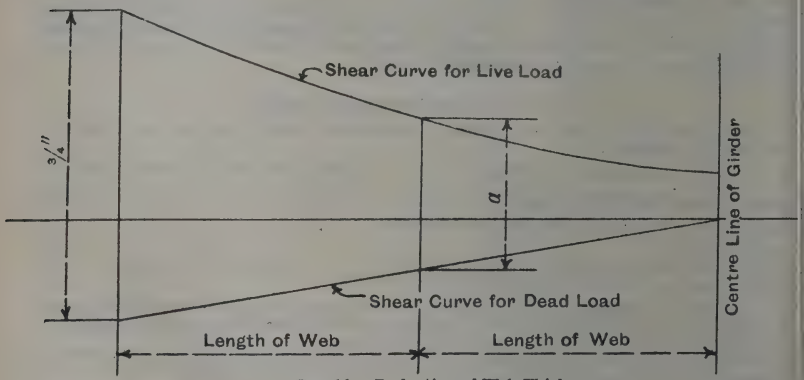


FIG. 10.—Reduction of Web Thickness.

JOINTS.

Thickness of Cover Plates.

The thickness of cover plates may be determined as follows:—

$$\text{Single covers} = t + \frac{t}{8};$$

$$\text{Sum of thickness of double covers} = t + \frac{t}{4};$$

where

t = thickness of plates joined.

Flange Angle Splices.

If a girder is so long that the angles cannot be obtained in one length, or if for any other reason it is necessary to splice the angles and the girder is to be shipped in one length, the splices in the angles should be as far apart as possible and on opposite sides of the web plate. Where the area of the flange angle is too great to be conveniently spliced by one angle, a splice angle with area equal to about $\frac{3}{4}$ of the area of the flange angle should be placed on each side of the girder.

Web Splices.

When part of the web is counted as flange area and the bending moment at the web joint actually requires this area of web to bring the flange stress down to the maximum allowed, there should be, in addition to the number of rivets required to take shear, sufficient rivets as near each flange angle as practicable to take the proportional part of the flange stress taken by the piece of web.

The net area of these splice plates must be made equal to area of web used as flange area multiplied by the depth of girder divided by the distance centre to centre of splice plates.

The number of rivets required to equal the net area of two splice plates, multiplied by the unit stress in flanges and divided by least value of one unit (shear or bearing) in web plates.

It is desirable to arrange the rivets so as not to cut out more than two rivet holes in the line next the joint, or at the ends of the plates; see fig. 11.

The vertical splice plates should have rivets enough on each side of splice to take the vertical shear at the position of the splice.

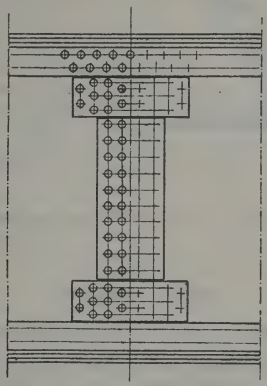


FIG. 11.—Web Joint.

Flange Splices.

If for any reason the flange plates have to be joined, a cover must be provided at each splice; the rivets connecting the cover must be such that their strength is equal to the plate spliced.

It is often possible to arrange the splices in a stepped manner with only one cover plate; such a joint is shown in fig. 12, and is suitable for a shipping joint.

The final cover must be at least equal in thickness to the thickest plate spliced, and, in the example, serves as a cover for the four plates.

The distance apart of the 'steps' must be such that the strength of the rivets between each is not less than will suffice to develop the full strength of each plate.

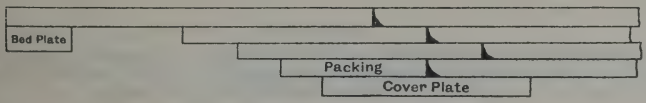


FIG. 12.—Arrangement of Flange Splices.

Rivets in Connection Plates.

When a single system of lateral bracing is used, the number of rivets connecting the plates to the girder should be sufficient to take the sum of components (in direction of girder) of both laterals connecting on the plate. (See fig. 13.) If AB requires 5 rivets and BC requires 4 rivets

lay off in the direction of *ab* to any convenient scale a distance *by* of 5 and in the direction *bc* a distance *bw* of 4. Drop perpendiculars *wv* and *yx* and scale the distances *vb* and *bx*. The sum of these two distances represents the number of rivets required to connect the plate to the girder.

If a double system of bracing is used, they are proportioned for tension only, and the number of rivets required to connect the plate to the girder will be the number required to take the component of one lateral in the direction of the centre line of the girder.

There should be rivets enough connecting the plate to the cross girder or strut (if any) to take the component of one lateral in the direction of the cross girder or strut.

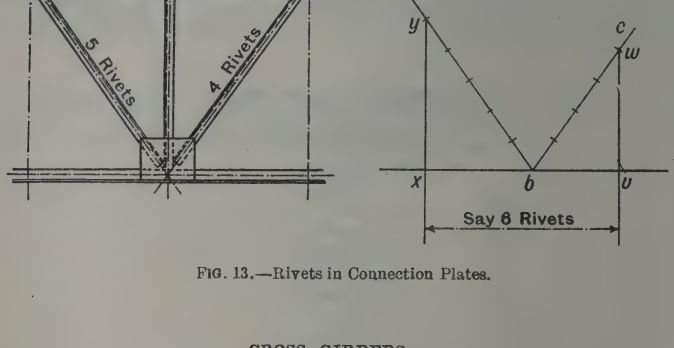


FIG. 13.—Rivets in Connection Plates.

CROSS GIRDERS.

Distance apart of Cross Girders.

Generally speaking, it is not economical to place the cross girders in railway bridges closer together than 5 ft.; at intervals shorter than 5 ft. the load will usually consist of the heaviest axle load of the live load, while for intervals of 5 ft. and upwards it is necessary to consider the several positions that may be occupied by the axles in the heaviest portion of the live load.

The distance apart should be considered in relation to the centres of the heaviest wheel loads which will come upon them.

It is often found that increasing the spacing of the cross girders adds but little to the load which they will have to sustain, and it is usually economical to adopt a wide spacing, say from 6–10 ft.

In lattice girders the spacing of cross girders, depth of truss, and panel length must all be considered in relation to each other, for the cross girders will usually be placed at panel points to avoid secondary stresses in the booms.

The economy of placing cross girders far apart only applies in a modified degree to highway bridges, as in such cases the dead weight of the roadway forms a considerable part of the total load.

PROPORTIONS.

The depth span ratio of cross girders should be not less than 1 : 10, preferably 1 : 8, otherwise in bridges with buckled plate flooring considerable trouble is likely to occur with the rivets holding the plates down, working loose, or the plates fracturing at the seatings.

CONNECTIONS.

The connections of the main girders should be rigid, and 50 per cent. should be added to the number of rivets required to take the shear to resist the bending action.

In plate girders the web stiffeners may be made to considerably strengthen the end connections of cross girders, and in lattice girders a bracket plate of ample proportions should be fitted.

RAIL AND ROAD BEARERS.

Rail Bearers.

These should be in general placed 5 ft. apart, and must be proportioned to take the greatest wheel loads, imposed by one, two, or more axles, as the case may be. Although they act as continuous girders, much depends upon the rigidity of the end connections and the deflection of the cross girders. Where they rest upon the cross girders they have a greater chance of acting continuously; but usually for the purpose of designing their section they will be treated as separate spans.

Road Bearers.

The distance apart of road bearers will be decided in relation to the width of the bridge and the centres of the wheels composing the maximum live load, and will be greatly decided by the type of bridge floor adopted. They should be designed as supported at the ends.

PROPORTIONS OF RAIL AND ROAD BEARERS.

The depth should not be less than $\frac{1}{12}$ of their span.

Curtailment of Flange Plates.

Unless this is done the girders will be stronger at the abutments than they need be. This can be remedied by either of the following methods :—

(1) Keeping the depth constant and varying the thickness of the flanges along the length.

(2) Varying the depth of the girder and keeping the flange thickness constant. By this method the girder theoretically becomes parabolic.

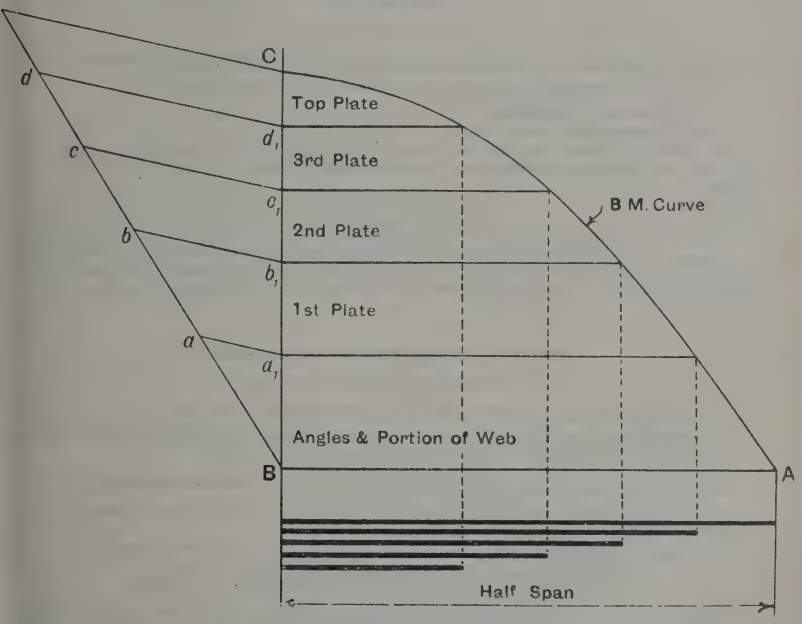


FIG. 14.—Curtailment of Flange Plates.

(1) and (2) Varying both the thickness and depth of the girder. By this method we get the hog-backed and fish-bellied girder according as the top or bottom flange is curved.

There are variations of this, for both top and bottom flanges are sometimes curved.

In most cases (1) is the most economical on account of there being less workmanship required in the manufacture.

The curtailment of flange plates in method (1) is carried out as follows :—
Referring to fig. 14, ABC is the bending moment curve on half the girder AB.

On any inclined line Be set out points *a*, *b*, *c*, *d*, as follows :—

Be = Modulus of section of total flange at centre of girder (including portion of web if allowed for in calculations).
de = Modulus of section of top plate (net).
cd = " " 3rd " "
bc = " " 2nd " "
ab = " " 1st " "
Ba = " " bottom plate and angles (including portion of web if allowed for in calculations).

Join *e*C and draw parallels dividing the vertical Be into similar spaces.

Lines drawn horizontally to meet the bending moment curve will now give the theoretical necessary lengths of the flange plates.

In practice the plates are continued for from two to four pitches of the rivets and the first plate over the main angles is always continued to the ends of the girder.

Deflection.

Elastic Deformation

Is one which disappears entirely on the removal of the external forces causing the stress.

The amount of deflection in girders depends mainly upon the following :—

(1) The length of the girder ;

(2) The unit stress in the flanges.

The deflection arises from the top flange being compressed and the bottom flange being extended, and the amount of deflection is not materially affected by the kind of web in deep girders.

Mohr's Theorem.

A loaded beam takes up the same form as an imaginary cable of the same span, which is loaded with the bending moment curve on the beam and subjected to a horizontal pull equal to the flexural rigidity (EI). The deflected form of the beam is called the *elastic line* of the beam.

Graphical Construction for any Loading.

(Flanges of beam of uniform section.)

(1) Draw the bending moment diagram for the given loading of the beam.

(2) Treat the bending moment diagram as a load diagram and divide it up into narrow vertical strips ; set down the mid-ordinates on a vector line.

(3) Draw the vector diagram with a polar distance equal to the flexural rigidity (EI).

(4) Draw the funicular polygon for this vector diagram and reduce it to a horizontal base, then the link polygon gives the elastic line.

The scale to which the deflections can be scaled is determined as follows :—

1 in. on the length of the bending moment diagram = x ft.
1 in. on the height of the bending moment diagram = y ft. tons.

Therefore in fig. 15 1 in. in height of any mid-ordinate of the bending moment diagram 1, 2, represents $d \times x \times y$ sq. ft. tons. Calculate the length of EI in sq. ft. tons to this scale $= \frac{EI}{144 \times d \times x \times y}$ inches), where E = modulus of elasticity in tons per sq. in., and I = moment of inertia in inch units).

Then the deflections will be to the scale of 1 in. = x ft.

It will be found convenient to reduce the length of EI for practical use, so the polar distance can be taken as $\frac{EI}{n}$, where n is some convenient divisor. The deflection scale will then be 1 in. $= \frac{x}{n}$ ft.

(E. S. Andrews, B.Sc., A.M.I.C.E.)

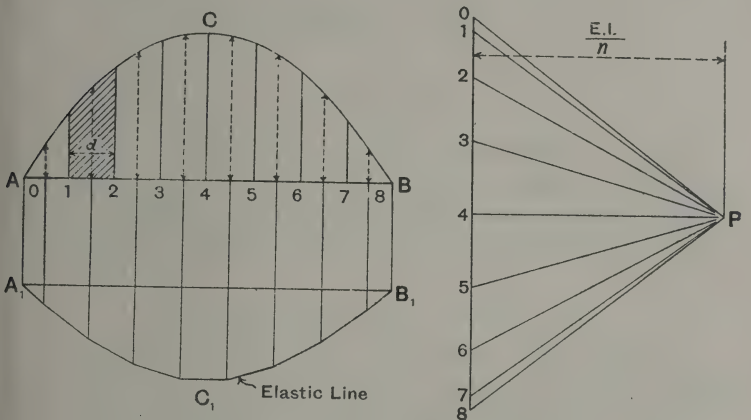


FIG. 15.—Graphical Determination of Deflection.

ACTUAL AND THEORETICAL DEFLECTION.

The difference between the actual and calculated deflection is due to various causes; in riveted girders the stiffness of riveted joints and covers, and the position and form of the floor, all tend to reduce the actual deflection, while poor quality of workmanship in the riveting and fitting together of parts tend to cause the actual deflection to exceed that calculated.

SECTION VII.

PART III.

LATTICE GIRDER BRIDGES.

LIVE AND DEAD LOAD STRESSES—PROPORTIONS OF BOOMS AND STRUTS—PIN-JOINTED MEMBERS—VARIATION OF STRESSES—PORTAL BRACING—DEFORMATION AND DEFLECTION.

LIVE AND DEAD LOAD STRESSES.

Criterion for Maximum Bending Moment and Maximum Shear.

The maximum bending moment at any joint in a bridge loaded with wheel loads will occur when the average load on the left of the section is the same as the average load on the whole span.

The maximum shear in any panel in a bridge loaded with wheel loads will occur when the load on the panel is equal to the load on the bridge divided by the number of panels.

(*Ketchum.*)

Maximum Loads on Inclined Braces.

The maximum tension in any inclined brace occurs when the leading axle is at the foot of the brace, the live load covering the larger segment of the bridge from the foot of the brace to the farthest support.

The maximum compression in any brace occurs when the leading axle is under the head of the brace; the live load covering the shorter segment of the girder to the nearest support.

(*R. J. Woods*).

Shears and Counterbracing.

(*a*) The maximum live load shear (positive) in any panel of a truss is equal to the left reaction when all the joints at the right of the panel are loaded and all joints at the left of it are unloaded.

(*b*) The dead load negative shear in any panel at the right of the centre is equal to the amount of dead load between the panel and the centre of the span (including a half panel load at the centre if the truss has an even number of panels).

(*c*) No counter is required in any panel beyond the centre of the truss in which the dead load negative shear exceeds the maximum live load positive shear; but in each panel beyond the centre in which the live load positive shear can exceed the dead load negative shear, a counter is required.

Stresses in Parallel-Flanged Girders with Uniform Rolling Load.

Divide span into a number of equal parts, one less than the number of bays (see fig. 16), obtaining points such as a, a_1. On the base A_1B_1 set up length $A_1C = \frac{PL}{2}\left(\frac{b-1}{b}\right)$, where P = intensity of load, L = span of girder, b = the number of bays.

Through C draw a parabola with vertex at B, and project points such as a, a_1, down to meet the parabola in points such as e, e_1, and project horizontally across bays as shown.

Then the maximum stresses in the diagonals for passage of the live load from right to left are obtained from this curve. Negative shears in a similar manner.

The position of the load to give maximum stresses in diagonals is obtained from

$$x = \left(\frac{n.y}{b-1}\right),$$

where

x = distance travelled by the load beyond end of nth bay, y = length of bay, and b = number of panels.

(E. S. Andrews, B.Sc., A.M.I.C.E.)

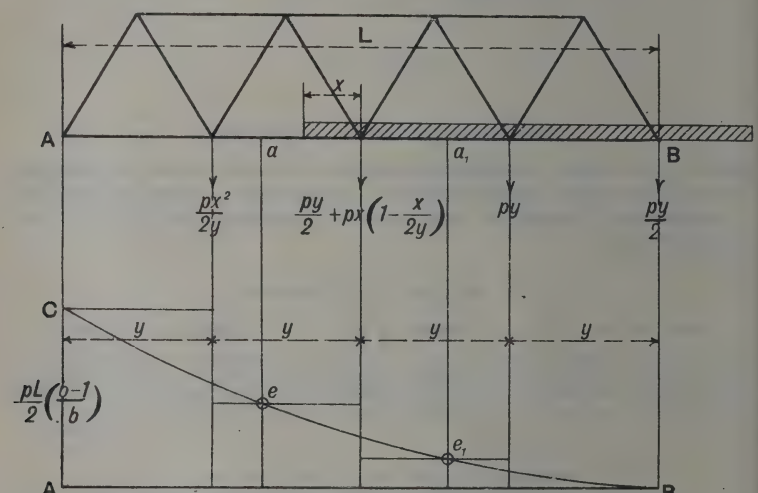


FIG. 16.—Stresses in Parallel-Flanged Girders with Uniform Rolling Load.

Distribution of Dead Load.

For spans under 200 ft. the total dead load shall be assumed to act at the loaded chord. For 200 ft. and over the total dead load will be distributed at top and bottom chords as follows :—

On Loaded Chords.

(*a*) Half the load resulting from trusses;
(*b*) Weight of horizontal wind bracing in plane of chords;
(*c*) Weight of floor system, permanent way, etc.;
(*d*) Half load resulting from weight of cross bracing in the case of deck bridges.

On Unloaded Chords.

(*a*) Half load resulting from trusses;
(*b*) Weight of horizontal wind bracing in plane of chords;

(*c*) Half the load resulting from weight of cross bracing in the case of deck bridges and the whole of it in the case of a through bridge. *(Sir Wm. Arrol & Co.)*

Stress in Members.

In parallel flanged lattice girders the stresses in the diagonals

$$= \frac{\text{load on diagonal} \times \text{length of diagonal}}{\text{depth of girder}},$$

i.e. load $\times$ sec. ϕ, ϕ being the angle which the diagonal makes with a vertical line.

RITTER'S 'METHOD OF SECTIONS.'

This consists of drawing 'lines of section' cutting the bridge truss in not more than three of its members. These lines divide the truss into two parts, one of which is supposed to be removed, the external forces acting on the other portion alone being considered.

The stress in any one of the three members cut by the 'line of section' can be found by taking moments round the point of intersection of the other two.

This method is not applicable to finding the stresses in the flanges of parallel-flanged girders; for the flanges if produced would not meet.

In fig. 17 draw the sectional line *ab*, cutting FE, FG, GA; then,

Stress in FG $\times x = 60 \times y$, J being the point of intersection of FE and AG.

It will be seen that the moments of the stresses on the members which meet at the point indicated become zero; and it is only necessary to equate the moment of the stress on the third member to the algebraic sum of the moments of all the external forces acting on the portion of the truss considered.

If it is required to find the stress in the member HE, with the live load in the position shown, then,

$$\text{Stress in HE} \times x' = (60 \times 10) - (20 \times 10).$$

Stresses in the vertical struts can be found in a similar manner.

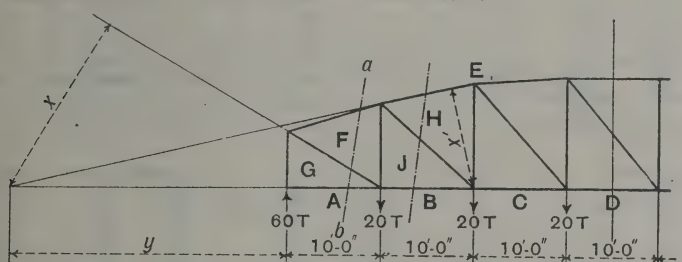


FIG. 17.—Ritter's Method of Sections.

Proportions of Booms, Struts, and Ties.

PROPORTIONS OF BOOMS AND STRUTS.

The width of booms should in general not be less than $\frac{1}{12}$ of the unsupported distance, and are usually of trough construction.

The unsupported width of plate subjected to compression should not exceed 30 times its thickness, except cover plates of top chords and end posts, which may be limited to 40 times their thickness.

The distance between webs (fig. 18), should be:

For Forms A B . . . . . $\frac{7}{8}$ W.
,, ,, F H . . . . . $\frac{1}{4}$ W.

BRACED OR LATTICE STRUTS

The least number of panels

$$= \frac{\text{Least radius of gyration of whole strut}}{\text{Least radius of gyration of unbraced portion}}.$$

In the case of a strut composed of an angle at each corner, the least radius of gyration of unbraced portion must be taken as one of the angles.

Batten plates should be spaced from 2–3 times the overall width of the side braced, while the inclination of diagonals to the axis of the member should not be less than 45°.

The thickness of bars with single lacing should not be less than $\frac{1}{40}$ of their length, with double bars, not less than $\frac{1}{60}$ of their length.

PROPORTIONS OF BOOMS AND STRUTS.

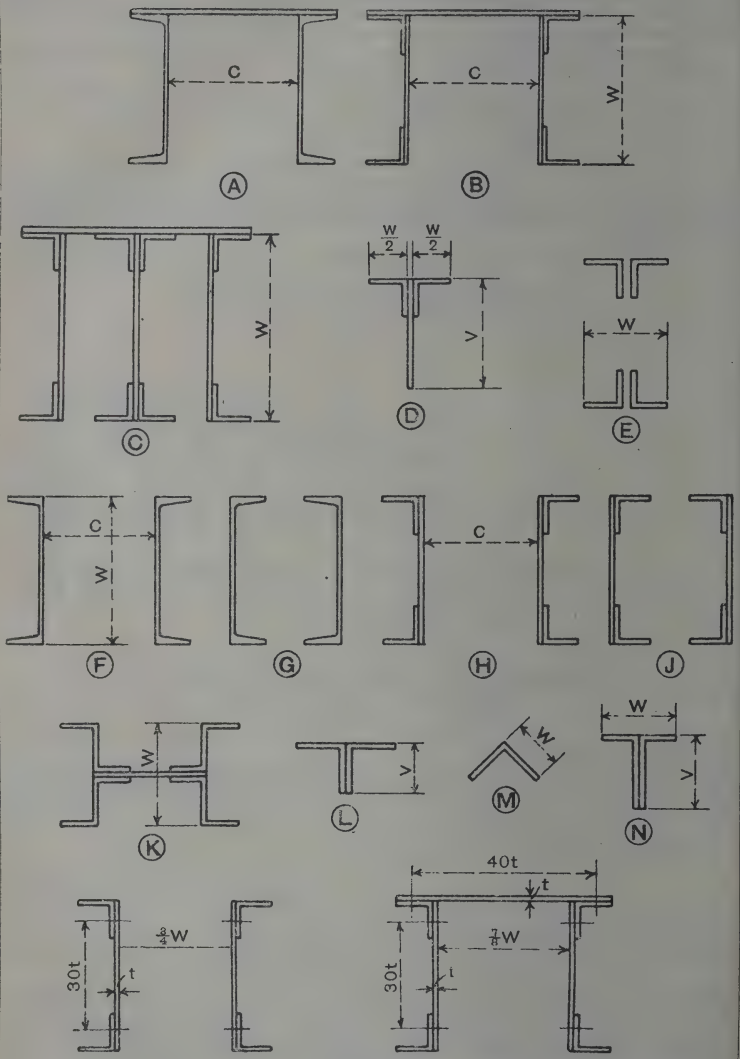


FIG. 18.

TABLE OF APPROXIMATE RADII OF GYRATION.

Form	Approximate Radius of Gyration (Least).
A B C	$r = \frac{4}{10}$ W.
F G H J	$r = \frac{3}{8}$ W.
K	$r = \frac{5}{16}$ W.
E	$r = \frac{24}{100}$ W.
L (equal legs)	$r = \frac{31}{100}$ W.
M ,, ,,	$r = \frac{1}{5}$ W.
N (longer legs together)	$rw = \frac{1}{2}$ W, $r_v = \frac{39}{100}$ V.
D	$r = \frac{1}{5}$ W (when V is equal to or greater than $\frac{8}{10}$ W).

For proportions of and stresses in struts, see ' Safe Working Stress,' p. 324.

TIES.

Ties should usually be designed to be of rigid construction, but may be of rolled flat bars except near the centre of the span, where they must be composed of rigid sections.

Counter bracing must be of similar construction to the centre ties.

Rolled bars forming long ties should be provided with distance pieces to reduce vibration.

Pin-jointed Members.

PIN CONNECTIONS.

The tearing, shearing, and bearing strengths of the joint should be made as nearly as possible equal to each other, and to the tensile or compressive strength of the bar in which the joint occurs.

Usually the bearing stress on the pin is taken at somewhat less than for rivets, to allow for imperfect fitting of the pin.

The bending strength of pins is very important, for if the pin becomes distorted the distribution of the loads and the calculation of the stresses is very uncertain.

Secondary bending in the top booms and strut members of a bridge merit greater attention when they are connected with pin joints. In this country pin joints will not often occur anywhere other than in suspension bridges, but in America pin-jointed bridges are very common.

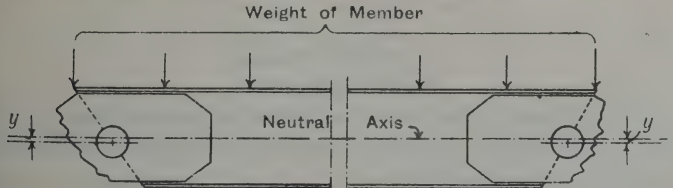


FIG. 19.—Pin-jointed Member with Eccentric Pins.

The position of pins may be so fixed that when the maximum stress (direct compression) comes upon the chord through the pins, it will produce an amount of bending moment equal to that produced by the weight of the member, but in the opposite direction.

In the ordinary type of top boom or end post section, this condition will be effected when the position of the pins is fixed at a distance y (see fig. 19), perpendicularly below the centre of gravity of the section, given by the formula

$$y = \frac{M}{Sc},$$

where M is the bending moment in inch pounds due to the weight of the member, and Sc is the total maximum direct compressive stress in the member in pounds.

Proportions of Eye Bar Heads.

The proportions of eye bars for suspension and other bridges, roof trusses, etc., according to various authorities, are given in fig. 20.

A — Berkley.
B — American Bridge Practice. The diagram is for an eye bar in which the diameter of the pin hole is equal to or greater than the width of the bar. For an eye bar where the diameter of the pin hole does not exceed ⅞ of the width of the bar, dimension (*a*) becomes 0·66.
C — Shaler-Smith (hydraulic forged).
D — Sir Charles Fox.

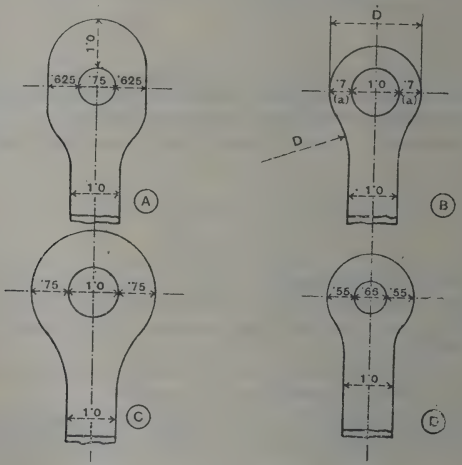


FIG. 20.—Proportions of Eye Bar Heads.

Variation of Stresses.

Wohler's Experiments.

When the elastic limit is not overpassed it is possible, under certain conditions, to fracture steel by repeating the stress a sufficient number of times. Wohler showed that it was the range of stress, and not the maximum stress, that determined the number of applications before rupture.

The general conclusions are that:

(*a*) The greatest tensile stress a bar will bear for an indefinite number of times is for iron and steel about half its ultimate static breaking stress.

(*b*) The number of repetitions required to produce fracture is increased if the range through which the stress is varied is reduced.

(*c*) A bar will be strongest when exposed to varying stresses of the same kind, and weakest when exposed to stresses of opposite kinds, *i.e.* tension and compression.

The stress caused by a load suddenly reversed is three times the static stress, and a load suddenly applied causes a stress of twice the static stress. (Refer to 'Impact,' p. 366.)

Relation between Sudden Loading and Repetition of Stress.

The similarity between the results of experiments on variation of stress and sudden loading has given rise to many assumptions that Wohler's results were really due to the effects of sudden loading, and that the two are really aspects of the same question.

Although there are many points which require to be decided in the consideration of these experiments, for practical reasons it seems best to allow for either one or the other, and not for both simultaneously in one member.

In the case of cross girders and vertical suspenders, allowance should be made for the full value of the elastic vibrations due to sudden loading; while rail bearers and main girders, both plated and latticed, of spans up to 100 ft., should be designed with an allowance for sudden loading or impact, using one of the impact formulæ evolved for the purpose.

In the flanges of girders and the principal members of arched and suspension bridges of large dimensions the stress variation takes place more gradually, and allowance for variation of stress can be made by adopting a reduced stress, based on the amount of variation of stress.

Launhardt-Weyrauch Method.

The working stress is varied according to the relative amounts of live and dead loads.

Members Subjected to Tension Only.

$$\text{Working stress} = \frac{f}{1{\cdot}5}\left(1 + \frac{\text{minimum load}}{2 \times \text{maximum load}}\right) \text{ tons per sq. in.,}$$

being the static or dead load working stress.

Dynamic Method.

$$\text{Working stress} = \frac{f}{1 + \dfrac{\text{live load.}}{\text{total load}}};$$

$$\text{The sectional area of a bar in tension} = \frac{\text{maximum load}}{\text{working stress}}.$$

Members subjected to Alternate Stresses.

Members of bridges subjected to alternate tension and compression should be proportioned as struts, to resist the greater stress added to $\frac{1}{2}$ of the lesser stress, except in the case of wind bracing, where the members should be proportioned to resist the greater stress. The sum of the stresses should be used in designing the connections.

Portal Bracing.

Design.

There are many types of portal bracing which may be used; A to F, fig. 21, show some common forms.

The fixing of the lower ends may be assumed as either hinged or fixed.

They may be considered as fixed by virtue of the direct stress due to vertical loading, when $V \times \frac{1}{2}s$ is $>$ M max. at A or B with fixed ends; M max. $= \frac{Rd}{4}$, where V = total stress in the column.

The following treatment for the calculation of the stresses is due to Mr. Milo S. Ketchum in 'Steel Mill Buildings,' in which book he deals with the stresses in many types, with both hinged and fixed ends.

Stresses in Portal (a). Columns Hinged

The deflections in the columns are assumed to be equal, then,

$$H = H_1 = \frac{R}{2}.$$

Taking moments about the foot of the windward column,

$$V_1 = -V = \frac{Rh}{s},$$

Having found the external forces, the stresses in the members may be found either by algebraic or graphical methods.

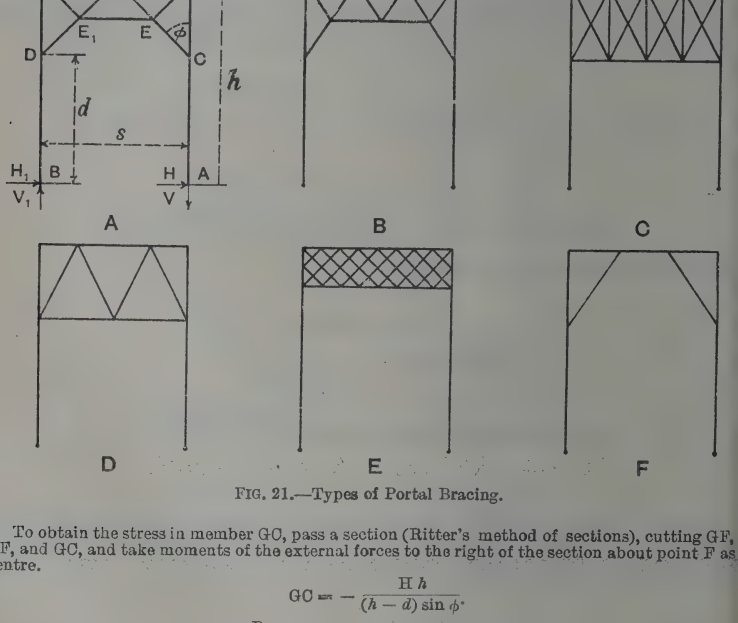


FIG. 21.—Types of Portal Bracing.

To obtain the stress in member GC, pass a section (Ritter's method of sections), cutting GF, EF, and GC, and take moments of the external forces to the right of the section about point F as centre.

$$GC = -\frac{H\,h}{(h-d)\sin\phi}.$$

But $$H = \frac{R}{2}, \text{ and } (h-d)\sin\phi = \frac{s}{2} \times \cos\phi.$$

Substituting these values in the above expressions,

$$GC = -\frac{Rh}{s\cos\phi} = -V\sec\phi.$$

Resolving at C and F we have: stress in EF = 0, and also stresses in EE_1 and $HE_1 = 0$.

To obtain stress in GD, pass a section cutting HG, HE_1 and GD, and take moments of the external forces to the left of the section about point H as centre.

$$GD = \frac{Hh}{(h-d)\sin\phi} = +V\sec\phi.$$

To obtain stress in GF, pass a section cutting GF, EF and GC, and take moments of the external forces to the right of the section about point C as centre.

$$GF = +\frac{R(h-d) + Hd}{h-d}.$$

To obtain stress in HG, pass a section cutting HG, HE, and GD, and take moments of the external forces to the left of the section about point D as centre.

$$HG = -\frac{Hd}{h-d}.$$

The stress in the windward post AF is zero above and V below the foot of the knee brace C; the stress in the leeward post is zero above and V, below the foot of the knee brace D.

The shear in the posts is H below the foot of the knee brace, and above the foot of the knee brace is given by the formula—

$$S = \frac{Hd}{h-d} = \text{stress in HG}.$$

The maximum moment in the posts occurs at the foot of the knee braces C and D, and is

$$M = Hd.$$

The stresses in portal (*b*) are found in a similar manner, but it will be found that all members are stressed in portals (*b*) and (*d*).

Deformation and Deflection.

Actual and Theoretical Deflection.

There is usually a difference between the actual and calculated deflection of framed structures. This is due to various causes, principally the rigidity and stiffness of the joints or otherwise, and the actual deflection is usually in excess of that calculated.

Contrary to statements that the amount of deflection is independent of any change of form which may take place in the web, and is not affected by the form of web, it is found that the deformation of the web members contributes largely to the total deflection.

Deflection of a Lattice Girder.

The theoretical deflection of a framed structure can be found both analytically and graphically when the elastic deformation of each member caused by the stress in it is known.

The following method is that developed by Maxwell and Mohr, and is taken from Sir W. Arrol & Co.'s Handbook :—

Example.—Find the deflection at the centre of a lattice girder 100 ft. span, 10 ft. deep, and loaded with a distributed load of 1 ton per ft. run.

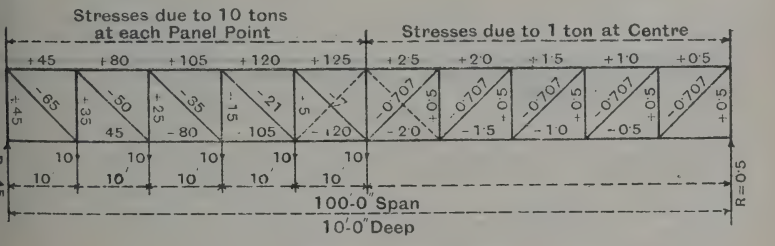


FIG. 22.—Deflection of Lattice Girders.

Let

L = length of any member in ft.; *l* = length of any member in ins.; S = total stress in any member due to 100 tons distributed load; P = stress per sq. in. in any member due to 100 tons distributed load; *b* = total stress in any member due to 1 ton placed at the point at which it is required to find the deflection; A = gross area of any member in sq. ins. plus 5 to 10 per cent. to allow for the effect of covers, joints, etc.; E = modulus of elasticity of steel which may be taken as 12,000 tons per sq. in.

First calculate the stresses in each member due to the distributed load of 100 tons and obtain the sectional areas of the members; then ascertain the stress per sq. in. (U), in each member due to the load of 1 ton at the point where the deflection is required.

The elastic deformation of any member is $\frac{lS}{EA}$ (or $\frac{LS}{1000\,A}$, if L is in ft.).

The results are then placed in tabular form as follows :—

Member.	L. Length	S. Total Stress	A. Area.	P. Stress per Square Inch.	$\frac{Pl}{E}$.	U.	Contribution to Deflection $\frac{PlU}{E}$	Summation.
Top Boom	Ft.	Tons.	Sq. Ins.	Tons.	In.	Tons	In.	In.
Bay 1	10	+ 45	9	+5	+0·05	+0·5	+0·025	
,, 2	10	+ 80	16	+5	+0·05	+1·0	+0·050	
,, 3	10	+105	21	+5	+0·05	+1·5	+0·075	
,, 4	10	+120	24	+5	+0·05	+2·0	+0·100	
,, 5	10	+125	25	+5	+0·05	+2·5	+0·125	
								+0·375
Bottom Boom								
Bay 1	10	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	
,, 2	10	− 45	7·5	−6	−0·06	−0·5	+0·03	
,, 3	10	− 80	13·4	−6	−0·06	−1·0	+0·06	
,, 4	10	−105	17·5	−6	−0·06	−1·5	+0·09	
,, 5	10	−120	20·0	−6	−0·06	−2·0	+0·12	
								+0·300
Web.								
Tie 1	14·14	− 65	13	−5	−0·0707	−0·707	0·05	
,, 2	14·14	− 50	10	−5	−0·0707	−0·707	0·05	
,, 3	14·14	− 35	7	−5	−0·0707	−0·707	0·05	
,, 4	14·14	− 21	4·5	−5	−0·0707	−0·707	0·05	
,, 5	14·14	− 7	1·4	−5	−0·0707	−0·707	0·05	
								+0·250
End Post	10	+ 45	11·25	+4	+0·04	+0·5	+0·02	
Strut 1	10	+ 35	8·75	+4	+0·04	+0·5	+0·02	
,, 2	10	+ 25	6·25	+4	+0·04	+0·5	+0·02	
,, 3	10	+ 15	3·75	+4	+0·04	+0·5	+0·02	
,, 4	10	+ 5	1·25	+4	+0·04	+0·5	+0·02	+0·100
							Half sum	+1·025 / 2
						Total	deflection	+2·050

The required deflection of the girder is thus found to be 2·05 in., the flanges contributing 1·35 in., and the web 0·70 in.

SECTION VII.

PART IV.

SWING AND BASCULE BRIDGES.

PARTICULARS OF BRIDGES—WORKING STRESSES—FRICTION AND LUBRICATION—HYDRAULIC LIFTING AND SLEWING MACHINERY—CIRCULAR GIRDERS.

SWING BRIDGES.

The most usual types are either of the 'centre bearing' or 'rim bearing' type, and may be either 'single leaf' or 'double.'

The depth of a single-leaf swing bridge is four times greater than that required for a double-leaf bridge of the same span, when the bridge is treated while in motion as a cantilever.

On the other hand, the length of a single-leaf swing bridge is less than the combined lengths of the two leaves for the same opening, but the double leaf type requires two sets of operating machinery.

The full advantages of swing bridges are only to be obtained when they span two openings; in such cases the necessity for counterpoises or kentledge does not exist and the effects of wind pressure are to a great extent neutralised.

A further classification of types is as follows:—

(*a*) Those which turn entirely upon rollers, *i.e.* the rim bearing type.

(*b*) Those where the weight is proportioned to be borne partly by rollers and in part by a centre pivot.

(*c*) Those swung entirely upon a pivot.

(*d*) Those which are lifted on a water centre by hydraulic power.

(*e*) Those which are lifted on a water centre by hydraulic power, but not sufficient to lift the whole weight.

In the latter type the tail is heavier than the toe, and the excess weight is borne by rollers running on a roller path, and adds stability to the bridge when swinging.

Lattice girders are preferable for all spans in excess of 100 ft. on account of their much less resistance to wind pressure.

In all cases where rollers at the tail end are provided, an excess of counter weight should be provided, so that the rollers are loaded when the bridge is swinging with not less than 10 tons when the bridge is covered with snow and allowance has been made for the increase in weight of the roadway and footpaths due to wet.

Hydraulic presses or wedges should be provided at heel and toe to relieve the rollers and pivot of weight when the bridge is in the fixed position for sustaining road traffic.

BASCULE BRIDGES.

Bascule bridges may be either single leaf or double, but are usually double-leafed.

The most modern types are as follows:—

(*a*) Those in which the pivot is overhead and the balance weight either overhead or below the level of the bridge floor.

(*b*) Those where the pivot is situated below the level of the bridge floor and the counter-weight likewise.

(*c*) Those in which there is no fixed axis, but the tail of the bridge is in the form of a circular segment, upon which the bridge rolls backward and forward.

Particulars of Bridges.

Swing Bridges.

Name of Bridge.	Span (Opening).	Width of Road.	Length of Long Arm.	Length of Short Arm.	Depth of Main Girders at Centre over Angles.	No. of Rollers.	Diam. of Roller Circle.	Weight (less Kentledge).
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.		Ft. Ins.	Tons.
Manchester Ship Canal, Old Quay, Runcorn .	120 0	20 0	139 0	96 10	28 0	60	22 11	650
Moore Lane .	120 0	25 0	140 0	98 0	27 8½	64	27 10½	790
Stagg Inn. . .	120 0	25 0	140 0	98 0	27 8	64	27 10½	790
Northwich Road .	120 0	36 0	148 0	100 0	30 0	60	38 9	1350
Knutsford Road .	120 0	36 0	148 0	100 0	30 0	60	38 9	1350
Barton Bridge .	90 0	25 0	111 0	81 0	26 0	64	27 10½	640
East India Docks, London (Road and Railway) .	80 0	11 6	95 0	30 0	16 8	Centre	Pivot.	480
King George V. Dock, London, (Skew Bridge, 22°) . .	108 0	20 8 and 2 footpaths.	150 0	50 0	25 0	Centre	Pivot.	950
Kilbowie (Railway) (Skew Bridge, 24°) . .	22 3	—	152 7 133 3	36 4	17 6	—	19 4	416
Dry Docks, Marseilles, France (one road, one rail-track, 3 main girders) .	92 0	52 6 and 1 footway	126 0	77 5	11 6	Centre	Pivot	575

Bascule Bridges.

Name of Bridge.	Span (Opening.)	Width of Road.	Depth of Main Girder at Cr. over Angles.	Type.	Weight.
	Ft.	Ft. Ins.	Ft. Ins.		Tons.
Southern Railway, over River Swale, Kent .	62	33 0 centre of girders.	—	Rolling lift.	520 (plus counterweight.)
Cart Navigation Trust, Inchinnan . . .	90	20 0	20 5	Rolling lift	207
King George V. Dock, London (double leaf) .	50	17 6 (and 2 footways)	29 0	Pivot.	381
Taylor Street, Chicago (Scherzer double leaf) .	295	28 0	40 0	Rolling lift.	—

Working Stresses.

Permissible Working Stresses.

The maximum permissible unit stresses per sq. in. should be less for the main girders, cross girders, and rail bearers than those allowed for simply supported spans; about 10 per cent. is a usual figure. (Refer to ' Working Stresses,' p. 360, Part I.)

Rollers.

Rollers supporting swing bridges should generally be of solid forged steel or cast steel, with suitable gun-metal liners and collars and provision for adjustment at the ends of the rollers.

The rollers and surfaces of both upper and lower paths should form parts of conical surfaces with a common vertex at the centre.

The size of the rollers should bear some relation to the diameter of the roller circle, and in general will not exceed 2 to 3 ft. diameter.

Bearing Pressure on Rollers.

The following safe bearing pressures in pounds per lineal inch on rollers are taken from the *Transactions of the American Society of Civil Engineers*, vol. xxxiii.

Description.	Rollers at rest.	Rollers in Motion.
Cast Iron	400 d	200 d
Rolled or Cast Steel (28–32 tons)	800 d	400 d
Axle Steel (35–38 tons)	—	500 d
Tool Steel (60 tons)	—	800 d
Tool Steel hardened	—	1000 d

where d is the diameter in inches.

The values given are for rollers and bearing surfaces of the same material; if they are of different materials, lower values should be used.

Sir W. Arrol & Co., in their Handbook, give the safe load in pounds per lineal inch on rollers, as 300 d, where d = the diameter of the roller, the mean diameter being taken for conical rollers, the rollers and plates being of cast iron, wrought iron, or steel; for rollers in motion one-half the above value to be taken. It is stated that the working stress is one-fifth the elastic limit for cast iron, and one-third the limit for wrought iron or steel, the elastic limit being reached in steel plates and steel rollers of 1 in. to 16 ins. diameter at 880 d.

Bearing Pressures on Rotating and Sliding Surfaces.

Maximum Bearing Values for Rotating and Sliding Surfaces in Pounds per Square Inch.

Bearings on which the Speed is slow and Intermittent.	
Pivots for swing bridges, hardened tool steel on special phosphor-bronze	3,500
Trunnion bearings for bascule bridges, axle steel on phosphor-bronze	2,000
Wedges, cast-iron on bronze	600
Wedges, cast-iron on cast-iron or structural steel	500
Screws which transmit motion on projected area of thread	200
Ordinary Cases, Parts moving at Moderate Speeds.	
Hardened steel on hardened steel	2,000
Hardened steel on bronze	1,500
Tool steel (not hardened) on bronze	900
Structural steel on bronze	600
Cast-iron on structural steel	400
Cast-iron on cast-iron	400
On crosshead slides, speed not exceeding 600 ft. per minute	50

In order to prevent heating and seizing at higher speeds, the pressure on pivots or foot-step bearings for vertical shafts and journals should not exceed :—

$$\text{On pivots, } p = \frac{160000}{n\,d}\text{ ; on journals, } p = \frac{300000}{n\,d},$$

where

n = number of revolutions per minute, d = diameter of journal or pivot in inches.

For crank pins and similar joints with alternating motion, the limit bearing values given in the above formula may be doubled.

Ball and Roller Bearings.

(See Section XX., p. 1041.)

Centre Pivots.

The construction of centre pivots for swing bridges requires careful consideration. They should be of ample proportions, and the pressure per square inch should not exceed 2 to 3 tons per square inch, or excessive friction will ensue.

The pivots should preferably consist of four parts; the lower casting and upper castings of steel, with an upper revolving pin of tool steel with a convex surface, and the lower fixed cup of phosphor bronze with a concave surface of slightly larger radius than the upper revolving pin, to assist lubrication.

Pivots have been designed in which a 'Tabloid' was placed between the upper revolving pin and the lower stationary cup. The 'Tabloid' was of phosphor bronze with spherical upper and lower surfaces, the upper pin on the bridge and the lower cup also having spherical surfaces. This type of pivot is, however, only suitable for bridges in which the slewing power is applied at two or more diametrically opposite points, for where the slewing force is applied at only one point, a slight displacement of the bridge on the seating has been found to occur, resulting in considerable eccentricity.

Pressures on Quadrants and Tracks of Rolling Lift Bascule Bridges.

The following data refer to four bridges constructed during recent years :—

Clear Span.		Radius of Quadrant.		Rolling Load.	Width of Bearing.	Pressure on Track.	Materials in Quadrants and Tracks
Ft.	Ins.	Ft.	Ins.	Tons.	Inches.	Tons per Lineal Inch.	
58	3	18	3	414	26·0	15·92	Mild steel 28–32 tons.
100	0	21	0	631	38·0	16·61	Quad. plate mild steel.
100	0	21	0	516	22·0	23·45	Track plate cast steel
							Track plate cast steel 35 tons.
150	0	28	0	2,922	50·25	58·15 average.	Quad. plate mild steel 36-40 tons.

(*Selected Paper No. 8, Inst.C.E.*)

Friction and Lubrication.

Rolling Friction.

Let

P = force required to propel roller (lbs.); W = load on roller (lbs.); R = radius of roller (ins.); h = depth of depression caused in track (ins.); K = a constant; then,

$$P = \frac{WK}{R - h},$$

or, as h is usually very small compared with R,

$$P = \frac{WK}{R}\text{ (nearly).}$$

The value of K varies from 0·007 to 0·015.

Some Experiments on Friction.

The following experiment, undertaken by Sir Wm. Arrol & Co., is particularly applicable to the friction of roller rings in turntable swing bridges :—

Two beams, each 175½ ins. long by 5¾ ins. broad, each weighing 1570 lbs., were planed to a smooth surface and accurately levelled. One beam was laid dry upon the other and afterwards two rollers, 2½ in. diameter, were placed 7 ft. apart between them. The force required to start motion was obtained for different loads.

In experiments with eleven American turntable swing bridges, the friction showed a maximum of 7·94 lbs. per 1,000 lbs. weight of moving structure ; but one bridge showed as low as 3·53 lbs.

Further experiments in America on new swing bridges, before the gearing, etc., had had an opportunity to wear smooth, were as follows ; for bridges which have been in operation for some time, the coefficients given will be less:—

Load.	Force to Start Motion.		Coefficient of Friction.	Percentage of Load.	Remarks.
	Total.	Pounds Per Ton.			
lbs.	lbs.	lbs.			
1570	450–500	650–716	0·29–0·32	29–32	Sliding Friction.
2130	475–560	500–590	0·224–0·263	22–26	,,
1570	2·73	3·9	0·00174	0·17	Rolling friction.
2240	5·44	5·44	0·00243	0·24	,,

For rim-bearing swing bridges, the late C. Shaler Smith found the total frictional resistance in the live ring to vary from 0·001 to 0·008 of the load on the rollers. Messrs. Boller & Schumacher found the coefficient to be 0·0035 for the Thames River Bridge, and Theodore Cooper found this to be 0·0038 for the Second Avenue Bridge.

For centre bearing bridges, Mr. C. Shaler Smith found the frictional resistance at the circumference of the pivot to be 0·09 of the weight turned. Mr. Schneider found the coefficient of frictional resistance at the circumference of the pivot, on hardened steel and phosphor bronze discs, with the usual working pressure of about 3,000 lbs. per sq. in., to be 0·067 at the start and 0·015 to keep the bridge moving at uniform speed. For the total frictional resistance, including that of the shafts and gearing required for hand operations, the highest coefficients observed were 0·115 for starting and 0·08 for keeping the bridge in motion.

(*Proceedings American Society of Civil Engineers.*)

Experiments by Beauchamp Tower show that a steel shaft in a lubricated gun-metal bearing seizes at about 600 lbs. per sq. in. under steady running, while in a dry bearing they seized at about 80 lbs. per sq. in.

Professor Goodman found that the seizing pressure increases as the viscosity of the oil increases.

Horse-Power Absorbed in Revolving Bearings.

Let

W = total load on bearing in lbs. ; D = diameter of bearing in ins. ; N = number of revolutions per minute ; ϕ = coefficient of friction.

For Cylindrical Bearings :

$$\text{Work done per minute in ft.-lbs.} = \frac{\phi W \pi D N}{12};$$

$$\text{Horse-power absorbed} = \frac{W \pi D N \phi}{12 \times 33{,}000} = \frac{\phi W D N}{126{,}000}.$$

For Flat Pivots :

$$\text{Horse-power absorbed} = \frac{\phi W D N}{189{,}000}.$$

Lubrication.

Oil should always be led to the point of least pressure in a bearing.

Oils for heavy pressure should be thick, that they may resist being forced out.

Lubricants for Various Cases.

Nature of Pressure, etc.	Type of Lubricant.
Heavy pressure with slow speed.	Graphite, soapstone, tallow, and other greases.
Heavy pressure with high speed.	Sperm oil, castor oil, and heavy mineral oils.
Light pressure and high speed	Sperm oil, refined petroleum, olive, rape, and cotton-seed oils.
Ordinary machines	Lard oil, heavy mineral and vegetable oils.

Oils act chemically in a varying degree on most metals, and care must be exercised in selecting the most suitable kind.

HYDRAULIC LIFTING AND SLEWING MACHINERY.

Power required for Lifting Swing Bridges.

This is a simple calculation based on the total weight of the bridge lifted and the friction due to moving parts, leathers, and so on.

Power required for Slewing Swing Bridges.

$P = 0{\cdot}015$, for rim-bearing; $P = 0{\cdot}15\ W \frac{r}{R}$, for centre-bearing; $H.P. = \frac{P\,v}{550}$; $v = \frac{R\,\pi}{2t}$,

where

P = Force required to turn the bridge, acting in centre line of track; W = total moving weight, in lbs.; H.P. = horse power; r = radius of pivot; R = radius of centre line of track; v = maximum linear velocity in centre line of track in feet per second; t = time, in secs., in which maximum velocity must be obtained, or one-half the number of seconds required to open the bridge.

The foregoing formulæ generally give results in excess of the power actually needed under ordinary conditions, and practically cover all contingencies.

If the bridge has to be operated by hand-power, the gearing has to be arranged either for the number of men available or for the time required to turn and operate the bridge. In calculating the strength of the gearing, etc., the power of one man should be taken at 125 lbs., as this is about the force a strong man, with a foothold, can exert for a short time.

Setting and Wedging Blocks.

It is usually not advisable to allow a bridge to rest upon the pivot when undergoing stress due to moving loads.

In some bridges the centre pivot is also the lifting press, bearing blocks being provided at suitable points to sustain the bridge when in position. In this case, however, there is difficulty in preventing the ram from turning in the cylinder.

With a solid pivot, the hydraulic lifting rams are placed at the tail of the bridge, where, when the rams have lifted the bridge off the pivot, a pair of sliding bearing blocks are inserted and the lifting power then withdrawn. In this type four or more rollers are provided to take a portion of the weight of the bridge while slewing, and to keep the bridge 'upon an even keel.'

The two leaves of a double swing bridge are often linked together at the meeting point, the object being to prevent any perceptible difference in level between the extremities of the bridge leaves when a heavy load is transferred from one to the other.

CIRCULAR GIRDERS.

Bending Moments in Circular Girders.

(Equally spaced Supports.)

No. of Points of Support.	Reaction at Point of Support (lbs.).	Maximum Shear (lbs.).	B.M. Over Point of support (in.-lbs.).	B.M. Midway between Supports (in.-lbs.).	Angular Distance Point of support to Point of Maximum Torsion.	Maximum Torsional Moments (in.-lbs.).
					° ′	
4	$\frac{W}{4}$	$\frac{W}{8}$	$-0{\cdot}03415\ Wr.$	$+0{\cdot}01762\ Wr.$	19 12	$0{\cdot}0053\ Wr.$
6	$\frac{W}{6}$	$\frac{W}{12}$	$-0{\cdot}01482\ Wr.$	$+0{\cdot}00751\ Wr.$	12 44	$0{\cdot}00151\ Wr.$
8	$\frac{W}{8}$	$\frac{W}{16}$	$-0{\cdot}00827\ Wr.$	$+0{\cdot}00416\ Wr.$	9 33	$0{\cdot}00063\ Wr.$
12	$\frac{W}{12}$	$\frac{W}{24}$	$-0{\cdot}00365\ Wr.$	$+0{\cdot}00190\ Wr.$	6 21	$0{\cdot}000185\ Wr.$

W = Total uniform load supported by girder in lbs.; r = radius of girder in ins.

SECTION VII.

PART V.

ARCH BRIDGES.

Types and Stresses.

ARCHED RIBS.

The arched rib or roadway girder may be in either of the following forms:—

(*a*) Rigidly fixed at each end.
(*b*) Hinged at each end.
(*c*) Hinged at centre and at each end.
(*d*) Hinged near one abutment.

STRESSES IN ARCHES.

The arch may be looked upon as an inverted suspension bridge, the links of the suspension bridge being in tension and those in the arch being in compression, but the latter would be in unstable equilibrium under any loading, and so in practice the arch is made capable of resisting bending stresses in addition to direct compression.

HORIZONTAL THRUST.

When once the horizontal thrust for any given arch has been found, it is a simple matter to obtain the stresses.

The horizontal thrust can be determined accurately in three cases only, viz.:—

(1) A parabolic arch uniformly loaded.
(2) A parabolic arch with uniform load over half the span.
(3) A three-pinned arch.

LINEAR ARCH AND LINE OF PRESSURE.

A linear arch is one which is theoretically supposed to be subject to direct compressive stress only and incapable of resisting flexure.

The line of pressure is the theoretical line, the ordinates of which vary as the bending moments for the load which the arch supports. It is synonymous with the curve of equilibrium.

Eddy's Theorem is thus:

'The Bending Moment at any point in an arch is equal to the product of the Horizontal Thrust into the vertical intercept between the centre line or neutral axis of the arch and the line of pressure.'

It is almost universally the practice with steel arches to hinge them at the abutments, and often at the crown also. By this means the alterations in form of the arch due to the passage of the load and variation of temperature more readily adapt themselves to the varying conditions. Moreover, the resulting thrusts pass through these points and the axis of the arch, or approximately so, and the bending stresses are thus reduced and can be determined with greater accuracy.

STRESSES IN PARABOLIC ARCH, HINGED AT THE ABUTMENTS.

Let

l = length of span of arch; v = versine or rise; w = load per unit of length, T = horizontal thrust at the crown and abutments; C = compressive stress at any point x from the centre, then

$$T = \frac{w l^2}{8v}.$$

This expression represents the horizontal component of the pressure at any point in the arch.

$$C = \sqrt{\left(\frac{w\,l^2}{8v}\right)^2 + (wx)^2}.$$

When loaded with a single weight W at the centre of the arch,

$$T = \frac{Wl}{4v}.$$

If W rests at a point x from centre of arch, then,

$$T = \frac{W\,(l - 2\,x)}{4v}.$$

When loaded with a uniform load over half the span,

$$T = \frac{wl^2}{16v}.$$

Stresses in Three-Pinned Arch.

When loaded with a single weight W (see fig. 23),

$$T = \frac{W\,l}{4v}.$$

If the lines of pressure be inclined at an angle ϕ to the horizontal, the direct compressive stress, s, at any section in the rib is

$$s = \frac{W\,l}{4v} \sec \phi \cos \delta,$$

where

δ = angle which the tangent at the section under consideration makes with the line of pressure.

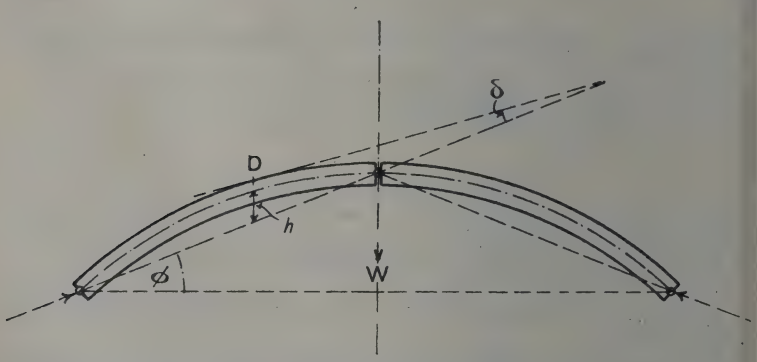


Fig. 23.—Three-Pinned Arch.

The bending moment at section D

$$= \frac{W\,l}{4v} \times h,$$

(h being the vertical distance between the line of pressure and the neutral axis of the rib at the given section).

For other loadings the same rules apply, the line of pressure always passing through the pin joints.

Combined Stresses in Arched Ribs.

In any arch where the line of pressure does not coincide with the neutral axis of the rib, there will be the following forces at any cross section :—

(1) A maximum compressive stress

$$= \frac{Q}{A} + \frac{M}{Z}$$

(2) A maximum tensile stress

$$= \frac{M}{Z_t} - \frac{Q}{A}$$

(3) A mean shear stress over the section

$$= \frac{S}{A},$$

where

Q = the thrust; S = the shear (obtained by resolving the horizontal thrust along (or tangential) and perpendicular to the neutral axis of the section under consideration); A = the area of the cross section of the rib; M = the bending moment obtained by applying Eddy's Theorem; Z_c and Z_t = the moduli of section in compression and tension respectively.

Stresses in Braced Arches.

Having found the direction and magnitude of the abutment reactions for any loading, the stresses can be found in a similar manner, those in the bracing being conveniently determined by Ritter's Method of Moments, described under 'Lattice Girders,' page 387.

Effects of Temperature Variation.

A rise in temperature causes an increased thrust in two-pinned and rigid arches, but theoretically causes no such increase in three-pinned arches, although practically some slight difference may be occasioned by any stiffness of the pin joints.

For a short research on Temperature Stress, see *The Theory and Design of Structures*, by Ewart S. Andrews, B.Sc., A.M.Inst.C.E.

Ratio of Rise to Span.

This is usually taken as from 1 : 5 to 1 : 10, but varies greatly according to local conditions of headroom.

The three-pinned arch over the river Exe—a road-bridge carrying tram-cars, erected in 1905, has a ratio of rise to span of 1 : 13·2, and is probably the flattest steel arch in existence in this country.

SECTION VII

PART VI.

SUSPENSION BRIDGES.

Types and Stresses.

Advantages and Disadvantages of Suspension Bridges.

The principal advantage is their cheapness, and in large spans the advantage of the suspension bridge is so great that bridges of this type of 800 or 900 ft. span can be constructed at much less cost per foot run than girder bridges of half this span.

There are many disadvantages attending suspension bridges, the chief being lack of stiffness and rigidity, both vertically and laterally, which makes them unsuitable for carrying railways unless elaborate means are taken for stiffening them.

A suspension bridge constructed on 'Bridge's System,' in which the suspension rods are inclined, is much stiffer vertically than one in which the rods are vertical.

Types of Stiffened Suspension Bridges.

In order to lessen the changes of shape and oscillations set up by a moving load, the roadway girders may be constructed of rigid form and braced laterally. The principal varieties of this and other types of stiffened suspension bridges are:

(*a*) Roadway stiffening girders hinged at each end and at centre.
(*b*) Roadway stiffening girders hinged at each end.
(*c*) Roadway stiffening girders hinged in either of the above ways and bridge consisting of two cables at each side stiffened by bracing.

Examples of some of the above types are as follows:—

Types (*a*) *and* (*b*).—Williamsburg Bridge, over East River, New York, built 1903, span 1,600 ft. Double line of railway, four lines of tramways, two roadways and two footways and cycle tracks

Manhattan Bridge over East River, New York, built 1909, span 1,470 ft., four lines of tramway, one roadway, and two footways.

Type (*c*).—Proposed Hudson River Bridge, New York, clear span 2,880 ft., four lines of railway, four lines of tramway, two roadways, and two footways. A further example of this type is the Tower Bridge, London, in which the side spans are of this type.

An example of a bridge constructed with inclined and vertical suspenders is the Brooklyn Bridge, New York, built in 1884, span 1,595 feet, which carries a double line of tramway, two roadways, and one footway.

Stresses in Cable Uniformly Loaded.

The shape which a loaded cable takes up is the same as the link polygon for the given load system, drawn from one support to the other, with a polar distance equal to the horizontal component H of the pull or tension in the cable.

If

d = the dip of the cable; L = span; W = weight carried by the cable, then,

If

$$H = \frac{WL}{8d}.$$

A = area of the cable; f = safe tensile stress,

$$fA = \frac{W}{2}\sqrt{\left(1 + \frac{L^2}{16d^2}\right)}.$$

Stresses in Anchor Cables.

There are two chief methods by which the cables of suspension bridges are carried over the piers—

(1) Main and anchor cables passing continuously over rollers fixed to the top of the piers.

(2) Main and anchor cables passing continuously over saddles mounted on rollers on the tops of the piers.

Let ϕ = angle which bridge cable makes with a vertical at point of support; δ = angle which anchor cable makes with a vertical at point of support; T = tension in bridge cable; T_1 = tension in bridge anchor cable.

Case (1).—Tension in anchor cable is equal to tension in bridge cable, whatever the inclinations,

$$= T_1 = T;$$

Horizontal force acting on piers $$= H\left(1 - \frac{\sin\delta}{\sin\phi}\right);$$

Vertical pressure on piers $$= \frac{W}{2}\left(1 + \frac{\cos\delta}{\cos\phi}\right).$$

Case (2).—Tensions in anchor and bridge cables not always the same, but there is no horizontal force on the piers,

$$T_1 = \frac{T\sin\phi}{\sin\delta};$$

Vertical pressure on piers $$= \frac{W}{2}(1 + \tan\phi\cot\delta).$$

Stresses in Suspension Bridges with Pin-Jointed Stiffening Girders. Type (*a*).

Uniform Rolling Load.

With a uniform load over the whole span there is no bending moment on the girders, the whole behaving as an unstiffened suspension bridge.

When the load covers half the span there will be a reverse or negative bending moment on the unloaded girder equal to the positive bending moment on the loaded girder.

$$\text{Maximum negative B.M.} = \frac{wl^2}{64};$$

and occurs at ¼-span.

The maximum positive bending moment at any point distant z from the centre pin, the head of the load being distant $x = \frac{l^2}{2l + z}$ from ditto

$$= \frac{wz(l^2 - z^2)}{2(l + z)}.$$

The absolute maximum positive bending moment $= 0{\cdot}0753\,wl^2$ (or $\frac{wL^2}{53}$ approximately), and occurs when $z = 0{\cdot}53l$, the lead of the load being distant x from the centre pin.

Isolated Rolling Load.

With a concentrated rolling load passing over the girders:—

$$\text{Maximum negative B.M.} = \frac{WL}{16},$$

and occurs at ¼ span.

When the load is on one of the girders the bending moment is a maximum at any point when the load just reaches it.

Maximum B.M. at any point distant y from the centre pin

$$= \frac{Wy}{2L^3}(L^2 - 4y^2).$$

Absolute maximum positive B.M. = 0·096 WL, and occurs when load is 0·289L from the centre pin.

Stresses with Stiffening Girders Hinged at Ends Only. Type (*b*).

In this case the stiffening girders will have to bear considerable stresses due to the increase in dip due to increase in temperature, which may amount to as much as half the safe stresses.

With a uniform rolling load passing over the span—

$$\text{Absolute maximum bending moment} = \frac{wL^2}{54},$$

and occurs at $\frac{1}{3}$-span, when the load covers $\frac{2}{3}$ of span.

The head of the load is always a point of contraflexure of the girder.

Assuming that the positive bending moment is a maximum at the mid point, then:

$$\text{Maximum bending moment in the length covered by the load} = \frac{wx^2(L-x)}{8L},$$

when head of load is distant x from the nearest pin.

In the foregoing:—

w = load in tons per foot run; W = concentrated rolling load in tons; L = length of span in feet; l = length of half span in feet.

Changes of Temperature.

In England the observed expansion of steel structures appears to be about $\frac{1}{4000}$ of their original length from their coldest temperatures. This corresponds to a range of temperatures of 60° F. In suspension bridges, with movable saddles at the tops of the piers, the augmented dip of the central cable is due to increase in length of the anchor cables and consequent movement of the saddles as well as the increase in length of the central cable itself.

Let

l = the half span of central cable; D = central dip; D_1 = augmented dip due to rise in temperature of 60° F.; L = length of semi-parabola measured along curve; then by the properties of the parabola,

$$L = \sqrt{l^2 + \tfrac{4}{3}D^2};$$

and

$$D = 0{\cdot}866\sqrt{L^2 - l^2};$$

therefore

$$D_1 = 0{\cdot}866\sqrt{\left(L + \frac{L}{2400}\right)^2 - l^2}.$$

To this must be added the increased dip due to inward movement of the saddles.

Economic Proportions.

Economy in the weight of a cable can be effected by adopting a liberal depth or dip, but it is impossible in practice to increase the depth beyond a certain amount, because the greater the dip the greater will be the distortion and oscillation caused by a moving load.

In most of the existing examples of suspension bridges of various types, the dip does not exceed $\frac{1}{10}$ of the span, and in many cases $\frac{1}{12}$ to $\frac{1}{16}$ has been adopted.

SECTION VIII

JOINTING BEAMS—TENONS—STRUTTING AND PUGGING—STRENGTH AND STIFFNESS OF BEAMS AND POLES—ROOFS AND ROOFING—FLOORS—JOISTS—FIRE-RESISTING FLOORS—EXPANDED METAL—PARTITIONS—STAIRS

(With Contributions by Alexander Drew, M.I.Mech.E., and Reginald Ryves, A.M.Inst.C.E.)

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SECTION VIII

JOINTING BEAMS—TENONS—STRUTTING AND PUGGING—STRENGTH AND STIFFNESS OF BEAMS AND POLES—ROOFS AND ROOFING — FLOORS — JOISTS — FIRE-RESISTING FLOORS — EXPANDED METAL — PARTITIONS —STAIRS.

JOINTING BEAMS.

Fishing.

To resist Tension.—For lengthening ties a plain fished joint is most economical for labour and material. The two ends of the beams are butted together, and secured on each side by means of bolts, as shown by fig. 414, which shows the fishing of a 6-in. × 4-in. beam with an iron plate on one side and a wooden plate on the other, the bolts being 1 in. in diameter with 1½-in. heads, and the washers 2½ ins. × ¼ in.

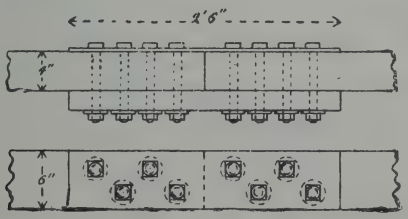

FIG. 414.

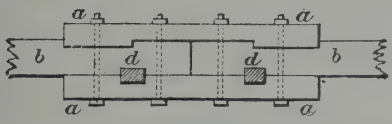

FIG. 415.

Another method is shown by fig. 415.

In this method, in order to relieve the strain on the bolts, the beam is indented or tabled as shown on upper side, or joggles or keys, *d*, *d*, are inserted. In either case the effective area is reduced by the indents or keys. The joint sectional area of the fish-pieces, *a*, *a*, should equal that of the beam, *b*. The joint sectional area of bolts should be at least one-fifth that of timber minus bolt-holes. Bolts are better square than round. Large washers should be under bolt-heads and nuts; for oak the washers should be 2½ times diameter of bolt, and for fir 3½ times.

Scarfing.

To resist Compression (fig. 416).—The bearing surfaces, *e*, *e*, should always be perpendicular to compressing force. Fig. 417 is a more elaborate form.

FIG. 416.

FIG. 417.

The lengths of scarfs should bear the following proportions to the depth :—

Wood.	Without Bolts.	With Bolts.	Bolts and Indents Combined.
Hard wood (oak, ash, elm) . .	6	3	2
Fir and straight-grained woods .	12	8	4

The sum of the depths of the indents should equal $1\frac{1}{2}$ depth of beam.

If assisted by fish-plates, it may be equal to the strength of a simple fished joint, which is as strong as the tie itself, less one rivet hole ; and no advantage is gained by making the joint complicated, but it should be formed similar to that shown by fig. 416.

To resist Tension.—Fig. 418 is often used. It will hold without bolts or straps. At *c* a key or joggle of hard wood is inserted, wedged in so as to tighten the joint moderately ; depth of key

FIG. 418.

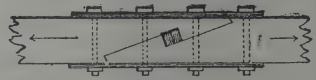

FIG. 419.

one-third depth of beam. This joint has only one-third the strength of solid timber tie ; it may be increased by bolting an iron fish-plate on each side, as in fig. 419.

To resist Compression and Tension.—Fig. 420 is suitable. The wedges at *c* are only required when bolts are to be added, in which case they are used to bring the parts together before the bolts are inserted, in order to prevent violent strains on the latter.

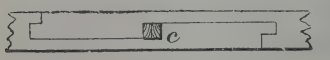

FIG. 420.

To resist Cross Strains.—Fig. 421 is the best. The joint at *a*, being in compression, should be kept square ; the lower, having to resist tension, may be oblique. There should be as great a thickness as possible at *b c*. To resist cross-strain, the scarf is strongest when made vertical, *i.e.*, the pressure in the figure being at right angles to the paper.

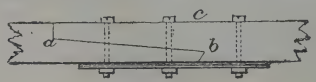

FIG. 421.

FIG. 422.

To resist Cross Strain and Tension.—The resistance to tension is given by indenting the beam and inserting wedges, as shown in fig. 422.

T Joint.

A very effective method of securing two pieces of wood, A and B, at right angles to each other, is to insert in a mortice hole in B a piece of aluminium *a* which has been drilled with a hole into which an ordinary wood screw *s* is forcibly screwed. The aluminium being comparatively soft enables the wood screw to readily work its way through the hole, whilst it forms a nut which enables the screw to be very tightly screwed up.

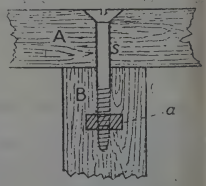

FIG. 422A.

Building-up.

For building-up or joggling beams the method shown by fig. 423 may be adopted. This figure shows a portion of a 9 × 18-inch beam, 22 feet long, formed of two 9 × 9-inch beams secured

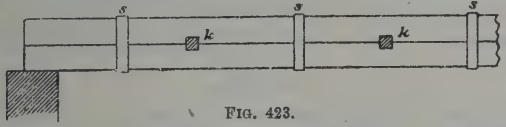

FIG. 423.

by wrought-iron straps, *s*, *s*, *s*, each 2 × $\frac{5}{16}$ inches; keys, *k*, each 2 × 2 inches, prevent the two pieces of which the beam is formed from sliding on one another.

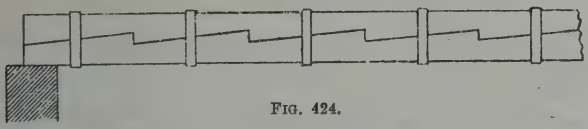

FIG. 424.

Fig. 424 shows a similar beam with the two halves indented the one into the other so as to prevent sliding.

Mortise and Tenon.

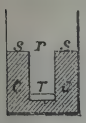

FIG. 425.

Mortising Upright into Horizontal.—The tenon, T (fig. 425), is usually one-third breadth of vertical. The pin-hole, if any, is generally placed at one-third length of tenon from shoulder, *s s*, and its diameter=one-fourth thickness of tenon. The mortise is made a little deeper, so that the shoulder may bear well; *r* is the *root*; C, C are the *abutment cheeks*.

Mortising Horizontal Beams.—The tenon is a projection from the end of the cross-beam, fitting closely into a mortise cut in the side of the main beam. It should be at the middle of its depth, so that the centre of the mortise may be at the neutral axis. Practically its lower edge is generally *on* the neutral axis.

Shouldered or Tusk Tenon.

To keep a cross-beam steady in its position a tenon requires length; to bear its share of load it requires depth; but a tenon long and deep would weaken the main beam too much. To avoid this a shouldered tenon is used. G (fig. 426) is the girder of a floor, B the binding joist, *a* the shoulder, *b* the tenon. The shoulder penetrates the girder about one-sixth depth of joist. Depth of tenon about one-sixth depth of joist; length about twice its depth, or it may be carried right through a thin girder and pinned, as in the case of a trimmer running into a trimming joist. Care should be taken that both tenon and shoulder bear exactly. Tredgold says the tenon should be one-third depth of joist above its lower edge. It should be, however, in the neutral axis.

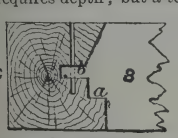

FIG. 426.

Post and Beam Joints.—To frame a horizontal beam into the side of post the 'shouldered tenon' is used, but the long tenon should be on edge or have its narrowest dimensions horizontal.

When the beam rests on the top of the post, a small tenon in centre of post may fit into mortise on the under side of the beam. Or the post may fit into a shallow rectangular notch in beam, the notch being divided into two parts by a *bridle* left uncut in the middle of the notch, about one-fifth breadth of beam.

Wedges.

When the end of the tenon is seen, it is kept tight by driving wedges of hard wood dipped in glue or white-lead between tenons and sides of mortise. When end of tenon is not seen, small wedges, called *fox wedges* (fig. 427), are inserted in saw cuts in end of tenon; when tenon is driven home, they enter and expand it. The mortise is dovetailed or made slightly wider at bottom. This joint, when properly made, has the advantage that the post or style shrinks towards the shoulder and not away from it, and for this reason is sometimes employed for first-class work.

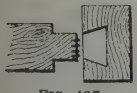

FIG. 427.

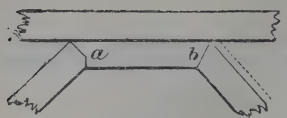

FIG. 428.

Joint of Straining-Beam.

In oblique joints under compression the joint should be either perpendicular to one piece, as at *a* (fig. 428), or bisect the angle, as at *b*; the latter is the best in the case given in the figure. With a thicker strut at *b* it would be as shown by the dotted line.

Joints in carpentry should have white-lead applied with a brush over the surface forming the joint.

Strutting.

Joists laid with boards on top, and lath and plaster underneath, are not found to be sufficient to prevent bending and vibration under pressure. To remedy this, which is injurious to walls and to timber, strutting is placed in straight, continuous rows, at intervals not more than 4 feet apart, which reduces to a great extent the defect.

The following are three methods of strutting :—

Herring-bone Strutting.—This consists of pieces about 2 inches square fixed as shown in fig. 429.

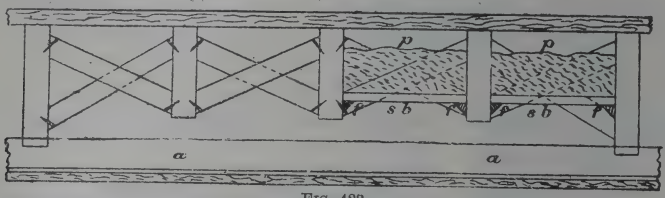

FIG. 429.

It is usual, instead of boring holes for nails, to make a saw cut at ends, and through this channel to drive the nail. By doing this any danger of splitting is avoided. This method has the recommendation that it acts where its leverage to prevent bending is greatest, viz., at the edges of joists, and is used largely in dwelling-houses.

FIG. 430.

Solid Strutting.—1 or 1½-inch boards, nearly the same depth as joists, are cut in tightly, and nailed between joists, as in fig. 430. This method is largely used for floors of factories and heavy buildings; and if cut so that the entire shoulder butts against the joists, is undoubtedly the firmest method; but unless care is exercised, the shoulders are apt to bite on the centre only. Sometimes long bolts, either of round bar or gaspipe, are passed through all the joists, and the strutting squeezed together with the joists and held tightly.

Key Strutting.—In this method struts are tenoned at their ends, and pass through mortises cut in the joists, and are secured with wooden keys. The method is expensive, weakens the joist, and altogether is a defective and unsatisfactory arrangement.

Pugging.

To prevent sound, sound-boarding, *s b* (fig. 429), is supported by fillets, *f*, *f*, cut diagonally out of 2-inch × 1½-inch stuff nailed to bridging joists half-way between floor-boards and ceiling joist, *a*, *a*; over these pugging, *p*, *p*, of coarse plaster about 1½ inch thick is put. Dry moss or a mixture of lime mortar, earth, and smith's ashes, or chopped straw, is sometimes used instead of plaster. Strips of felt are sometimes placed between the joists and boarding to deaden sound.

Strength and Stiffness of Beams and Poles.

b = breadth, *d* = depth, L = span.

Strength of Rectangular Beams.—For fir, safe distributed dead load, in cwts.

$$= \frac{bd^2 \text{ in inches}}{\text{L in feet}}.$$

For cedar and mahogany, about the same load as for fir.

For larch	¾	Above load for fir.
For beech, Dantzic oak	1¼	
For English oak, ash	1½	
For teak	1¾	
For greenheart	2	

This formula gives a theoretical factor of safety of about 8; the practical factor of safety for large scantlings is about 5.

Strength of Circular Poles is $\frac{6}{10}$ strength of square beam, diameter of pole being equal to side of square.

Stiffness of Beams and Poles.—When the beam or pole is loaded with the safe load given above the deflection will be about $\frac{1}{50} \cdot \frac{\text{L}^2 \text{ in feet}}{d \text{ in inches}}$ for fir, oak, mahogany; for teak, about half that for fir.

Deflection of Beams.

In timber beams for permanent purposes, supported or fixed at both ends, the deflection usually allowed is $\frac{1}{360}$ inch per foot run; $\frac{1}{180}$ for those fixed at one end.

$$\text{V} = \frac{n\text{W}c^3}{e\text{I}},$$

where

V = deflection in inches, W = load in pounds, c = length in inches for beams fixed at one end, half length if supported or fixed at both ends; I = moment of inertia, e = modulus of elasticity (page 238)

Description.	Value of n.		
	Uniform Cross Section.	Uniform Strength and Depth.	Uniform Strength and Breadth.
Fixed at one end, loaded at other	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$
" " loaded uniformly	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$
Supported at both ends, loaded in middle	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$
" " loaded uniformly	$\frac{5}{48}$	$\frac{1}{8}$	·1427
Fixed at both ends, loaded in middle	$\frac{1}{24}$		
" " loaded uniformly	$\frac{1}{48}$		

In the case of a beam of uniform strength, fixed at both ends and loaded at a point distant a_1 from one end and a_2 from the other, the deflection at point of application of load is—

$$\text{V} = \frac{(a_1 a_2)^2 \text{W}}{6elc}.$$

The greatest deflection is at a point distant from one end $= a_2 - \sqrt{\frac{1}{3}a_2(a_2 - 2a_1)}$, a_2 being the larger division.

TABLE OF MOMENTS OF INERTIA.

Section of Beam.	I =	Section of Beam.	I =
Rectangular and square	$\frac{bd^3}{12}$	Ellipse, vertical semiaxis a, horizontal c	$\frac{\pi ca^3}{4}$
" hollow, $bd - b_1d_1$, also I-shaped section, where d_1 = depth of hollow parts, b_1 = sum of breadths of hollow parts	$\frac{bd^3 - b_1d_1^3}{12}$	Ellipse, hollow	$\frac{\pi}{4}(ca^3 - c_1a_1^3)$
Circle, radius r	$\frac{\pi}{4}r^4$	Semicircle standing with semicircular part up or down	$\cdot 11r^4$
" hollow	$\frac{\pi}{4} \cdot (r^4 - r_1^4)$	Isosceles triangle, base = b, height = d, standing on either base or apex	$\frac{bd^3}{36}$

All dimensions in inches; $\pi = 3{\cdot}1416$.

ROOFS.

Weight of Components of Roofs.

	Per Square Foot.
Lead covering, including laps, but not boarding or rolls	5½ lbs. to 8½ lbs.
Zinc " " " 14 to 16 zinc gauge	1½ " " 1¾ "
Corrugated iron, galvanised, 16 W.G.	3½ "
" " " 18 W.G.	2½ "
" " " 20 W.G.	2 "
Sheet iron, 16 W.G.	2½ "
" " 20 W.G.	1½ "
Slating laid with a 3-inch lap, including nails but not battens or iron laths :	
Doubles, 13 inches × 6 inches, at 18 cwt. per 1,200	8½ "
Ladies, 16 inches × 8 inches, at 31·5 cwt. per 1,200	8½ "
Countesses, 20 inches × 10 inches, at 50 cwt. per 1,200	8 "
Duchesses, 24 inches × 12 inches, at 77 cwt. per 1,200	8½ "
Tiles, plain, 11 inches × 7 inches, laid with a 3-inch lap, and pointed with mortar, including laths and absorbed rain	18 "
" pan, 13½ inches × 9½ inches, laid to 3-inch lap, and pointed with mortar, including laths and rain	12 "
" Broomhall, laths excluded, rain included	8½ "
" Italian (ridge and furrow), not including the boarding, but including the mortar and absorbed rain	14 "
Slate battens, 3½ inches × 1 inch :	
For doubles	2 "
For countesses	1¼ "
Slate boarding, ¾ inch thick	2¾ "
" " 1 inch thick	3½ "
" " 1¼ inch thick	4¼ "
Wrought-iron laths, angle irons :	
For duchess slates	2 "
For countess slates	1¾ "
Cast-iron plates, ⅜ inch thick	15 "
Thatch, including battens	6½ "
Felt, asphalted	3 "
Rok	½ lb. to ½ lb.
Ruberoid	½ lb. to ½ lb.
Lath-and-plaster ceiling	8 lbs.
Ceiling joists	3 "
Common rafters	3 "
Collar beams	2 "

Framing for wooden roofs, including purlins and ridge boards, but exclusive of tie beams :			
20 feet span, king post, rise one-fourth span	2 lbs. per foot super.		
30 " " " "	2 " " "		
40 " queen post " "	2 " " "		
50 " " " "	3 " " "		
60 " " " "	4 " " "		
Tie beams : 20 feet span, king post	11 lbs. per foot run of tie.		
30 " "	20 " " "		
40 " queen post	18 " " "		
50 " "	20 " " "		
60 " "	30 " " "		

Angles of Roofs for Different Coverings.

Kind of Covering.	Inclination to the Horizon.	Height of Roof in Parts of Span.	Kind of Covering.	Inclination to the Horizon.	Height of Roof in Parts of Span.
	° ′			° ′	
Copper	3 50	1/30	Thin slabs of stone or flags	29 41	2/7
Lead	3 50	1/30	Pantiles	24 0	2/5
Zinc	4 0	1/29	Thatch of straw, &c.	45 0	1/2
Slates, large	22 0	1/6	Plain tiles	45 0	1/2
" ordinary	26 33	1/4	Ruberoid	3 50	1/30
Asphalted felt	3 50	1/30			

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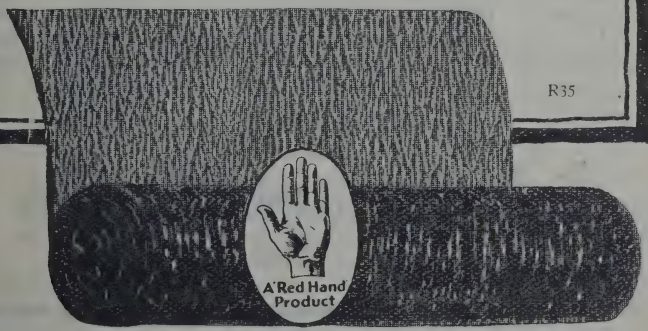

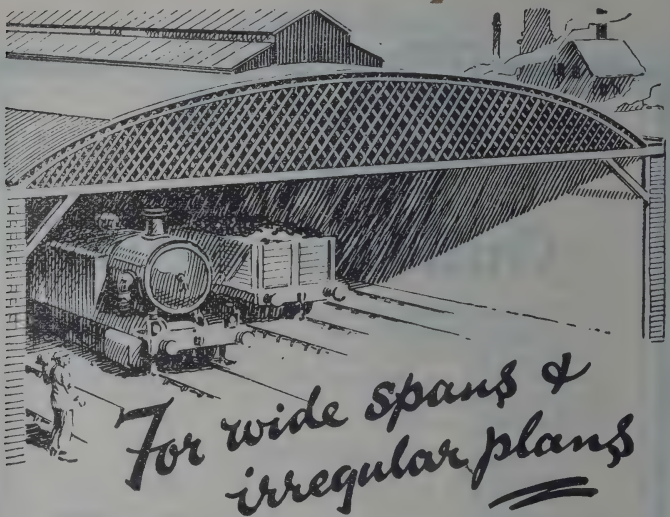

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Plans and estimates for construction and erection, from Mr. K. E. Brace,

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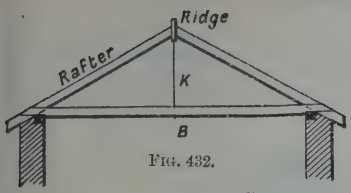


FIG. 432.

Single-span or Couple Roof.

May be used when walls can take the thrust without spreading; when they cannot, insert 4″ × 1″ binders as B (fig. 432), or $\frac{5}{8}$′ iron ties, at about 10′ intervals, supported by a light iron king rod (K).

SCANTLINGS FOR COUPLE ROOFS.

Pitch up to 30°, with countess slates on 1″ boards.

Span.	Rafter.	Ridge Board.	*Ceiling Joist.	Span.	Rafter.	Ridge Board.	*Ceiling Joist.
Feet.	Inches.	Inches	Inches.	Feet.	Inches.	Inches.	Inches.
8	3 × 2	7 × 1½	4 × 2	14	4½ × 2	7 × 1½	7 × 2
10	3½ × 2	7 × 1½	5 × 2	16	5 × 2	8 × 1½	8 × 2
12	4 × 2	7 × 1½	6 × 2	18	5½ × 2	8 × 1½	9 × 2

Collar-beam Roof.

Ceiling carried on under side of rafter and collar; collar best placed half-way up rafter; used for roofs up to 18′ span, under the same conditions as to wind, walls, and ties as given for couple roofs (fig. 433).

The rafters are nailed to ridge-piece and bird's-mouthed over wall-plate, 1′ apart in the clear, or from centre to centre on very exposed sites.

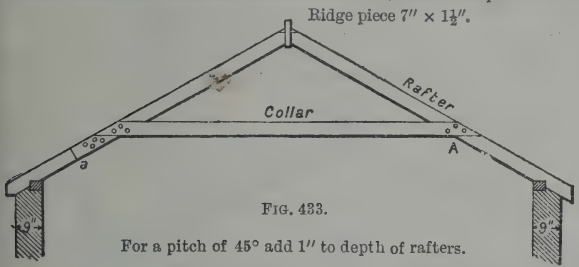


FIG. 433.

For a pitch of 45° add 1″ to depth of rafters.

SCANTLINGS FOR COLLAR-BEAM ROOFS.

Pitch up to 30°. If 45°, add 1″ to depth of rafters.

Span in Feet.	Rafters. For Countess Slates on $\frac{3}{4}$″ Boards, 1′ clear apart, or centre to centre if very exposed Site.				Collars.	
	† Thrust taken by Walls or Ties, Collars ½ way up.		‡ Tied by Collars ½ way up to prevent Walls spreading.		From ¼ to ½ way up.	At any Height.
	No Ceiling.	Ceiled to Collars.	No Ceiling.	Ceiled to Collars.	No Ceiling.	Ceiled to Collars.
	Inches.	Inches.	Inches.	Inches.	Inches.	2″ wide × $\frac{1}{8}$″
8	1½ × 2½	1¾ × 3	2¼ × 3¼	2½ × 3¾	1¾ × 2½	added to $\frac{1}{8}$′
10	1⅝ × 2½	1⅝ × 3	2¼ × 4	2¼ × 4½	2 × 2½	for every foot
12	1⅜ × 2¾	1¾ × 3¼	2¼ × 4½	2½ × 5	2 × 2¾	run of clear
14	1⅝ × 3	1¾ × 3½	2⅜ × 5	2½ × 5½	2 × 3	length of
16	2 × 3½	2 × 3¾	2½ × 5½	2½ × 6	2 × 3½	underside of
18	2 × 3¾	2 × 4¼	2½ × 6	2½ × 6½	2 × 4	collar.

* When used they act as ties, B (fig. 432), but without K. † Halve these collars on to rafters without cutting into latter. ‡ These rafters allow of the tension joint (fig. 434, page 420). If the collar is required halfway up, about one-fourth must be added to both breadth and depth of rafters, and ¾ in. to depth of collars. But with unstable walls, ties are far cheaper, and may be at long intervals if secured to wall-plates of sufficient width to take the thrust between the ties.

Fastenings of Collar-beam Roof.—Collars should never cut into rafters unless acting as ties; even then, the rafter being weakened at its weakest point, it has to be strengthened. If the walls or plates can take the thrust, the collars are struts, and under transverse stress if ceiled. Collar roofs to wooden huts constantly push out the walls, owing to the wall-plate or top sill not being stiff enough. Fig. 434 shows method of fastening collar C to rafter R, when collar acts as a tie,

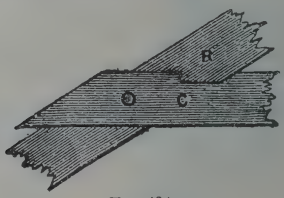


FIG. 434.

and, whether ceiled or not, it is better than a dove-tail; the collar and rafter are both notched about $\frac{1}{2}''$. When collar is a strut it may be halved on, as at A (fig. 433, p. 413); when intended also to be ceiled it should, in addition, rest on a bearer spiked to side of rafter, as at *a* (fig. 433, p. 419), the rafter being uncut in either case. The rafters abut on the ridge, and are nailed to it. They are bird's-mouthed on to wall-plate.

King-Post Roof.

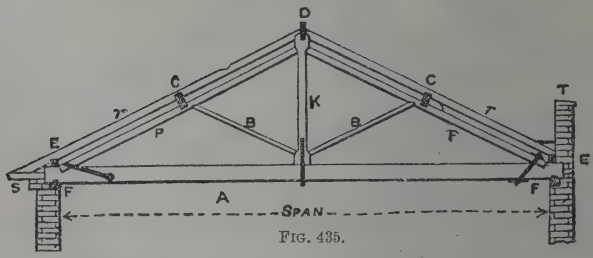


FIG. 435.

Used for spans from 20′ to 30′ (fig. 435).

A, tie-beam; B, braces or struts; C, purlins; D, ridge-board; E, pole-plate; F, wall-plate. K, king post; P, principal rafter; *r*, small or common rafter; S, eaves boarding; T, parapet.

SCANTLINGS FOR KING-POST ROOFS.

Span.	Tie Beam. A.	King Post. K.	Principal Rafters. P.	Braces. B.	Purlins. C.	Common Rafters. *r*.	Ridge. D.	Pole-plate E.
Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
20	$9\frac{1}{2} \times 4$	4×3	4×4	$3\frac{1}{2} \times 2$	$8 \times 4\frac{3}{4}$	$3\frac{1}{2} \times 2$	6×2	4×4
22	$9\frac{1}{2} \times 5$	5×3	5×3	$3\frac{3}{4} \times 2\frac{1}{4}$	$8\frac{1}{2} \times 5$	$3\frac{3}{4} \times 2$	6×2	4×4
24	$10\frac{1}{2} \times 5$	$5 \times 3\frac{1}{2}$	$5 \times 3\frac{1}{2}$	$4 \times 2\frac{1}{2}$	$8\frac{1}{2} \times 5$	4×2	7×2	4×4
26	$11\frac{1}{2} \times 5$	5×4	$5 \times 4\frac{1}{2}$	$4\frac{1}{2} \times 2\frac{1}{2}$	$8\frac{3}{4} \times 5$	$4\frac{1}{2} \times 2$	8×2	4×4
28	$11\frac{1}{2} \times 6$	6×4	$6 \times 3\frac{1}{2}$	$4\frac{1}{2} \times 2\frac{3}{4}$	$8\frac{1}{4} \times 5\frac{1}{2}$	$4\frac{1}{2} \times 2$	8×2	4×4
30	$12\frac{1}{2} \times 6$	$6 \times 4\frac{1}{2}$	6×4	$4\frac{5}{4} \times 3$	$9 \times 5\frac{1}{2}$	$4\frac{3}{4} \times 2$	8×2	4×4

Trusses, 10′ apart; angle of roof, 26° 33′; covering, slate; wood, Baltic pine.

Wall-plates, F, 4″ × 4″ to 5″ × 4″; if the trusses are over openings the wall-plates should be increased.

Queen-Post Roof.

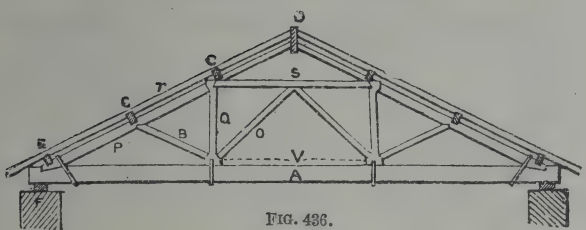


FIG. 436.

Used for spans over 30 and up to 46 feet (fig. 436). The braces, O, are generally omitted, and a straight straining-sill placed at V.

SCANTLINGS FOR QUEEN-POST ROOFS.

Span.	Tie Beam. A.	Queen Posts. Q.	Principal Rafters. P.	Straining Beam. S.	Braces. B.	Purlins. C.	Common Rafters r.	Ridge. D.	Pole-plate. E.
Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
32	10 × 4½	4½ × 4	5 × 4½	6¾ × 4½	3¾ × 2¼	8 × 4¾	3½ × 2	6 × 2	4 × 4
34	10 × 5	5 × 3½	5 × 5	6¾ × 5	4 × 2½	8½ × 5	3¾ × 2	6 × 2	4 × 4
36	10½ × 5	5 × 4•	5 × 5½	7 × 5	4¼ × 2½	8½ × 5	4 × 2	6 × 2	4 × 4
38	10 × 6	6 × 3¾	6 × 6	7¼ × 6	4½ × 2½	8½ × 5	4 × 2	6 × 2	4 × 4
40	11 × 6	6 × 4	6 × 6	8 × 6	4½ × 2½	8½ × 5	4¼ × 2	7 × 2	4 × 4
42	11½ × 6	6 × 4½	6¼ × 6	8¼ × 6	4½ × 2¾	8½ × 5½	4½ × 2	7 × 2	4 × 4
44	12 × 6	6 × 5	6½ × 6	8½ × 6	4½ × 3	9 × 5	4¾ × 2	8 × 2	4 × 4
46	12½ × 6	6 × 5½	7 × 6	9 × 6	4¾ × 3	9 × 5½	5 × 2	8 × 2	4 × 4

Trusses, 10 apart; pitch of roof, 26° 33′, or ½; countess slates; timber, Baltic pine.
Wall-plates, F, 5″ × 4″ to 6″ × 4″; more if trusses are over openings.

Common Rafters.

12″ from centre to centre, or apart if not very exposed site.

Bearing in Feet.	Breadth in Inches.				
	1¾	2	2½	2½	3
	Depth in Inches.	Depth in Inches.	Depth in Inches.	Depth in Inches.	Depth in Inches.
5	3	2⅞	2¾		
6	3½	3½	3¼	3⅜	
8	4¾	4⅝	4⅜	4¼	4
10	6	5¾	5½	5⅜	5
12	7	6¾	6⅝	6⅜	6
14	8½	8	7¾	7½	7
16	9½	9¼	8¾	8½	8
18	10½	10¼	10	9½	9
20	11⅝	11½	11	10½	10

Thin and deep rafters most economical; should not be thinner than 1¾″ to 2″, or may split when boards are nailed to them. For stone or tile covering should be one-third stronger.

Joints of Wooden Roofs.

Joint at Foot of Principal Rafter (fig. 437).—Wood, Northern pine, *i.e.* red fir; rafter, 4″ × 5″; tie, 10″ × 4″; *ad*, 3″; tenon, $\frac{1}{3}$ width of rafter.

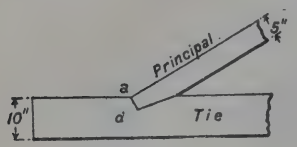


FIG. 437.

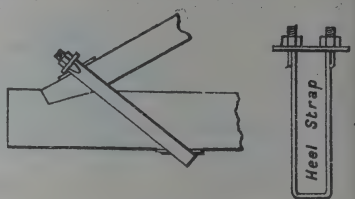


FIG. 438.

Iron Straps to Wood Roofs (fig. 438).—When longest unsupported part of tie beam

= 10 feet, strap should be . . . . . $1\frac{1}{2}'' \times \frac{3}{16}''$;
= 15 feet, " " . . . . . $1\frac{1}{2}'' \times \frac{1}{4}''$;
= 20 feet, " " . . . . . $2'' \times \frac{1}{4}''$.

The straps at the feet of the principal rafters may be of the same section as that for supporting the tie beam; a width less than $1\frac{1}{2}''$ is liable to cut into the fibres of the wood.

The strap in small roofs is generally fixed as shown on left-hand side of fig. 438.

Purlin.—Should be in pieces as long, and as nearly over strut B, as possible (fig. 439). The purlin, C, is notched over principal rafter, P, which is cogged to receive it; notches about 1″×1″. Common rafter, *r*, is notched on to purlin. The strut or brace, B, is tenoned into the principal rafter, P, as shown.

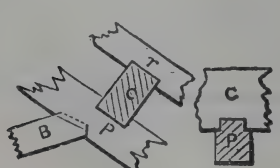


FIG. 439.

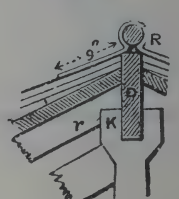


FIG. 440.

FIG. 441.

Ridge Board and Roll.—The ridge board, D (fig. 440), is let into king post, K, as shown. The common rafter, *r*, butts against and is nailed on to ridge board. R shows the ridge roll of wood with lead covering, ridge tiles, or Williams' patent ridge (fig. 441), in two pieces; the ends of the roll butt against each other, and are fixed with white lead, copper dowels, and 2″ copper screws.

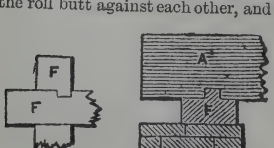


FIG. 442. FIG. 443.

Wall-plate and Tie Beam.—Fig. 442 shows a wall-plate, F, cogged to receive tie beam, A, which should have a clear space round to prevent rotting. A stone template is sometimes substituted for the wall plate.

F, F, shows joint of wall-plates at angles of buildings, an arrangement which is better than a dovetail.

Rafter bird's-mouthed on to wall-plate or pole-plate, &c., spiked or skew-nailed down to it, is shown by fig. 443.

Pole-plate.—Generally rests on end of tie beam (fig. 435, page 420), or on foot of principal, being nailed or notched down. The position, however, depends upon the nature of the eaves.

King Post.—The king post, K (figs. 435 and 444), suspends the tie beam, with attached ceiling, if any, and also the principals, by means of the braces, B.

The principal rafter should abut square on the king post, as P. When head of post is not sufficiently long for this the joint may be made as P¹. The braces, B, should also abut perpendicularly on the king post. The ends of the principal rafters and braces are mortised into the king post.

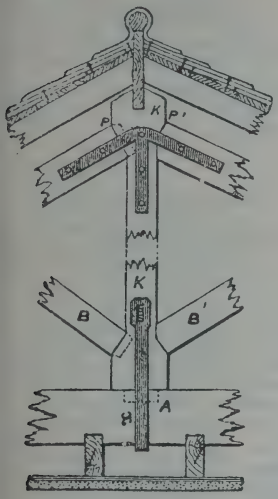


FIG. 444.

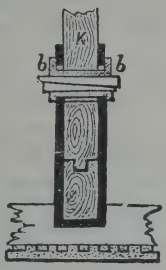


FIG. 445.

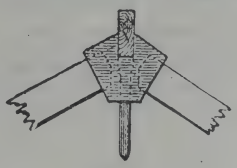


FIG. 446.

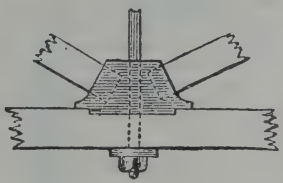


FIG. 447.

The king post is tenoned into the tie beam, A, with a short tenon, and fastened to it by an iron strap or *stirrup* iron. Gibs and cotters, as at *b*, *b* (fig. 445), enable the strap to be raised so as to tighten up the roof.

If a wrought-iron rod is substituted for a king post, its diameter in inches = square root of span of roof in feet × ·02.

Fig. 446 shows cast-iron head to receive rafters, and fig. 447 iron shoe to receive struts; a block of wood is often used for the feet of struts to butt against. When there are no gibs and cotters wedges may be driven in between underside of tie beam and foot of strap to force tie beam against foot of king post.

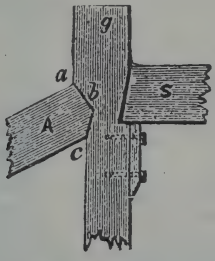


FIG. 448.

Queen Posts.—The abutments of the principal rafter, A, and struts of queen-post roof are the same as for the king-post. Joint of straining beam, S, with queen post, shown in fig. 448. If the head, *g*, of the post is narrow, the end of A should be cut away at an angle, *a b c*, so as to enable it to abut closely against the head; but if the latter is wide enough to admit of it, then the end of A may be cut square. If a wrought-iron rod is substituted for a queen post, diameter in inches = square root of length in feet of that portion of beam supported by queen bolt × ·29.

Pressure of Wind and Weight of Snow on Roofs.

The *Wind Pressure* is usually assumed to be equal to 40 lbs. per foot in cases where the inclination of the roof is 60°; for less angles than this the pressure is taken as follows :—

Inclination	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
Pressure in lbs. per sq. ft.	5·1	9·6	14·2	18·4	22·6	26·5	30·1	33·3	36·0	38·0	39·4	40·0

The *Weight of Snow* in Great Britain varies from 5 to 11 lbs. per cubic foot. It is not likely to accumulate on roofs to a greater depth than 6 inches; 5 lbs. per superficial foot of horizontal surface covered seems a quite sufficient allowance to make.

In Canada and the United States snow has been found in some instances to weigh as much as 30 lbs. per cubic foot some hours after it has fallen, and an allowance of at least 12 lbs. per superficial foot of horizontal surface covered should be allowed for it.

ROOFING MATERIALS.

Heat-Insulating Value of Roofing Materials.*

A National Physical Laboratory test of roofing by measuring the heat lost from a heated room leads to the remarkable conclusion that the rate of emission of heat by radiation from the covering surface has more effect on the inside temperature than the rate of conduction of heat through the material. This result is of importance in the roofing of large factories of a semi-permanent nature, where the temperature depends more upon the covering than in the case of buildings having a closed air space under the roof.

Old galvanised iron allows more heat to pass than glass, a remarkable result. Slates are good, but in proportion heavy. Deal boarding covered with asphalted felt, though thick, is not so heavy as Welsh slate, and is one of the best insulators. In this case its poor conductivity is evidently not negligible, and in all thick roofing materials it is probably of importance.

HEAT TRANSMITTED THROUGH ROOFING MATERIAL EXPOSED TO STRONG RADIATION.

Material.	Rise of Temperature in Testing Chamber Deg. C. per Minute.	British Thermal Units per 100 sq. ft. per Hour.	Thickness in Inches.	Weight in Pounds per Square Foot.
1. Bright galvanised iron sheet .	0·268	111	0·04	1·6
2. Galvanised iron, blackened below	0·40	108	0·04	1·6
3. Galvanised iron, blackened above	0·93	385	0·04	1·6
4. Galvanised iron, blackened above and below	1·40	581	0·04	1·6
5. Galvanised corrugated iron after one month's exposure to the weather	0·75	310	0·033	1·28
6. Do. one year	1·02	422	0·033	1·28
7. (6) painted black above . .	1·13	472	0·033	1·28
8. Roofing glass, serrated . . .	1·10	453	0·22	2·25
9. Welsh slate	0·81	337	0·17	2·9
10. Westmoreland slate	0·60	248	0·25	4·8
11. ¾-in. T.G. deal covered with asphalted felt	0·30	124	1·0	2·6
12. Corrugated fibrocement after one month in use	0·78	325	0·2	1·8
13. Do. after one year in use . .	0·80	334	0·2	1·8
14. Do. painted dead black . . .	0·82	341	0·2	1·8
15. Do. 'aluminium-finished' outside	0·50	207	0·2	1·8
16. Do. laid on top of thin asphalted felt	0 51	211	0·25	2·0

A suggestion was made in the National Physical Laboratory Report that air spaces in roofing materials might be advantageous. A satisfactory means of doing this is to lay corrugated asbestos cement plates on the thinnest asphalted felt or other light sheet material supported by the roof frames. The effect of this is shown by the table to be equal to that of an aluminium surface, and where heat insulation and lightness are of the first importance a strong and efficient roofing can be made in this way at a reasonable cost.

* W. M. Thornton, D.Sc., D.Eng., Armstrong College, Newcastle-on-Tyne; *Engineering*, October 19, 1917.

Permanence

Roofing with Everite is roofing with economy. Everite sheets can be erected over an exceptionally light substructure. They do not deteriorate, cannot corrode and are non-conductors of heat and cold. Everite is a combination of Asbestos and Cement which is impervious to moisture, requires no preservative treatment and is highly resistant to fire.

Bell's Poilite and Everite Co. Ltd.

Asbestos House, Southwark Street, London, S.E.1

29 Peter Street, Manchester

Everite Corrugated sheets are readily cut and easily handled. They can be fixed to steel angles or timber purlins. The 1½ corrugations sidelap gives the same effective cover as the two corrugations sidelap required with ordinary Asbestos-Cement sheets, and allows a saving of 7% in material.

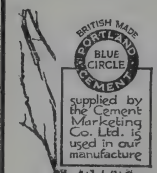
Ask for particulars of the strongest Asbestos Cement sheet in the world—'Everite Big Six.'

EVERITE

Bell's Asbestos-Cement

CORRUGATED SHEETS

40-118



Durable - Economical and Artistic - - -

Poilite is a high grade Asbestos-cement material produced in slates, tiles and flat sheets. Its light weight reduces cost of substructure and effects substantial economy in labour. It is resistant to fire, rot, vermin and extremes of temperature. Poilite requires no maintenance and its strength increases with age.

Flat Sheets for Walls and Ceilings.

Poilite flat sheets are readily adapted to cavity construction. Poilite walls can be quickly erected and distempered or enamelled after priming. Poilite ceilings do not crack nor buckle and are unaffected by vibration, damp, heat or cold. Standard sizes 8′×4,′ 6′×4′, 4′×4′ by $\frac{5}{32}$″ thick and upwards

Tiles for Roofing.

Poilite for roofing is produced as rectangular slates and diagonal tiles, Roman type tiles and artistic russet brown Pantiles. Poilite tiles are lighter than natural slates and less costly. They harden with exposure and are unaffected by heat or frost.

Bell's Poilite and Everite Co. Ltd.,

Asbestos House

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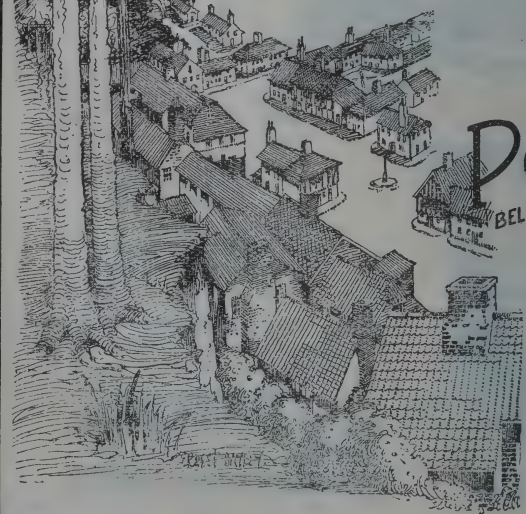

Poilite

BELL'S ASBESTOS-CEMENT

The Famous Poilite & Everite Products are:

Corrugated Sheets (Big-six)
Decorated Poilite
Rectangular Slates
Pantiles
Diagonal Tiles
Flat Sheets
Roman Type Tiles
Rubber Floor Tiles
Gas Flues & Fittings
Rainwater Goods
Ridgings, Etc. Etc.

Not for an age, but for all time

40-62

'Poilite.'

(Bell's Poilite & Everite Company, Ltd., Southwark St. London, and Peter St., Manchester.)

'Poilite' is a tough, weather-proof, fire-safe, and permanent material, the constituents of which are British Portland cement and asbestos, the latter being employed in its fiberised form, known as 'mineral flax,' serving the purpose of an aggregate, thereby increasing the initial strength of the cement tenfold.

'Poilite' is produced in specially designed rolling mills, in the form of layers or films of cement and asbestos uniformly distributed and interlaced so as to constitute a species of tough woven fabric. The layers adhere so firmly to each other that, after reaching the mature stage, a 'Poilite' asbestos cement sheet is found on fracture to be void of all stratification or lamination. The fibre not only gives the product a pre-eminent degree of incombustibility, resiliency, and durability in varying conditions of climate, but also gives great resistance to transverse mechanical and tensile stresses, which increases in ratio with its age.

Tensile strength is 5,973 lbs. per sq. in.; crushing is 7,000 lbs. per sq. in. It is impervious to all atmospheric conditions, age, or decay, is non-corrosive, and requires no preservative treatment at any time.

'Everite' Corrugated Sheeting.

The sheets are light for transport and fixing and reduce cost of sub-structure, require no painting or other treatment, improve with age, are not affected by atmospheric changes, and, therefore, ensure equable temperature of the interior, proof against fire and water.

'*Bigsix Everite*' is claimed to be the strongest asbestos-cement corrugated sheet. When placed on purlins at 4 ft. centres it has been found to support thirteen men without deflection. Its thickness of $\frac{5}{16}$ in. gives the advantage of improved insulation from external climatic conditions, and the storm-proof half corrugation side lap of 2 ins. only of material eliminates any necessity for providing against expansion and contraction of the roof structure.

The sheets are manufactured in successive 6-in. lengths, up to 10 ft. long; standard width, 41½ ins.; reputed thickness, $\frac{5}{16}$ in.; purlin spacing up to 4 ft. 6 in. centres; end lap, 6 ins.; side lap, 2 ins.; number of corrugations per sheet, 7½ ins.; pitch of corrugations, 5¾ ins.; depth of corrugations, 2 ins. Actual cover of an 8-ft. sheet as laid, 7 ft. 6 ins. by 3 ft. 3½ ins.—*i.e.* 24·69 sq. ft. Weight of 100 sq. ft. of finished roofing with fixing accessories is about 350 lbs.—*i.e.* about 3½ lbs. per sq. ft.

Special close nesting adjustable ridging is supplied for use with this material, as also apron pieces, barge boards, ridge ends, corner pieces, etc.

'*Standard Everite.*'—This is manufactured in successive 6-in. lengths up to 10 ft. long. Standard width, 30 ins.; reputed thickness, ¼ in.; number of corrugations, 10½ per sheet; pitch of corrugations, 2⅞ ins.; horizontal lap, 6 ins. for roofs of ordinary pitch, say 30° or over; side lap, 4¼ ins. (1½ corrugations). Actual cover of 10 ft. sheet, 9 ft. 6 ins. by 2 ft. 2 ins., or say 20½ sq. ft.; 13½ sq. yds. of sheeting sufficient to cover 100 sq. ft. of roofing. Weight per sq. yd. of sheeting about 19 lbs. Weight per 100 sq. ft. of roofing about 256 lbs.

Sheets are so designed that 1½ corrugations side lap give the effective covering of 2 corrugations; this makes a 7 per cent. saving in the amount of material required.

Sheets up to 10 ft. by 2 ft. 6 ins., or up to 8 ft. by 3 ft. 7½ ins.

'Poilite' Straight Cover Slating.

The slates can be supplied either with or without the chamfered corners, and, when laid, their appearance is equal to the best North Wales or Westmorland slates.

Slates 24 ins. by 12 ins. are made in grey, blue, red, or russet-brown colours. Slates 15¾ ins. by 15¾ ins. or 15¾ ins. by 7¾ ins. can be supplied.

'Poilite' Pantiles.

The tiles 15¾ ins. by 13¼ ins. (actual cover of 11¾ ins. by 11⅜ ins.), are light for transport and fixing, and reduce cost of sub-structure, are rapidly fixed, improve with age, and are not affected by atmospheric changes.

Number of tiles required per square, net, is 108, but, including eaves and cuttings, 111 to 113.

Weight of tiles per 1,000, about 29 cwt.

These tiles are made in grey and russet-brown colours.

'Poilite' Standard Tiles.

Poilite tiles for diagonal fixing (available in red, blue, grey, and russet-brown colours), size 15¾ ins. by 15¾ ins. are made in two varieties, viz. the Standard (or C4) pattern and the Honeycomb (or F5) pattern. The former, when laid, shows diagonal lines on the roof, while the latter, owing to the lower point being cut off, produces a design of honeycomb form.

'Poilite' Roman Tiles.

'Poilite' tiles, Roman type, 4 ft. by 1 ft. 8¼ ins., are made in grey, red, and russet-brown colours.

Glazed tiles can be supplied for use with Poilite Roman tiles.

'Poilite' Flat Sheets.

For outside work an excellent effect of old half-timber work and plaster can be obtained by the use of these sheets and creosoted boards for covering the joint. If preferred, the rough side of the sheet can be fixed to show. It is quite as impervious as the smooth side.

For inside work the joint can be covered with a wood moulding, thereby forming panelling to taste, which can be decorated with paper, paint, or distemper immediately after it has been primed with a suitable priming.

The sheets are available in the following sizes (from $\frac{5}{32}$ in. thick upwards): 8 ft. by 4 ft. 6 ft. by 4 ft., 4 ft. by 4 ft., 6 ft. by 3 ft., 4 ft. by 3 ft.

Sheets $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick are recommended for internal linings, but for external work $\frac{1}{4}$ in. or $\frac{3}{8}$ in. sheeting should be used.

For lining ceilings, sheets 4 ft. by 4 ft. by $\frac{3}{16}$ in. are most suitable and easily handled.

'Poilite' Louvres.

'Poilite' louvres can be drilled ready for attaching to upright standards with bolts or screws and for an efficient fixing these standards, of either metal or wood, should be arranged at the junction of each length of louvre and should support same both inside and out. Alternatively, the louvres may be bolted to cleats in the sides of standards at each end of the louvre length, or a third method fixing sometimes adopted is to cut a notch with a saw in the corner of the louvre, which is then slipped into a slot in the timber uprights.

Supplied in 4-ft. lengths (standard section).

'Poilite' Wall Tiling.

'Poilite' wall tiling is available in all grey, all red, or checker pattern red and grey, and is supplied in 2-ft. squares of 16 tiles each.

The squares are easily applied to plaster, brick, or breeze walls by simply nailing direct, or to suitably spaced battens.

The nails are afterwards hidden by pointing the joints between the tiles with cement.

'Fibrent' Asbestos-Cement.

(The British Fibrocement Works, Erith, Kent.)

'Fibrent,' the registered trade mark for asbestos-cement sheets and slates, sometimes termed Fibrocement, is a form of concrete or reinforced cement, the mineral fibres fulfilling this function of reinforcement, and the highest grade British Portland cement and specially selected asbestos fibre only being used for the purpose.

'Fibrent' Asbestos-Cement Slates.

These slates are manufactured in straight, diagonal, or honeycomb patterns, 15¾ ins. by 7⅞ ins., 12 ins. by 12 ins., 15¾ ins. by 15¾ ins., 24 ins. by 12 ins., and 24 ins. by 24 ins., cut and holed for various laps as required.

By exposure to climatic extremes the slates become absolutely impervious. They are non-conductive of heat or cold, fire resisting to the highest degree, of extreme durability, and possessing considerable elasticity are immune from cracking or scaling under frost or extremes of temperature.

'Fibrent' slates are extremely light, weighing when fixed about 20 lbs. to the square yard, thus great economy may be effected in general roof construction, rafters being spaced at a minimum of 24 ins. to maximum 30 ins. They may be fixed direct to light battens or rough boarding by means of two nails and a copper disc rivet, and, invariably, a perfectly satisfactory, inexpensive, and effective roof covering is the result. 'Fibrent' has been used upon a number of modern factories where slating is the roof covering with very satisfactory results.

'Fibrent' Ladies' Countess and Duchess Slates.

Sizes 15¾ ins. by 7⅞ ins., 20 ins. by 10 ins., and 24 ins. by 12 ins. are fixed for straight cover similar to ordinary natural slates; they can be used with satisfactory results for all classes of private dwelling houses, the cost of up-keep being reduced to a minimum. A guarantee against disintegration is given for a period of twenty years, that is to say at the end of twenty years there will be no signs of disintegration.

'Fibrent' slates are manufactured in colours of grey, red, purple, blue-black, and antique brown.

'Fibrent' Fibrotiles

(Registered Patent, No. 200,703).

Have been designed to obviate many difficulties which have been experienced in fixing asbestos-cement tiles of other patterns; they are specially adapted for roof construction of all buildings in connection with commercial, railway, agricultural work, etc. The tiles are manufactured in lengths up to 8 ft., rising by increments of 6 ins., by 3 ft. 10 ins. wide, $\frac{5}{32}$ in. thickness, each tile having five corrugations spaced at 9½-in. centres.

'Fibrent' Corrugated Asbestos-Cement Sheets

Combine the advantages of corrugated metallic roofing in point of economy, and in addition they are non-conductive, fire-resisting, practically everlasting in their original form, and require no treatment for preservation purposes, etc.

'Fibrent' corrugated sheets are manufactured in lengths of 10 ft., rising by increments of 6 ins., 2 ft. 6 ins. and 2 ft. 7½ ins. wide, 3-in. corrugations, ¼ in. thickness.

BRITISH FIBROCEMENT WORKS

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ASBESTOS-CEMENT

for Roofs, Walls, Partitions, Ceilings, etc.

STANDARD CORRUGATED SHEETS

Sizes 4′ to 10′. Width 30″ & 31½″.
¼″ thick. Fibro Supers 4′ to 10′
Width 45″, $\frac{9}{32}$″ thickness.
Straight or Curved to any Radius.

ROOFING TILES

15¾″×15¾″, 24″×24″
Ladies 15¾″×7⅞″
Countess 20″×10″
Duchess 24″×12″

FLAT SHEETS

8′×4′, 4′×4′, 6′×3′
Thickness $\frac{5}{32}$″, $\frac{3}{16}$″, ¼″ etc.

Panel Sheets for Internal Decorative Work.

Regd. Patent 'FIBROTILES' *Sizes up to* 8′×3′ 10″ *wide,* $\frac{3}{32}$″ *thickness*
for greater Economy in Roofing,
Non-Conductive, Indestructible, Everlasting.
Specify 'FIBRENT.'

Manufacturers of H.P. Jointings, Asbestos Millboard Boiler Coverings, Yarns, etc., and 'Fibrent' Brake Linings.

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ALL ROOFS
Should be Roofed with RUBEROID

The evidence in support of such a strong claim is in Ruberoid's remarkable 30-year record of roofing service in all climates. It is entirely satisfactory through dry and wet seasons. Ruberoid is suitable for all types of roof surfaces—flat, curved or pitched. It is supplied in two permanent colours, grey and red. Time—sun—water—insect—and fume proof.

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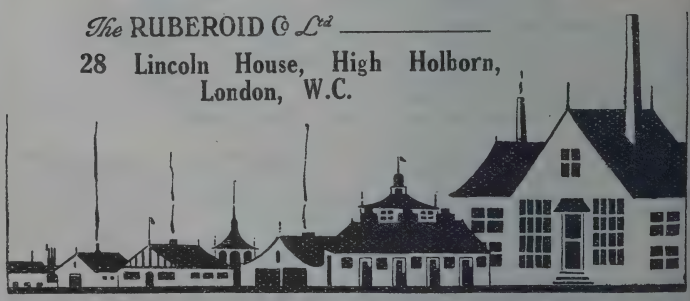


F. 427

'Fibro' Supers Corrugated Sheets

'Fibrent' corrugated sheets are manufactured in lengths of 10 in. rising by increments of 6 ins., 2 ft. 6 ins., and 2 ft. 7½ ins. wide, comprising nine 3 ft. corrugations, and ¼ in. thickness. The 2 ft. 7½ in. wide sheets allow for a 1½ corrugation vertical lap, giving covering capacity in width of each sheet of 2 ft. 3 ins.

'Fibro Supers' corrugated sheets give all the advantages of 'Fibrent' asbestos cement materials. They are the largest and strongest asbestos cement corrugated sheets manufactured, embodying new features by their method of construction, fulfilling all the requirements of a satisfactory roofing material, being also used with equal success for sides and ends of buildings.

'Fibro Supers' patent ridge and eave sheet supplied in conjunction with 'Fibro Supers' allow no space between the gutter and the sheeting, thus allowing free fall of water from roof into gutter, and give a well-secured fixture at the ridge, eliminating the chance of percolation in large span roofs through any blowing back of water.

'Fibro Supers' patent eave sheets besides the great advantage of their use at the ridge and eaves, can also be used over glazing, thus sealing the open corrugations.

Close fitting ridging, apron pieces, barge boards, corner sections, and cap finials are supplied in conjunction with 'Fibro Supers' to complete and give an adequate finish to all types of buildings.

'Fibrent' Flat Sheets

Have the same advantages claimed for the slates and corrugated sheets, but are not so heavily compressed. The sheets are used for both external and internal walls, partitions, and ceilings. The standard sizes of 'Fibrent' flat sheets are 8 ft. by 4 ins., 6 ft. by 4 ins., 6 ft. by 3 ft., and 4 ft. by 4 ft., in thicknesses varying from $\frac{5}{32}$ in. to ½ in.; ¼ in. thickness sheets are generally used for external walls, $\frac{3}{16}$ in. thickness for internal, and $\frac{5}{32}$ in. thickness for ceilings. 'Fibrent' asbestos-cement flat sheets can be cut to requisite sizes by means of a good hand saw at the time of fixing, and, in consequence, waste is obviated. For panel effect, covered strips in required widths and thicknesses are obtainable, and when fixed the sheets can be distempered, enamelled, papered, or grained, after application of concentrated size, thus producing effects which are obtainable with other methods of forming partitions and ceilings. If fixed to timber studding, the supports are spaced at not more than 2-ft. centres.

'Fibrent' Panel Sheets

Have the same advantages and qualities as 'Fibrent' asbestos-cement flat sheets, and give a very artistic finish for any interior work for which they may be required. The extra advantage of 'Fibrent' panel sheets is that the use of a covered strip of the joints is obviated, the rib overlapping the panel by 1 in. These sheets are also embossed with the reproduction of a timber grain, and if waxed and polished giving an effective interior decoration.

'Fibrent' panel sheets can be supplied at any length up to 8 ft. by 4 ft., ½ in. wide, each sheet containing five ribs 3 ins. wide. The sheets are manufactured in thicknesses of $\frac{3}{16}$ in. and ¼ in.

Ruberoid Roofing.

(Ruberoid Co. Ltd., Lincoln House, High Holborn, London, W.C. 1.)

Ruberoid, an exceptionally light material (made in England and used generally throughout the world for over 30 years), weighing only ¼ to ½ lb. per sq. ft., is manufactured in rolls 36 ins. wide, 2 ft. long, containing sufficient material to cover 2 squares. On pitched roofs the Ruberoid is laid from ridge to eaves on wood sheathing boards, which should be close butted. The arris at ridges and hips should be slightly rounded. The strips of Ruberoid are joined by lapping at the seams at least 2 ins. (fig. 469), well coating with Ruberoid cement between the laps and nailing to the boards down centre of each seam, spacing the nails 2 ins. apart. The nail heads and seams are further protected by being painted with Ruberoid cement.

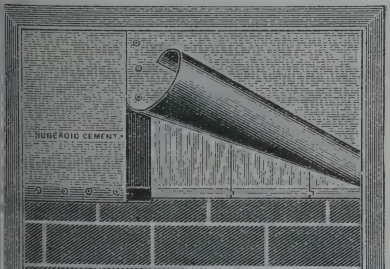


Fig. 469.

On flat roofs of wood the same method is employed. No drips or rolls are needed. Roofs should fall 2 ins. in 10 ft. to allow drainage. Ruberoid can be flashed to parapet walls in the same manner as lead, and box gutters, cesspools and outlets lined with it.

Flat concrete roofs are waterproofed with one or two layers of Ruberoid cemented to the surface of the concrete with Ruberoid compound; the joints in this case are lapped 3 inches. This method of waterproofing is also largely used for cracked concrete and asphalt roofs.

A Ruberoid roof being airtight, proper ventilation should be provided at the highest point.

As it is easily laid in position and is unaffected by moist heat it is largely used in tropical countries, particularly on the West Coast of Africa, in India, and South Africa.

Paint does not adhere well to it, and it should not be tarred; if desired it can be coated with Ruberine roof paint, which is made in three colours, red, green, and black. Ruberoid, being acid and alkali proof, can be safely used on chemical works and other places where it is subjected to fumes, as well as on the sea-coast.

Price of Standard Ruberoid Roofing per roll, to cover 200 sq. ft. of roof, including accessories:—

½-ply Grey . 21*s.* 6*d.* per roll.	1-ply Red . 28*s.* 0*d.* per roll.	2-ply Grey . 32*s.* 8*d.* per roll
1-ply „ . 26*s.* 8*d.* „ „	2-ply Red . 35*s.* 0*d.* „ „	3-ply „ . 39*s.* 2*d.* „ „

The manufacturers, *The Ruberoid Co. Ltd.*, Lincoln House, High Holborn, London, W.C. 1 quote prices on application, fixed complete in any part of the United Kingdom.

'Ruberoid' roofing is supplied in rolls of 72 ft. by 3 ft. wide, in the following grades, per roll:—

½-ply, 45 lbs.; 1-ply, 60 lbs.; 2-ply, 85 lbs.; 3-ply, 100 lbs.; 1-ply red, 60 lbs.; 2-ply red 85 lbs.

Approximate number of super ft. of roof which can be covered with one ton:—

½-ply, 9,400; 1-ply, 7,100; 2-ply, 5,300; 3-ply, 4,280; red, 5,000.

'Rok' Roofing.

(D. Anderson & Son, Ltd., Park Works, Stretford, Manchester; Roach Road, Bow, London, E., and Lagan Works, Belfast.)

'Rok' roofing forms a permanent and easily applied roof covering. Only the highest grade of wool felt is used in its manufacture. This is saturated with an elastic water-proofing compound which does not dry out or evaporate in any climate, as it contains no oils, or volatile matter. The coating on the surface is a permanent one, composed of a natural bitumen of very high melting point. There is nothing of an organic nature in either the saturating or coating compound. It is acid and alkali proof and not affected by white ants. It is suitable for pitched, flat, or circular ('Belfast') roofs, and for reinforced concrete roofs it will be found to make a thoroughly water-tight job.

Rain water from roofs covered with it can be used for domestic purposes.

Being an excellent non-conductor, it ensures an even temperature, and is therefore an ideal roofing for hot climates.

It is laid on close jointed boarding, which should not be less than ¾ in. thick, either plain edged or tongued and grooved. The purlins or rafters should be so spaced that there is no appreciable spring in the boarding.

It may be fixed either longitudinally from gable to gable, or vertically from eaves to eaves. It is, however, considered advisable to lay it crosswise to the boarding. The joints should be formed with at least 2 ins. overlap, being stuck together with 'Rok' cement and carefully nailed with tacks not more than 2 ins. apart placed in the centre of the seams. The heads of the tacks where exposed and the outside of the seams should be dressed with 'Rok' cement.

'Rok' roofing is supplied in rolls of 72 ft. by 3 ft. wide, in the following grades:—

½-ply average weight, 50 lbs. per roll, 21/6 per roll 2-ply average weight, 82 lbs. per roll, 30/- per roll
1-ply „ 62 „ 24/6 „ 3-ply „ 102 „ 36/- „

(The above weights do not include the nails and cements.)

The prices include the supplying of special galvanised broad-headed nails and liquid cement for fixing.

Sufficient tacks and cement to fix the roofing are supplied free by the manufacturers with each roll. Each roll, if carefully laid, should cover 200 sq. ft.

The manufacturers will undertake to carry out the fixing if desired.

'Rok' roofing may also be used on concrete, fixed with special 'Rok' mastic, and it is advisable to write the manufacturers for full directions as to the method of applying.

It may also be used for covering flats and gutters. In this case it is recommended to use two layers, the first layer being tacked to the boarding, and the top layer stuck to the under on with 'Rok' mastic. In this way no nail heads are exposed. Flashings to walls, round lights etc., may be made in the material.

Mineral Surfaced Rok Roofing.

'Mineral Surfaced Rok' is a new variety of roofing specially produced for use on dwelling-houses and other buildings where a more attractive appearance is desired than that of the usual bitumen roofings. It is made of similar materials to 'Rok,' and is of the same high quality in every respect, but the surface is covered with crushed minerals, in either red or green natural unfading colours. These minerals are firmly embedded in the surface of this roofing, which is quite as attractive in appearance as are slates or tiles, with the advantage that there is no possibility of breaking or cracking, and that no wind or water can ever penetrate to the interior. Mineral-surfaced 'Rok' is, in fact, storm-proof.

Supplied in rolls 12 yds. by 1 yd., sufficient to cover 100 sq. ft. Weight 85 lbs. per 100 sq. ft., *i.e.* about ¾-lb. per sq. ft. Price, including nails and cement, red or green, 22*s.* 6*d.* per roll.

'Italit' Corrugated Asbestos-Cement Roofing.

(*Eternit Pietra Artificiale (London), Ltd., Norfolk House, Laurence Pountney Hill, London, E.C.4.*)

'Italit' corrugated sheets are made in lengths of 4 ft. 0 in. to 8 ft. 0 in., rising by even 6-in. lengths. Greater lengths up to 10 ft. can be supplied in Superstrong and Standard only to special order. The sheets are 3 ft. 2 ins. wide and provide a cover of 3 ft. 0 in. to the weather as laid. The corrugations have a pitch of 6 ins. and a depth of 2 ins., providing 6½ corrugations per sheet. Side lap, 2 ins. wide, as illustrated in fig. 470.

The following show details:

	Superstrong.	Standard.	Lightweight.
Thickness of sheet . . .	¼ in. to $\frac{8}{32}$ in.	$\frac{7}{32}$ in. reputed	$\frac{3}{16}$ in. reputed
Minimum end lap . . .	6 ins.	4¼ ins.	4¼ ins.
Weight allowance per square foot	3·25 lbs.	2·60 lbs.	2·20 lbs.

'Italit' corrugated sheets are available in (natural) grey and red colours.

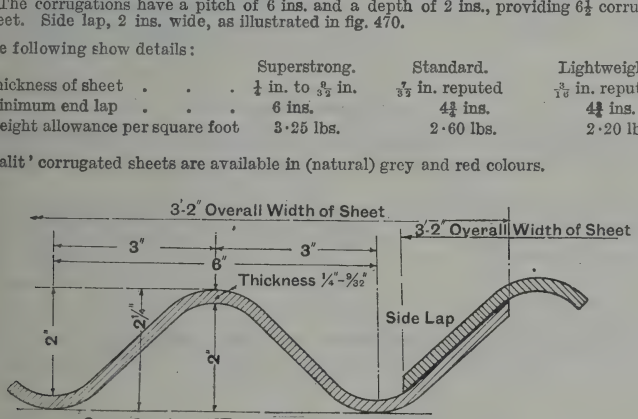


FIG. 470.

Purlin Spacings.

For roofs having a rise of 4 ins. or more, per ft., the following indicates the relationship between the sheets and spans of purlins, based upon a uniformly distributed load not exceeding 80 lbs. per sq. ft. of roof area:

Lightweight—$\frac{3}{16}$ in. thick, for spans up to 3 ft. 0 in.
Standard—$\frac{7}{32}$ in. reputed, for spans up to 4 ft. 0 in.
Superstrong—¼ in. to $\frac{8}{32}$ in., for spans up to 5 ft. 0 in.

These distances are of necessity conservative, and dependent upon the location and nature of the structure, the prevalence or otherwise of high winds, snow loads, and other contingencies. In practice, they are frequently exceeded by as much as 25 per cent.

Side Rail Spacings.

While the spacing of side rails varies with the nature and class of the structure, 'Italit' corrugated sheets for vertical work may be fixed to side rails or supports spaced at distances up to 25 per cent. in excess of the minimum purlin spacing indicated for roofs.

Ridging and Flashings.

Ridges—Corrugated Ridges 3 ft. 6 ins. provide a cover of 3 ft. 0 in. as laid.
Adjustable Interlocking Ridges to closely fit any pitch of roof are supplied in pairs and provide a cover of 3 ft. 0 in. as laid.
Flashings—Apron Flashings 3 ft. 3 ins. long. Stop End Flashings, Side Wall Flashings, Corner Flashings, and Barge Boards are available.

FLOORS

Single-joisted Floor.

Fig. 471 shows a single set of bearers, *b*, called common or bridging joists, to which ceiling joists, *a*, are attached when desired. The ceiling is more liable to crack with a single than with a double floor, but this may be obviated by making every third or fourth joist deeper, and fastening the ceiling to them only. The ceiling joists are notched, and nailed to the joists *b*.

FIG. 471.

This is the strongest and cheapest floor, the maximum strength to be got from a wooden, untrussed floor being with deep tingle joists placed close together, and such a floor with a plaster ceiling below is fire resisting.

Double Floor.

Figs. 472, 473, show a double set of bearers, *i.e.*, binding joists or binders, *d*, and bridging joists, *b*. The binders are the chief supports of the floor, and are generally about 6′ apart. The bridging joists are notched over them, and any ceiling joists, *a*, under them. The bridging as well as the ceiling joists can be framed between the binders, or supported by fillets spiked to their sides when it is required to reduce the depth of the floor. The binders rest on stone templates.

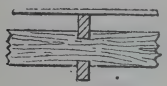


FIG. 472.

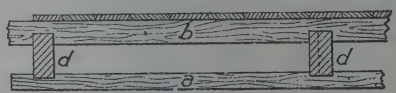


FIG. 473.

Framed Floors

differ from double floors only in having the binders framed into a third set of bearers, called girders.
The girders, *a* (fig. 474), are the chief support; the binding joists, *d*, are tusk-tenoned into them (fig. 426, page 409); the latter support the bridging joists, *b*, and ceiling joists, *c*. The

FIG. 474.

girders should not be more than 8′ to 10′ apart. When the breadth of a girder is considerable it is sometimes sawn down the middle, reversed, and bolted together with sawn sides outward slips being placed between to allow air to circulate freely. This allows centre of balk to be examined, and is less liable to rot; it slightly diminishes strength of girder. Such girders are sometimes strengthened by wrought-iron flitches bolted in between the two halves.

The ends of girders should be on stone templates (fig. 475), and should have a space round them to prevent decay.

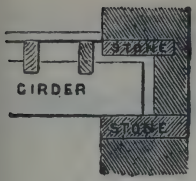


FIG. 475.

Camber of Joists.

Floors, when first framed, should always be kept about $\frac{3}{4}''$ higher in the middle than at the sides of a room; also the ceiling joists should be fixed about $\frac{3}{4}''$ in 20′ higher in the middle than at the sides of room. If laid level they are sure to sag when used.

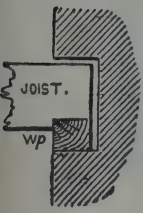


FIG. 476.

Wall-plates for Floors.

On ground-floor generally placed on offset. May be let into wall, care being taken that free space is left round end of joists or girders, as in fig. 476; but, as the wall-plate is perishable, the effective strength of the wall is reduced by the width of the plates. They should, if possible, rest on stone corbels or brick corbel courses. The joists are usually only nailed to the wall-plates, but sometimes notched (fig. 476) or cogged; the latter is quite unnecessary.

For 20′ bearing, wall-plate is $4\frac{1}{2}'' \times 3''$; for 30′ bearing, $6'' \times 4''$; for 40′, $7\frac{1}{2}'' \times 5''$.

(*Tredgold.*)

Wooden Girders for Floors,

10 feet from centre to centre.

b = breadth; d = depth, in inches; L = length, in feet.

$$d = \sqrt[3]{\frac{L^2}{b}} \times 4{\cdot}2 \text{ for fir; by } 4{\cdot}34 \text{ for oak.} \qquad b = \frac{L^2}{d^3} \times 74 \text{ for fir; by } 82 \text{ for oak.}$$

To obtain maximum stiffness make $b = \frac{1}{5}d$.

Girders of Wood with Wrought-iron Flitches.—The wood and iron of these girders bend differently; therefore, only half strength of wood is exerted if the iron is not unduly strained. If thickness of iron is less than $\frac{2}{17}$ that of wood, the beam will be weaker than without iron. If thickness of iron = $\frac{2}{17}$ wood, the beam will have the same strength as if without iron, and be twice as stiff. If thickness of iron exceeds $\frac{2}{17}$ wood, beam will be stronger than plain wooden beam.

Rolled-iron Joists.

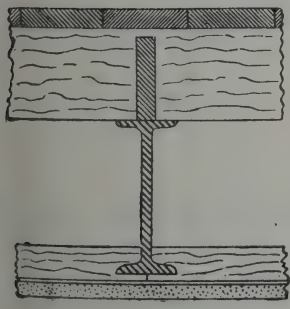


FIG. 477.

Rolled-iron joists are now extensively used as binders, the upper flange of which may support the floor joists, and the lower flange the ceiling joists, as in fig. 477.

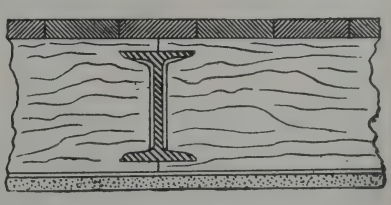


FIG. 478.

When the depth of the floor is required to be as shallow as possible, rolled-iron joists for binders are useful, as the floor may be constructed without increasing the depth required by the bridging joists, as shown in fig. 478.

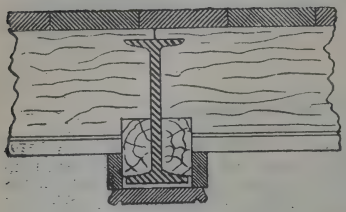


FIG. 479.

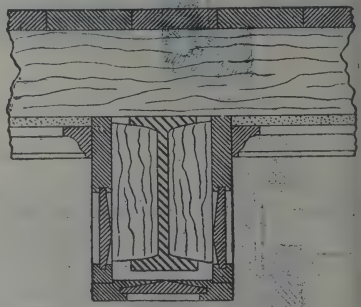


FIG. 480.

Figs. 479 and 480 show rolled-iron joists used as binders, and arranged so as to give the ceiling a panelled appearance.

GIRDERS OF BALTIC YELLOW FIR,

10 feet from centre to centre.

Bearing in Feet.	Depth, 10 Inches.	Depth, 11 Inches.	Depth, 12 Inches.	Depth, 13 Inches.	Depth, 14 Inches.	Depth, 15 Inches.	Depth, 16 Inches.	Depth, 17 Inches.	Depth, 18 Inches.	Depth, 19 Inches.	Depth, 20 Inches.	Depth 21 Inches
	Breadth in Inches.											
10	7½	5½	4	3½	2⅝	2¼	1⅝	..	1¼			
11	9	6⅝	5	4¼	3¼	2⅝	2¼	..	1⅝			
12	10½	8	5⅝	5	3⅝	3½	2⅝	2¼	2			
13	12¼	9½	6⅝	5⅝	4⅛	3⅝	3	2½	2¼			
14	14⅛	10⅝	7⅜	6⅝	5¼	4⅛	3½	3	2⅝			
15	16⅛	12¼	9	7⅜	6	5	4	3½	3			
16	18⅜	14	10¼	8⅜	7	5⅝	4⅝	4	3¼			
17	..	16	11¼	9⅜	8	6¼	5¼	4½	3⅝			
18	..	17¾	13	11	8⅜	7¼	6	5¼	4			
19	..	19¾	14⅓	12	9⅝	8	6½	5½	4⅜			
20	..	..	16	13½	10¾	9	7¼	6	5¼			
21	..	..	17½	15	12	9⅝	8	6⅝	5⅜			
22	..	..	19½	16½	13	10⅝	8⅝	7⅛	6¼			
23	..	..	..	18	14¼	11⅓	9⅛	8	6⅝			
24	..	..	..	19½	15½	12⅝	10¼	8⅝	7⅛			
25	..	..	..	..	16⅝	13⅝	11¼	9½	8			
26	..	..	..	..	18¼	15	12¼	10¼	8⅝			
27	..	..	..	..	19⅝	16	13	11	9¼			
28	..	..	..	..	..	17½	14¼	11⅝	10			
29	..	..	..	..	..	18½	15⅛	12¾	10⅝			
30	..	..	..	..	..	19¾	16¼	13½	11⅛	9¾	8½	7¼
31	..	..	..	..	..	..	17¼	14⅓	12¼	10¼	9	7⅝
32	..	..	..	..	..	..	18⅛	15⅛	13	11	9½	8¼
33	..	..	..	..	..	..	19¾	16⅛	14	11¾	10	8⅝
34	..	..	..	..	..	..	..	17⅛	14⅔	12⅛	10⅔	9⅓
35	..	..	..	..	..	..	..	18¼	15¾	13¼	11½	10
36	..	..	..	..	..	..	..	19½	16½	14	12	10½

SINGLE OR BRIDGING JOISTS OF BALTIC YELLOW FIR,
12′ from centre to centre.

Bearing in Feet.	Breadth, 1½ Inch.	Breadth, 2 Inches.	Breadth, 2½ Inches.	Breadth, 3 Inches.	Breadth, 3⅜ Inches.	Breadth, 4 Inches.
	Depth in Inches.					
5	5¾	5½	4¾	4⅜	4⅛	4
6	6½	5¾	5⅜	5	4¾	4½
7	7	6½	6	5½	5¼	5
8	7⅜	7	6½	6¼	5⅞	5⅜
9	8½	7⅛	6⅞	6½	6	5¾
10	9	8	7½	7	6¾	6¼
11	9½	8⅜	8	7⅛	7	6⅝
12	10	9½	8¼	8	7½	7¼
13	10⅜	9⅜	9	8½	8	7¾
14	11	10	9½	9	8½	8
15	11½	10½	9¾	9¼	8⅝	8¼
16	12¼	11	10⅜	9¾	9¼	8⅞
17	12¾	11½	10⅝	10¼	9⅝	9¼
18	13½	12	11¼	10½	10	9½
19	13⅞	12½	11½	10⅞	10¼	10
20	14½	13	12	11¼	10⅝	10¼
21	14¾	13½	12½	11⅝	11	10¾
22	15	13¾	12¾	12	11½	11
23	15½	14	13	12¼	11⅝	11¼
24	16	14½	13½	12¾	12	11⅝
25	16½	15	14	13	12½	12

For ordinary floors up to 16′ span, with the above scantlings, the joists may safely be spaced 12″ apart, instead of centre to centre. For spans over 16′ stiffness requires them 12″ from centre to centre, and over 20′ the scantlings are rather deficient in stiffness.

Ceiling Joists.

2″ thick is sufficient. They are nailed and notched to the joists.

Rule for Depth of Ceiling Joists.

L = length ; b = breadth ; d = depth.

If $b = 2''$, then $d = \frac{1}{2}''$ for each foot run of span $= \frac{L}{\sqrt[3]{b}} \times \cdot 64$ for fir ; $\times$ 0·67 for oak.

CEILING JOISTS OF BALTIC YELLOW FIR,
12″ from centre to centre.

Bearing in Feet.	Breadth, 1½ Inch.	Breadth, 1¾ Inch.	Breadth, 2 Inches.	Breadth, 2¼ Inches.	Breadth, 2½ Inches.	Breadth, 2¾ Inches.	Breadth, 3 Inches.
	Depth in Inches.						
4	2¼	2⅛	2				
5	2¾	2⅝	2½				
6	3⅜	3⅛	3	2⅞			
7	4	3⅞	3⅞	3⅜	3⅛		
8	4½	4⅛	4	3⅞	3⅝	3⅜	3⅛
9	5	4⅝	4½	4⅜	4⅛	4⅛	4
10	5⅝	5⅛	5	4⅞	4⅝	4⅜	4½
11	6¼	5⅞	5½	5⅜	5⅛	5⅛	5
12	6⅝	6⅛	6	5⅞	5⅝	5⅜	5¼
13	7⅜	7	6½	6¼	6	5⅞	5⅝
14	8	7⅜	7	6⅝	6⅜	6⅛	6¼
15	8½	7⅞	7½	7⅛	7¼	7	6⅝

(*Tredgold.*)

Ceiling joists should never have very long bearings, particularly those for ceilings next the roof of a house, as long joists are subject to warp, which breaks the plastering.

The distance from centre to centre should never exceed 12″, otherwise the bearing for the laths becomes too long. If the distance from centre to centre exceeds 12″, double laths should be used.

Lintels.

Lintels over doors and windows are of wood, generally 1″ in depth for every foot of span in width, or = $\frac{1}{12}$ span; the weight of the wall above being taken off them by a relieving arch of brick or stone of span equal to their full length. If, as for very cheap and temporary work, no relieving arch is used, they should have a depth of 1½″ to 1½″ for every foot of span, or more if part of the weight of a floor or roof falls over them. The ends should bear 9″ on the wall, although sometimes only given 4½″.

Details of Flooring Boards.

Thickness of Flooring Boards.—1¼″ in ordinary houses.

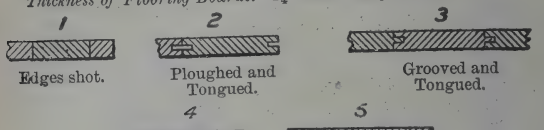


FIG. 481. Edge Joints.

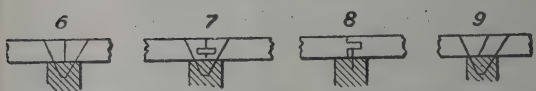


FIG. 482. Heading Joints.

Edge Joints (fig. 481.)—1 is used for inferior floors; 2 and 3 for ordinary floors of a high class; 4 for very superior floors; 5 where the traffic is heavy.

Tongues and Fillets are of wood or hoop iron; the latter, if for good work, should be galvanised. If of wood, should be ¼″ thick, cut across the grain; for strength as well as to prevent splitting, cross or feather tongues are used, the grain running at an angle across the tongue. Iron tongues for 1¼″ boards are 1⅛″ wide, 17 B.W.G.; for 1½″ boards, 1½″ wide, of 17 B.W.G.; for 2″ boards 1⅞″ wide, of 15 B.W.G.; for 2½″ and 3″ boards, 1½″ wide, of 15 B.W.G. Tongues are put one-third of depth from bottom of board to give more wear to the upper edges.

Heading Joints.—Fig. 482 shows various forms of heading joints, the inclined black lines being the securing nails.

Secret Joints.

Joints for important or polished floors are secured in such a manner as not to show their fixing, or present gaps or unsightly holes, as would occur in ordinarily fixed flooring, and as they are all fixed on one edge only, are free to shrink or swell without splitting.

Figs. 483, 484 show boards secured by dowel pins and screwed to joists through one edge only, a cheap and effective method, but one which does not prevent dust passing through.

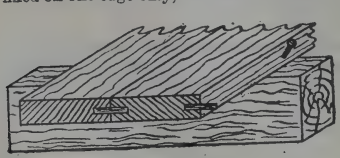


FIG. 483.

FIG. 484.

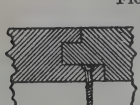


FIG. 485.

FIG. 486.

FIG. 487.

Figs. 485 and 486 show the method by rebate, groove and tongue, secured by screws on one edge only. These can be easily fixed or taken up when required, and prevent any dust passing through. The expense of these joints is the great objection to their use. The method shown in fig. 487 possesses the advantages of the two previous joints at a less cost.

Clasp nails or wrought or cut *flooring brads* are used, two to each board, over each joist. The nails should be from 2″ to 2¼″ longer than thickness of board; 3¾″ (32 lbs. to the 1,000) may be used for 1½″ boarding.

Nail heads, for good work, should be punched down, and the holes stopped with lead putty.

Width of Floor Boards.—For important rooms, 4½″; in ordinary rooms, 7″; for common and

temporary purposes, 9″. The narrower the boards, the less they shrink. All the boards should be *listed*, or have the sapwood removed from edges. They should be very well seasoned; if not, they should be temporarily laid, and left a year before being finally laid and nailed down.

Ventilation of Floor Joists, &c.

The spaces between the timbers of floors and flat roofs should be well ventilated by air bricks in walls. Ground below a floor should be thoroughly drained, and covered in some cases with a layer of lime concrete, or with ashes and quicklime.

Fire-Resisting Floors.

FIG. 488.

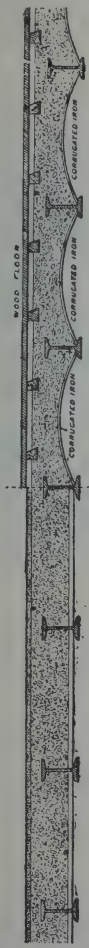


FIG. 489.

FIG. 490.

FIG. 491.

See also 'Fire Resistant Construction,' *Building Research Board Report No.* 8 (1927). Published by His Majesty's Stationery Office, Imperial House, Kingsway, London, W.C. 2; price 1*s.* 6*d.* net.

'Expamet' Expanded Metal.

'Expamet' Expanded Metal, as manufactured by *The Expanded Metal Company, Ltd.* (of London and West Hartlepool), is made from blank metal sheets and plates—steel, brass, copper, etc.—which are cut and expanded into meshes of various shapes and sizes. Each size of mesh is made in several weights, for, while a particular mesh remains constant in size, centre to centre, it can be produced from several thicknesses of sheets or plates, and strands of various widths can be made; the different styles and weights have all a distinguishing number assigned to them, and each may be specified and ordered under its List Reference No.

The material is machine-made, of meshwork formation, and has no joins, no welds, and no loose or separate strands or attachments; the junctions between the meshes remain uncut, and all the strands or members in a sheet are connected rigidly, and have continuous fibres—important features peculiar to Expanded Metal.

'Expamet' Diamond Mesh Expanded Steel Reinforcement for Concrete.

'Expamet' Expanded Steel has been in successful and ever-increasing use all over the world for some thirty years past. As reinforcement for concrete it has exceptional qualities, especially in large plain and curved areas. It is particularly suitable for reinforcing concrete in roads, foundations, walls, floors, roofs, lintels, arches, bridges, grain silos, coal pockets, tanks, reservoirs, dams, retaining walls, piers, abutments, pipes, sewers, conduits, etc. 'Expamet' Expanded Steel of the 3-in. mesh weights is used mostly for such work, and the 1½-in. and 6-in. meshes also may be used in some cases; the lighter weights of the ¾-in. and 1½-in. meshes are used frequently in concrete for encasing steelwork, and various weights of 6-in. mesh in concrete roadways, pavings, tramway tracks, and the like. It is supplied in rolls or flat sheets cut to size and ready for use, sheets up to 16 ft. × 8 ft. being sent in flat bundles and larger sheets in rolls of small diameter; it is simple, economical, and effective in practice, and has the great advantage for shipping purposes that it packs closely and is easily transported and quickly handled. Its unique feature is that it is a sheet of steel network, wherein all the strands or members are connected rigidly; thus they cannot be displaced, when in position, by the laying and tamping of concrete: it follows that expanded steel reinforcement is entirely to be relied upon in either skilled or unskilled hands, and the steel goes where it is planned to go without expensive setting out and labour. The respective meshes 'key' into each other, and interlock where sheets overlap; thus a layer of the reinforcement may be made absolutely continuous, no matter how large the area to be treated.

Effective mechanical and cross bond and end anchorage is obtained, for being a double-way reinforcement of peculiar formation, it cannot slip within the concrete.

As meshwork with a dependable grip is a most efficient form of reinforcement for resisting both tensile and thermal stresses, 'Expamet' Expanded Steel-Concrete slabbing is well adapted for heat and fire resistance, as well as for load carrying.

The distribution of stress by 'Expamet' Expanded Steel is complete, for there is steel to transmit in all directions the stresses due to a load; and, no matter where it may be imposed, the load does not affect merely the portion of slab directly under it. Also, as each mesh contains its own concrete, the mass is bound together very effectively; and the concrete enclosed within the mesh being brought into compression, the effective value of the reinforcement is increased.

'Expamet' Expanded Metal Lathings for Plasterwork.

'Expamet' Expanded Metal Lathings are made from mild steel sheets. They form an ideal key for plaster in ceilings, steelwork encasing, solid and hollow partitions, exterior walls, and other plasterwork. All lathing is coated with a mineral oil, and then dipped once in asphaltum paint. Unpainted lathing should not be used for plasterwork, and it is advisable to paint all clips, hangers, ceiling bars, etc., as well as the lathings.

The latest type is known under the trade name of 'BB' Expanded Metal Lathing, and it supersedes the older Diamond Mesh types, but for hairless plaster the 'BB' and ¼-in. Diamond Meshes are preferable, while for hair plaster the ⅜-in. mesh may be used. Both types are suitable for use for all purposes to which metal lathings can be applied. For special ceilings, heavy ornamental plasterwork, heavy facing such as tiling, mosaic, etc., and for exterior work, the heavier lathings should be employed, especially in horizontal work.

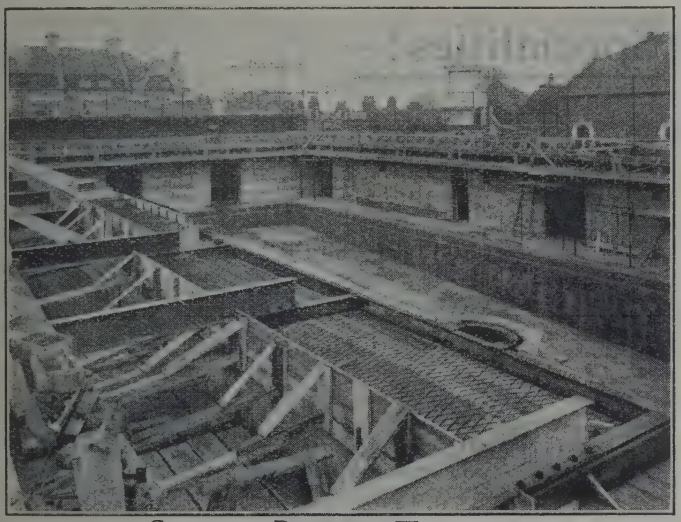
The 'BB' mesh is made from 26, 24, and 22 gauges, and is stocked in sheets 9 ft. × 2 ft.; the Diamond Mesh from 24, 22, and 20 gauges, and in sheets 6 ft. × 2 ft., 7 ft. × 2 ft., and 8 ft. × 2 ft. 3 ins.

'Exmet' Reinforcement for Brickwork.

'Exmet' Reinforcement is specially suitable for reinforcing brickwork, concrete-block work, partition slabs, asphalt, etc. It is manufactured from 24, 22, and 20 gauge mild steel, in 2½-in., 7-in., and 12-in. widths, and is supplied in standard coils containing 270 or 75 feet lineal. It is coated with a mineral oil, and then dipped in asphaltum paint, but can be obtained unpainted if ordered specially. Flat strips of any length up to 16 ft. can be supplied, either uncoated, painted, or galvanised.

"EXPAMET" (REG.) EXPANDED METAL

The Ideal Reinforcement for Concrete.



GREENWICH BATHS AND WASHHOUSES.

"EXPAMET"—Concrete Walling, Flooring, Bath Surrounds, Balconies, Etc.

Architects: MESSRS. HORTH & ANDREW, Hull.

Contractors: MESSRS. HOLLIDAY & GREENWOOD, LTD., London.

WRITE FOR ILLUSTRATED LITERATURE.

THE EXPANDED METAL Co., Ltd.

Patentees and Manufacturers of Expanded Metal.
Engineers for all forms of Reinforced Concrete Work.

YORK MANSION, PETTY FRANCE, LONDON, S.W. 1

Works: WEST HARTLEPOOL Established over 35 years.

"EXPAMET"
(REG.)
EXPANDED METAL

Specialities:—

"EXPAMET" STEEL SHEET
REINFORCEMENT FOR CONCRETE.

"BB" LATHING
FOR PLASTERWORK.

"EXMET" REINFORCEMENT
FOR BRICKWORK.

"EXPAMET" STEEL SHEETS
For Fencing, Openwork Partitions, Machinery Guards, Switchboard Enclosures, Etc.

"RIBMET"
FOR CONCRETE AND PLASTER WORK.

WRITE FOR ILLUSTRATED LITERATURE.

THE EXPANDED METAL Co., Ltd.

Patentees and Manufacturers of Expanded Metal.
Engineers for all forms of Reinforced Concrete Work.

YORK MANSION, PETTY FRANCE, LONDON, S.W. 1
Works: WEST HARTLEPOOL Established over 35 years.

'Ribmet' for Concrete and Plaster Work.

'Ribmet' (Regd.) is composed of the company's well-known 'BB' Lathing, in 26, 24, and 22 gauge mild steel, with U-shaped ribs attached securely to the sheets, in the direction of their longway and parallel to the sides. Standard size sheets are 2 ft. to 9 ft. long inclusive, rising 6 ins. at a time; sheets of other lengths between 2 ft. and 9 ft., and sheets over 9 ft. and up to 12 ft., can be supplied. The material is half an inch thick overall.

There are two types of 'Ribmet'—'X' type and 'Z' type; in the first the lathing is grooved to receive the ribs; in the second the ribs are attached to the flat sheet of lathing with the meshwork passing across the opening of the ribs—novel and unique features in material of its kind.

The standard ribs are made from 19 gauge mild steel, and are attached to the lathing, at frequent regular intervals, with strong half-round steel wire. The ribs can be spaced apart at practically any required dimensions, but 3 ins., 4 ins., and 5 ins. are the standard centres; generally, the outer ribs are about 2 ins. from the outer sides of the sheets, and the intermediate ribs at the respective spacings, but ribs can be attached along the edges if required.

Concrete Flooring, Roofing, etc.—'X' type 'Ribmet' is to be preferred for suspended concrete flooring, roofing, and the like—particularly as a permanent centring; the lath corrugation stiffens the rib, and the meshwork is small enough to retain the concrete while it is being poured.

For long spans and heavy superloads, 3-in. mesh 'Expamet' reinforcement should be used along with the 'Ribmet'; laid on the ribs, it is distanced mechanically from the lathing; thus the reinforcement is embedded within the concrete, and there is a lath face to receive a plaster finish.

In flooring and similar work, while temporary close-boarding is rendered unnecessary by the use of 'Ribmet,' temporary bearers are essential, as spacings of 18 ins. and upwards, according to the weight of the concrete to be imposed and whether the soffit is straight or curved.

For designs and estimates for 'Ribmet,' in any work for which it is suitable, application should be made to the company.

Plaster Ceilings, Partitions, etc.—'Z' type 'Ribmet' has the unique feature of the lathing passing across the openings of the ribs; it is thus particularly desirable for suspended plasterwork in ceilings, walls, partitions, and the like; it gives a continuous and unbroken lath face and 'key' for the plaster, a uniform thickness of which is obtained throughout, and the ribs are filled with it. It follows that the possibility of the plaster cracking along the ribs is reduced to a minimum and, filled with plaster, there can be no condensation inside them.

Unless there is some very good reason to the contrary, the ribs should never be within the thickness of the plaster, but on the back face of the lathing, except in solid partitions and the like.

'Ribmet' should be fixed securely, longway of the sheet, from bearer to bearer, to ensure a level and rigid ground to receive plaster. The strands in the various sheets should all slope in one direction; in vertical work they should slope inwards and downwards from the plaster face. It should be secured, at each rib, to the bearers supporting it, and be wired together at 3-in. to 4-in. intervals between supports. The sheets should be overlapped not less than one mesh where they join; overlaps should not be made at angles or curves—at such places the sheets should be bent, or angle pieces of plain lathing should be used to cover and connect butt-joints. Galvanised slice-cut staples or tenterhooks, not less than 1¾ ins. long, are recommended for timber bearers, and not less than 14 gauge galvanised soft iron wire for tying to steel bearers; 18 gauge galvanised soft iron wire is sufficient for tying the sheets together at overlapped joins.

Practical tests and actual experience show that No. Z 244 'Ribmet' may be used for ordinary plasterwork, with entirely satisfactory results, up to 3 ft. spacings in horizontal work, and 4 ft. in vertical; but the heavier weights are recommended for special, ornamental, and exterior work.

'Expamet' Expanded Metal Make-up Goods.

Practically any of the meshes may be used for openwork partitions, shop divisions, fencing, etc.; guards for machinery, windows, trees, etc.; lockers for clothes, tools, etc.; baskets for waste-paper, letters, etc.; and similar articles.

'Expamet' Expanded Metal Lathing and Plaster Partitions.

These are constructed solid or hollow, according to requirements.

The weight per super foot of surface area, measured one side only, is for 2-in. solid walling about 18 lbs.; and for 6-in. hollow walling about 21 lbs., with a slight increase in weight if the outside skin is back-plastered.

EXPANDED METAL SUSPENDED CEILINGS.

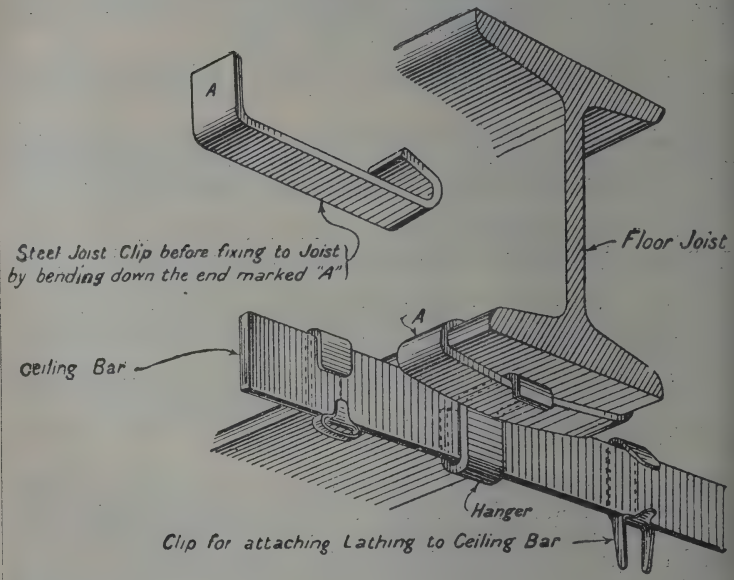


FIG. 491A.

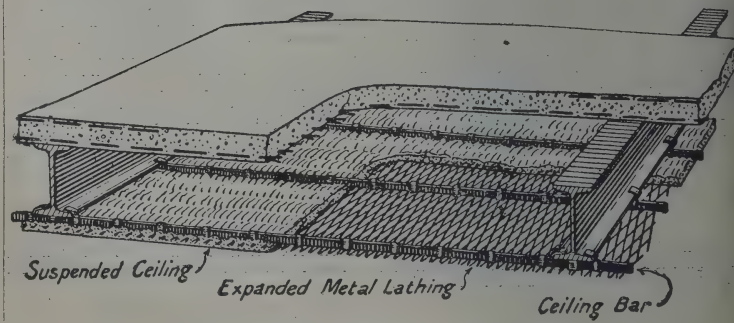


FIG. 491B.

The lighter lathings may be used for both systems, but the heavier lathings are recommended for exterior work.

Solid Partitions, etc.—The metal grounds for solid walls, etc., are formed of 'BB' Expanded Metal Lathing securely fastened to ⅜-in. diameter steel rods, or other suitable sections, placed vertically 12 ins. to 15 ins. apart. Tension rods are fixed tautly at their ends with screws to timber, hangers or spikes to concrete, and clips to steelwork; in some cases it suffices if their ends are bent round structural members, as in steel-frame buildings.

When the metal groundwork is completed, it must be temporarily strutted and railed at half height on one side to keep it in a vertical plane. The first or 'render' coat should then be applied on the opposite side, ½ in. thick, and allowed to set hard previous to the second coat being applied. When these two coats are set the temporary supports may be removed, and the reverse side floated. The finishing coat is then applied in the ordinary way. Interior solid partitions are sometimes built only 1½ in. thick, but usually they are made 2 ins. thick; exterior solid walls are generally made 2½ ins. to 3 ins. thick.

Hollow Partitions, etc.—The metal grounds for hollow walls, etc., are formed of 'BB' Expanded Metal Lathing, securely fastened on both sides to steel studs spaced from 12 ins. to 18 ins. apart. These studs are formed of two angle bars, connected at intervals by distance straps, and by angle foot and head pieces, which are holed to allow of the studs being fixed to flooring, etc. If the studs have to be fixed to steelwork a clip is riveted to the foot and head pieces to form means of attachment. Overall thickness is regulated by the length of the cross straps and pieces; 6 ins. is a usual overall dimension, and ¾-in. of plaster is sufficient for the interior skin, and 1½-in. for the exterior. It is wise to back-plaster lathing in exterior work, and thus embed it.

Suspended Ceilings.

These ceilings (figs. 491A and 491B) can be suspended at any desired level and to any desired shape. They may be fixed flush with the soffits of floor joists, roof principals, etc., or they can be suspended below them at suitable distance to accommodate pipes, electric wires, etc. The ceilings may be carried to the side walls, in bays or coves of any desired form, for obtaining artistic or decorative effects.

A flat ceiling with hangers varying in length, or a curved ceiling with hangers made to follow the contour, may be suspended below arched flooring, etc.; ceilings suspended from roof principals may be dealt with in the same manner.

For spans of up to 8 feet, flat steel bars, of suitable sections, are suspended on edge from the floor joists, etc., at intervals according to the weight of 'Expamet' or 'BB' lathing and plaster to be used, by means of mild steel hangers made for the purpose. The section of bar to be used will depend upon the character of the work to be done in each case. For spans of over 8 feet it is more economical to use tee or angle bars supports, at say 6-ft. centres, and from them to suspend the ceiling bars.

Where bars join they should overlap, at least 2 ins., in a hanger. In wall-end bays the bars should be pinned not less than 2 ins. into the masonry. In corridors and other places, where the spans are not too long, intermediate support is not necessary—the bars may be pinned at their ends into the brickwork, etc. In long spans, it is wise, at the half-span, to tie a bearer bar on top of, and at right angles to, those on edge, to maintain them in a vertical plane.

The hangers should be secured by screws to timber joists, attached to R.S.J.'s by means of mild-steel clips, bent over tie members of roof trusses, and pinned into reinforced concrete beams. The bars should be fastened in the hangers with wire, and also at lapped joints, to prevent the metal grounds from rising.

The lathing should be fixed to the ceiling bars with lathing clips or with galvanised soft iron wire, and when this is completed the ceiling grounds are ready to receive plaster.

The weight of these suspended ceilings, including metal grounds and plaster, ranges from 8 to 12 lbs. per foot super; and the air space provided affords a perfect fire and sound-resisting construction.

Steelwork Encasing.

For plasterwork, the 'Expamet' Lathings, and sometimes the lighter weights in ⅜-in. 'Expamet' expanded steel, such as No. 38, are used; while for concrete encasing, formed with temporary centring, the lighter weights in 1½-in. 'Expamet,' such as No. 6, are recommended.

Structural Steelwork Encasings.—In many cases lathing is simply wrapped round the steelwork, secured in position when necessary, and wired together at lapped joints, and then covered with plaster. A better system, however, is to use metal cradling, such as ½-in. or ⅜-in. round

DIAMOND MESH EXPANDED STEEL-CONCRETE SLABS, FOR FLOORING, ROOFING, ETC. SAFE SUPERIMPOSED LOADS PER FOOT SUPER.

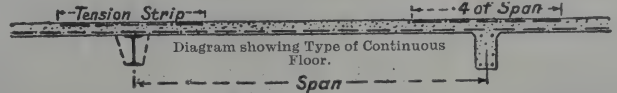


Diagram showing Type of Continuous Floor.

Continuous Slabs.

$BM = \frac{WL}{12}$

SPAN Ft. Ins.	56 lbs.		70 lbs.		84 lbs.		100 lbs.		112 lbs.		150 lbs.		224 lbs.		280 lbs.		336 lbs.		392 lbs.		448 lbs.	
	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.
4 0	3	15	3	15	3	15	3	15	3	15	3	15	3	15	3	9	3	9	3½	9	3½	9
4 6	3	15	3	15	3	15	3	15	3	15	3	15	3	9	3	9	3½	9	3½	8	3½	8
5 0	3	15	3	15	3	15	3	15	3	15	3	15	3	9	3½	9	3½	8	4	8	4	8
5 6	3	15	3	15	3	15	3	15	3	15	3	9	3½	9	3½	8	4	8	4	11	4½	11
6 0	3	15	3	15	3	15	3	9	3	9	3	9	3½	8	4	8	4	11	4½	11	5	11
6 6	3	15	3	15	3	9	3	9	3	9	3½	9	4	8	4	11	4½	61	5	61	5½	61
7 0	3	15	3	9	3	9	3	9	3½	9	3½	8	4	11	4½	61	5	61	5½	61	5½	10
7 6	3	9	3	9	3	9	3½	9	3½	8	3½	8	4½	11	5	61	5½	61	5½	10	6	10
8 0	3	9	3½	9	3½	9	3½	8	3½	8	4	8	4½	61	5½	61	5½	10	6	10	6½	62
8 6	3½	9	3½	9	3½	8	3½	8	4	8	4½	11	5	61	5½	10	6	10	6½	62	6½	62
9 0	3½	9	3½	8	3½	8	4	8	4	11	4½	61	6	61	6	10	6½	62	6½	62	7	62
9 6	3½	8	3½	8	4	8	4	11	4½	11	5	61	6	10	6½	10	6½	62	7	62	7½	31
10 0	3½	8	4	8	4	11	4½	11	4½	61	5½	61	6	10	6½	62	7	62	7½	31	8	30
10 6	4	8	4	11	4½	11	4½	61	5	61	6	61	6½	62	6½	62	7½	62	8	31	8	30
11 0	4	8	4½	11	4½	61	5	61	5½	61	6	10	6½	62	7½	62	8	31	8	30	9	30
11 6	4	11	4½	61	5	61	5½	61	6	61	6	10	6½	62	7½	31	8	30	9	30	10	30
12 0	4½	11	4½	61	5	61	6	61	6	10	6½	10	7½	62	8	30	8½	30	9½	30	10	68
12 6	4½	61	5	61	6	61	6	10	6	10	6½	62	7½	31	8	30	9½	30	10	68	10	68
13 0	5	61	5½	61	6	10	6	10	6½	10	6½	62	8	30	9	30	10	30	10	68	10	68
13 6	5½	61	5½	10	6	10	6½	10	6½	62	7	62	8	30	9½	30	10	68	10	68	10½	68
14 0	5½	10	6	10	6½	10	6½	62	6½	62	7½	31	8½	30	10	30	10	68	10	68	11	68
14 6	6	10	6	10	6½	62	6½	62	6½	62	8	31	9½	30	10	68	10	68	11	68	12	68
15 0	6	10	6½	62	6½	62	7	62	7½	62	8	30	10	30	10	68	10½	68	12	68		
15 6	6½	10	6½	62	6½	62	7½	62	7½	31	8	30	10	68	10	68	11	68				

Note.—Generally it is not economical to use thicknesses shown below the zigzag line in the table. *(The Expanded Metal Co., Ltd.)*

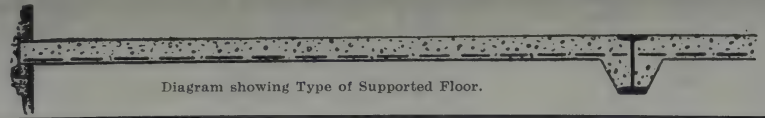


Diagram showing Type of Supported Floor.

Supported Slabs. $BM = \frac{WL}{8}$

SPAN Ft. Ins.	56 lbs.		70 lbs.		84 lbs.		100 lbs.		112 lbs.		150 lbs.		224 lbs.		280 lbs.		336 lbs.		392 lbs.		448 lbs.	
	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.	Concrete Thickness Inches.	Expanded Steel List Ref. No.
4 0	3	15	3	15	3	15	3	15	3	15	3	15	3	9	3	9	3½	8	3½	8	4	8
4 6	3	15	3	15	3	15	3	15	3	15	3	9	3½	9	3½	8	4	8	4	11	4½	11
5 0	3	15	3	15	3	15	3	9	3	9	3	9	3½	8	4	8	4½	11	4½	61	5	61
5 6	3	15	3	9	3	9	3	9	3	9	3½	9	4	8	4½	11	4½	61	5	61	6	61
6 0	3	9	3	9	3	9	3½	9	3½	9	3½	8	4½	11	5	11	5½	61	5½	10	6	10
6 6	3	9	3	9	3½	9	3½	8	3½	8	4	8	4½	61	5½	61	5½	10	6	10	6½	62
7 0	3½	9	3½	9	3½	8	3½	8	4	8	4½	11	5	61	5½	10	6	10	6½	62	6½	62
7 6	3½	9	3½	8	3½	8	4	8	4	11	4½	61	6	61	6	10	6½	62	6½	62	7½	62
8 0	3½	8	3½	8	4	8	4½	11	4½	11	5	61	6	10	6½	62	6½	62	7½	62	8	31
8 6	4	8	4	8	4½	11	4½	61	4½	61	6	61	6½	10	6½	62	7½	62	8	31	8	30
9 0	4	8	4½	11	4½	61	5	61	5	61	6	10	6½	62	7	62	8	31	8	30	9	30
9 6	4½	11	4½	61	5	61	5½	61	6	61	6½	10	7	62	8	62	8	30	9	30	10	30
10 0	4½	61	5	61	5½	61	5½	10	6	10	6½	62	7½	62	8	30	9	30	10	30	10	68
10 6	5	61	5½	61	5½	10	6	10	6½	10	6½	62	8	31	8½	30	10	30	10	68	10	68
11 0	5½	61	5½	10	6	10	6½	10	6½	62	7	62	8	30	9½	30	10	68	10	68	10½	68
11 6	5½	10	6	10	6½	10	6½	62	6½	62	7½	62	8½	30	10	30	10	68	10½	68	11½	68
12 0	6	10	6	10	6½	62	6½	62	7	62	8	31	9½	30	10	68	10	68	11½	68	12½	68
12 6	6½	10	6½	10	6½	62	7	62	7½	31	8	30	10	68	10	68	11	68	12½	68		
13 0	6½	62	6½	62	7	62	7½	62	8	31	8½	30	10	68	10	68	12	68				
13 6	6½	62	7	62	7½	62	8	62	8	30	9½	30	10	68	11	68						
14 0	6½	62	7½	62	8	31	8	30	8½	30	10	30	10	68	12	68						
14 6	7½	62	8	62	8	30	8½	30	9	30	10	68	11	68								
15 0	8	62	8	30	8½	30	9½	30	10	30	10	68	12	68								
15 6	8	30	8	30	9	30	10	68	10	68	10	68										

Note.—Generally it is not economical to use thicknesses shown below the zigzag line in the table.

(*The Expanded Metal Co., Ltd.*)

rods, bent to the shape of the steelwork, and secured in position, to which to tie the lathing, and to allow of the plaster having a better 'key.' In high-class work, the encasing should be in one body and not less than 2 ins. thick; that thickness can be obtained in the following ways: for plaster finish, by fixing the lathing 2 ins. from the face of the steelwork, filling in the space with concrete, and covering the lathing with plaster; for concrete finish, by using temporary centring and filling in the concrete encasing, with 1½-in. 'Expamet' expanded steel at the centre of its thickness.

Girder Encasing.—For boxing-in exposed girders, etc., not more than 12 ins. on side or soffit, 'Expamet' expanded metal lathing can be wrapped round the beam and secured by staples, tenter hooks, or spikes to the underside of the floor above; or, preferably, it can be wired to ⅜-in. round rod cradling fixed at 12-in. to 15-in. centres along the beam. In the first system the long way of the mesh in the lathing should be vertical on the sides, and in the second it should be horizontal. For larger section beams, for high-class and for heavy work, the second system should always be used.

Wall Casing or Deafening is constructed by means of holdfasts, set into the wall at about 4 ft. centres vertically, and spaced horizontally according to the weight of the lathing to be used. These holdfasts are holed or hooked at their outer end to receive flat vertical bars, which are either bolted or wired in position, the lathing and plaster being applied as described elsewhere.

Air-ducts, False Beams, Cornices, Pilasters, etc., can be constructed by means of light steel framework fixed to receive the lathing, and if the cradles cannot be placed sufficiently near each other themselves to take the lathing, they should be aligned with ⅜-in. diameter rods wired to them, horizontally or vertically, as the case may be, to form backing for the lathing as well as stiffeners for the cradles.

Concrete Pipes, Conduits, Sewers, etc., built in situ.

'Expamet' Expanded Steel sheets can be cambered either long way or short way of the mesh to suit any requirements. The diagonals of the meshes should run one with, and the other at right angles to, the periphery of the pipes. The reinforcement should not only be laid, but it should also be fixed in place, so that there may be no possibility of its losing its correct position; it is advisable to clip or wire the sheets together at overlapped joins, and for pressure pipes to allow an overlap of not less than two meshes.

With particular regard to pressure pipes, the concrete forming the main shell should not be depended upon for impermeability, for experience has shown that the tamping seams are to be feared, no matter how carefully fresh material may be added to that which has already been laid.

For pressures of up to 50 feet, a ⅜-in. facing of cement and sand, 1 to 2, laid in one body on the centring immediately before the concrete or on the concrete after the removal of the forms, has proved effective. But for greater pressures, say up to 100 ft., the facing should be laminated or put on in coats, the first coat not less than ¼ in. of cement and sand 1 to 2; the second of about ¼-in., 1 to 1, troweled to a hard polished surface, and a final wash of thick grout.

Generally speaking, the thickness of the concrete shell should in no place be less than one-twelfth of the greatest internal diameter of the pipe, with an allowance of 1 in. for cover to the reinforcement, whilst the steel should be designed to resist the whole of the tensile stress.

Concrete Mixtures for 'Expamet' Expanded Steel Reinforcement.

The following mixtures of concrete, all parts by measure, are recommended for use with 'Expamet' expanded steel reinforcement:—*For floors, walls, etc., up to 3½ ins. thick:* 3 parts of aggregate, 1½ parts of sand, to 1 part of Portland cement; *thicker than 3½ ins.:* 4 parts of aggregate, 2 parts of sand, to 1 part of Portland cement. *For general concrete work such as foundations and heavy work:* 5 parts of aggregate, 2½ parts of sand, to 1 part of Portland cement. *For concrete to retain liquid pressures:* 3 parts of aggregate, 2 parts of sand, to 1 part of Portland cement. The aggregate should be clean sharp broken flint gravel, or hard and durable broken stone. For steelwork encasing, flooring and similar work, if such aggregates are not readily obtainable hard broken brick or hard furnace clinker, or a mixture of the two, free from combustible materials, old mortar, ashes and dust, may be used. Cinders and coke breeze are not recommended for reinforced concrete work. The aggregate should be of various sizes between ¾ and ¼ in. for the 4½, 5, and 6–1 mixtures, and from 1½ in. to ¼ in. for the 7½–1 mixture, all fine stuff below ⅛ in. may be used in place of sand. The sand should be clean sharp gritty sand consisting of mixed or graded sized grains from ¼ in. down, with the coarse grains predominating. Portland cement must be used, and it should be in accordance with the requirements of the current British Standard Specification. The concrete should be mixed three times dry and three times after water has been added, and must be deposited before the cement has reached its initial set, and must not afterwards be disturbed.

Fire-Resisting Materials.

The best materials to resist fire are brickwork, burnt clay in any form, plaster, and concrete.

Girders and Arches form a heavy floor; the girders may be protected by blocks of fireclay, or plaster, or concrete. Fire-brick arches 4′ to 12′ span, spandrels filled in and backed up with concrete, or arches may be of concrete only.

Figs. 488 to 491 (page **435**) show various forms of fire-resisting floors. The concrete in some cases is made of calcined gypsum, which does not lose its cohesive power even when raised to a white heat and drenched.

The American Concrete Institute recommends that for fire-resistive construction, limestone trap rock, blast-furnace slag, and burned clay be given a preference over highly siliceous gravels; that in cases where gravel aggregate is to be used, with no additional protective material over the concrete, round columns be given a preference over rectangular ones; and that where gravel aggregate is used all columns, but especially rectangular columns and round columns with spiral reinforcement, be given the additional protection of approximately 1 in. of Portland cement plaster either on metal lath or reinforced by light expanded metal.

Bracket.

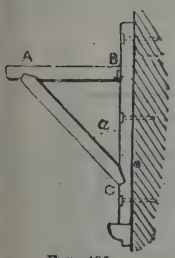


FIG. 495.

If a weight, W, is placed at point A, fig. 495, tension tending to pull bracket out of socket at B

$$= W \tan a = W \frac{AB}{OB}.$$

Compression on $AC = \frac{W}{\cos a} = W \frac{AC}{BC}$. If W is distributed over AB, these strains will be $\frac{1}{2}$ W tan a and $\frac{1}{2} \frac{W}{\cos a}$; and there will be a maximum bending moment on $AB = \frac{W \times AB}{8}$ which is lessened by the tensile stress $\frac{1}{4}$ W tan a tending to prevent bending and to draw it out at B.

Vertical strain on BC = W.

Partitions.

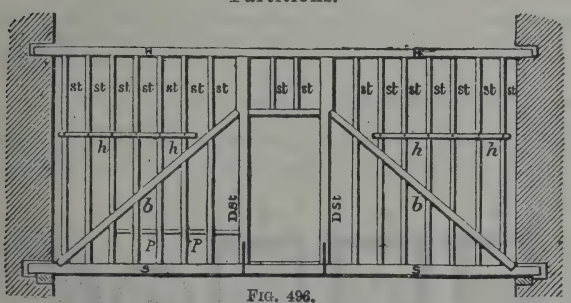


FIG. 496.

Partitions (fig. 496) should be framed so as to be supported only by the walls. *b* braces, H head, S sill, *st* studs, D*st* door-studs.

BLOCKS FOR PARTITION WORK.

A form of block suitable for partition work has been developed in the United States. The material is composed of five parts by volume of ground quicklime, ten parts of slaked lime, and one of wood fibre. The block can be removed from a mould in ten minutes, and in twenty minutes can be handled. After seven days it has a compression strength of 100 lbs. per sq. in. It can be sawn, and nails can be driven into it.

Dimensions of principal timbers, *b*, H, D:—

4″ × 3″	for a bearing not exceeding	20	feet.
5″ × 3½″	,,	,,	,,	30 ,,
6″ × 4″	,,	,,	,,	40 ,,

The filling-in pieces, 'studs, 'or 'quarterings,' need not be thicker than 2″, or just sufficient to nail the laths to. They are tennoned to the top and bottom plates, but butted and nailed on to the braces. If they exceed 3′ or 4′ in length they should be strengthened by short struts or horizontal pieces, as at *p*, *p*, called 'nogging pieces,' or,what is better, by a continued rail, *h h*, notched across the uprights and nailed to each. In a brick nogged partition the nogging pieces are essential. They are much thinner than in a lath-and-plaster partition, being about ¾″ thick and 2″ wide, placed at every fourth course of the brickwork in height.

The studs or quarterings for a lath-and-plaster partition should be spaced at from 12″ to 18″ from centre to centre; in a brick nogged partition they should be 18″, 2′ 3″, or 3′ apart. If a partition is not well framed, or is made with unseasoned timber, the plastering will crack. Weight of a square (100 feet super) of partitioning may be taken at 1,480 to 2,000 lbs.

Slag wool, packed in the full depth of the joists between ceiling and floors, is an effective deadener of sound, and this method has the advantage of leaving no hollow spaces in which vermin can congregate, or in which fire can work its way unseen. Sprips of hair felt should be laid along the joists to prevent continuity of woodwork, otherwise sound will be transmitted through the woodwork itself. The approximate quantity of slag wool required to fill a square yard of flooring, say 9 inches deep, will be 80 lbs. This method is perhaps a little more costly than some architects care to adopt, and lesser thicknesses of slag wool produce very satisfactory results.

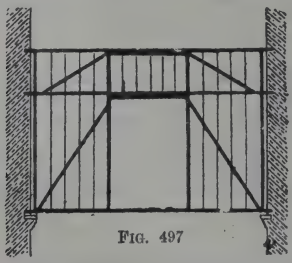


FIG. 497

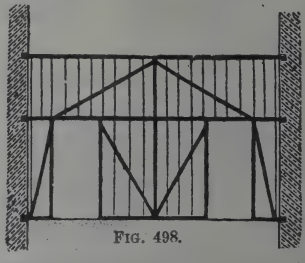


FIG. 498.

Figs. 497 and 498 show arrangements for partitions having doorways; in both cases the main portion of the partition is suspended from the truss forming the upper part of it.

For rendering partitions, as far as possible, sound-proof, 'Willesden Paper' (*The Willesden Paper and Canvas Works, Ltd.*) may be used with advantage; it is also damp-proof.

Stairs.

Stairs (fig. 499) are described according to their form in plan, viz.:—

1. *Straight—a.*

2. *Dog-legged—b*; when the flights rise alternately in opposite directions with no interval between the flights.

3. *Open newel—c*; when the flights are ranged round an open well-hole, with a newel post at each angle.

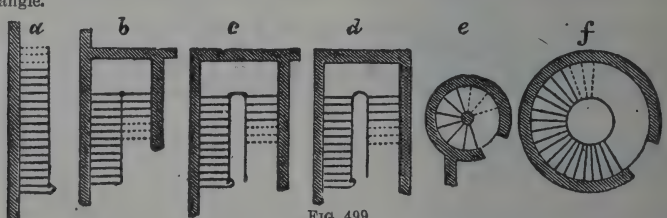


FIG. 499.

4. *Geometrical—d*; similar to the last but with no newel posts; the handrail running uninterruptedly from bottom to top. The angles of the well-hole are generally rounded.

5. *Circular newel—e.*

6. *Circular geometrical—f*; when without a central newel.

Width—Stairs should be 3′ 6″ wide to allow two persons to pass easily.

Tread and Rise.—Tread should be from 9″ to 12″, rise from 6″ to 7½″. Tread increases as rise decreases. The following rules are in use for proportioning rise and tread of steps :—

1st. Tread in inches + twice rise in inches = 24. 2nd. Tread × rise = 66.

Flights.—It is dangerous to have a stair between two floors in one continuous flight. Considering convenience and effect, it is desirable to limit height of one flight to about 7′, and to avoid having two flights in one direction. *Winders* should be avoided if possible.

Handrail.—Upper surface should be from 2′ 7″ to 2′ 9″ above the surface of the tread at the nosings, and on landings from 3′ to 3′ 3″. Or, taking the height at landings as 3′ subtract ½ the rise for height of rail from nosings of steps.

Materials.—In lofty dwellings it is desirable that stairs should be of stone or concrete, to be fireproof, at any rate in the lower storeys.

Stone Stairs.—Steps are supported by a wall at one or both sides. When at one side only they are called hanging steps, and should be built at least 9″ into the wall. The bottom step is bedded on the floor, and the lower front edge of each other step rests on the upper back edge of the step below. The best form for the joint is shown in fig. 500, where the face *ab* is at right angles to the general inclination of the stair, and about 1″ wide. Spandrel steps should have the sides which are built into the wall left square.

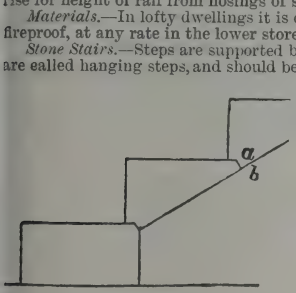
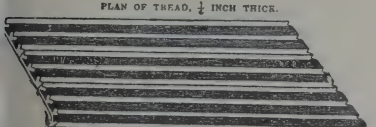


FIG. 500.

Repairing Stone Steps when Worn.—One plan is to fill up the hollows with Portland cement concrete made with fine sharp washed gravel about the size of a pea, 1 part gravel, 1 part cement. The worn part should be chiselled down, so as to give at least ¾″ thickness of concrete in every part. The edge of concrete steps should always be rounded. Another method is to insert and cement slabs of artificial stone instead of concrete; the stone known as the 'Silex' brand is very suitable for the purpose.



Lines thus ▭ *represent Lead—other parts Chilled Steel. Brass, or other Hardened Metals.*

FIG. 501.

MASON'S TREADS.

(*Patent.*)

These treads, fig. 501, which have remarkable unwearable and non-slipping qualities, are adapted to either wood or stone stairs. The arrangement is such that a hard metal withstands the wear, and a soft one gives the foothold.

Wooden Stairs.—Fig. 502.—Treads should be of hard wood, 1½″ thick, for steps 4′ long, increasing ¼″ for every additional 6″ of length.

The treads and risers are supported by a wall string and an outer string, the former 1½″ thick, the latter 2″. Treads and risers are housed into the wall string, and secured by wedges.

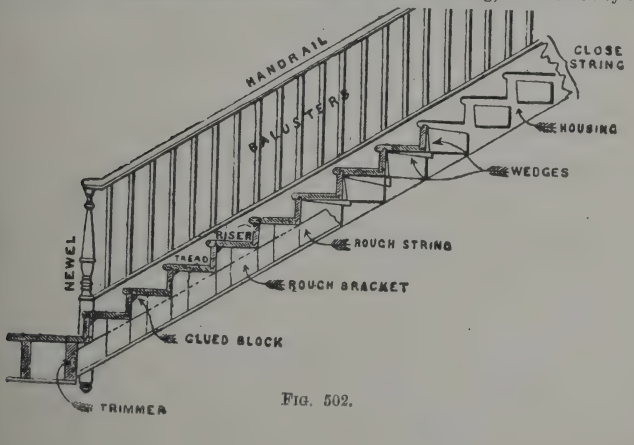


FIG. 502.

The outer ends may be either housed into a close string, or may rest on and be mitred to the notches of an open string.

When stairs are more than 3 ft. wide, treads should be supported by rough strings or carriages fixed underneath and framed into the trimming joists of the landings. Scantlings of rough strings are calculated as bridging joists. Rough brackets are nailed to the side of the rough string to support the treads.

Joints between treads and risers are grooved and tongued, feathered or rebated. The last is the best joint.

Heat Transmission through Walls, Concretes and Plasters.

See *Building Research Board, Special Report, No.* 7, 1923 (published by His Majesty's Stationery Office, Imperial House, Kingsway, London, W.C. 2; price 1*s.* 6*d.* net).

This report gives the results of experiments carried out at the National Physical Laboratory by Ezer Griffiths, D.Sc.

SECTION IX

BUILDING MATERIALS AND CONSTRUCTION

(With Contributions by A. L. Howard, F. A. W. Philips, M.I.C.E., J. T. Rea, A. B. Searle, Robert S. Vesey, G. Stanley Walpole, D.Sc., F.I.C., and other authorities.)

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TIMBER — WOODEN PILLARS — ROOFS — BRICKWORK — WALLS — LONDON BUILDING ACTS — FOUNDATIONS — MASONRY (pp. 449-484)

PART II

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PART III

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SECTION IX

BUILDING MATERIALS AND CONSTRUCTION

PART I

TIMBER—SEASONING—CREOSOTING—WOODEN PILLARS—ROOFS—BRICKWORK—WALLS—LONDON BUILDING ACTS—FOUNDATIONS—MASONRY.

TIMBER.

(Contributed by Alexander L. Howard.)

In all specifications for building materials and construction, it is customary to use the terms 'Timbering,' 'Joiners' work,' and 'Cabinet work.' The first-named applies only to the wood used in constructional work. These terms are again subdivided into the following :—

Baulks.—Small-sized squares up to 9 ins.

Timber.—Includes everything, whether hewn or sawn, above the size of baulks.

Planks.—Includes everything above 1½ ins. in thickness, and more than 9 ins. in width.

Deals.—Confined entirely to widths of 9 ins. of thicknesses above 1½ ins. Thicknesses less than this are termed deal boards.

Battens.—Includes any thickness above 1½ ins., and over 4 and under 9 ins. in width.

Boards.—Includes everything, whatever the width, of 1½ ins. in thickness and under.

Scantlings.—An inclusive term which covers the whole of the requirements with the exception of prepared floorings, skirting or joiners' work, but which is generally used more particularly to describe small-sized pieces which are not named specifically above, such as 3 ins. × 4 ins., 2½ ins. × 3 ins., etc.

Lumber.—The term used in Canada and the United States for sawn wood of all descriptions.

It is customary in some specifications to require that the boards shall be of deal widths or of batten widths. In such case the above limitations are observed.

For scaffolding, etc., round timber is described by the following terms :—

Scaffold poles.—These range in size from 2½ to 6 ins. in diameter in the middle.

Spars.—Above 6 ins. in diameter in the middle.

Rickers.—Sizes less than the above.

In specifying thicknesses and widths it is customary, except in the case of Government contracts, to accept these after planing; thus, where 1-in. thickness is specified, the completed work is ¼ in. in thickness, while a width of 12 ins. should actually finish a full 11¾ ins.

Timber Measures.

BAULKS AND TIMBER.—Sold at per load of 50 ft. cube. Deals, planks, battens and scantlings at per Petrograd standard. (One standard = 165 ft. cube.)

PREPARED FLOOR BOARDS.—These are usually sold at per square. This is a standard measurement which equals 100 ft. superficial. Till recently it was the trade custom to supply a specific number of feet, according to the width of the board, which should approximate to the square. These were as follows :—

4-in. boards	. . .	300 ft.	
4½	„ . . .	270 „	
5	„ . . .	240 „	
5½	„ . . .	220 „	
6-in. boards	. . .	200 ft.	
6½	„ . . .	190 „	
7	„ . . .	180 „	

This practice, which was always unsatisfactory owing to the inaccuracy of the figures, has now been discontinued.

LUMBER (see above) AND AUSTRALIAN WOOD.—Sold at per 1,000 ft. of 1-in. superficial measure for all thicknesses of 1 in. and over. Under 1 in. at per 1,000 ft. superficial of their thicknesses. Teak at per load of 50 cub. ft.

Descriptions of Soft Woods.

PINE, SCOTS (*Pinus sylvestris*, Linn.).—Commonly called 'red' or 'yellow,' 'red' or 'yellow fir,' 'yellow deal,' 'deal.' Used for joists, floors, roofs, sash-frames, sashes, doors, centering, scaffolding, piles, etc., that is, for all timbering work in buildings excepting where baulks or logs hewn or square sawn are necessary. When reasonably free from sap and in bright condition is very durable. Archangel, Onega, Petrograd, and a few of the Swedish ports supply the best quality, but good qualities also come from other districts.

SPRUCE (*Picea excelsa*, Link.).—Commonly called 'white,' 'white fir,' 'white deal,' or 'white battens.' Used in Scotland and the north-west districts generally, for timbering work and for floorings, skirtings, and joiners' work of the cheaper class. In the midlands and south used for the latter purposes, but there usually considered unsuitable for timbering work. When used for boards, skirtings, joiners' work, etc., and properly ventilated, is fairly durable, though not in the same degree as Scots pine. Archangel, Onega, Petrograd, and some Swedish ports supply, as with Scots pine, the best quality, though good timber also comes from other districts.

SPRUCE, CANADIAN AND AMERICAN (*Picea alba*, Link.).—Although used to a certain extent in Scotland and the north-west districts, and occasionally elsewhere, it is not suitable for building construction as it is not durable, nor does it possess a sufficient degree of strength for such work.

LARCH (*Larix europœa*, DC.).—Not commonly used for building construction, though its strength and durability would recommend it equally with Scots pine. Although the supplies of British-grown larch are not ordinarily made use of for such work, yet its good qualities recommend it for more general consideration.

PINE, PITCH (*Pinus palustris*, Mill.).—Commonly used for large timbering sizes, joiners' work and flooring. Not usually employed for ordinary timbering work. Stronger than the descriptions named above, and equally durable, but only when completely ventilated. Should not be used for constructional work when thorough ventilation is impossible. Imported in all sizes and descriptions sawn and hewn square of large sizes and long lengths. Planks, deals, battens and boards are imported in three qualities described as 'prime,' 'unsorted or rio,' and 'merchantable.' In the import of square sawn or hewn timber the further standard of quality is indicated by the terms 'long leaf' or 'short leaf.' It is probable that the best quality only, i.e. 'long leaf,' is the produce of *Pinus palustris*, while that described as 'short-leaf' is the produce of many sorts, including the Loblolly pine (*P. taeda*, Linn.).

PINE, RED CANADIAN (*Pinus rubra*, Mich.).—Used commonly in Scotland and the north-west districts, and only occasionally in the south and the midlands. Generally shipped in lengths of from 10-16 ft., though occasionally in shorter lengths; on this account generally unsuitable for timbering work: also in deal and plank sizes, and small quantities of other scantlings. Similar to Scots pine in appearance, though slightly redder in colour. Excellent in constructional and joiners' work, though for the latter, perhaps, rather hard in texture. Very durable in all situations, but requires good ventilation.

PINE, AMERICAN WHITE (*Pinus strobus*, Linn.).—Known in England as 'yellow pine,' in Scotland as 'white pine,' or 'yellow pine,' but in America always as 'white pine.' Formerly used for joiners' work in England and largely so in Scotland and the north-west districts, but of late years has been too expensive for such uses.

PINE, OREGON (*Pseudotsuga Douglasii*, Carr.).—Known also as 'British Columbian pine,' and 'Douglas fir.' Obtainable in very long lengths and large sizes, very free from knots and generally only carrying a moderate amount of sapwood. Not very favourably received hitherto as it is not considered durable. Mostly used for roofing timbers for public buildings and for floorings; also a restricted amount for joiners' work; for this purpose not much in favour as the hard grain rises or the soft grain sinks, so presenting a ridgy surface under paint or varnish.

Descriptions of Hard Woods.

ACACIA (*Robinia Pseudacacia*, Linn.).—Weight, 51 lbs.* Europe. Golden-yellow. Hard, very durable, especially in contact with the ground, and in alternate wet and dry. When well seasoned is stronger, stiffer, and tougher than oak. Used for sills, wall-plates, posts, palings, trenails for ships. Would be well adapted for decorative cabinet work.

ACAPU (*Andira aubletii*).—Weight, 70 lbs. Brazil. Dark brown, very hard, durable and strong; excellent for flooring and frame-work.

ALDER (*Alnus glutinosa*, Gaert.).—Weight, 30 lbs. Great Britain. Brown; very durable under water, works well and easily. Valuable for piles, planking, sluices, pumps, etc. Used also in turnery and for other light purposes; large quantities also in the form of plywood.

ALMOND WOOD, INDIAN (*Chickrassia tabularis*, Adr. Juss.).—Weight, 49 lbs. India. Yellowish to reddish-brown, with beautiful satiny lustre and fine silver grain. Seasons and works well. Used for furniture and carving.

ANJAN (*Hardwickia binata*, Roxb.).—Weight, 82 lbs. India. Dark-red, streaked with black or purple; cross-grained, extremely durable, very hard; liable to split, does not warp. Excellent for sleepers but difficult to work; used for naves for cart-wheels, and for agricultural implements.

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* Weights given are average dry weight per cubic foot.

(*Anogeissus latifolia*, Wall.).—Weight, 62 lbs. India. Purple-brown, shining, very hard, strong, and tough but liable to split in seasoning. Used in shipbuilding, for axles of carts and also for furniture.

ASH, ENGLISH, CANADIAN AND AMERICAN (*Fraxinus excelsior*, Linn., *F. americana*, Linn. etc.).—Weight, 41–46 lbs. The British Isles and North America. White to brownish-white, sometimes with darker streaks. Easily worked, very flexible; strong, tough and elastic, therefore well adapted for work exposed to sudden shocks and strains. Not durable unless thoroughly ventilated. Largely used in air-craft construction.

ASH, JAPANESE (*F. mandschurica*, Rupr.).—Weight, 34 lbs. Japan. Not so strong or tough as the English species, although strong enough for many purposes, including carriage building. Takes a high finish; useful for interior fittings and cabinet work. Liable to shrink more in seasoning than English ash, but stands well when seasoned; has an average weight of from 12 to 15 per cent. less.

BASSWOOD (*Tilia americana*, Linn.).—Weight, 30 lbs. North America. Pure white to whitish-brown, soft, easily worked, durable after seasoning though liable to shrink in the process. Used for turnery, carpentry and furniture, and is especially useful in the pianoforte trade. Should not be confounded (although it generally is) with canary whitewood (*q.v.*).

BEECH (*Fagus sylvatica*, Linn.).—Weight, 42 lbs. Europe. Light, yellowish-brown, showing when cut on the quarter the silvery flecks of the medullary rays. Hard, close, fine and even-grained. Very durable when submerged, therefore suitable for piling; used also for machinery, chair-making, tool-handles, turnery, and a great variety of other purposes.

BIRCH (*Betula lenta*, Linn.).—Weight, 48 lbs. Europe and North America. Firm, tough; works up easily to a satiny lustre. Used for wheelwrights' work and for furniture; large quantities also for plywood.

(*Bischofia javanica*, Blume).—Weight, 45 lbs. India. Red, tough, moderately hard. Though liable to warp and crack above ground, yet when in wet ground or completely submerged is almost imperishable. Suitable for piling and all constructional work, and for building.

BLACKBUTT (*Eucalyptus pilularis*, Sm.).—Weight, 57 lbs. Australia. Light-brown, heavy and somewhat difficult to work owing to interlocked grain; very strong and durable. Used in large quantities for street paving and for sleepers; suitable for all constructional work.

BLACKWOOD, AFRICAN (*Dalbergia Melanoxylon*, Guill. and Perr.).—Weight, 74 lbs. Tropical Africa. Sometimes known as Senegal ebony. Dark-brown to jet-black with slightly fragrant scent. Used in turnery and for musical instruments.

BLACKWOOD, AUSTRALIAN (*Acacia Melanoxylon*, R.Br.).—Weight, 45 lbs. Australia. Dark reddish-brown with a lustrous sheen, often beautifully figured. Easily worked, liable to warp unless thoroughly seasoned, but when seasoned stands exceedingly well under the most trying conditions. Useful for all kinds of construction, carpentry and cabinet work. The figured wood is used in the form of veneer for panelling, etc.

BLACKWOOD, BOMBAY. See Rosewood, Indian.

(*Boehmeria rugulosa*, Wedd.).—Weight, 41 lbs. India. Red, moderately hard, smooth and even-grained; seasons well and is easily cut. A splendid wood for carving; suitable for turnery.

BOXWOOD (*Buxus sempervirens*, Linn.).—Weight, 30 to 60 lbs. Europe, Asia Minor, etc. Exceedingly hard, very dense and close in the grain. Cuts well without splintering; susceptible of a fine polish; liable to split unless carefully and thoroughly seasoned. Used largely for blocks for wood-engraving, also in turnery, for instruments for sports and games, etc., and for a great variety of other purposes.

BOXWOOD, KNYSNA, OR EAST LONDON (*Gonioma Kamassi*, E. Mey.).—Weight, 58 lbs. South Africa. Uses as above.

(*Calophyllum spectabile*, Willd.).—Weight, 38 lbs. India and Ceylon. Shining, light-red, cross-grained; squares up to 25 ft., siding 18 ins. Used for masts, spars and planking.

CAMPHORWOOD (*Cinnamomum camphora*, Nees.).—Japan. A medium-grained, fragrant, cinnamon-coloured wood. Used for the linings of drawers and cabinets.

CAMPHORWOOD, BORNEO, or KAPOR (*Dryobalanops aromatica*, Gaert.).—Weight, 47 lbs. Malay Peninsula. Straight-grained, hard, tough, and durable. Used for heavy constructional work, planks, beams, piles, etc., and for joiners' work and shipbuilding.

CEDAR.—A name given erroneously to many species of *Juniperus* and *Cedrela*, etc. True cedars are the Himalayan (Deodar), Atlantic and Lebanon cedars.

CEDAR, CIGAR BOX (*Cedrela odorata*, Linn.).—Weight, 30 lbs. Tropical America. Also known as West Indian cedar. A soft, red, fragrant wood; used as its name implies.

CEDAR, MOULMEIN (*Cedrela Toona*, Roxb.).—Weight, 30 lbs. India. Warm red, durable and easy to work. Used for cabinet-making, furniture, cigar boxes and carving.

CEDAR, PENCIL (*Juniperus virginiana*, Linn.).—Alternatively known as red cedar and Virginian cedar. Weight, 30 lbs. United States. Light, soft and fine-grained. Very durable, especially in contact with the soil. Used chiefly for pencil-making; also employed, though to a limited extent, for cabinet work and panelling.

CHAPLASH (*Artocarpus Chaplasha*, Roxb.).—Weight, 34 lbs. India. Yellow to brown, even-grained; seasons well and is durable. Suitable for building and joiners' work; also for furniture.

CHESTNUT (*Castanea vesca*, Gaert.).—Weight, 30–40 lbs. Europe. Commonly called 'Sweet Chestnut,' or 'Spanish Chestnut.' Light to dark brown; resembles oak, from which it is only distinguished by the absence of the pronounced medullary ray so evident in that timber. A very valuable wood, insufficiently appreciated. Easier to work than oak, although more tough,

not so strong or stiff. Very durable in water when wholly submerged, or in outdoor work where ventilated, and in joiners', cabinet and panelling work. Does not shrink or swell much; gives way suddenly under cross-strains. Used in the past for roof timbers and panelling; often mixed with oak (a very intelligent manner of use, as, unlike oak, insects, fungus, wood-boring beetles, etc., dislike it, so that its use mixed with oak has helped to preserve the latter from such attacks). Also largely employed for fencing, posts and rails, hop-poles and furniture. Large-sized trees are much spoilt by spiral growth and cup and heart shakes, suggesting careless forestry during growth.

CHESTNUT, HORSE (*Aesculus hippocastanum*, Linn.).—Weight, 30 lbs. Europe. Yellowish-white, soft, and not very durable. Used for rollers in cotton mills.

COCOBOLO.—Weight, 70 lbs. South America. A handsome, rich dark-red wood streaked with black or orange; hard, strong and durable. Used chiefly in the form of veneer for decorative work, such as brush backs, handles, and turnery.

COCOBOLO, INDIAN (*Dalbergia cultrata*, Grah.).—Weight, 70 lbs. Burma. Dark red to purple, streaked with black; very hard. Uses as above.

COCUS-WOOD (*Brya ebenus*, DC.).—Weight, 70 lbs. The West Indies. Dark bronze to brown or purple; very heavy, fine and even-grained, durable. Used for musical instruments and general turnery.

COROMANDEL or CALAMANDER-WOOD (*Diospyros quaesita*, Thw.).—Weight, 57 lbs. Ceylon. Greyish-brown streaked with black. A most valuable ornamental wood, in demand for cabinet work.

CUTCH or KHAIR (*Acacia Catechu*, Willd.).—Weight, 65 lbs. India. A hard wood, varying from light to dark red; seasons well, takes a fine polish and is durable. Employed in house-building, wheelwrights' work and for agricultural implements.

DILO (*Calophyllum inophyllum*, Linn.).—Weight, 42 lbs. India and Burma. Sometimes known as the Alexandrian laurel. Reddish-brown, close-grained. Used in India for such work as shipbuilding, machinery and masts, but would be excellent for cabinet-making.

EBONY (*Diospyros ebenum*, Kœnig, etc.).—Weight, 60–80 lbs. India, Ceylon, Africa. Ebonies vary in their degree of blackness, few are jet black; all, however, are heavy, hard and close-grained, and generally durable. Often used in the form of veneer for decorative cabinet work; also employed for inlay and turnery.

ELM, ENGLISH AND AMERICAN (*Ulmus campestris*, Linn., *U. americana*, Linn., etc.).—Weight, 40 lbs. Europe, N. America. Dark-brown, tough, twisted in grain, and therefore difficult to work. Durable both when completely submerged, as in piles, and when perfectly dry, but soon rots when exposed to alternate wet and dry. Warps and twists in seasoning and shrinks very much, but is not liable to split; takes nails well; not so strong, stiff, or tough, as oak. Used largely for piles, water-pipes, pumps, etc., also for coffins, agricultural tools, naves of wheels, sheaves of blocks, keels of ships, and also for chair-making.

ELM, ROCK (*Ulmus racemosa*, Thomas).—Weight, 45 lbs. Canada and the United States. Light yellowish-brown, becoming paler on exposure. Tough, elastic, very strong; durable when submerged or when thoroughly ventilated. Used for boat and ship building, ladders for ships, rubbing pieces, hoops for casks, and many other important works. Supplies of good quality growing scarce.

ELM, WYCH OR SCOTCH (*Ulmus montana*, Smith).—Lighter-brown in colour, softer and more straight-grained and therefore more easily split than English elm. Used largely in chair-making, boat-building, and for agricultural implements.

ENG or IN (*Dipterocarpus tuberculatus*, Roxb.).—Weight, 54 lbs. Burma. This dark reddish-brown wood is one of the valuable timbers of Burma. Very durable and in great demand for house and boat-building. Has been used in this country very successfully for parquet flooring; excellent for all constructional work.

(*Gmelina arborea*, Roxb.).—Weight, 36 lbs. India, Burma. Golden-yellow to greyish-white, with a glossy sheen; soft, even-grained, durable; does not warp or crack, easily worked. Used for furniture, door-panels, carriage-building, boats, light planking, etc., and in all works where shrinkage is to be avoided. Roxburgh, writing considerably over a century ago, spoke of the great value of this wood. Will probably be most appreciated for cabinet work.

GREENHEART, DEMERARA AND SURINAM (*Nectandra rodioei*, Schomb.).—Weight, 70 lbs. British and Dutch Guiana and tropical South America. Dark greenish-brown, clean and straight in the grain, hard and heavy; tough, strong and elastic. Heartwood extremely durable. Resists teredo and therefore largely used for piles, wharves and jetties; also in shipbuilding, machinery and planking; one of the best woods for fishing rods. In strength exceeds most other woods, whether tried by transverse or tensile strain. When tested for crushing force in the direction of the fibres it bears the addition of weight after weight till the crushing force is obtained. It then, with a loud report, gives way suddenly and nothing is left but a loose mass of shapeless fibres.

GREENHEART, BURMA (*Heterophragma adenophyllum*, Seem.).—Weight, 48 lbs. India, Burma Andaman Islands. Bronze to greenish-yellow, greatly resembling the Surinam. Does not warp or split. Suitable for cabinet work.

GUM, BLUE (*Eucalyptus Globulus*, Labill.).—Weight, 50 lbs. Australia. Light-brown hard, heavy, tough, elastic; somewhat interlocked grain, durable. Used for shipbuilding telegraph poles, felloes, shafts, spokes and piles. Employed for the piles in Dover Harbour.

GUM, RED (*E. calophylla*, R.Br.).—Weight, 60 lbs. Australia. Yellowish-red, fairly dens

and hard, splits readily; the prevalence of gum veins impairs its suitability for constructional work. Not durable underground. Used for axe and other handles, spokes, naves, fencing rails, and agricultural implements.

GURJUN (*Dipterocarpus turbinatus*, Gaert.).—Weight, 50 lbs. Andaman Islands and Burma. Reddish-brown, capable of a smooth finish, durable; possessed of an agreeable aromatic scent which is fairly persistent. Has a close, hard, non-fibrous grain which makes the wood very suitable for a number of purposes where smoothness of surface and hard wear are required. Long lengths and large sizes can be obtained free from all defects, and the supply is expected to be on a very extensive scale. The wood seasons slowly, but although unreliable if unseasoned, when properly dried stands well. Where used for joinery work, cabinet work, ships' fittings, and floorings should always be artificially seasoned. Should be quarter sawn where employed in works of importance. Suitable for all the above named purposes and particularly for floorings, solid and parquet, especially where hard wear is required.

HALDU, INDIAN (*Adina cordifolia*, Hook. f.).—Weight, 42 lbs. India, Burma. Lustrous golden-yellow, even-grained, capable of a fine finish from the tool; durable, seasons well. A beautiful wood for cabinet-making and turnery, and is especially suitable for carving.

HICKORY (*Hicoria alba*, Britt., etc.).—Weight, 50 lbs. North America. Brownish-white to reddish-brown, hard, strong, exceedingly tough, springy and elastic; smooth and straight-grained. Liable to shrink and warp, not durable if exposed. Used very largely for spokes and rims of carriage wheels; also for gunstocks, chair-making, and carriage-building; the best wood yet discovered for golf shafts.

HINOKI (*Cupressus obtusa*, Koch.).—Japan. Yellow to rose-red, sweet-scented, fine-grained, takes a high polish. Used in Japan for decorative work in buildings, etc.

HORNBEAM (*Carpinus betulus*, Linn.).—Weight, 50 lbs. Europe. Yellowish-white; hard, heavy, close-grained; loses much weight in drying, tough and difficult to split. Durable if kept dry, but decays quickly if exposed to wet. Used for cogs, handles, mallets and pianoforte keys.

IROKO (*Chlorophora excelsa*, Benth. and Hook. f.).—Often miscalled African teak. Weight, 54 lbs. Tropical Africa. Yellow to brown, darkening on exposure; strong, straight-grained, very durable. Used as a substitute for teak for gun carriages, joinery and cabinet work, building and constructional work.

IRONBARK (*Eucalyptus leucoxylon*, F. v. M.).—New South Wales. Deep red, hard, heavy, strong, difficult to work. Suitable for piers, wharves, etc., and constructional work generally.

JARRAH (*E. marginata*, Sm.).—Weight, 60 lbs. Western Australia. Reddish in colour, hard, dense, straight-grained, with somewhat interlocked fibres; very durable both in and above ground, and almost non-inflammable. An excellent timber, obtainable in very long lengths and wide widths. Used for all heavy constructional and engineering works, piles for docks, wharves, jetties, and fencing. Excellent for flooring, house-building and for street paving blocks; suitable also for cabinet work.

JARUL (*Lagerstroemia Flos-reginae*, Retz.).—Weight, 43 lbs. India, Burma. Light red and lustrous. Used for shipbuilding, constructional work, and for carts; suitable for cabinet-making.

KAKI (*Diospyros Kaki*, Linn. f.).—Japan. Dark grey streaked with black. This is the Japanese ebony. Used in turnery and ornamental work.

KARRI (*Eucalyptus diversicolor*, F. v. M.).—Weight, 63 lbs. Western Australia. Greatly resembles jarrah in appearance; red, dense, tough, elastic; produces timber of exceptional size. Suitable for most of the uses to which jarrah is put, though it is not so durable for underground work or in damp situations. Somewhat prone to dry rot; almost non-inflammable. The heart-wood core should be avoided. When 'Powellised,' is now reported as exceedingly durable and termite-proof for sleepers, etc.

KAURI PINE or COWDIE PINE (*Agathis australis*, Salisb.).—Weight, 38 lbs. New Zealand. Yellowish-white or straw colour, strong, fine, and even-grained; planes well and takes a good polish with a silky lustre on the surface; shrinks very little and is remarkably free from defects. Very valuable for deck planking and for fitments in ships; also used for joiners' work and ornamental purposes.

KEYAKI (*Zelkowa acuminata*, Planch.).—Japan. Hard and strong; lustrous and often highly-figured, when it is used for fine cabinet work. Also employed in building and naval architecture; excellent for carving.

KINGWOOD.—Brazil. A handsome dark brown streaked with crimson to violet and purple, fine grained. Used in fancy cabinet work and turnery, generally in the form of veneer.

LABURNUM (*Cytisus laburnum*, Linn.).—Europe. Dark brown to bronze, hard and close grained; takes a good polish. Used in turnery and for pulleys and blocks.

LANCEWOOD (*Guatteria virgata*, Dun.).—Weight, 50 lbs. Central and South America. Light yellow, hard and close grained, elastic. Used for carts, carriages, and shafts, and also for fishing rods.

LANCEWOOD, BURMA (*Homalium tomentosum*, Benth.).—Weight, 59 lbs. India and Burma. Greyish-brown, fine, close and even grained. Takes a very smooth surface, is apt to split in seasoning, durable. Suitable for furniture.

LANCEWOOD, INDIAN GREY (*Vitex glabrata*, Br.).—Weight, 42 lbs. India, Ceylon. Light greyish-brown with a lustrous sheen and a ripple-like figure. Takes a good polish and would be excellent for furniture.

LAUAN (*Dipterocarpus thurifer*, Blanco).—The Philippine Islands. Dark brown, strong, and heavy. Suitable for shipbuilding and furniture.

LAUREL-WOOD. See Walnut, Indian.

LEZA-WOOD (*Lagerstroemia tomentosa*, Presl.).—Weight, 50 lbs. Burma. Grey to greyish-brown, soft, works easily and takes a good polish. Would be suitable for furniture.

LIGNUM-VITAE (*Guaiacum officinale*, Linn.).—Weight, 70 lbs. Central and tropical South America. Dark greenish-brown to black, hard, heavy, strong and close-grained; almost imperishable; liable to cup-shake. Used for pestles, mortars, croquet, and other mallets, and for a great variety of purposes. Has a unique value for propeller shafts for steamers on account of its lubricating qualities.

LIGNUM-VITAE, INDIAN (*Berrya ammonilla*, Roxb.).—Weight, 62 lbs. India. Brown to purplish-red, flecked as in English beech; firm, hard texture, and satiny lustre; has a sticky feeling to the touch, planes well. Suitable for decorative cabinet work and turnery.

LIME (*Tilia cordata*, Miller.).—Weight, 30 lbs. Europe. Pale yellowish-white, soft and light; easily cut and carved; not very durable when exposed to the weather. Excellent for carving, for pianofortes and models of buildings.

LUMBAYAO (*Tarrietia javanica*, Bl.).—Weight, 44 lbs. The Philippines. Dark to light red, light and easy to work. Used for furniture.

MAGNOLIA (*Magnolia acuminata*, Linn.).—Weight, 30 lbs. United States. White, soft, not strong, but very durable. Used for interior fittings and occasionally in cabinet work. Somewhat similar to canary whitewood.

MAHOGANY.—Species uncertain. Supplies received from St. Domingo (Spanish), Cuba, Honduras, Mexico, Panama, Nicaragua, Colombia and the districts of Central America generally; the West Coast of Africa. One of the most valuable of all decorative woods, the merits of which are so universally acknowledged that further description is unnecessary.

MAHWA (*Bassia latifolia*, Roxb.).—Weight, 62 lbs. India, Burma. Reddish brown; used for house-building, furniture, naves of wheels, etc.

MALLET-WOOD, INDIAN (*Schleichera trijuga*, Willd.).—Weight, 68 lbs. India and Burma. Light reddish-brown, seasons well, takes a good polish; strong and durable but somewhat difficult to work. Suitable for handles, agricultural implements, and for furniture.

MAPLE (*Acer saccharinum*, Wang.).—Weight, 40 lbs. Canada and the United States. Creamy to yellowish-white; has a fine, smooth surface and a dense, even grain; tough and strong. Excellent for flooring, especially for hard wear, and for veneering and interior finish; also for furniture. Birds-eye maple is the figured variety, and is appreciated for cabinet work.

MARBLE-WOOD, ANDAMAN (*Diospyros Kurzii*, Hiern.).—Weight, 61 lbs. Andaman Islands. A unique and handsome wood, grey streaked with black, smooth and cold to the touch; liable to shrink and warp unless thoroughly seasoned. Valuable for cabinet work and for walking-sticks, etc.

(*Melia composita*, Willd.).—Weight, 28 lbs. India. Pale brown, resembling cedar in this, as also in grain and texture; durable and light in weight. Suitable for sugar boxes, and for boat and yacht building.

(*Mesua ferrea*, Linn.).—Weight, 72 lbs. India, Burma. Dark red, extremely hard, strong and heavy; good sizes procurable. Suitable for sleepers, wood-paving blocks, etc.

MINGRIS (*Koompassia Beccariana*, Taub.).—Borneo. Light red, very hard and heavy; not durable.

MIRABOW or MIRABOO (*Intsia Bakeri*, Prain.).—Weight, 54 lbs. Borneo, Malay States. Reddish-brown, darkening with age, hard, fine, even-grained; often beautifully figured. Tough, durable, and susceptible of a fine polish. Suitable for decorative furniture.

MORA (*Mora excelsa*, Baill. and Benth.).—Weight, 60 lbs. British and Dutch Guiana. Chestnut-brown, hard, heavy, tough. Usually straight in the grain, but sometimes wavy, which gives a beautiful figure. Takes a good polish, and therefore suitable for furniture. Extremely durable; useful for sleepers, and for beams, keelsons, etc., in shipbuilding; and also in a general way in large scantlings for civil and naval architecture.

MULBERRY, YELLOW (*Morus laevigata*, Wall.).—Weight, 45 lbs. India, Burma. Very beautiful golden to chrome yellow, shining and lustrous; has a pretty silver grain; hard and close grained. Suitable for furniture, turnery, and decorative work generally.

MYALL or VIOLET-WOOD (*Acacia pendula*, A. Cunn.).—Weight, 76 lbs. Australia. Rich dark brown, hard, heavy, close grained, often figured. Has a faint scent of violets. Suitable for veneer, turnery, etc.

NIRI (*Xylocarpus borneensis*, Becc.).—Borneo and the Philippines. Dark red, hard and heavy; fine grained and durable, shrinks little in seasoning. Useful for furniture.

OAK (*Quercus pedunculata*, Ehrh., and *Q. sessiliflora*, Sm., etc.).—Europe, etc.

British.—Weight 53 lbs. Light-brown in colour, hard, tough, very strong. Does not easily splinter; durable under water, above ground and in alternate wet and dry. Apt to warp and split in seasoning, but when once thoroughly seasoned few woods stand better. Must not be used in immediate contact with iron. Uses so extensive that it would be impossible to enumerate. Should be more extensively used, however, for panelling and decorative work generally, in place of other supplies which are not so good.

Austrian.—So-called Austrian oak was largely used before the war for decorative panelling, floorings, etc., although in point of fact it was more often specified than supplied. A clean, mild oak, generally free from much defect.

Dantzig.—Similar to the above, though slightly stronger and harder; possesses elasticity in marked degree.

Riga, Libau, and *Odessa* oak are similar to Austrian. The last-named yields slightly larger mensions.

French.—Resembles supplies of British, but is generally milder in character.

Italian.—Heavier and less elastic than the British; harder and more difficult to work. No pplies have been forthcoming of late years.

American (*Quercus alba, etc.*).—Weight, 42 lbs. Supplies of American oak include the produce over twenty-two different botanical species, consequently supplies vary largely in quality, xture, durability and colour. American oak is not employed in the best descriptions of work.

Japanese (*Quercus grossesserrata,* Bl., *Q. crispula, etc.*).—Weight, 40 lbs. Similar in appear- nce to the European, generally closer in texture; slightly milder than the Austrian, from hich it is almost impossible to distinguish it except by examination with the lens. Possesses a ery uniform colour. Suitable for the best descriptions of work.

Wainscot.—A term used to describe the produce of any oak when hewn, sawn, or reft on the uarter.

PADAUK, ANDAMAN (*Pterocarpus dalbergioides,* Roxb.).—Weight, 48 lbs. Andaman Islands. handsome crimson-coloured wood, sometimes streaked with black or brown, often finely figured. easons and works well, takes a good polish; shrinks very little, does not crack or split; not bject to dry rot. Excellent for all interior decoration and fittings and for furniture. One of e best woods for gun-carriages and ordnance work; has given good results for flooring. Used America for such work as the trimming of Pullman cars, the decoration of public and private uildings and for furniture.

PADAUK, BURMA (*P. macrocarpus,* Kurz.).—Weight, 60 lbs. Burma. Resembles the An- aman variety, but is darker in colour, harder and heavier. Used for the same purposes, though ossibly a slightly inferior wood.

PARTRIDGE WOOD (*Andira inermis,* Kunth.).—Brazil. Reddish-brown to black, figured and ottled. Used for cabinet work, turnery, umbrella and walking-sticks, etc.

PEAR TREE (*Pyrus communis,* Linn.).—Weight, 50 lbs. Europe. Pale brown, tough and ifficult to split; close grained. Cuts with great facility in any direction without splitting, and herefore used largely for carving and wood-engraving; also for musical instruments and for rnery. Needs careful and thorough seasoning.

PLANE (*Platanus occidentalis,* Linn.).—Weight, 30 lbs. North America. Sometimes known s button-wood. Light brownish-yellow, shows a fine figure when cut on the quarter. Used r blocks, screws, etc.

POON (*Calophyllum tomentosum,* Wight.).—Weight, 40 lbs. India. Pale, rather reddish ahogany colour with darker red veins. Close, firm, hard grain; takes a smooth surface, stands ell. Suitable for decorative cabinet work.

POPLAR (*Populus alba,* Linn., and *P. nigra,* Linn.).—Weight, 30 lbs. Europe. Light reddish- rown, soft, light; neither strong nor durable. Used for such work as turnery, clog-making, nd toys; latterly in much demand for plywood.

PRIMA VERA or WHITE MAHOGANY.—North America. Light creamy yellow, often figured. sed for interior decoration.

PURIRI (*Vitex littoralis,* A. Cunn.).—Weight, 60 lbs. New Zealand. Dark brown, hard, eavy, close grained; very strong and durable. Suitable for heavy constructional work such as iles, posts and sleepers.

PURPLEHEART (*Peltogyne paniculata,* Benth.).—Weight, 50 lbs. Tropical South America. ich purple, hard, heavy, and lustrous; works well. Used for flooring and all ornamental work, uch as marquetry and turnery.

PYINMA (*Lagerstroemia hypoleuca,* Kurz.).—Weight, 40 lbs. Andaman Islands. Red, hard, easons well, durable; easy to work. Suitable for house-building, and for spokes and felloes of heels.

PYINKADO (*Xylia dolabriformis,* Benth.).—Weight, 60 lbs. India. Rich, warm reddish- rown; close, firm; hard, rather cross-grained texture; cold and sticky to the touch. Very eavy, and becomes harder with age. Extremely durable, probably on account of the resinous ibstances contained in it. Largely used for railway sleepers. Suitable also for paving blocks, legraph posts, building, piles, and beams of bridges and similar constructional work.

RASPBERRY-JAM WOOD (*Acacia acuminata,* Benth.).—Weight, 60 lbs. Australia. Dark eddish-brown to purple, streaked with black; has a scent like crushed raspberries; somewhat ifficult to work. Used in ornamental cabinet work and turnery.

ROSEWOOD, BAHIA AND RIO (*Dalbergia nigra,* Fr. Allem.).—Weight, 60 lbs. Brazil. The rst-named is the superior wood. Dark reddish or purplish-brown, streaked with black; faint ent like rosewater. Dense and heavy, takes a fine polish; liable to heart-shake. Used both olid and in veneer for ornamental cabinet work. Less used now than formerly.

ROSEWOOD, INDIAN (*Dalbergia latifolia,* Roxb.).—Weight, 50 lbs. India. Alternatively nown as East Indian or Bombay rosewood and Bombay blackwood. Dark purple streaked ith black, hard and close grained; takes a good polish. Available in long lengths and very rge sizes of perfect quality. Useful for cabinet work; would be excellent for panelling.

SABICU (*Lysiloma Sabicu,* Benth.).—Weight, 50 lbs. The West Indies. Dark brown, some- mes streaked with black, often finely figured; hard, heavy, close grained; susceptible of a good olish. Used for shipbuilding, interior fittings, cabinet work, furniture, etc.

SAL (*Shorea robusta*, Wall.).—Weight, 60 lbs. Burma. Similar in colour to Indian sal, but more even grained; hard and durable. Used for building and also for small work such as tool handles.

SALMON WOOD, INDIAN (*Eriolaena Candollei*, Wall.).—Weight, 51 lbs. Burma. Bright salmon-red, handsomely marked; hard, shining, close grained, takes a fine polish, seasons well. Suitable for decorative cabinet work, bandings, and inlay.

SANDERS, RED (*Pterocarpus santalinus*, Linn. f.).—Weight, 75 lbs. India. Dark claret-red, sometimes nearly black, streaked with dark violet. Valuable for decorative cabinet work and inlay.

SATINEE (*Ferolia guianensis*, Aubl.).—Weight, 55 lbs. South America. Light reddish-brown, hard, tough, elastic; takes a good polish. Suitable for furniture, also for fishing rods.

SATIN WALNUT (*Liquidambar styraciflua*, Linn.).—Weight, 40 lbs. North America. Should be called gum, by which name it is known in America; has been called hazel pine, sweet gum, and Californian red gum in England. Has no qualities which justify its being called either walnut or pine. Pale reddish-brown, soft, close grained, has a smooth, satiny sheen. Warps and twists badly in drying, and even when seasoned is susceptible to change in the atmosphere. Used for cheap furniture; quite unfitted for street-paving, for which purpose it was tried in London some years ago.

SATINWOOD, WEST INDIAN (*Zanthoxylum*, sp.).—Porto Rico, St. Domingo and the West Indies generally. Chrome yellow to golden, maturing with age to a rose yellow; has a beautiful satin lustre, often finely figured. Used for the finest cabinet work, brush backs, etc.

SATINWOOD, EAST INDIAN (*Chloroxylon Swietenia*, DC.).—Weight, 60 lbs. Ceylon and occasionally from India. Uses similar to the above.

SISSOO (*Dalbergia Sissoo*, Roxb.).—Weight, 50 lbs. India. Rich warm brown, sometimes streaked with golden or darker brown. Firm, hard, even texture; takes a very smooth surface and a good polish; strong and durable, seasons well. Capable of being carved to any depth in the most intricate shapes without splintering. Suitable for furniture and carving, also for gun-carriage wheels.

STRINGYBARK (*Eucalyptus obliqua*, L'Hérit.).—Weight, 60 lbs. Australia and Tasmania. Brown, hard, heavy, strong, tough and close grained. Splits easily; requires careful seasoning; liable to shakes and gum veins. Useful for a large variety of purposes, including fencing, flooring, piling, paving, mine timbering, and shipbuilding.

SYCAMORE (*Acer Pseudo-platanus*, Linn.).—Weight, 40 lbs. Europe. Yellowish-white, often finely-figured, even grained, lustrous, easily worked; apt to crack and warp during seasoning. Used for rollers for calico printing, also for washing machines, and, in the form of veneer, for panelling in carriages and railway coaches. When stained grey forms the 'greywood' of commerce.

TALLOW-WOOD (*Eucalyptus microcorys*, F. v. M.).—Weight, 60 lbs. Australia. Yellowish-brown, sometimes wavy in grain, strong and durable; liable to shakes. Used for wheelwright's work, piling, and flooring.

TALLOW-WOOD, INDIAN (*Terminalia Chebula*, Retz.).—Weight, 48 lbs. India. Purplish-grey to brown, with a fine ripple marking. Fairly durable, takes a good polish; cross grained and hard, somewhat difficult to work. Suitable for furniture, house-building, and golf heads.

TAPANG (*Koompassia excelsa*, Taub.).—Borneo. Dark reddish-brown, dense and heavy; durable and strong, but very brittle; obtainable in large sizes. Suitable for heavy construction work.

TEAK, BORNEO.—This term is an entire misnomer, having been wrongfully applied to a Borneo wood which is certainly not teak; *Tectona grandis* has never been found in Borneo.

TEAK, JAVA (*Tectona grandis*, Linn. f.).—Weight, 43 lbs. Java. Shorter in length and inferior in quality to Indian teak; otherwise similar.

TEAK, MOULMEIN, RANGOON, and BANGKOK (*Tectona grandis*, Linn. f.).—Weight, 45 lbs. India, Burma and Siam. Yellow to brown, darkening with age; moderately hard and strong. Contains an essential oil which acts as a preservative; extremely durable; often unsound at the centre. The chief export timber of India and Burma. Used for an immense variety of purposes for the backing of armour plates in battleships, also house and boatbuilding and all constructional work; flooring, sleepers, carpentry, carriage-building, etc.

THINGAN (*Hopea odorata*, Roxb.).—Weight, 40 lbs. India. Bright canary yellow, resembling satinwood; mild, straight grain similar to mahogany and of the same texture; very durable; large supplies available in good sizes. Excellent for cabinet work, etc.

THITKA (*Pentace burmanica*, Kurz.).—Weight, 44 lbs. India. Light red, resembling cedar with a pretty silver grain. Strong and durable; takes a very smooth surface and a fine polish. Suitable for artistic decorative work.

TOTARA (*Podocarpus Totara*, A. Cunn.).—Weight, 30 lbs. New Zealand. Red, fine, and even grained, hard, heavy, tough, and very durable. Does not warp or twist; resists teredo. Used for piles, sleepers, telegraph poles and general building purposes; suitable also for interior fittings, etc.

TUART (*Eucalyptus gomphocephala*, DC.).—Weight, 70 lbs. Australia. Creamy-yellow, hard, very heavy, tough, durable; has an interlocked grain. One of the strongest timbers known and in demand where special strength and hardness are necessary. Used for railway wagons, engine-bearers, ships' beams, planking, shafts, naves and felloes, and wheelwright's work generally.

TULIP-WOOD (*Physocalymma scaberrimum*, Pohl.).—Brazil. Striped pink to rose colour. sed chiefly for bandings, inlay, and marquetry.

TULIP-WOOD, INDIAN (*Dalbergia Oliveri*, Gamble).—Weight, 66 lbs. India. Striped pinkish- d; very hard and cross-grained. Suitable for similar purposes to the above.

TUPELO (*Nyssa sylvatica*, Marsh.).—Weight, 40 lbs. North America. Also called tupelo um. White to light yellow, paling somewhat on exposure to air; smooth and close-grained; able to warp. Used in a general way as a substitute for whitewood, also for electric casings nd for furniture.

VENGAI (*Pterocarpus marsupium*, Roxb.).—Weight, 55 lbs. India. Golden yellowish-brown ith lighter and darker streaks; smooth and lustrous; firm and hard with contrary grain; has good figure when cut on the quarter. Used for cabinet work and interior fittings.

WALNUT (*Juglans regia*, Linn.).—Weight, 40 lbs. Europe and Asia. Greyish-brown, often nely marked and figured; hard, firm, close-grained; takes a good polish. Liable to the attacks f worm (beetle) when used for furniture. The finest wood for gun-stocks, as it withstands nock and does not warp. Used for pianofortes and furniture generally.

WALNUT, BLACK (*Juglans nigra*, Linn.).—Weight, 40 lbs. North America. Chocolate- rown to grey, darkening with age. Easily worked and more durable than European walnut; lso less liable to insect attack.

WALNUT, INDIAN (*Albizzia Lebbek*, Benth., and *A. procera*, Benth., *A. odoratissima*, Benth.). -Weight, 46 lbs. India. Rich warm brown, streaked with yellow and black; often has wavy arks and broken roe and mottle. Firm, hard texture; takes a good surface from the tool nd has a bright lustre; seasons and stands well; available in large sizes. Suitable for furniture, anelling, veneer, turnery, and all decorative work.

WALNUT, INDIAN BLACK (*Terminalia tomentosa*, W. and A.).—Weight, 55 lbs. India. Dark rown, variegated with darker streaks; needs careful seasoning; large supplies available. Suit- ble for decorative, cabinet, and instrument work.

WANDOO (*Eucalyptus redunca*, Schau.).—Weight, 70 lbs. Australia. Brownish-red, very ard, strong, dense and durable. Equal to jarrah for railway sleepers; also used for piles, ridge-building, wheelwrights' work, boat-building, fencing, and general building work.

WHITEWOOD, CANARY (*Liriodendron tulipifera*, Linn.).—Weight, 30 lbs. North America. alled in America, poplar, yellow poplar, tulip tree, etc.; known in England as whitewood, anary whitewood, and canary wood; in Scotland, wrongly called basswood. Pale yellow, oft, light, tough; easily worked, takes a good polish and stains well; liable to shrink and warp. seful for indoor building, joinery, wainscoting, chairmaking, carriage-building, etc.

WILLOW (*Salix alba*, Linn., and *S. coerulea*, Linn.).—Weight, 30 lbs. Europe. White, ght, soft, smooth-grained; very durable in water. Used for brake blocks on railway wagons, s it does not readily fire with friction. Largely employed for the making of artificial limbs nd for cricket bats.

YACAL (*Shorea*, sp.).—The Philippines, Borneo. Brown, darkening on exposure; good and urable. Used for railroad ties and for constructional work generally.

YANG (*Dipterocarpus*, sp.).—Siam. Similar in all respects to the Eng of Burma (*q.v.*).

YELLOW HEART (*Fagraea fragrans*, Roxb.).—Weight, 60 lbs. Burma. Light yellowish- rown, hard, close-grained, very durable. Used in Burma for house-building, piles and joinery, ut in this country, where supplies are now arriving, it will probably be most appreciated as first-class cabinet-wood.

YELLOW JACK-WOOD (*Artocarpus integrifolia*, Linn. f.).—Weight, 40 lbs. India, Burma. ich gamboge yellow, darkening somewhat on exposure; has a hard and soft contrary grain. sed for decorative furniture work, brush backs, etc.

YEW (*Taxus baccata*, Linn.).—Weight, 50 lbs. Europe, India, etc. Reddish-brown to amber, ften finely figured; very hard, close-grained and heavy. Said to be more durable than other uropean wood. Tough and elastic. Used for chair-making, walking sticks, furniture; and n the form of veneer for decorative work generally; also for axles, cogs for mill-wheels, etc.

ZEBRA WOOD, RED (*Melanorrhœa usitata*, Wall.).—Weight, 56 lbs. India. Red, with darker d or golden streaks; very hard. Useful for tool handles, and general decorative work. Has een recommended for building, sleepers, gun-stocks, etc.

Durability of Timber.

WOODS WHICH RESIST THE SEA-WORM (*Teredo navalis*).—No complete list of such timbers is ossible, for reports vary as to this quality being possessed by any particular timber, while the ncrease of scientific research and the resultant preventive measures might cause such a list to e considerably enlarged. It is therefore recommended to institute enquiries concerning the imber at the time of purchase.

This same principle should be applied when considering the durability of timber in other articular circumstances.

Strength of Australian Timber.

The following table, compiled by Professor Warren, of the Sydney University, sets forth the respective values of all the Australian best hardwoods in comparison with the Western Australian Jarrah, Karri, and Red Gum :—

Timber.	Weight per Cubic Foot.	Average Strength in Lbs. per Square Inch. Transverse Strength. Modulus of Rupture. 54 ins. × 6 ins. × 4 ins.	Tensile Strength.	Compressive Strength 12 ins. × 3 ins. × 3 ins.	Shearing Strength 6 ins. × 6 ins. × 3 ins.
N.S.W. Timbers :	Lbs.				
Ironbark	75·18	18,204	17,900	10,500	2,200
Tallow-wood	77·06	15,300	13,400	8,500	1,660
Blackbutt	66·69	14,800	21,000	8,600	1,700
Blue gum	73·64	14,700	15,900	7,800	1,800
Grey gum	67·32	17,600	22,000	9,500	2,100
Spotted gum	62·19	15,300	16,400	8,500	2,200
Turpentine	69·34	14,400	17,800	8,500	1,600
Grey or white box	73·62	15,950	21,564	8,021	2,110
Murray red gum	62·19	11,267	13,618	9,397	2,039
Stringybark	71·33	13,083	15,976	6,098	2,089
W.A. Timbers :					
Jarrah	62·0	12,040	16,047	6,839	1,878
Karri	—	11,208	13,920	7,132	1,637
Red Gum	62·5	10,739	22,725	5,476	1,556

Content Sizes and Weights of Timber.

40 cubic feet of unhewn timber
50 „ squared „
600 super. feet of 1-inch planks or deals
400 „ 1½ „ „
300 „ 2 „ „

240 super. feet of 2½-inch planks or deals
200 „ 3 „ „
170 „ 3½ „ „
150 „ 4 „ „
} = 1 load.

120 deals = 1 hundred. Battens are not over 7 inches wide. Deals are not over 9 inches wide. Planks are mostly 11 inches wide.

One square (100 *feet superficial*) *of flooring requires :—*

12-feet deal boards :—	Number.
Rough	12½
Edges shot	12½
Wrought and laid folding	13
Wrought and laid straight joint	13½
Wrought, ploughed, and tongued	14

12-feet battens :—	Number
Rough	16
Edges shot	16½
Wrought and laid folding	17
Wrought and laid straight joint	18

Number of cubic feet in one 1 of timber : Ash, 45 ; elm, 60 ; mahogany, 34 ; beech, 51 ; fir, 65 ; oak, 39.

Standards by which Deals are Sold.

Planks, deals, and battens are usually sold by the number required to make up the same cubic content as 6 score or a long hundred of some standard size; thus, in London the Petrograd standard is used, which with others is given below :—

Standard.	No. of Pieces.	Size.	Feet Cube.	Feet Superficial.
Petrograd	120	12 ft. × 11 ins. × 1½ ins.	= 165	= 1,320
London and Dublin	120	12 ft. × 9 ins. × 3 ins.	= 270	= 1,080
Christiana hundred	120	11 ft. × 9 ins. × 1½ ins.	= 103⅛	= 990
„ „	60	15 ft. × 11 ins. × 1½ ins.	= 103⅛	= 825
Quebec short hundred	100	12 ft. × 11 ins. × 2½ ins.	= 229⅛	= 1,100
„ long „	120	10 ft. × 11 ins. × 3 ins.	= 275	= 1,000
Drammen	120	9 ft. × 6½ ins. × 2½ ins.	= 121⅝	= 585

Prepared floorboards are sold by the customary square, a given number of feet run, as below, arying with the width, so as to approximate to the square of 100 feet superficial :—140 feet run 9-inch boards, 160 feet of 8-inch, 170 feet of 7½-inch, 180 feet of 7-inch, 185 feet of 6¾-inch, 0 feet of 6-inch, 210 feet of 5¾-inch, 220 feet of 5½-inch, 230 feet of 5¼-inch, 240 feet of 5-inch.

To cut the Stoutest Rectangular Beam from a Log.

Divide the diameter into 3 equal parts, *a*, *a*, *a*, and draw lines at right ngles as represented. $h = 1 \cdot 414\, b$. b = diameter ÷ 3.

To cut the Stiffest Rectangular Beam from a Log.

Divide the diameter into 4 equal parts, and draw lines at right angles as presented. $h = 1 \cdot 732\, b$. b = diameter ÷ 2.

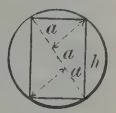


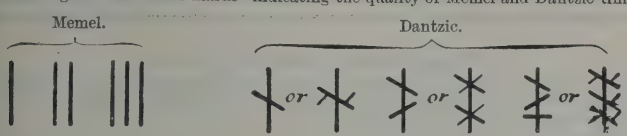
FIG. 1.

Selection of Timber.

In selecting timber the most convenient sizes are 12 inches square. Choose the highest in olour, where the strong red grain appears to rise to the surface; avoid spongy hearts, porous ain, and dead knots.

SCRIBE MARKS.

The following are the 'scribe marks' indicating the quality of Memel and Dantzic timber :—



Memel timber is generally about 13½ or 14 inches square; Dantzic timber about 18 or 19 inches. hen the *slab deals*, or outsides, have been cut away, the log that remains of this timber is nerally 14 to 15 inches square.

Seasoning Timber.

When freshly hewn timber is allowed to dry it shrinks considerably, the effect of the rinkage depending on the shape of the timber. Thus, a sector, A (fig. 4), becomes narrower, a am of square section, B, becomes rhomboidal, and a pole of circular section, C, becomes elliptical. a tree (fig. 2) is sawn lengthwise into nine pieces, the outer layers, being youngest and

FIG. 2.

FIG. 3.

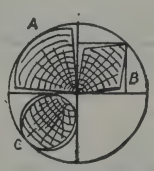


FIG. 4.

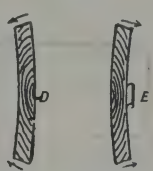


FIG. 5.

ore full of sap, will shrink the most, so that the planks, instead of being straight, will be curved g. 3), the centre plank contracting chiefly at its ends, and the side planks as at D (fig. 5). ven when a plank has been thoroughly dried in the open air, if a thick shaving is taken off it, e newly exposed surface will shrink, drawing the wood inwards as in E. In consequence of shrinkage, freshly felled timber will warp badly in use, unless it has been *seasoned*—i.e. eated in such a manner that all the shrinkage takes place before the wood is used. For this rpose the timber is sawn into planks and 'seasoned' by (*a*) exposing it to the weather, immersing it in water for some weeks and then allowing it to dry, (*c*) drying it by artificial

heat in suitable chambers known as 'kilns.' The first method is the most effective, but is crude and very slow, as the drying is frequently suspended for long periods by adverse weather. Prolonged immersion in water is unnecessarily severe for most purposes, and adds greatly to the time subsequently required for drying. Moreover, if the timber is immersed too long, it subsequently becomes brashy and useless.

Seasoning by artificial heat is, for most purposes, quite as good as natural seasoning; if the kilns are well designed and properly managed they reproduce the most favourable atmospheric conditions, eliminate the adverse ones, and will do in a week or so what would otherwise require several months. For woodwork which is to be exposed to the weather, natural seasoning is preferable, though it may be assisted by a preliminary artificial seasoning.

It is not possible by any rapid tests to compare the liability of woods which have been seasoned by different methods, but the following results, obtained by a Government Department are interesting:

Nature of Timber.	Natural Seasoning.		Artificial Seasoning.	
	Breaking Load. lbs./sq. in.	Elastic Limit. lbs./sq. in.	Breaking Load. lbs./sq. in.	Elastic Limit. lbs./sq. in.
American Walnut	15,300	7,030	15,000	7,000
Mahogany	11,700	6,230	12,700	6,880
English Ash	10,900	5,500	14,000	7,000
Spruce	8,500	4,500	9,000	4,000

Time Required for Seasoning Timber.

Oak.—From 4 to 8 square inches, about 6 months; under 12 square inches, 10 months; under 16 square inches, 14 months; under 20 square inches, 18 months; under 24 square inches 22 months; above 24 square inches, 26 months.

Fir.—Half the foregoing time in each case.

Decrease in Dimensions of Timber by Seasoning.

Wood.	Shrinkage	Wood.	Shrinkage.
	Inches.		Inches.
Canada cedar	14 to 13½	Southern pitch pine	18⅜ to 18½
Elm	11 „ 10⅜	Spruce	8½ „ 8⅜
English oak	12 „ 11⅜	American white pine	12 „ 11⅞
Northern pitch pine	10×10 „ 9¾×9¾	Northern yellow pine	18 „ 17⅞

Comparative Weight of Green and Seasoned Timber.

Wood.	Weight of Cubic Foot in Lbs.		Wood.	Weight of Cubic Foot in Lbs.	
	Green.	Seasoned.		Green.	Seasoned.
Ash	43⅜–63½	32½–59	Oak	58½–63	43–62½*
Beech	56¼–63½	41–52	Riga fir	23⅜–63¾	—

(*Nördlinger.*)

* The similarity in the maximum figures for green weight of all four species, and the near approximation to the weight of a cubic foot of water (62¼ lbs.) should be noted.

Percentage of Loss of Weight in Seasoning.

Red pine	12 to 25	Larch	16 to 25	Elm	About
American yellow pine	18 to 27	Oak, British	16 to 30	Mahogany	16 to

Artificial Seasoning of Timber.

(Contributed by G. Stanley Walpole, D.Sc., F.I.C.)

In all systems of artificial seasoning the timber is stacked in a kiln or chamber in such a manner that practically the whole surface of the timber is exposed to currents of air warmed to the temperature and supplied with such an amount of steam, determined by experience, which ensure that evaporation of moisture takes place at a 'safe' rate, so that the timber is not deteriorated in any way.

Timber dryers can be divided into two classes: (*a*) *Progressive* or *Tunnel Dryers*, in which the timber is moved through zones of air each differing in temperature and humidity from the neighbouring one; (*b*) *Compartment Dryers*, in which the timber remains stationary, the air conditions being varied.

Progressive dryers may be divided into two sections: first those employing the use of fan air circulation (Sturtevant type), and secondly those in which the air is circulated automatically without any power cost (Erith type). In compartment dryers, fans are almost invariably used, as thermal circulation would not be satisfactory for that type.

Where the duty of the seasoning plant is definitely known in advance, and where such duty consists of the drying of quantities of timber of more or less uniform grade and thickness, the progressive type dryer is by far the most economical. Where it is impossible to predict the exact duty of the plant, as where many different kinds and thicknesses of timber have to be dealt with, the compartment system may be preferred, as when properly installed it is very elastic' in nature. If there is a possibility that the nature of the trade will alter, the compartment system may be preferable to the progressive type, by reason of the fact that, should different classes of timber have to be dealt with the fans and heater coils originally installed may require little, if any, modification.

Progressive or Tunnel Dryers.

In this type of dryer the timber is piled on trucks which run on suitable rails right through a tunnel constructed of brickwork or concrete or, in some cases, of timber, with doors at both ends. The tunnel is first completely filled with trucks stacked with timber; afterwards the introduction of a truck of green timber displaces a similar truck of seasoned material at the opposite end. The movement of the trucks is thus said to be 'progressive.' In the 'fan-less' progressive automatic dryers (Erith type) there are a number of steam pipe coils arranged below the rails. Where the rail level of the kiln must be the same as the general ground level, the space for the coils must be excavated, but sometimes the rail level of the kiln may be a few feet above ground level in order to give the necessary space for the pipes under the tracks.

The steam pipe coils are arranged in such a manner that circulation of air is obtained from end to end of the kiln, and the majority of the heating coils are grouped together near the 'dry' end of the plant. The air in passing over the timber absorbs moisture, and the plant is so arranged that the trucks of green timber meet first air having a low temperature and a high humidity. As each truck passes through the dryer it meets air of gradually increasing temperature and decreasing humidity.

Another type of progressive dryer (Sturtevant) depends for air circulation upon centrifugal fans, the air circulation and temperature being under *separate* control. The arrangement of trucks and rails in this type is generally similar to those for the 'fan-less' system, but in this case the fans and heater are fixed entirely outside the dryer in a small room or shed adjoining. As previously indicated, both systems of tunnel or progressive dryers are suitable for large quantities of uniform timber such as floorboards, match boarding, etc. The application of the progressive systems is, however, somewhat limited, and for small installations, and in cases where the ground space is insufficient for progressive working, compartment dryers have to be adopted.

Compartment Dryers.

In this system a number of compartments or kilns, generally of brick or concrete, are filled with timber either by hand piling or by truck piling. It should be noted, however, that if truck piling is adopted it is only for convenience in handling the material, and is not essential to the working of the dryer as such. The number of compartments may vary from one to (say) six, all being supplied by one central heating plant. For a larger number of compartments it is generally desirable to divide the same into groups, each dealt with by a separate heating plant.

Air is introduced through a duct in each compartment along the side walls near the floor, the air passing over and under the piled timber (which is arranged with its length in the direction of the length of the chamber), and then out through a corresponding duct on the opposite side of the kiln. The air circulation is made positive by means of centrifugal fans arranged in a small chamber either at one side or on top of the dryer, and means are provided to enable each compartment to be under separate and independent control both as to temperature and humidity.

Thus it is quite possible to deal with different classes of timber in adjacent compartments simultaneously. Further, the stage of drying reached in each of the different compartments may be quite different, and the benefits of this must be at once apparent to those interested.

A very important adjunct to the compartment system is the *Guide Chart System of Control* (Sturtevant patent), the object of which is to reproduce in each kiln, during the whole period of seasoning, conditions previously determined by investigation and experience. The working of the system is briefly as follows: In each compartment, or kiln, is a self-recording hygrometer comprising wet and dry bulb thermometers actuating levers terminating in pen points which rest against a paper chart on a revolving drum rotated by clockwork. Upon this chart are marked guide lines indicating both the dry bulb and wet bulb temperatures which should be given from day to day in that particular compartment. The dampers, etc., in connection with each compartment are operated by hand at intervals, so that the conditions in the compartment correspond to those given by the guide lines on the chart. Thus not only do the guide lines give the conditions to be aimed at, but the pen pointers make a permanent record showing how nearly the actual conditions have approached the ideal condition. In this way the Guide Chart System acts also as a check on the attention of the kiln operator.

A large number of guide charts have already been prepared by the Sturtevant Engineering Co. Ltd., to suit various classes and thicknesses of timber, both hard and soft, and once the best conditions for a particular grade of timber have been established, similar conditions for subsequent batches can be reproduced as required.

Storage and Preservation of Timber.

Seasoned timber should be stored under shelter and kept dry. The bottom timbers should be 2 ft. above the ground, and each overlying timber should have 1 in. space between it and the timber below. A free, gentle circulation of air should play around it, so as to keep it well ventilated. Some timbers, such as oak, beech, elm, and others, will last for a very long time if kept constantly under water; oak piles have been known, under these conditions, to last hundreds of years. Timber exposed to alternate moisture and dryness lasts a very short time.

Slaked lime hastens decay of timber, which should therefore be protected from contact with mortar.

Timber is destroyed by either wet- or dry-rot. Both wet- and dry-rot are due to fungoid growths, and in both cases gases, principally carbon dioxide and hydrogen, are given off. Dry-rot is usually caused by want of ventilation: damp and moderate warmth encourage it. The sap-wood is usually attacked first. It often occurs where ends of beams are built into walls, where wet and unseasoned timber is painted, where a damp floor is covered with oil-cloth or other impervious covering, and in warm cellars. The seeds of the dry-rot fungi are carried about readily, and once it breaks out in one part of a building the timber in other parts may become infected.

Painting or tarring will preserve timber, provided the latter is thoroughly dry and well seasoned; otherwise it only confines the sap and moisture and causes rot.

Timber is also preserved by creosoting prior to use. Tredgold doubted the utility of painting timber which was not exposed to the weather.

Storing Logs.

Logs stored on skidways or left in the woods during the summer months may be damaged in a number of ways, principally through sap-staining, insect attack, decay, and checking.

Storing under water will prevent 'blue stain,' checking, insect attack, and decay, except that logs in sea-water, where marine borers are active, would be subject to attack. Wood of any species completely submerged in water will resist decay indefinitely. Alternate wetting and drying favour decay. Storing on skids in such a way that the air can circulate freely around each log will prevent the accumulation of moisture and thus retard decay. Such storing, however, is liable to increase checking, and, unless the bark is removed, will have little effect in preventing insect attack. The skids should be situated where there is good air circulation, and they should be raised off the ground. Weeds and brush should be cut down. Peeling the bark completely from the logs will do much to eliminate insect attack and retard decay by removing the protection required by many insects and by allowing the logs to dry more rapidly. It will favour checking, however. Painting the ends of the logs will very materially retard the loss of moisture and thus retard end checking. If the logs are peeled and properly piled on skids, painting should not increase the danger from decay or sap stain. A yellow ochre or barn paint will do fairly well for the purpose. Painting the peeled surfaces with coal-tar creosote will be useful in preventing sap decay, and if applied soon enough may be effective in retarding sap stain. Any grade of creosote in common use for wood preservation is suitable, and expensive oils are unnecessary. (*'Bulletin of the Hydro-Electric Commission of Ontario.'*)

Preservative Processes.

Charring timber.—The ends of posts sunk into the ground are often charred in order to prevent rot, but recent experiments appear to show that the charring is ineffective and useless.

Vulcanising.—The wood is heated in a closed cylinder from 8 to 12 hours under a pressure of 50 to 200 lbs. per square inch and a temperature of from 300° to 500° F.

Drying.—Compressed, superheated and dried air is circulated in order to remove excessive moisture: it is claimed that the sap undergoes a chemical change and solidifies in the pores as an antiseptic matter in cooling.

Sugared timber.—A paper was read before the British Association at their meeting in 1903 on the preservation, seasoning, and strengthening of timber by means of boiling it in a saccharine solution and afterwards evaporating the moisture in a drying chamber. This process filled the interstices of the wood with a substance akin to the wood itself, rendering it more solid, firm and compact. The dried sap of the sugar-cane acted in timber much as mortar did in a stone wall, binding the otherwise loose materials strongly together.

Different methods of preserving timber by impregnation with solutions of metallic salts, such as bichloride of mercury (*Kyanising*), sulphate of copper (*Boucherising*) and chloride of zinc (*Burnetising*), have met with little success.

In the 'Ferell' process, the principal constituents of the injected solution are sulphate and chloride of aluminium.

Creosoting.

(Contributed by Robert S. Vesey, Member of the Society of Chemical Industry.)

Modern Methods of Creosoting.

Creosoting is recognised as the most efficient method of preserving timber, and all Railway Companies in this country have their sleepers and crossing timbers treated in this way. The process is also generally used for the preservation of telegraph poles, piles, posts, and the like. Softwood sleepers untreated seldom last more than three to four years, whereas their average life when creosoted is about fifteen years, and even then, in most cases, the sleepers are only removed from the track owing to their having become chair-worn, and thereafter the bulk have many years life in them as siding sleepers or fence posts.

The 'Full Cell' Process of creosoting is generally preferred to the 'Empty Cell' or 'Ripping' process, which latter principally aims at penetration and the withdrawing of two-thirds of the creosote at the end of the operation. Although only about one-third of the creosote used for the 'Full Cell' Process is left in the timber in the case of the Ripping Process, the cost of this treatment is nearly two-thirds the cost of the 'Full Cell,' and in this country it has seldom been made use of.

Construction of Creosoting Plants.

Creosoting is carried out in cylinders or retorts 75 to 105 ft. in length by 7 ft. in diameter, the average plant consisting of three, which are erected upon underground covered storage tanks of $\frac{3}{8}$-in. steel, and usually 7 ft. deep, two of these tanks being used in conjunction with each cylinder. The cylinders are of $\frac{7}{8}$-in. steel plate tested to stand at least 400 lbs. pressure per sq. in., and are each fitted at the bottom with two suction pipes for lifting and dropping the creosote to and from the cylinders; at the top of each there is a vacuum valve, pressure valve, overflow pipe, and safety valve. They are fitted with a railway track of about 2 ft. 6 ins. gauge, to take the steel bogies loaded with the timber which is to be creosoted, and 'holding-down' bars are fitted throughout the entire length to prevent the bogies floating while the process is being carried out; each load is either chained or fixed to the bogie by means of arms. Modern plants are fitted with doors at each end of the cylinders to allow the same to be charged or withdrawn from either end, the doors being fixed to the cylinder and swinging on a projecting arm fixed to the top; they can be easily opened and closed by two men. These doors are sealed with about twenty screws 12 ins. long by $2\frac{1}{2}$ ins. diameter, and are tightened by means of a large hand spanner.

The storage tanks cover the whole area occupied by the cylinders, and generally project about 2 ft. to 3 ft. at the sides, and about the same distance at the ends. This additional length at the ends is left open for a space of about 3 sq. ft. and is necessary for allowing the drainage from the cylinders, at the end of the process, to enter the tanks. A portable bridge of rails connects the creosoting cylinders with the bogie roads in the works, and this is of course removed when the cylinder doors are being opened or closed. The cylinders are usually covered with asbestos to enable the heat of the creosote to be maintained, although in impregnating the timber there is always a reduction in the temperature of the oil; in some cases steam coils are fitted in the cylinders. The storage tanks should always be fitted with coils to enable the creosote to be kept at a temperature of 140° to 150° F., although in America very much higher temperatures are used. These tanks are used for the filling of the cylinders, and to obtain additional creosote for impregnation a smaller underground tank is installed, which is usually built in concrete and is placed in the boiler-house; it is known as the 'Pressing' tank, and on it are fitted the vacuum and pressure pumps.

Working Process.

About 50 cu. ft. of the timber to be creosoted is selected as an average to test the amount of creosote absorbed, and this is weighed before and after creosoting. Immediately the doors have been screwed down, the vacuum pump is started and the air extracted from the cylinder, about 25 ins. of mercury being obtained. This vacuum being maintained, the suction cocks are opened and the cylinder is nearly filled from the two storage tanks immediately underneath; but to complete the filling, the suction cocks are closed, and the pressure pump used for about two minutes to pump in sufficient creosote, the additional oil being taken from the pressing tank. The operator then records from the gauge the number of gallons of oil in the pressing tank, and continues working the pressure pump until the required number of gallons to impregnate the timber have been injected, the amount varying according to the specification. In the case of well-seasoned Baltic Red Fir or Scots Fir, 8 to 10 lbs. per cu. ft. may be injected with 60 to 80 lbs. pressure per sq. in. As soon as sufficient oil has been injected the pressure pump is stopped, the suction valves opened, and the creosote dropped back into the storage tanks. The cylinder doors are then opened and superfluous oil allowed to drain from the timber, and although circumstances will not always permit, no charge should be withdrawn for at least two hours.

Time taken for Carrying out Process.

However well stowed the bogies might be with the timber to be creosoted, the cylinders are only from 50 to 55 per cent. filled, so that a large quantity of creosote is required in connection with each charge. The following is about the average time taken to carry out the creosoting of seasoned Baltic Red Fir with a modern plant:—

Obtaining 25 in. vacuum and lifting oil from storage tanks to cylinder, and completely filling by means of pressure pump—8 to 10 minutes.

Injecting 10 lbs. of cresote per cu. ft. with pressure pump at 60 to 80 lbs. pressure per sq. in. (not maintained, but which is sufficient to inject this quantity of oil)—6 to 10 minutes.

Dropping creosote to storage tanks at end of process—15 minutes.

During the years 1919 and 1920 when supplies of Baltic Red Fir were very short, considerable quantities of Oregon Pine and Pitch Pine sleepers were imported, and very much higher pressures were required for the efficient creosoting of these, and a much longer time was taken to carry out the process. Generally speaking, however, Baltic Red Fir is much preferred to Oregon and Pitch Pine, now that large supplies of the first named are available. Seasoned Oregon Pine will seldom take more than 2 to 4 lbs. of creosote per cu. ft. at 200 lbs. pressure maintained for 4 hours with the creosote at 150° F., although if sappy pieces are selected it is possible to inject up to 10 lbs. per cu. ft., but these cases are very exceptional in this country. With the various classes of Pitch Pine met with in England ('Longleaf,' 'Shortleaf,' and 'Loblolly') the absorption varies very considerably, and seasoned hard grown 'Longleaf' Pitch Pine will seldom absorb more than an average of 5 lbs. per cu. ft. with a pressure of 200 lbs. per sq. in. maintained for 4 hours. In the case of 'Shortleaf' the absorption would average 8 to 12 lbs. per cu. ft. with the same pressure and time, but 'Loblolly,' which is very sappy and unsuitable for use where strength is required, will absorb up to 20 lbs. of creosote per cu. ft. Seasoned Portuguese Pine will also absorb 10 to 14 lbs. of creosote with low pressure, but this timber is seldom met with in this country. Seasoned Larchwood (Northern Europe and home-grown) will on the average only absorb 5 to 7 lbs. per cu. ft. with high pressure maintained, as in the case of Oregon Pine. Although other species of timber are creosoted in this country, at least 95 per cent. are of Baltic Red Fir, Scots Fir, Oregon, and Pitch Pine, the majority being Baltic Red Fir, which is nearly always preferred for sleepers.

Specification of Creosote Oil.

There has been a good deal of controversy over the question of the best grade of creosote for use in the preservation of timber, some authorities favouring the naphthalene bases, and others placing more importance upon the tar acids. The following is the *average* specification stipulated by those who have creosoting to carry out in this country:—

1. The creosote used, to be obtained from the distillation of coal-tar, free from all impurities and to be fluid at 75° F.
2. Specific gravity to be between 1·040 and 1·080 (water at 60° F. being 1·000).
3. To yield not more than 75 per cent. upon being distilled to 600° F.
4. Tar acids, not less than 8 per cent.
5. Water, 3 per cent. maximum.
6. In some cases the percentage of naphthalene is not mentioned; in others a minimum of 10 per cent., and a maximum of 30 per cent., and sometimes the specification states that this is to be kept as low as possible. There is no doubt that in the case of piles which are in contact with water they should be creosoted with oil containing a percentage of naphthalene, as this prevents the exudation of the more fluid parts of the creosote, and also assists in preventing the entrance of the water.

British Standard Specification for Creosote.*

Suitable for the treatment of Railway Sleepers and Telegraph, Telephone, and Hangar Poles.
(No. 144—*August*, 1921.) (*Abstract.*)

1. The material shall consist essentially of a distillate of coal tar, and shall be free from any admixture of petroleum or similar oils.

2. The specific gravity shall not be less than 1·015, and not more than 1·07 at 38° C. (100° F.) when compared with water at the same temperature.

3. The material shall become completely liquid on being slowly warmed to 38° C. (100° F.) with stirring, and on cooling down shall remain completely liquid after standing for two hours at 32° C. (90° F.).

4. The amount of water in the creosote shall not exceed 3 per cent.

5. When 100 c.c. measured at 38° C. (100° F.) of the dry creosote are distilled from a 250 c.c. distillation flask at such a rate that the distillation is complete in about twenty minutes, there shall distil at 760 m.m. pressure,

up to 205° C. (401° F.) not more than 7 c.c.
„ 230° C. (446° F.) „ 40 c.c.
„ 315° C. (599° F.) „ 78 c.c.

the volumes of all fractions being measured at 38° C. (100° F.).

The residue above 315° C. (599° F.) shall be soft and not sticky, and its weight shall be not less than 22 gms.

6. The amount of tar acids shall be not less than 5 per cent. and not more than 18 per cent. by volume.

7. The amount of matter insoluble in benzol (benzene) shall not exceed 0·4 per cent. by weight.

B.S.S. Alternative for Scotch Creosote.

Scotch creosote shall conform to the above specification with the following exceptions:—

2. The specific gravity shall be not less than 1 at 38° C. (100° F.). In the case of the blast furnace oil the specific gravity may be lower, but shall not be less than 0·940 at 38° C. (100° F.)

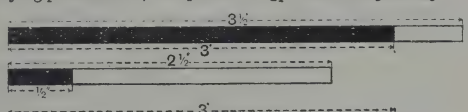
5. The distillate at 315° C. (599° F.) shall be not more than 85 c.c. and the residue not less than 15 grms.

6. There shall be no upper limit to the amount of tar acids.

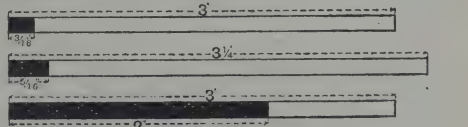
General Notes on Creosoting.

It is erroneous to think that in creosoting under pressure the oil penetrates throughout the timber, as this is not the case, and only occurs when timber is of small dimensions. It may be taken as a general rule in the case of Baltic Red Fir, Pitch Pine, and Oregon, that the timber showing sapwood will readily absorb the creosote, and the reverse is the case with that showing little sapwood. The heart penetration is from $\frac{1}{32}$ in. to $\frac{1}{4}$ in., according to the growth and species. In the case of Baltic Red Fir the impregnation varies considerably, according to the nature of the timber, and in all specifications for creosoting, care should be taken that the words 'average per cu. ft.' are inserted, as to obtain identical impregnation in each piece is impossible. Presuming that an average of 10 lbs. of oil per cu. ft. has been injected into the charge of timber, it does not necessarily mean that the timber which has absorbed 12 lbs. per cu. ft. will last longer than pieces with 8 lbs. per cu. ft., as the latter has a greater percentage of the heart of the tree, which prevents the admission of a large amount of creosote. The oil has done its work as far as possible, and with the smaller impregnation has considerably extended the life of the timber. The following illustrations (which are extremes) show test cores or borings taken from timber of 10 ins. by 5 ins. section showing varying penetrations, the species being creosoted separately:—

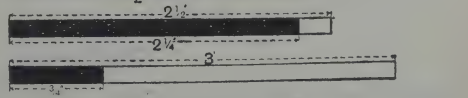
Baltic Red Fir, charge absorbing an average of 12·00 lbs. per cu. ft.



Longleaf Pitch Pine, charge absorbing an average of 5·33 lbs. per cu. ft.
Note.—No. 3 was very sappy for Longleaf.



Shortleaf Pitch Pine, charge absorbing an average of 8·60 lbs. per cu. ft.



* By permission of the British Engineering Standards Association.

The cores are two-thirds the actual size, and the impregnation shown in black.

A Creosoting Plant of the foregoing description would be capable of annually treating over two million cu. ft. of the softwood species referred to, and one million cu. ft. of the hardwood, provided the works were of about 15 acres extent with 5 or 6 travelling cranes for the transportation of the timber.

See also p. 641, 'Creosote Treatment of Railway Sleepers.'

To ascertain Weight of Timber-work, Timber Flooring.

Multiply breadth in feet by length in feet by the thickness in inches, and by one of the following factors, according to the material: For elm, use 2·92 lbs.; for yellow pine, 3 42 lbs.; for white pine, 2·97 lbs.; for dry oak, 4·95 lbs.

To find the Weight of Timber Beams, Posts, and Joists.

Multiply length in feet by the breadth in inches and the depth in inches, and the product by one of the following factors: For elm, ·243 lbs.; yellow pine, ·285 lbs.; white pine, ·247 lbs.; dry oak, ·404 lbs.

WEIGHT PER THOUSAND (M), FEET BOARD MEASURE.

Wood.	Dry.	Partially Seasoned.	Green.
	Lbs.	Lbs.	Lbs.
Pine and hemlock	2,500	2,750	3,000
Norway and yellow pine	3,000	4,000	5,000
Oak and walnut	4,000	5,000	—
Ash and maple	3,500	4,000	—

AVERAGE WEIGHT PER CUBIC FOOT OF WOODS.

Wood.	Weight.	Wood.	Weight.	Wood.	Weight.	Wood.	Weight.	Wood.	Weight.
	Lbs.		Lbs.		Lbs.		Lbs.		Lbs.
Ash	45	Birch	44·5	Larch	35	Yellow pine	42	White pine	35
Beech	43	Elm	35	Mahogany	50	Oak	58	Yew	50

Wooden Pillars.

APPROXIMATE RULE FOR THE DIMENSIONS OF WOODEN PILLARS.

W = weight in lbs., to be supported by the pillars. L = length of the pillar, in feet. D = diameter of pillar, in inches.

$$D = x \sqrt{L} \sqrt{W}.$$

x = ·80 for oak, ·87 for red deal.

Shingles.

1 bundle of 16-inch shingles will cover 30 sq. ft., and 1 bundle of 18-inch shingles, 33 sq. ft. when laid 5½ inches exposed to the weather.

6 pounds of fourpenny nails will lay 1,000 split-pine shingles.

Clapboards.

1 bundle laid 3½ inches exposed to the weather will cover 26 square feet. To be laid with fivepenny nails.

To find Solidity of Round Timber.

WHEN ALL DIMENSIONS ARE IN FEET.
Length × ($\frac{1}{4}$ mean girth)² = cubic feet.

WHEN LENGTH IN FEET, GIRTH IN INCHES.
Length × ($\frac{1}{4}$mean girth)² ÷ 144 = cubic feet.

WHEN ALL DIMENSIONS ARE IN INCHES.
Length × ($\frac{1}{4}$ mean girth)² ÷ 1728 = cubic feet.

To find Solidity of Square Timber.

WHEN ALL DIMENSIONS ARE IN FEET.
Length × breadth × depth = cubic feet.

WHEN ONE DIMENSION IS IN INCHES.
Length × breadth × depth ÷ 12 = cubic feet.

WHEN TWO DIMENSIONS ARE IN INCHES.
Length × breadth × depth ÷ 144 = cubic feet.

For BOARD MEASURE depth always equals 1 inch.

To FIND SURFACE IN SQUARE FEET, proceed as per rules for solidity of square timber.

Roofs.

LOAD ON ROOFS.

Description of Covering.	Per Square of 100 Superficial Feet.	Minimum Slope.	Description of Covering.	Per Square of 100 Superficial Feet.
	Lbs.	Degrees.		Lbs.
Lead covering weighs .	784	4	Timber framing for	
Zinc	168	4	slated or tiled	
Corrugated iron	336	4	roofs	560 to 672
Slates	840 to 1,008	25½ to 30	Additional load for	
Tiles	896 to 1,680	26½ to 30	pressure of wind .	4,032
Boarding ¾ inch thick .	290	25	Ditto for Hurricanes,	
Boarding 1½ inch thick .	580	25	say	8,960

The angle of gothic roofs should not exceed 60°.

CORRUGATED-IRON ROOFING.

B. Wire Gauge.	Size of Sheets.	Weight per Square.	Square Feet per Ton.	B. Wire Gauge.	Size of Sheets.	Weight per Square.	Square Feet per Ton.
No.	Feet.	Lbs.		No.	Feet.	Lbs.	
16	6 × 2 to 8 × 3	350	800	22	6 × 2 to 7 × 2½	175	1,550
18	6 × 2 to 8 × 3	258	1,000	24	6 × 2 to 7 × 2½	136	1,880
20	6 × 2 to 8 × 3	204	1,250	26	6 × 2 to 7 × 2½	118	2,170

One-tenth of the weight to be added for lappage. Sheets should overlap about 6 inches, and be double riveted at joints. 3 lbs. of rivets required per square of roofing. Purlins should be 6 feet apart. Curved roofs may be made up to 20 feet span without framing; tie-rods 12 feet apart.

ANGLES OF ROOFS.

Proportion of Rise to Span.	Angle.	Slope.	Proportion of Rise to Span.	Angle.	Slope.
	° ′			° ′	
$\frac{1}{6}$	18 25	3 to 1	$\frac{2}{3}$	53 0	$\frac{3}{4}$ to 1
$\frac{1}{4}$	26 35	2 to 1	$\frac{3}{4}$	56 20	$\frac{4}{5}$ to 1
$\frac{1}{3}$	33 42	1½ to 1	1	63 30	$\frac{1}{2}$ to 1
$\frac{1}{2}$	45 0	1 to 1			

(See also page 418.)

DIMENSIONS OF PARTS OF WOODEN ROOFS.

Span.	Section.						
	Principal.	Tie Beam.	King Posts.	Queen Posts.	Small Queens.	Straining Beam.	Struts.
Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
20	4 × 4	9 × 4	4 × 4	..	..	..	3 × 3
25	5 × 4	10 × 5	5 × 5	..	..	..	5 × 3
30	6 × 4	11 × 6	6 × 6	..	..	..	6 × 3
35	5 × 4	11 × 4	..	4 × 4	..	7 × 4	4 × 2
45	6 × 5	13 × 6	..	6 × 6	..	7 × 6	5 × 3
50	8 × 6	13 × 8	..	8 × 8	8 × 4	9 × 6	5 × 3
55	8 × 7	14 × 9	..	9 × 8	9 × 4	10 × 6	5½ × 3
60	8 × 8	15 × 10	..	10 × 8	10 × 4	11 × 6	6 × 3

BRICKWORK.

Bricks.

Description.	Size.	Weight.	Weight Per 1,000.
London stocks . . .	8¾ × 4¼ × 2¾ ins.	6·8 lbs.	60¾ cwt.
Red kiln	8¾ × 4¼ × 2¾ „	7·0 „	63 „
Welsh fire	9 × 4½ × 2¾ „	8·0 „	72 „
Paving	9 × 4½ × 1¾ „	5·0 „	45 „
Dutch clinkers . . .	6¼ × 3 × 1½ „	1·5 „	14 „

8¾ × 4¼ × 2¾ bricks, when laid in cement, occupy a space of 9 × 4½ × 3 ins. approximately.

The thickness of walls is regulated by the size of the bricks, and walls are 4½ ins. or half-brick thick, 9 ins. or 1 brick thick, 14 ins. or 1½ bricks thick. The standard thickness of reduced brickwork is 14 ins., or 1½ bricks.

1 rod of brickwork × 272 superficial ft., 1½ bricks thick; = 11½ cubic yards = 306 cub. ft.; = 235 ft. of bricks and 71 of mortar; = 4,300 stock bricks; = 4,500 place bricks; = 5,370 stock bricks laid dry; = 4,900 stock bricks laid dry in wells and circular cesspools; = 15 tons average weight.

1 load of mortar = 1 cubic yard. 1 load of sand = 1 cubic yard. 1 bag of cement = 3 bushels. 1 sack of cement = 5 bushels.

1 rod of brickwork requires about { 1 cubic yard of stone lime, 3½ cubic yards of sand; or 1½ yards of chalk lime, 3 yards of drift; or 36 bushels of cement, 36 bushels of sharp sand.

1 cubic yard of brickwork requires about { 6½ cubic feet of sand. 2½ „ „ lime.

1 builder's cart load of bricks = 500 bricks. 1,000 stock bricks, closely stacked, = 55 ft. cube. 1,000 old bricks, cleaned and loosely stacked, = 70 ft. cube. 1 foot of reduced brickwork = 10 bricks. 1 foot of superficial facing = 7 bricks. 1 foot superficial of gauged arches = 10 bricks. 1 yard superficial in bricknogging, laid flat, = 45 bricks and ¾ cubic foot of mortar. 1 yard superficial in bricknogging, laid on edge, = 30 bricks and ¼ cubic foot of mortar.

1 yard of paving = 36 stock bricks laid flat, = 52 bricks on edge, = 82 paving bricks on edge = 125 Dutch clinkers laid flat, = 140 Dutch clinkers on edge, = 136 Dutch clinkers laid herring bone.

Bricks absorb one-fifth of their weight of water, but the proportion varies greatly. Engineering bricks should be quite impervious to water.

A bricklayer's hod will hold 20 bricks, ⅜ cubic foot of mortar, or nearly ½ bushel.

1 rod of brickwork requires 130 gallons of water to slack the lime and mix the mortar.

In a day of 10 hours a bricklayer can lay about 1,500 to 1,600 bricks where the joints are left rough, about 1,000 when both faces are worked fair, or 500 when carefully pointed and faced with picked bricks.

For ordinary purposes, assume roughly that a bricklayer and labourer can, if they choose, turn out 2 cubic yards per diem, containing 800 bricks.

Bonds for Brickwork.

(Revised by E. A. W. Phillips, M.Inst.C.E., M.C.I.)

ENGLISH THIN-WALL BOND (fig. 669) is the simplest for all ordinary work where the walls do not exceed three brick-lengths in thickness. The heading and stretching courses always alternate in this class of bond. No stretchers occur except those seen on faces of walls. No bricks in the same course should break joint with each other. All vertical joints in any course should be covered (by one-quarter brick laps at least) by the courses above and below, and this whether offsets occur or not, or other differences in the thicknesses of the walls.

FLEMISH BOND (fig. 669A) shows headers and stretchers alternately in each course on the faces of walls. Is quite as strong as *English Thin-wall Bond*, since the quarter laps are in the

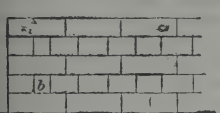


FIG. 669. English Bond.

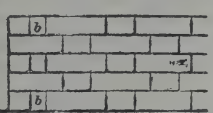


FIG. 669A. Flemish Bond.

FIG. 669B. English Thick-wall Bond.

same manner equally well maintained. *Flemish Bond* gives a better appearance for 9-inch walls, as a smoother face can be shown on both sides. In *double Flemish Bond*, both back and front of walls show Flemish Bond; in *single Flemish Bond*, one face shows Flemish, the other English bond, as above.

ENGLISH THICK-WALL BOND (fig. 669B). In this bond, every brick in a stretcher course should be a stretcher, and every brick in a header course should be a header. The bricks not only break joint, by half their lengths, with the bricks in the same description of course (i.e., stretcher or header) next above or below them, but also break joint, by half their lengths, in the same course. This is the strongest form of bond known, and should invariably be used in heavy walling, of 3½ bricks thickness and over. The quoin difficulty is best overcome by having a few specially moulded bricks, one brick-length in length, and ¾ of a brick-length in width, and of the usual thickness. The half-bricks on faces in fig. 669B are shaded.

GARDEN-WALL BOND is the *English Thick-wall Bond* adapted to thin one-brick walling, several courses of stretchers occurring to one course of headers. The same thing may be done with *chimneys*, where the walls are 9 ins. thick.

DIAGONAL BOND and HERRING BONE BOND are only useful for paving. *English Thick-wall Bond* is stronger than either.

HEADER BOND consists entirely of headers, and is used for sharp curved or quick-sweep walls.

STRETCHER BOND, entirely of stretchers, is used in ½-brick walls of all kinds.

Other bonds, Roman bond, and the Sussex bonds, are described in 'Indian Engineering.' See also papers in the Minutes of Proceedings of Civil Engineers, vol. clxxi.

CLOSERS, *b* (figs. 669, 669A), are necessary in every alternate course to close the work on to any vertical line, or to start the bond from it; they run through the thickness of the wall.

QUEEN CLOSERS, as *b*, are ½-headers formed by cutting a brick or a half-brick, called a *bat*, longitudinally in half; ¾-stretchers, or ¾-*bats*, can be used as closers, but not so economically.

KING CLOSERS are bricks cut to a splay, so as to obtain as strong a bond as possible in closing on recessed openings, as for doors and windows.

HOOP-IRON BOND, for walls, is generally formed of hoop iron, from 1 in. to 1½ in. wide and 18 B.W.G. ($\frac{1}{20}$ in.) to 16 B.W.G. ($\frac{1}{16}$ in.) thick; it should be clean bright and bedded in cement, for if allowed to rust it swells and injures the wall; it holds better if the edges are jagged. Useful in erecting works on bad foundations, but must not be relied on to give permanent strength, unless laid as carefully as reinforcement.

WALLS.

General Rules for Building Walls.

To prevent unequal settlement the whole building should be run up together, no part rising more than about 3 ft. above the rest. Work, unless done in cement, should take its bearings gradually; at least a fortnight should be allowed for completing each storey of a high building. New work should never be bonded to old, unless built in cement. The new work should be built into a chase cut in the old work. Bricks and stones should be clean, to allow the mortar to adhere to them, and well wetted, to prevent them absorbing moisture from the mortar. Building should not be carried on in frost, but rain is good. If obliged to be carried on in frost, cement should be used, and it should be covered up with straw or boards every night, for cement which freezes before it has set is worthless.

Terra-cotta air bricks should be built into the wall, below the level of the ground-floor, for ventilation. Holes should be left in the sleeper walls.

Hollow Walls

keep houses dry, and tend to maintain a more equable temperature within them. They may be of two types: capacity walls and walls built of hollow blocks. A *cavity wall* consists of two thicknesses of brickwork separated by an air-space of 2½ ins., sometimes 4½ ins. Exterior wall, 4½ ins. thick; interior wall, of such thickness as will give the whole the necessary stability (9 ins. for two-storeyed building, 4½ ins. for ordinary one-storeyed). The two thicknesses should be tied together by bonding-ties of brick or slate, or wrought-iron ties 1 in. by $\frac{3}{16}$ in. (fig. 670), at horizontal distances of 3 ft., and alternately at vertical intervals of three courses; this requires five ties to the superficial yard. The half-brick thickness is sometimes put on the inside, in which case the weight of roof should fall on the outer thickness of wall. The air-space should be carried round all angles and up to the sides of door- and window-frames, commencing at damp-proof course, which will form its bottom, and ending in a covering course of brickwork which closes the top, so that the air-space has no communication with open air.

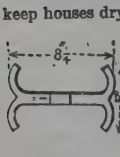


FIG. 670.

Walls of *hollow blocks* (fig. 670A) are less liable to accommodate vermin and are less risky as regards fire, as the hollow portions can be divided into a series of independent cells. The blocks may be of concrete or burned clay, the latter being usually preferred, not only on account of their porosity, but also on account of their possessing the advantageous properties of bricks, whilst being much cheaper to erect, as they commonly only measure 12 or 18 ins. by 12 ins. by 9 ins., and so are equivalent to 10 or 16 common bricks. Hollow blocks are usually rectangular tubes, which must be laid in such a manner as to provide a seal where required. Various patents have been granted for making blocks with a sealed hollow cell, but though ingenious they are not much used. For further information respecting hollow blocks see page 531.

FIG. 670A.

Hollow blocks have ample strength for all ordinary requirements or brickwork, especially if laid in a 1 : 6 cement mortar. Reinforcement may be used if desired, but otherwise the hollows or cores are left 'empty.' The blocks are usually arranged with the hollow or tubular portion vertical, the joints being broken as with masonry and common brickwork. Care should be taken to arrange the detailed dimensions of the buildings so that the blocks need not be cut.

Although the hollow portion of each block may be completely seated, if desired, it is usually better to allow a small opening through which a sufficient current of air may pass, so as to secure efficient removal of moisture and to allow the air, when heated, to expand without being under pressure.

The Damp Course

is placed in a wall, 6 ins. or 9 ins. above the ground line, in order to prevent moisture from the foundations rising in the walls by capillary attraction. The following are the most satisfactory forms of damp course:—

(i) Two courses of impervious bricks (preferably 'Staffordshire blues') laid flat in a mortar composed of 1 part of Portland cement, 5 parts of sand and a waterproofing agent such as 'Pudlo' (page 496). Ordinary lime mortar is useless, as it is too porous.

(ii) One or two courses of slate or thin impervious stone laid in the cement mortar mentioned in (i).

(iii) A layer of waterproofed cement mortar (see (i)) ½ in. to 1 in. thick.

(iv) A mixture of gravel or fine grit and asphalt or tar (preferably heated together) and laid in a thickness of ⅝ in. to 1 in.

(v) An elastic waterproof material such as bitumen (*George M. Callender & Co. Ltd.*), in roll form, has distinct advantages in cases where settlement in the foundations would break any rigid material, such as slates or mastic asphalt, the material being sufficiently pliable to conform to such settlement. Bitumen damp course is easily handled, even by unskilled workmen, as the material simply requires to be unrolled on to the foundations, a small lap joint being made at the end of each length. It is not necessary to seal the joint, as the weight of the next course of bricks is quite sufficient to keep the damp course in position.

(vi) Hollow tubes of stoneware or other impervious material, set vertically and laid in water-
ofed cement mortar as mentioned in (i).

The essential feature of a damp course is that it must be wholly impervious to water, as other-
e it is useless. This important fact is often overlooked, as in the case where good, impervious
cks are laid in a porous lime mortar or in a porous cement-mortar.

Brick Noggings

thin walls or partitions, usually 4½ ins. thick, constructed with vertical posts framed into
and bottom plates, filled in with brickwork in mortar, either flat or on edge. They require—

Per yard super 45 stock bricks laid flat, and ¼ cubic. ft. mortar.
" 30 " on edge, and ¼ " "

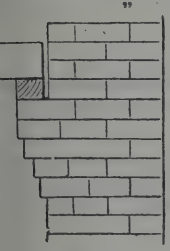


Fig. 671.

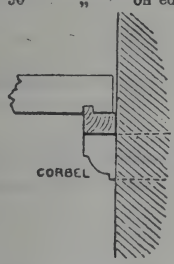


Fig. 672.

Corbelling

(Figs. 671 and 672) keeps joists clear of masonry, and prevents walls from being weakened by the insertion of timber; in brickwork the projections of the courses should not be more than a quarter brick. When great strength is required, they may project only one-eighth brick. Stone corbels should be of York or equally hard stone, about 4 feet from centre to centre, according to depth of wall plate.

Coping.

of brick, should be the hardest and least porous, set in cement. In stone, should be of as long ones as possible. Fig. 673 shows brick-on-edge coping. The course A may be two courses of

Fig. 673.

Fig. 674.

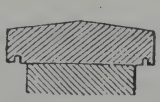


Fig 675.

les laid in cement, breaking joint, called *tile-creasing*. Fig. 674 shows another form; but moulded rick copings are preferable, being made of various patterns to suit walls of different thicknesses. ig. 675 is a stone saddle-back coping.

Thickness of Walls.

In walls not more than 30 feet high top storey may be 8½ inches thick.

Thickness of higher walls at top and 16 feet below = 13 inches.

From 16 feet below top to base the wall not to be less than the space contained in the two raight lines drawn from each side of the walls, at the base, to each side of the wall 16 feet below ie top.

The thickness to be in no case less than one-fourteenth of the height of the storey; but any ldditional thickness may be confined to piers whose collective width equals one-fourth length of all. Footings to be double the width of the base, diminishing in regular offsets half the width their height.

Cross-walls to be two-thirds of the thickness of the external or party walls, but never less than inches.

Thickness of Walls of Buildings (Gwilt's Rule).

H = height of wall; L = length between party walls; D = diagonal of face of wall = $\sqrt{H^2+L^2}$; = thickness of wall; all in feet.

Then

$$T = \frac{HL}{nD},$$

here n = 22 for dwelling-houses of brick, 20 for warehouses of brick, 18 for public buildings brick.

When the height of wall is less than half its length, then n may be increased to 27, 23, and 20 spectively.

The dimensions in the following Tables may be safely adopted.

THICKNESS OF BRICK EXTERNAL WALLS FOR DIFFERENT SORTS OF ONE-STOREYED BUILDINGS.

Description.	Main Wall.	Piers 2 ft. 3 in. Wide, 10 Feet from Centre to Centre.
Single-storeyed buildings up to 10 feet high and 30 feet wide, with cross-walls every 14 feet	9 inches	
Ditto, with principals, but without cross-walls, any length	9 „	14 inches
Ditto, over 10 feet and not exceeding 20 feet high, with principals, but not cross-walls, any length, width up to 30 feet	14 „	18 „

NOTE.—Where it is not considered advisable to have piers, the greater thickness, *i.e.*, the thickness of the piers, should be adopted.

THICKNESS OF BRICK EXTERNAL WALLS FOR DIFFERENT SORTS OF TWO-STOREYED BUILDINGS.

Description.	Lower Storey.	Upper Storey.
Two-storeyed buildings with cross-walls every 14 feet up to 30-feet span	14 inches	9 inches
Ditto, 30-feet span, with principals, but not cross-walls	18 „	14 „

Stonework should be, as a rule, one-third thicker than brickwork.

For inhabited buildings the walls are better built hollow.

When concrete (1 Portland cement, 6 ballast) is used, the wall is usually about one-third thicker than brickwork.

Rules for the Walls of Buildings not Public and not of the Warehouse Class.

(*London Building Act*, 57 & 58 *Vict.* 1894.)

According to this Act the external and party walls of dwelling-houses must be made throughout the different storeys of the thickness shown in the following Table, arranged according to the heights and lengths of the walls, and arranged for walls up to 120 feet in height, and supposed to be built of bricks not less than 8½ inches long or of stone or other blocks of hard and incombustible substance, the beds or courses being horizontal, the heights of the storeys being subject to the conditions given after the Table.

TABLE I.

1. Height up to 25 Feet.	Length up to 30 Feet. Not more than two storeys. From base to top of wall, 8½ ins.	Length unlimited. More than two storeys. Wall below topmost storey, 13 ins. Topmost storey, 8½ ins. Remainder 8½ ins.	
2. Height up to 40 feet.	Length up to 35 Feet. Wall below two topmost storeys, 13 ins. Remainder, 8½ ins.	Length unlimited. One storey, 17½ ins. Rest of wall below topmost storey, 13 ins. Remainder, 8½ ins.	
3. Height up to 50 Feet.	Length up to 30 Feet. One storey, 17½ ins. Rest of wall below topmost storey, 13 ins. Remainder, 8½ ins.	Length up to 45 Feet. Two storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. One storey, 21½ ins. One storey, 17½ ins. Remainder, 13 ins.

TABLE I. (*continued*).

4. Height up to 60 Feet.	Length up to 45 Feet. Two storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. One storey, 21½ ins. Two storeys, 17½ ins. Remainder, 13 ins.
5. Height up to 70 Feet.	Length up to 45 Feet. One storey, 21½ ins. Two storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. Each storey below uppermost two storeys to be increased 4½ ins. beyond thicknesses for length up to 45 feet.
6. Height up to 80 Feet.	Length up to 45 Feet. One storey, 21½ ins. Three storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. Each storey below uppermost two storeys to be increased 4½ ins. beyond thicknesses for length up to 45 feet.
7. Height up to 90 Feet.	Length up to 45 Feet. One storey, 26 ins. One storey, 21½ ins. Three storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. Each storey below uppermost two storeys to be increased 4½ ins. beyond thicknesses for length up to 45 feet.
8. Height up to 100 Feet.	Length up to 45 Feet. One storey, 26 ins. Two storeys, 21½ ins. Three storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. Each storey below uppermost two storeys to be increased 4½ ins. beyond thicknesses for length up to 45 feet.
9. Height up to 120 Feet.	Length up to 45 Feet. One storey, 30 ins. Two storeys, 26 ins. Two storeys, 21½ ins. Three storeys, 17½ ins. Remainder, 13 ins.	Length unlimited. Each storey below uppermost two storeys to be increased 4½ ins. beyond thicknesses for length up to 45 feet.

10. If any storey exceeds in height sixteen times the thickness prescribed for the walls of such storey in the above Table, the thickness of each external and party wall throughout such storey shall be increased to one-sixteenth part of the height of the storey, and the thickness of each external and party wall below that storey shall be increased to a like extent; but any such additional thickness may be confined to piers, properly distributed, of which the collective widths amount to one-fourth part of the length of the wall.

11. No storey enclosed with walls less than 13 inches in thickness shall be more than 10 feet in height between the floor and the ceiling thereof, or between the floor and the tie of the roof.

12. All buildings, excepting public buildings and such buildings as are in the Act defined to be buildings of the warehouse class, shall, as respects the thickness of their walls, be subject to the foregoing rules.

Rules for the Walls of Buildings of the Warehouse Class.

(London Building Act.)

The external and party walls of buildings of the warehouse class must at the base be made of not less thickness than that shown in the following Table, arranged for walls up to 120 feet in height, and supposed to be built of bricks not less than 8½ inches, or of stone or other blocks of hard and incombustible substance, the beds or courses being horizontal.

TABLE II.

1. Height up to 25 Feet.	Length unlimited. Base, 13 inches.		
2. Height up to 30 Feet.	Length up to 45 Feet. Base, 13 ins.	Length unlimited. Base, 17½ ins.	
3. Height up to 40 Feet.	Length up to 35 Feet. Base, 13 ins.	Length up to 45 Feet. Base, 17½ ins.	Length unlimited. Base, 21½ ins.
4. Height up to 50 Feet.	Length up to 30 Feet. Base, 17½ ins.	Length up to 45 Feet. Base, 21½ ins.	Length unlimited. Base, 26 ins.
5. Height up to 60 Feet.	Length up to 45 Feet. Base, 21 ins.	Length unlimited. Base, 26 ins.	
6. Height up to 70 Feet.	Length up to 45 Feet. Base, 21½ ins.	Length unlimited. Length to be increased in thickness from the base up to within 16 ft. from the top of the wall by 4½ ins.	
7. Height up to 80 Feet.	Length up to 45 Feet. Base, 21½ ins.	Length unlimited. Length to be increased in thickness from the base up to within 16 ft. from the top of the wall by 4½ ins.	
8. Height up to 90 Feet.	Length up to 45 Feet. Base, 26 ins.	Length unlimited. Length to be increased in thickness from the base up to within 16 ft. from the top of the wall by 4½ ins.	
9. Height up to 100 Feet.	Length up to 45 Feet. Base, 26 ins.	Length unlimited. Length to be increased in thickness from the base up to within 16 ft. from the top of the wall by 4½ ins.	
10. Height up to 120 Feet.	Length up to 45 Feet. Base, 31 ins.	Length unlimited. Length to be increased in thickness from the base up to within 16 ft. from the top of the wall by 4½ ins.	

11. The thickness of the wall at the top, and for 16 feet below the top, shall be 13½ inches; and the intermediate parts of the wall between the base and such 16 feet below the top shall be built solid throughout the space between straight lines drawn on each side of the wall, and joining the thickness at the base to the thickness at 16 feet below the top; nevertheless, in walls not exceeding 30 feet in height the walls of the topmost storey may be 9 inches thick, provided the height of that storey does not exceed 10 feet.

12. If in any storey of a building of the warehouse class the thickness of the wall, as determined by the foregoing Table, is less than one-fourteenth part of the height of such storey, the thickness of the wall shall be increased to one-fourteenth part of the height of the storey, and the thickness of each external and party wall below that storey shall be increased to a like extent; but any such additional thickness may be confined to piers, properly distributed, of which the collective widths amount to one-fourth part of the length of the wall.

13. The thickness of any wall of a building of the warehouse class, if built of materials other than such bricks as aforesaid, shall be deemed to be sufficient if made of the thickness required by the above Tables, or of such other thickness as may be approved by the County Council.

(*London Building Act.*)

The thickness of a cross-wall shall be two-thirds of the thickness hereinbefore required for an external or party wall of the same dimensions, and belonging to the same class of buildings, but never less than 8½ inches; and no wall subdividing any building shall be deemed to be a cross-wall unless it is carried up to the floor of the topmost storey, and unless in each storey the aggregate extent of the vertical faces or elevations of all the recesses and that of all the openings therein taken together does not exceed one-half of the whole extent of the vertical face or elevation of the wall.

Rules for Structural Steelwork for Buildings.

London County Council Act (1909).

Part IV., section 22, of the London County Council (General Powers) Act, 1909, which came into operation August 16, 1909, makes certain provisions, summarised below, with respect to buildings of iron and steel skeleton construction, and with the foundations, walls, floors, staircases, etc. of such buildings.

(1) All rolled steel shall comply with the British standard specification for structural steel for bridges and general building construction, and every pillar or girder shall be of iron or steel or any other metal which may be standardised by the Engineering Standards Committee.*

(2) The skeleton framework of a building, together with the party wall or walls upon which such framework bears, shall be capable of safely and independently sustaining the whole dead load and superimposed load bearing thereon.

(3) Pillars in external walls to be completely enclosed and protected from the action of fire by a casing of brickwork, etc., or incombustible material, at least 4 inches thick, properly bonded.

(4) Girders in external walls to be similarly encased with brickwork or other incombustible material at least 4 inches thick, properly secured to the adjoining work. The casing on the underside of such girders and to the edges of the flanges, plates, and angles may be not less than 2 inches thick.

(5) All other pillars and girders to be protected from the action of fire by being encased to the satisfaction of the district surveyor to a thickness of not less than 2 inches. The casing on the upper surface of girders and on the lower surface of subsidiary joists may be not less than 1 inch. Wood firrings must not be used in connection with any casing. This subsection does not apply in the case of buildings of only one storey and not more than 25 feet in height.

(6) Girders to be secured against buckling if the length of the girder exceeds thirty times the width of the compression flange. The web of every girder to be secured against buckling when the depth of the web exceeds sixty times the thickness.

(7) The span of a girder must not exceed twenty-four times the depth of the girder unless the calculated deflection is less than one four-hundredth part of the span.

(8) Two or more girders arranged alongside and closely adjacent to one another, so as to act together, must be fixed together by means of iron separators and bolts, or in any efficient manner approved by the district surveyor. Separators or other members acting as separators must not be placed at a distance apart exceeding five times the depth of the girders, and must be placed immediately over all supports and immediately under all concentrated loads.

(9) Girders for supporting external walls must be placed at the floor level of a storey or not more than 5 feet above or below floor level.

(10) Rivets must be used where reasonably practicable. Where bolts are used they must extend through the full thickness of the nuts, and the nuts must be so secured as to avoid risk of their becoming loose. The distance from the edge of a rivet or bolt hole to the edge of the member may not be less than the diameter of the rivet or bolt. Rivets must be so placed that their centres shall not be closer together than three times the diameter of the rivets. The pitch of rivets measured in a continuous straight line in girders, pillars, and roofwork must not exceed sixteen times the thickness of the thinnest member through which they pass.

(11)—(A) An external wall may not be less than 8½ inches thick for the topmost 20 feet of its height, and 13 inches for the remainder of its height below such topmost 20 feet. A less thickness may be allowed in any case in which under the London Building Act, 1894, such less thickness is prescribed.

(B) All party walls shall be of the thicknesses prescribed by the principal Acts.

(C) All brickwork and work in which terra-cotta, concrete, or other similar materials are used must be executed in Portland cement (British standard specification) mortar bedded close up to the metal framework without intervening cavity, and all joints must be made full and solid. In party walls (exclusive of any parts thereof immediately surrounding metal framework), or other internal brickwork not constructed to carry loads or stresses, lime mortar may be used.

(12)—(A) No plate or bar in any steel or wrought-iron pillar may in any part be less than ¼ inch thick, and the bases of all such pillars must be at right angles to the axis.

(B) Joints in such pillars must be close-butted with riveted cover-plates, and joints between such pillars must be properly fixed and made, and, unless unavoidable, no joint may be made between such pillars except as near as practicable to the level of a girder secured to such pillars.

* Now British Engineering Standards Association.

(c) The foot of every such pillar must have a proper base-plate riveted thereto with sufficient gusset pieces to distribute properly the load on the foundations, and the gusset pieces shall have sufficient rivets to transmit the whole of the load on to the base-plates.

(d) Where any pillars are built up hollow the cavities must be filled with concrete or be covered at both ends by metal plates riveted thereto.

(13)—(a) The width of cast-iron pillars may not be less than 5 inches, and the metal may not be in any part less than $\frac{3}{4}$ inch thick or one-twelfth of the least width of such pillar (whichever is the greater).

(b) The cap and base of every pillar must be in one piece with the pillar, or be connected thereto with a turned and bored joint.

(c) The ends of all pillars must be at right angles to the axis.

(d) Joints between such pillars shall be at or as near as practicable to the level of a girder secured to such pillars, and shall be fixed with not fewer than four bolts of not less diameter than the least thickness of metal in the pillar. If more than four bolts are used the diameter of the bolts may be reduced proportionately, but no bolt may be less than $\frac{3}{4}$ inch in diameter.

(e) The base of every such pillar shall have sufficient area to distribute properly the load on the foundations.

(14) The base of every pillar shall be bedded so that the load may be transmitted uniformly to the foundations.

(15) The stress in any metal interposed between the ends of a superimposed pillar and a pillar beneath must not exceed the stress on the superimposed pillar, and the least width across such interposed metal may not be less than the least width of the superimposed pillar.

(16) All floors and staircases (together with their enclosing walls) shall be constructed throughout of fire-resisting materials and be carried upon fire-resisting supports.

(17) All structural metalwork comprised in the skeleton framework of a building must be cleaned of all scale, etc., and be coated with one coat of boiled oil, tar, or paint before erection, and after erection shall receive at least one additional coat. Where embedded or encased in brickwork or other incombustible materials one coat of Portland cement wash applied after erection may be used.

(18)—(a) The dead load of a building consists of the actual weight of walls, floors, roofs, partitions, and all other permanent construction comprised in such building.

(b) The superimposed load in respect of a building consists of all other loads.

(c) For calculating the loads on constructions carrying loads in buildings the superimposed load on each floor and on the roof shall be estimated as equivalent to the following dead load:—

For a floor intended to be used for the purposes of human habitation or domestic purposes, 70 lbs. per square foot of floor area;

For a floor intended to be used for the purpose of an office, or for any similar purpose, 100 lbs. per square foot.

For a floor intended to be used for the purpose of a workshop or retail shop, 112 lbs. per square foot;

For every floor in a building of the warehouse class not intended to be used for any of the purposes aforesaid, not less than 224 lbs. per square foot. In every building of the warehouse class a notice shall be exhibited in a conspicuous place on each storey stating the maximum superimposed load per square foot which may be carried on such floor;

For a roof the plane of which inclines upwards at a greater angle than 20° with the horizontal, the superimposed load (which includes wind pressure) shall be estimated at 28 lbs. per square foot of sloping surface;

For all other roofs the superimposed load shall be estimated at 56 lbs. per square foot measured on a horizontal plane.

If the superimposed load on any floor or roof is to exceed that specified, such greater load shall be provided for pursuant to subsection (2).

In the case of any floor intended to be used for a purpose for which a superimposed load is not specified, the superimposed load shall be provided for pursuant to subsection (2).

(19) For calculating the total load to be carried on foundations, pillars (including brick pillars), piers, and walls in buildings of more than two storeys in height, the superimposed loads for the roof and topmost storey shall be calculated in full in accordance with the last preceding subsection; but for the lower storeys a reduction may be allowed, as follows:—

For the storey next below the topmost storey a reduction of 5 per cent. of the full superimposed load;

For the next succeeding lower storey a reduction of 10 per cent. of the full superimposed load, and for each succeeding lower storey a further reduction of 5 per cent. of the full superimposed load. Provided always that the total reduction in respect of any storey shall not exceed 50 per cent. of the full superimposed load for such storey;

No such reduction as aforesaid shall be allowed in the case of a building of the warehouse class.

(20) All buildings shall be so designed as to resist safely a wind pressure in any horizontal direction of not less than 30 lbs. per square foot of the upper two-thirds of the surface of such buildings exposed to wind pressure.

(21)—(a) The working stresses on pillars of cast iron or mild steel due to the loads thereon (other than stresses induced by wind pressure) shall not exceed those specified in the two following tables, according to the several ratios therein specified, or a proportionate load for other ratios:—

CAST-IRON PILLARS.

Ratio of Length to least Radius of Gyration.	Working Stresses in Tons per Square Inch of Net Section.		
	Hinged ends.	One end hinged and one end fixed.	Both ends fixed.
20	3·5	4·0	4·5
30	3·0	3·5	4·0
40	2·5	3·0	3·5
50	2·0	2·5	3·0
60	1·5	2·0	2·5
70	1·0	1·5	2·0
80	0·5	1·0	1·5

MILD STEEL PILLARS.

Ratio of Length to least Radius of Gyration.	Working Stresses in Tons per Square Inch of Section.		
	Hinged ends.	One end hinged and one end fixed.	Both ends fixed.
20	4·0	5·0	6·0
40	3·5	4·5	5·5
60	3·0	4·0	5·0
80	2·5	3·5	4·5
100	2·0	3·0	4·0
120	1·0	2·5	3·5
140	0·0	2·0	3·0
160		1·0	2·5
180		0·0	1·5
200			0·5
210			0·0

(B) The working stresses on wrought-iron pillars due to the loads (other than wind-pressure stresses) may not exceed two-thirds of the stresses specified for mild steel pillars.

(C) Any pillar eccentrically loaded must have the combined stresses resulting from such eccentricity at any part added to all other stresses at that part, and the sum of the stresses may in no case exceed the working stresses specified.

Provided that working stresses exceeding those specified in paragraphs (A), (B), and (C) by not more than 25 per cent. may be allowed where such excess is due to wind pressure.

(D) The eccentric load of a pillar may be considered to be distributed uniformly over its cross-section area at the next lower level at which it is fixed and secured in the direction of eccentricity.

(22) The working stresses of iron and steel (except in the case of pillars as hereinbefore provided) may not exceed the following :—

Metal.	Working Stresses in Tons per Square Inch.			
	Tension.	Compression.	Shearing.	Bearing.
Cast iron	1·5	8	1·5	10
Wrought iron	5	5	4	7
Mild steel	7·5	7·5	5·5	11

(23) Any rivet used in double shear the working shear may not exceed one and three-quarter times the shear allowed on a rivet used in single shear.

(24) The pressures of foundations on the natural ground may not exceed the following :—

Material.	Tons per Square Foot.
Natural bed of soft clay or wet or loose sand	1
Natural bed of ordinary clay or confined sand	2
Natural bed of compact gravel, London blue clay, or chalk	4

(25) The pressure on concrete foundations may not exceed 12 tons per square foot.

(26) No disengaged brick pillar without lateral supports may have a height of more than six times its least width; but a pillar with lateral supports may have a height between such supports not more than twelve times its least width, but in no case less than 13½ inches.

(27) The pressure on any brickwork may not exceed the following :—

Material.	Tons per Square Foot.
Blue brick in cement mortar	12
Hard brick (including London stock) in cement mortar	8
Ordinary brick in cement mortar	5

(28) The Council may prescribe the materials and the proportions to be used in concrete provided under the provisions of this section.

(29) It shall be lawful to make any addition, alteration, or do other work upon a building in accordance with this section, provided that the loads and stresses in a building so altered are transmitted from the roof to the foundations by a skeleton framework of metal, or partly by a skeleton framework and a party wall, and the foregoing provisions shall apply as if the part so altered were a separate building.

Foundations.

Brick walls are made wider at the base, in order to spread the weight of the building over a larger area and produce an equality of settlement.

Figs. 676 to 682 show sections of footings (the wide courses at the base of a wall) of walls in English bond from one to three bricks in thickness. Trenches are excavated for beds of concrete usually from 2 feet to 7 feet in depth, and 12 inches wider than base of footings (6 inches on each

FIG. 676. Elevation.

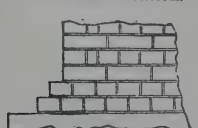


FIG. 677. Section.

FIG. 678. Frontage for 2½-Brick Wall.

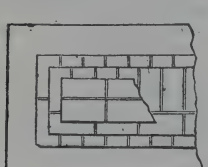


FIG. 679. Plan.

FIG. 680.

FIG. 681.

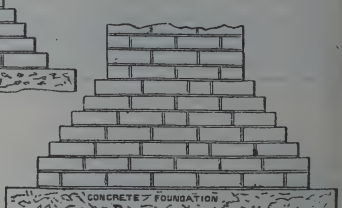


FIG. 682.

side). If the site on which a building is to be built be gravel, sand, or natural virgin soil, no concrete bedding must be used ; but otherwise the whole site should be covered with a layer of concrete not less than 6 inches thick.

The foundations of the walls of a building should be on a bed of good concrete not less than 9 inches thick, and projecting at least 4 inches on each side of the lowest course of footings of walls. If the site be upon a natural bed of gravel, concrete is not required.

MASONRY.

Lifting Stones.

There are various ways of laying hold of stones which are too heavy to be moved by hand. The following are those most frequently used :—

1. By a pair of nippers or iron claws or hooks, as in fig. 683, the ends of which catch in holes

made, one in each side of the block, in the same vertical plane as, and at a convenient distance above, the centre of gravity of the block. 2. By a *Lewis*, or iron dovetail, as in fig. 684, made in three pieces, the two outer ones being first dropped into a corresponding dovetailed hole cut in the stone directly over its centre of gravity, then the centre-piece slipped in between them, the suspending-tackle put in its place, and finally a bolt passed through the whole and keyed up. 3. By two curved iron plugs, with a chain passing through eyes in their heads, placed in a dovetailed hole directly over the centre of gravity of the stone, as shown in fig. 685. 4. By an iron conical plug, with an eye at the top for a chain or hook to pass through, placed in a rather

FIG. 683.

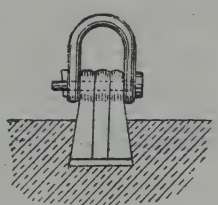


FIG. 684.

larger conical hole directly over the centre of gravity of the stone, with an iron wedge curved so as to fit the plug and the circumference of the hole, tightly driven in by its side, as shown in fig. 686. This plug was used for setting the heavy granite coping on the Thames Embankment

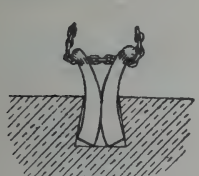


FIG. 685.

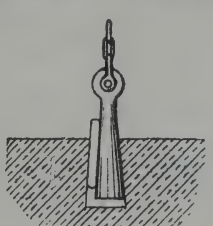


FIG. 686.

wall. 5. By a single iron plug, very slightly tapered, and driven into a cylindrical hole directly over the centre of gravity of the stone. By this simple means hard stones, such as granite, may be lifted with ease, a few side taps being sufficient to loosen the plug when required to be withdrawn.

Setting Stones.

All stones, except under peculiar circumstances, should be laid on their natural or quarry beds, or with their natural beds as far as possible perpendicular to the pressures they have to bear.

All dry and porous stones should be well wetted before being laid, so as not to absorb the moisture required for the proper setting of the mortar. Iron should never be placed in contact with stonework where, by rusting, it might disfigure it with stains, or split the stone, either by its increase in bulk during the process of oxidation, or by its expanding and contracting under the influence of heat and cold.

Descriptions of Masonry.

There are three descriptions of masonry in ordinary use, viz. :—

Rubble. Block-in-Course. Ashlar.

If the stone at disposal is thinly bedded, rough, or intractable, it should be used as *Rubble work*; if obtainable in blocks, and more or less easily wrought, it should be used as *Block-in-Course* or *Ashlar*, according to circumstances.

The various systems are illustrated by figs. 687 to 695.

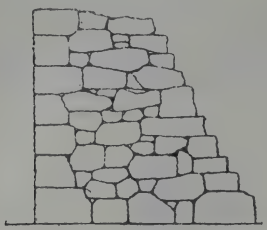


FIG. 687. Common, Rough, Uncoursed, or Random Rubble.

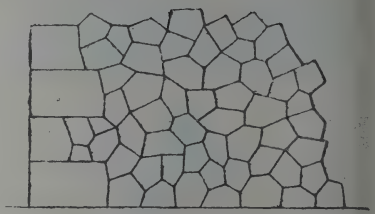


FIG. 688. Random Rubble, with hammer-dressed joints and no spalls on face.

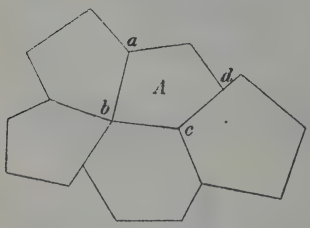


FIG. 689. Hammer-dressed Joints for Random Rubble.

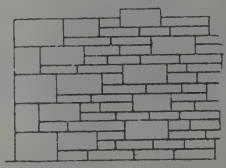


FIG. 690. Irregular-coursed, Random-coursed, Snecked, or Squared Rubble.

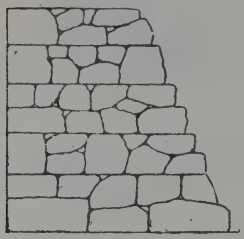


FIG. 691. Built up to Courses.

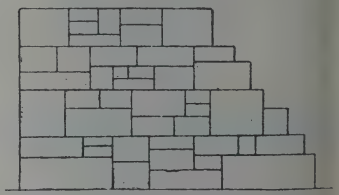


FIG. 692. Built up to Courses, with beds horizontal and joints vertical.

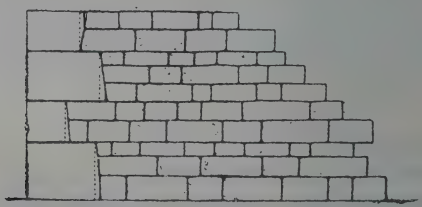


FIG. 693. Coursed Rubble.

Rubble masonry.

The best stones for rubble masonry are those that scabble freely, and such as lie in 4 or 5 in. beds. Basalts and stones of a crystalline structure are troublesome to use, as they fly under the hammer; but granite and sandstones work in well.

Rubble may be either *uncoursed*, *irregular*, or *random-coursed*, *worked up to courses*, or *coursed*, chiefly depending upon the character of the stone at disposal; some stones, such as Kentish rag, from their intractable nature, and the absence of any distinct lines of bedding, are specially adapted for *uncoursed* rubble, whilst others readily work into courses, and therefore should be used as *coursed* rubble.

In common, rough, uncoursed, or random rubble (fig. 687) the stones are laid at random, without being brought up to any level courses, the only tools required being a trowel, waller's hammer, and plumb or battering rules, as the case may require.

One bond stone should be used to at least every yard super of the face, and these should run about two-thirds to three-fourths through the wall, alternately from the opposite sides; this, in the case of dwelling-houses, diminishes the chances of damp being transmitted to the interior and is in all cases much preferable to a smaller number of *through* stones. In boundary and similar walls *through* stones may, of course, be used. In thick walls, such as piers, abutments, and retaining walls, the bond stones should tail into the work as far as possible; and the whole should be bonded together in the best way the sizes of the blocks will admit of.

It is necessary to see the bond stones actually built into the wall, for builders are apt to set large stones on edge, running only 3 or 4 ins. into the wall, instead of true bond stones—a trick which cannot well be detected after they have once been covered up. In random work (figs. 688 and 689) the stones cleave into irregular shapes, and are fitted closely together. Thus, in order to get A (fig. 689) into place the angles *abc*, *dch*, are taken with the mason's bevel, and the joints are hammered and punched to fit truly. This is the most expensive kind of rubble work, and requires much more skill to build properly than any other class of rubble walling.

If the rubble stone is distinctly bedded, the beds varying much in depth, and often running very thin, the stones should be put together as in fig. 690, in what is called *irregular* or *random-coursed* rubble. The joints in this case are not necessarily vertical; but in a superior class of the same work all the joints are specified to be vertical and the beds horizontal, by which a more regular appearance is given to the work. The stones are all shaped and roughly squared as required, and hammer or axe faced, in the gross, ready for the waller to set in the wall. This class of masonry is very bold and effective for engineering purposes, when a good proportion of large stones are used, roughly hammer-dressed on face.

Both of the kinds of rubble masonry just described are very commonly worked up at intervals, with the line and level, to level courses, either regular or irregular in depth, the latter being preferable on account of its appearance and more suitable to the irregular sizes of the stones used. From 18 to 14 ins. are the ordinary depths of the courses, according to the nature of the stone. Figs. 691 and 692 show both common and irregular coursed rubble worked up to courses; the latter being also called *coursed header work* when the headers, occurring at intervals, run the full depth of the course. In fig. 693 a superior class of work is shown, the joints being all vertical, by which means a more regular appearance is obtained.

Rankine's 'Civil Engineering,' speaking of coursed rubble (such as fig. 693), says: '*One-fourth part* at least of the face in each course should consist of bond stones or headers, each header to be of the entire depth of the course, of a depth ranging from one and a half times to double that depth, and of a length extending into the building to from three to five times that depth, as in ashlar. These headers should be roughly squared with the hammer, and their beds hammer-dressed to approximate planes; and care should be taken not to place the headers of successive courses above each other, for that arrangement would cause a deficiency of bond in the intermediate parts of the course. Between the headers each course is to be built of smaller stones, of which there may be one, two, or more in the depth of the course. These are sometimes roughly squared, so as to have vertical side-joints; sometimes the stones are taken as they come, so that the side-joints are irregular; but no side-joint should form an angle with a bed-joint sharper than 60°. Care should be taken, not only that each stone shall rest on its natural bed, but that the sides parallel to that natural bed shall be the largest, so that the stone may be flat, and not be set on edge or on end. However small and irregular the stones may be, care should be taken to make the course break joint. Hollows between the larger stones should be carefully filled with smaller stones, completely embedded in mortar.'

The same authority gives the resistance of good coursed rubble masonry to crushing at about four-tenths of that of single blocks of the stone it is built with.

Coursed, or regular coursed rubble, as shown in fig. 693, is applicable where the beds, though thin, are pretty regular, so that a sufficient number of stones of a uniform depth can be got to allow of their being laid in regular courses of one stone only in depth. Larger stones, often of cut stone, equal in depth to two or three courses of the rubble work, are generally used at the quoins.

Whenever cut-stone is used in connection with rubble work, as at the quoins of a building, the ends adjoining or tailing into the rubble should never be cut square, but be left comparatively rough, so as to harmonise with the masonry in the body of the wall, and not appear as if cut off from it by straight lines.

Dry-walling is the simplest class of rubble work, and consists of stone roughly hammered, and bedded by pinning with spalls, without any mortar. It requires considerable skill to build properly, as its stability depends entirely on the firm bedding and bonding of the different stones. It is chiefly used for fencing land, for railway and canal embankments and cuttings, or at the backs of retaining-walls, to diminish the pressure of the earth on them, and to allow of water finding its way down to the drains below. Such walls—which are generally about 5 ft. high, increasing in thickness towards the bottom, and averaging about 18 ins. thick—are usually built to lines strained between trestles (fig. 694), in order to avoid plumbing the face.

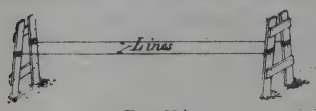


FIG. 694.

Dry-rubble walling is generally built in courses about 12 ins. high, and should have a waterproof top, or *coping*, to keep the water from getting into the body of the work and bursting it in frosty weather. The coping may be made of stones laid on edge in mortar, bituminous concrete, or, for want of anything better, clay puddle, or even sods.

When the stones come out in thin slabs the walls may be specified to be built of 'good sound, flat bedded stones of a fair average size (none less than 6 ins. broad across the narrowest part), set dry, and coped with stones, not less than 9 ins. deep, set on edge; each coping stone to extend across the full breadth of the wall, and to be properly set in good hydraulic mortar.' A high joint with a projecting ledge is very frequently used to mark the joints of rubble work; this is a bad system, and is sure to peel off under the influence of wet and frost.

A cubic yard of rubble masonry will, as a rule, require ½ cubic yard of mortar and 1½ cubic yard of stone.

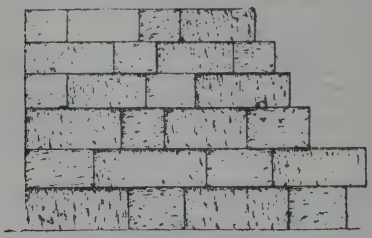


FIG. 695.—Block-in-Course.

FIG. 696.—Ashlar.

BLOCK-IN-COURSE MASONRY.

Block-in-Course (fig. 695) is a term applied by engineers to a class of masonry much used in piers, abutments, wing walls, &c., when there is a suitable stone in the district and good solid work is required. The stones are all squared and brought to good fair joints, the faces being more or less worked, according to taste, but generally merely hammer-dressed; and the courses consist of single stones only in depth. It chiefly differs from ashlar in the smaller size of the stones and depth of the courses, the stones at command being—ordinarily rougher and more thinly bedded—chiefly *shoddies*, or stones under 12 ins. deep, whereas *ashlar* blocks range, as a rule, from 12 ins. to 14 ins. in depth.

The best stone for the purpose is a hard, self-bedded stone which will work easily into courses from 3 ins. to 10 ins. or 12 ins. in depth, the length of each stone being four or five times its depth. No attention is paid to uniformity in the depth of the courses.

ASHLAR MASONRY.

The term *ashlar* is applied to masonry built up of a thick-bedded stone which admits of being scabbled, or sawn into square blocks of given dimensions. It is also used to denote roughly squared blocks of stone over 12 ins. deep, as delivered from the quarry or stonecutter, or as prepared for setting. Ashlar work (fig. 696) is built in courses of uniform, or nearly uniform, depth—generally from 10 ins. to 14 ins.—ranging throughout with the quoins and dressings. It goes by different names according to the face put upon the stone, from quarry-pitched or rock ashlar up to wrought ashlar.

No stone should be laid in mortar without being first fitted into place and any irregularities in shape corrected. Large ashlars are first accurately fitted into place, and then set on a bed of mortar carefully spread out to receive them; after which the vertical joints have to be filled by stopping them up on the outsides with cement, and pouring in cement or mortar grout, which should be worked about with a piece of hoop iron, so as to ensure its completely filling the joints. The beds and joints are worked to plane surfaces, so as to allow of close-fitting joints. These surfaces should not be too smooth, otherwise the mortar will not adhere so well to the stones, but in good work should be true enough to allow of joints not over ⅛ in. thick; they are generally

her left as they come from the saw (if sufficiently true), or taken out of winding by running isel draughts round the margins, and dressing them down with the point, as in half-plain work, king off any parts left projecting beyond the level of the chisel draughts with a chisel.

Proportions for Stones, Bond, &c.

In both block-in-course and ashlar masonry it is necessary to proportion the length, breadth, d thickness of the stones according to their hardness, in order to guard against their breaking ross. Rankine says that in the weaker sandstones and granular limestones the length of a one should not exceed three times its depth, nor the breadth one and a-half to double its depth. harder stones—such as require 2½ or more tons to the inch to crush them—the length may be ur or five times the depth, and the breadth three times the depth.

The best bond in masonry is that which shows on the face of the work alternate headers and retchers in each course, as in Flemish bond in brickwork, each header coming over the centre a stretcher in the course below. In such work one-third of the face consists of headers, if the ngth of the stretchers is twice the breadth of the headers; but as stones are rarely cut to actly the same dimensions, it may be laid down that not less than one-fourth of the face of the ll should consist of headers, and that the stones should break joint from one to one and a-half nes the depth of a course.

The thickness of the joints will vary from ½ to ⅛ inch, according to the smoothness of, or amount of work bestowed upon, the beds, as it must be sufficient to transmit the pressures from stone to stone without permitting of actual contact at any point of their surfaces.

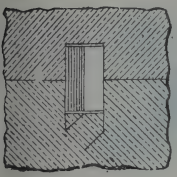


FIG. 697.

Dowelling.

For securing stones in places where the adhesion of the mortar or cement is not sufficient *dowelling* is the best method. Fig. 697 shows a method of doing this. It consists in making exactly opposite each other, in the two stones two holes, either circular or square in section, and fitting into them a dowel or pin. These may preferably be of good hard slate, run with either brimstone or cement.

Measurement and Valuation of Masonry.

In districts where stone abounds, and forms the principal material for building purposes, dinary walls are built of rubble stone, and measured by the cubic yard, or some other local andard, such as, in Ireland, by the running perch (21 feet), of a given height and thickness, or by e square perch of 21 feet super, at a standard thickness of 18 inches. In the West of England e square perch is employed, of 18 feet super, at a standard thickness of 2 feet, to which walls any thickness are reduced; or the price per perch may vary with the thickness of the wall. other parts masonry walling is measured by the rood of 36 square yards, or 24 cubic yards, e standard thickness being 2 feet; or by the rod of 272 feet super, as in brickwork, at a standard ickness of 18 inches or 2 feet.

In engineering, as distinct from architectural constructions, masonry is rarely valued otherise than by the cubic yard for the roughest descriptions of work, and by the cubic foot for perior work.

The price in all cases varies with the quality and description of work, as 'coursed' or 'unoursed,' in 'walling' or 'foundations.'

The superficial content of the surface-work is paid for separately by the square foot, yard, or od of 36 square yards, including jointing or pointing, and such squaring to beds and joints as ay be required, quoins, &c., of selected stones being often paid for at so much extra per foot in.

Superior work, such as squared masonry, whether in wallings or dressings, is usually valued by e foot cube as block stone, merely scabbled or sawn to the required dimensions and set. The ork upon it is taken separately by the foot super.

When different descriptions of masonry occur in a wall, such as rubble faced with ashlar, instead cubing out the rubble and ashlar work separately—in which case the latter is valued by the bic foot prepared and set, including all beds and joints, the facework being taken by the foot perficial as tooled, pointed, &c.—the whole may be taken as rubble masonry, and so much extra lowed per foot superficial for the superior facing, including all extra labour, dressing, and ointing.

When walls are built of rubble masonry, it is invariably cheaper to buy bricks, and build them nto such parts as jambs and arches, the labour upon which would be much less than in those nown on the face of the wall.

The block stone for the cut stonework in a building is ordinarily sold at the quarries, or delivered, by the cubic foot, or in large rough blocks by the ton, or from 13 to 17 cubic feet, according o the description of the stone, 1 inch being allowed each way for irregularities and waste.

QUANTITY OF STONE EQUIVALENT TO 1 TON IN WEIGHT.

Description.	Feet Cube.	Description.	Feet Cube.
Vein marble	13	Craigleith	14¾
Statuary marble and granite	13½	Portland	15 to 16
Purbeck	14	Derby	15
Yorkshire	12 to 15	Bath	16 to 17

Description.	Feet Super.	Description.	Feet Super.
3½-inch York paving (tooled)	58½	3-inch granite	54
3 " " " "	49½	6 " "	27
2½ " Purbeck paving	68	7 " curb	23
3 " " "	56		

ELECTRIC CHIPPING HAMMER.

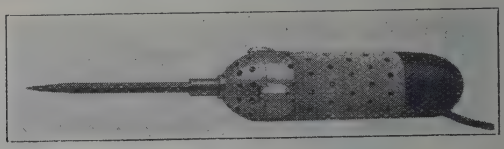


FIG. 698.

This hammer, fig. 698 (*The Consolidated Pneumatic Tool Co., Ltd.*), is for stone dressing, carving, lettering (and also for boiler scaling work); it only weighs 5 lbs. A heavier type hammer is also used for drilling holes through concrete, stone, or brick work.

SECTION IX

PART II

MORTARS—CONCRETES—CEMENTS—PLASTERS—GLUES

Revised and amplified by Alfred B. Searle
(Consulting Advisor on Cementitious Materials).

MORTARS.

Mortars are pasty substances which gradually harden on exposure; they are used for uniting tones or bricks in the construction of masonry or brickwork.

The chief kinds of mortar are:

Lime mortar, composed of lime and sand.

Trass mortar, composed of lime, sand, and trass or brick-dust, or of lime and trass without sand.

Cement mortar, composed of Portland cement (or other silicious cement) and sand.

Hydraulic mortar, composed of either hydraulic lime or cement, and sand, and characterised by its power of hardening under water.

Clay mortar, consisting of a mixture of fireclay and crushed firebricks, and used chiefly in the construction of furnaces, kilns, and other structures which have to be heated to high temperatures.

Lime Mortar.

The chief ingredients of ordinary lime mortar are lime and sand, but other materials, such as crushed bricks, ground stone or trass, and waste products such as ground slag, ashes, or coke, may, under suitable conditions, replace some of the sand. The tenacity of the mortar may be increased by the addition of hair or other fibrous material.

The best mortar for use in air * consists of a mixture of lime, sand, and brick-dust, but the latter is usually omitted on account of its cost.

Lime mortars made of fat or pure lime should not be used for roads, bridges, viaducts, waterworks, or any structure exposed to water, and some authorities maintain that even for churches, houses, and other buildings, it should not be used without the addition of trass or its equivalent, so as to prevent the flaking, crusts, and canker which are produced when too fat a lime is used.

Hydraulic lime mortar is composed of hydraulic lime and sand, the proportions varying from 3 to 6 measures for each measure of the lime (see *Lime Concrete*, p. 490). The chief use of this kind of mortar is for structures exposed to water, but unless the hydraulic lime is well selected, the structures may develop crusts and canker. Portland cement mortar is usually much superior to mortar made with hydraulic lime.

Trass Mortar.

Trass mortar is but little used in Great Britain, but has been used extensively abroad, and particularly in the East. The term 'trass mortar' is not confined to mortars containing true trass, but includes those containing similar materials, such as brick- or tile-dust, pozzolana, santorin earth, and other metamorphosed alumino-silicates, which combine with free lime to form an indefinite compound having cementitious properties. The use of trass or similar material overcomes the disadvantages which accompany the use of fat-lime. The best proportions for trass mortars are shown in the table on p. 488. An excess of trass does no harm.

Cement Mortar.

Cement mortar consists of a mixture of sand and Portland cement, the usual proportions being 2 to 6 measures of sand to 1 of cement, according to the strength required. The best proportions for various purposes are shown in the table on p. 488. For structures exposed to the air there should be more than twice as much sand as cement, but for completely waterproof structures the proportion of cement should not be less than half the sand used.

Lime is sometimes added to cement mortar to increase its plasticity and to make it easier to use. The addition of not more than 20 per cent. of hydrated lime slightly increases the strength of the concrete, but if the latter is exposed to water (inch rain), the free lime may be washed out, leaving a porous material which soon flakes and disintegrates when exposed to frost. These drawbacks can be avoided by adding trass instead of lime—a cement mortar composed of two measures of cement, one of trass and six measures of sand, being of wide application and easy to work.

All cement mortars are hydraulic—i.e. they harden readily under water.

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* Mortars for use under water are termed *hydraulic* mortars.

Raw Materials for Mortars.

The chief materials for mortars are *lime* and *sand*, but *Portland Cement* (p. 503) is sometimes used to replace part or all of the lime.

The *lime* should be made by burning a calcareous limestone low in magnesia; magnesian limestone, or dolomite, is much less suitable. The burning should be effected in such a manner that the lime contains at least 85 per cent. of calcium oxide in the form of quicklime. Limes which have been imperfectly burned, and so contain 15 per cent. or more of unaltered calcium carbonate, are not suitable for mortar to be used on important work. A very pure lime (containing 95 per cent. of free calcium oxide) is not necessary for building and is usually too costly. The idea that a pure lime is, in itself, objectionable, is incorrect, provided a suitable sand is used. If a very pure lime is used with a very coarse sand, the absence of fine siliceous matter may result in a weak mortar which chiefly hardens externally.

Lean (i.e. less pure) lime * and hydraulic lime, on the contrary, harden in a manner similar to cement. The addition of trass or brick-dust to slaked lime has a similar effect on the manner in which the mortar hardens.

Hydraulic limes differ from the 'fat' or quick limes in consisting of an indefinite compound of lime and clay, which may be regarded as a crude Portland cement (p. 503), containing a large excess of free lime. The hydraulic limes owe their power of setting and hardening under water to this lime-clay compound, and consequently form a stronger brickwork or masonry than is produced by common mortar. Some hydraulic limes consist of a mixture of quicklime, true hydraulic lime, and inert or unburned material; for important work they should be tested and the proportions of these ingredients ascertained, as in hydraulic lime the proportion of cementitious matter present is more important than the percentage of lime.

Lias lime is hydraulic lime obtained from clayey limestones occurring in the Lias formations.

Quicklime should be slaked or hydrated before use; hydraulic lime should be bought in the form of a powder. To save the trouble and time involved in slaking and the risk of 'blowing' and other defects due to imperfectly slaked lime, it is becoming increasingly the custom to use *hydrated lime*. This has been slaked under skilled supervision, so as to produce a fine powder which is free from all coarse material and quicklime; it is sold in bags of 1 cwt. and is ready for immediate use. Slaked or Hydrated lime should pass completely through a 60-mesh sieve, and should not leave more than 8 per cent. residue on a 100-mesh sieve. Hydraulic lime should not leave more than 8 per cent. of residue on a 100-mesh sieve.†

A hydraulic lime, when mixed with 30–50 per cent. of its weight of water and stored under water at 60° F., should harden sufficiently not to be indented with the finger-nail in about three days.†

The *sand* used for mortars should consist of sharp (angular) grains of various sizes. Rounded grains do not interlock sufficiently to produce a strong mortar.†

Crystalline quartz sand is to be preferred to mica or felspar sand; the usual description 'good, clean, sharp sand' is much too wide. The grains of sand which are angular give the best results of tensile strength, those that are round give the highest compression strength. It is advisable to submit the sand to a microscopic examination to ascertain its suitability, as a considerable variation in the strength of mortar may occur, owing to the form and variety of the sand particles. From trials made with mortar composed of 1 of cement and 3 of sand a difference of strength varying from 171 lbs. to 313 lbs. per sq. in. was found, owing entirely to the difference in the sand; normal sand mixed in above proportions gave 256 lbs. per sq. in. in 28 days.

It is very important that the sand used for mortars and concrete should be free from clay and decomposed vegetable matter (*humus*). A simple test, devised by D. Abrams and O. Harder, consists in shaking the sand vigorously with a dilute solution of caustic soda, allowing the sand to settle and noting the colour of the overlying liquid. If it is dark-coloured, the sand is probably unsuitable for use; a very pale yellow colour may be neglected.

The grading of the sand, i.e. the proportions of grains of different sizes, deserves far more attention than has yet been paid to it. By the use of a suitably graded sand, it is easy to reduce the proportion of the more expensive lime or cement by about 33 per cent. of that required for a less suitable sand. For most purposes the sand should contain about 30 per cent. of air-spaces or voids between the grains. The proportion of voids may be estimated by filling a measure with sand, and then pouring in water until the water is level with the top of the sand. The ratio of the volume of water, added to the volume of the sand, is that of the volume of the voids to that of the sand.

The *water* used in the preparation of mortar should be free from decaying substances; hence, peaty water should not be used. Apart from this, its source and character are of small importance. Brackish water, and even sea water, does little harm as regards the strength of the mortar, but may cause scum or efflorescence on the structure.† If both are available, soft water is better than hard. For cement-sand mortar the average will be about 22 per cent. of the cement and sand by volume, or about 20 per cent. by weight, for trass-cements and mortar 8 to 10 per cent. by volume.

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* Limes which produce less than twice their volume of slaked lime in the form of an apparently dry powder are termed 'lean' or 'poor' limes.

† See Tentative Specifications (p. 487), which give different figures.

	Quicklime.			Hydrated Lime.		Hydraulic Lime.		
	Class A.	High Magnesium. Class A.	Class B.	Class A.	Class B.	Class C1.	Class C2.	Class C3.
Composition	Not less than 95% CaO + MgO.† Not more than 10% CO_2.	Not less than 95%. CaO + MgO.† More than 20% MgO.† Not more than 10% CO_2.	Not less than 85% CaO + MgO.† Not more than 10% CO_2.	Not less than 95% CaO + MgO.† Not more than 5% CO_2.	Not less than 85% CaO + MgO.† Not more than 5% CO_2.	Not less than 60% CaO + MgO.† Not more than 10% CO_2 and 15% SiO_2 + Al_2O_3.†	Not less than 60% CaO + MgO.† Not more than 10% CO_2. Not more than 25% or less than 15% SiO_2 + Al_2O_3.†	Not less than 60% CaO + MgO.† Not more than 10% CO_2. Not more than 35%, or less than 25% SiO_2 + Al_2O_3.†
Fineness and residue.	Not more than 5% when slaked and washed through I.M.M. Standard No. 20 sieve.	(As Class A)	(As Class A)	All through No. 20 sieve. Not more than 10% on No. 200 sieve. Not more than 1% on No. 50 sieve.	All through No. 20 sieve. Not more than 15% on No. 200 sieve.	*Either* not more than 5% when washed through No. 20 sieve. *Or* ground to pass through No. 20 sieve, and not more than 15% residue on No. 200 sieve.	(As Class C1)	(As Class C1)
Soundness	—	—	—	See below ‡	—	—	—	—
Tensile strength	—	—	—	—	—	—	See below §	See below §

‡ Hydrated Lime (Class A)—

Soundness: Accelerated steaming test on 4 in. × ¼ in. pat, made with lime 1 part, standard sand 5 parts, allowed to set in air 24 hours, covered with lime paste and kept 24 hours, then immersed 5 hours in steam to show no signs of cracking, pitting, or disintegration.

§ Hydraulic Lime (Classes C2 and C3)—

Tensile Strength: On lime slaked, stored 24 hours, mixed with three times its weight of standard sand and sufficient water, and briquettes stored in moist air 72 hours and in water for 28 days. Briquettes same shape and size as for cement.

Average of six briquettes not less than 75 lbs. per sq. in. after 28 days.

* Published by His Majesty's Stationery Office, Imperial House, Kingsway, London, W.C. 2; price 1*s.* 9*d.* net.

† On ignited sample.

Proportions for Mortars.

Mortars are usually made largely by guess-work, but to secure the best results—which are often the cheapest, as a large saving can be effected by preventing a waste of lime—it is necessary to determine the best proportion of sand for the particular lime used.

For many purposes, the most suitable proportions are from 2 to 5 measures of sand to 1 measure each of lime and brick-dust, or trass, but the latter is usually omitted, and large quantities of mortar consist of 1 measure of lime to 3 measures of sharp sand. When ashes * or coke dust are used, one measure of these materials usually replaces an equal amount of sand. For the cheapest mortar, 1 part of lime and 4 parts of sand is used, but such a mortar is weaker than is desirable for general work.

According to J. A. van der Kloes, who has investigated the matter very thoroughly, the best proportions for mortars for various purposes are as shown in the following table:—

Number.	Lean Lime.	Fat Lime.	Lime-Putty.		Trass.	Portland Cement.	Trass or Pozzolana Cement.	Sand.
			Solid.	Fluid.				
A.—Waterproof Mortars for Work which is continually under Water.								
I.	1	—	—	—	1½	—	—	1½
II.	—	1	—	—	1½	—	—	2
III. (*a*)	—	—	1	—	3	—	—	4
III. (*b*)	—	—	—	1	2½	—	—	3
IV.	—	—	—	—	—	1	—	2
V.	—	—	—	—	1	1	—	2½
VI.	—	—	—	—	—	—	1	1–1½
B.—Mortars for Quays, Sluice Walls, Damp-proof Courses, etc.								
VII.	1	—	—	—	1½	—	—	2–2½
VIII.	—	1	—	—	1½	—	—	2½–3
IX. (*a*)	—	—	1	—	3	—	—	5–6
IX. (*b*)	—	—	—	1	2½	—	—	3½–4½
X.	—	—	—	—	—	1	—	3
XI.	—	—	—	—	1	1	—	4
XII.	—	—	—	—	—	—	1	2
C.—Mortars for Foundations and Buildings.								
XIII.	1	—	—	—	1½	—	—	3–4
XIV.	—	1	—	—	1½	—	—	4–5
XV. (*a*)	—	—	1	—	3	—	—	8–10
XV. (*b*)	—	—	—	1	2½	—	—	6–7½
XVI.	—	—	—	—	—	1	—	3
XVII.	—	—	—	—	1	1	—	4–5
XVIII.	—	—	—	—	—	—	1	2½–3

For 1 cu. yd. of cement mortar, the following quantities of sand and Portland cement will be required:—

Proportions. Cement.	Sand.	Sand. Cub. ft.	Cement. Lbs.
1	0	—	2,800
1	1	18·8	1,695
1	2	24·9	1,120
1	3	28·7	860
1	4	30·3	682
1	5	31·4	565
1	6	32·2	483

* The use of ashes in mortar is a frequent cause of scum or efflorescence in brickwork.

·87 cu. ft. of neat cement mortar will result from mixing 0·36 cu. ft. of water with 1 cu. ft. of loose cement.

. cu. ft. of loose Portland cement will make about—

4·1	cu. ft. of	concrete	mixed 1 : 2 : 4
5·0	,,	,,	1 : 2½ : 5
5·8	,,	,,	1 : 3 : 6
7·5	,,	,,	1 : 4 : 8

. cu. ft. of loose Portland cement neat as cement mortar will cover about 10·4 sq. ft., 1 in. thick.
. cu. ft. of loose Portland cement to 1 sand will cover about 17 sq. ft. 1 in. thick.
. cu. ft. of loose Portland cement to 2 sand will cover about 25 sq. ft. 1 in. thick.
. cu. ft. of loose Portland cement to 3 sand will cover about 34 sq. ft. 1 in. thick.
. cu. ft. of loose Portland cement to 2 sand will lay about 146 bricks with ⅜-in. joint, and 247 bricks with ½-in. joint.
cu. ft. of loose Portland cement to 3 sand will lay about 212 bricks with ⅜-in. joint, and 317 bricks with ½-in. joint.
yd. super. of pointing brickwork in neat cement requires about 8 lbs. of cement.

The proportion of water required varies with the nature of the lime and sand used. (See the ıar. on *water*, on p. 486.)

Mixing Mortars.

If a mortar is to answer its purpose satisfactorily, it is obvious that the various constituents nust be mixed as uniformly and intimately as possible, for wherever sand or other powdery ır gritty substances accumulate in the mortar, no hardening or adhesion will take place, and the nortar will be almost useless at such points.

Small quantities of mortar may be mixed by repeatedly turning over the materials with a hovel, and afterwards with a trowel, so as to mix them very thoroughly. As the labour is ıard, and workmen are not always sufficiently conscientious, machine-made mortar is often nore reliable than that mixed by hand. The most suitable machine for mixing mortar consists of an edge-runner or pan-mill of moderately light construction, in which the materials are treated for 20 to 30 minutes. Some builders introduce large pieces of material into such a mill, and grind them therein. This is not desirable. No pieces larger than ¼ in. diameter should be ntroduced into a mortar mill, and if any materials more than $\frac{1}{16}$ in. diameter are present, the nixing must be prolonged until they have all been reduced to $\frac{1}{32}$ in. or less in diameter.

Choice of Mortar.

Mortar made with ordinary lime should not be exposed to water.

Mortar made with hydraulic lime should not be exposed to running water, unless the mortar also contains trass.

Cement-mortar is best where great strength is required a short time after completing the structure, but where a longer period of hardening is permissible, lime-trass mortar is cheaper and equally durable.

For the interior of kilns, furnaces, and flues, clay mortar should be used.

Coloured Mortars.

TINTS GIVEN TO PORTLAND CEMENT MORTAR CONTAINING TWO PARTS OF RIVER SAND TO ONE PART OF CEMENT.

Pigment.	Weight of Dry Pigment to 100 Pounds of Cement.			
	½ Lb.	1 Lb.	2 Lbs.	4 Lbs.
Lamp black	Light slate	Light gray	Blue gray	Dark blue slate
Prussian blue	Light green slate	Light blue slate	Blue slate	Bright blue slate
Ultramarine blue	—.	Light blue slate	Blue slate	Bright blue slate
Yellow ochre	Light green	—	—	Light buff
Burnt umber	Light pinkish slate	Pinkish slate	Dull lavender pink	Chocolate
Venetian red	Slate, pink tinge	Bright pinkish slate	Light dull pink	Dull pink
Chattanooga iron ore	Light pinkish slate	Dull pink	Light terra cotta	Light brick red
Red iron ore	Pinkish slate	Dull pink	Terra cotta	Light brick red

(*L. G. Sabin.*)

Specifications of Mortars.

There are no official specifications for mortar in the British Isles, but the Department of Scientific and Industrial Research has issued in *Building Research Board Report No.* 9 (1927) (p. 487), the following tentative specifications :

Quicklime for mortar—quicklime, Class A or B.

Hydrated lime for mortar—hydrated lime, Class A or B. Hydrated hydraulic lime is *not* suitable.

Hydraulic lime for mortar—hydraulic lime, C2 or C3.

Mortar for structural work (*i.e.* exclusive of plaster, stucco, and parging) to consist of a plastic mixture of lime, putty, or hydrated lime, sand, and water, with or without pozzolanic material. The *lime* for work above ground-level should be Class C1, or preferably C2 or C3 (see table), and for below ground or water level, C2, C3, or a lime-cement mixture. Lime and hydrated lime of Class A should not be used without a pozzolanic material in such proportion that the lime, when mixed with three parts by weight of sand and the proposed proportion of pozzolanic material, shall have a minimum tensile strength of 50 lbs. per sq. in. The pozzolanic material may replace an equal weight of sand up to one-third of the weight of sand stated above. Mixtures containing less sand must have higher tensile strengths (see the *Report*). The *sand* shall not pass more than 10 per cent. of its weight through a Standard I.M.M. No. 80 sieve, and the proportions of particles of different sizes shall be well distributed. In lieu of sand, hard rock, slag, clean bricks, clean clinker, coal-cinder of approved origin or hard-burned clay, may be used if crushed so that all the material passes through a Standard I.M.M. No. 5 sieve. The *water* must be free from unusual proportions of dissolved salts and gases and must not be brackish.

In structures below ground or water level and subject to load, not more than one volume of sand shall be used to one volume of hydraulic lime. In structures above ground-level, subject to load, two volumes of sand may be used to one volume of hydraulic lime. In structures above ground not subject to load and in work of less importance, three volumes of sand to one volume of hydraulic lime may be used. Pozzolanic material may replace part of the lime by agreement with the architect.

CONCRETES.

Concretes are very coarse mortars, containing stones, gravel or ballast, sand, and a binding agent such as lime or cement. They are known by various names, according to the binding agent employed.

Lime concrete usually consists of a mixture of 1 part lime, 4 parts gravel, and 2 parts sand.

The best way of making lime concrete is by mixing together unslaked or hot, fresh-ground lime with sand and ballast, in the required proportions, on a stone, brick, or wooden floor, turning it over twice to dry, and then, as it is shovelled to a third heap, adding from the rose of a watering-can sufficient water only to slake the lime and make the ingredients cling together in a pasty mass, turning it over well as the water is added. Generally speaking, it will take about ¾ gallon to each cubic foot of ballast, but much will depend on the nature of the concrete and the dryness of the ballast employed.

Although frequently employed, fat or quick lime should not be used for lime concrete exposed to the weather, only hydraulic lime being suitable.

Beton is a French term, originally applied to lime concrete, but now used for any kind of concrete.

Cement concrete (more commonly known as *concrete* or *mass concrete*) is a mixture of stones, gravel or ballast, sand, and cement. Coke, clinker, and other materials are sometimes used to replace part of the stones, etc.

Breeze concrete consists of a mixture of 3 measures of small pieces of coke (preferably gas-works coke breeze), 1 of sand, and 1 of Portland cement. It is cheap, and nails can readily be driven into it. Its great disadvantage is that, in the event of a conflagration, it may take fire and increase the resulting damage instead of diminishing it.

Concrete made of ashes or clinker is sometimes, but erroneously, termed ' breeze concrete.'

Slag concrete is a mixture of crushed slag and Portland cement. It has been reported as having a greater compressive strength, less weight per cubic yard, and greater resistance to impact than concrete made with natural stone, but various failures which have occurred when slag concrete has been used have made many engineers unwilling to employ it. According to Dr. J. E. Stead, these failures were chiefly due to (1) using too little cement, and (2) the use of fine slag contaminated with ashes and other deleterious substances. In Dr. Stead's opinion, pieces of slag of less than ¼-in. diameter should not be employed in concrete. Fine slag, when moistened, is liable to evolve sulphuretted hydrogen, which has a very objectionable odour.

Reinforced concrete or *ferro-concrete* consists of a concrete structure, the strength of which is increased by the immersion of steel rods or wires in the concrete (see Section XI, p. 511).

Raw Materials for Concrete.

All concretes consist essentially of a coarse aggregate, a fine aggregate, and a binding material cement.

The *coarse aggregate* should consist of suitable stone, gravel or ballast, coke breeze, clinker, other hard material of ample resistance to crushing, low porosity (absorbing less than 6 per nt. of its weight of water), and not liable to rapid disintegration by frost. The aggregate ould be clean, and if necessary it should be washed before use. Except for the largest and ughest work, all the pieces of coarse aggregate should pass through a 2-in. ring.

The *fine aggregate* should consist of sharp, quartzose sand, similar to that used for mortar . 486). If trass is added, the concrete will be more resistant to water. Wet sand requires ore cement than dry sand. The sand should be free from clay, and if necessary should be ashed before use.

The *cement* may consist of hydraulic lime, Portland cement, or one of the cruder cements, ch as *natural cement*, *Roman cement*, *Grappier cement*, *slag cement* (*iron Portland cement*), or rious mixtures of Portland cement with sand, blast furnace slag (*Montan cement*), iron e, etc.

Of these, Portland cement is the strongest and most reliable. It should conform to the andard Specification (p. 505).

The *water* used for concrete should be the same as that for mortar (p. 486).

Proportions for Concrete.

To obtain the best results, the proportion of coarse aggregate (stones, gravel, etc.) should such that the interstices or voids between its particles are wholly filled with sand, the inter-ces or voids in the sand being then filled with cement: additional cement, sufficient to cover the particles of aggregate with an adhesive coating, should also be present.

As the determination of the voids is often troublesome, many engineers adopt definite oportions of coarse and fine aggregate and cement. For reinforced concrete work where very od concrete is required, the proportions are usually 1 of Portland cement to 2 of sand to 4 coarse material. For a medium quality concrete, such as is used for foundations, walls, ches, ordinary floors and stairs, the proportions should be 1 : 2½ : 5. For heavy walls, retaining lls, piers, and abutments which are subjected to considerable strain, the concrete can, however, poorer, 1 : 3 : 6. Wherever concrete is employed in large masses, and is subjected to simple mpression of small intensity, or is used for a backing for brickwork or masonry, or for covering e site of a building to prevent the damp rising from the soil, a still poorer concrete can be ed of 1 : 4 : 8. In such work and in foundations large stones (commonly called 'plums') n often be placed by hand in the mass some little distance apart so as to allow them to be rrounded by the concrete; these economise considerably, without greatly reducing the strength the mass.

For concrete to be used under water, a mixture corresponding to a cement-trass mortar is eferable (see the table on p. 488).

The following table shows the relative weights required to produce the proportions men-oned in the first column; from it the cost of materials per cu. yd. of concrete for various mixtures n be ascertained.

MATERIALS FOR 1 CU. YD. OF CONCRETE.

Based on loose cement weighing 90 lbs. per cu. ft., with an average specific gravity of 3·12 d a cu. ft. of loose, moist, coarse sand weighing 89 lbs. when dried.

'roportions.	Kind of Coarse Material.	Lbs. Portland Cement in 1 cu. yd.	Sand cu. yds. in 1 cu. yd.	Coarse Material, cu. yds. in 1 cu. yd.
1 : 1½ : 3	Shingle (40 per cent. voids)	666	·41	·82
Do.	Broken stone (45 per cent. voids)	697	·43	·86
1 : 1¾ : 3½	Shingle	610	·42	·84
Do.	Broken stone	640	·44	·88
1 : 2 : 4	Shingle	520	·43	·86
Do.	Broken stone	543	·45	·90
1 : 2½ : 5	Shingle	430	·44	·88
Do	Broken stone	450	·46	·92
1 : 3 : 6	Shingle	364	45	·90
Do	Broken stone	383	·47	·94
1 : 4 8	Shingle	280	·46	·92
Do.	Broken stone	294	·48	·97

This table does not apply to concrete made with a single aggregate, such as Thames ballast, which no sand is added, but where proper scientifically proportioned concrete is employed,

as should always be the case, the values given in the table are accurate and correspond with experience.

In measuring out the materials, the fact must not be overlooked that about 34 cu. ft. of stone, sand, and cement will be required for each cu. yd. of concrete, as the sand and cement occupy the interstices between the pieces of coarse aggregate.

Gravel passing same screens as stone always has less voids than the stone.

Fine sand concrete has smaller weight per cubic foot than coarse sand concrete.

Fine sand plus large aggregate (without cement) gives *smaller* volume than coarse. Fine sand plus large aggregate (with cement) gives *larger* volume than coarse.

Fine sand concrete is easier worked than coarse sand concrete for equal amounts of sand.

The finer the aggregate the more deleterious material and air it carries with it into the concrete.

The finer the sand the less should be used.

Mixing Concrete.

Concrete may be mixed by hand, as described on p. 489, but large quantities are preferably mixed by machinery. Various types of mixing machines have proved satisfactory, but the ones most largely used consist of a cylinder, fitted with baffle plates internally and mounted on trunnions so as to be revolved rapidly.

COMBINED TABLE OF WORKING CAPACITIES AND LEADING DIMENSIONS OF CONCRETE MIXERS.

No. of Mixer.	00	0	1	2	3	4	5
Nominal batch capacity (cu. yds.)	0·08	¼	½	¾	1	1½	2
Hopper batch (cu. ft.)	3	6·75	13·5	20	30	56	80
Approximate output per batch of broken stone (cu. ft.)	2	5	11	16	24	38	54
Approximate output per batch of ballast or gravel (cu. ft.)	2·25	5·5	12	18	27	42	60
Approximate output per 10-hour day of broken stone (cu. yds.)	22	55	118	180	270	415	592
Approximate output per 10-hour day of ballast or gravel (cu. yds.)	25	60	133	200	300	470	660
Capacity output which has been obtained per 10-hour day (cu. yds.)	50	120	266	400	600	940	1,320
R.P.M. (driving shaft)	174	132	118	122	94	99	90
R.P.M. (drum)	24	18	16	15	14½	14	12
Mean speed of elevator (ft. per min.)	50	50	45	47	50	50	50
Size of pulleys (ins.)	15×2½	18×4½	21×6½	24×7½	32×9½	42×10½	60×12½
Diameter of driving shaft (ins.)	1½	1⅞	2⅛	2⅛	2½	3	3½
Capacity of water tank (galls.)	4	10	20	30	35	35	70
Diameter of drum	2′ 9″	3′ 6″	4′ 6″	5′ 0″	5′ 6″	6′ 6″	7′ 6″
Width of drum	2′ 0″	2′ 6″	3′ 0″	3′ 6″	4′ 6″	5′ 0″	5′ 9″
Approximate B.H.P. absorbed (varies according to material)	2	5	7	12	15	20	40

NOTE.—In the production of concrete it is impossible to guarantee definitely the exact amount of mixed material which will be produced from a given quantity of aggregate, owing to the varied nature and size of the stone used, but the above figures, based on actual results may be taken as approximately correct.

The mixing should be as rapid as possible, consistent with thoroughness, as the concrete should be placed in position before it has begun to set.

Remixed concrete should never be used.

For descriptions of mechanical mixers and further information on mixing concrete, see 'Cement, Concrete, and Bricks,' by A. B. Searle (Constable).

Placing Concrete.

In ordinary foundations, the concrete should be deposited in horizontal layers, not more than a foot thick, and care should be taken to cover any joints in one layer by the succeeding one, as the joint between two days' work is always a weak part; moreover, the last-laid layer should be well wetted, to ensure a proper connection with the next.

The chief mistake made in placing mass concrete is in failing to secure sufficient adhesion to the previously placed material. In reinforced concrete there is often a danger of incomplete filling, particularly around the more complex portions of the reinforcement; this may be minimised by the use of a wetter mixture or by efficient damping or vibration. If the latter is effected mechanically, care must be taken not to continue it so long that the setting of the concrete is disturbed.

Fine concrete or cement mortar may be sprayed on to the surface to be covered by means of a *Cement Gun* operated by compressed air (see p. 496). This method is particularly effective for 'plastering' with cement mortar, or in the construction of walls about 2 ins. thick on a basis of expanded metal or wire netting.

As the right placing of concrete is of great importance, it may be desirable to consult one or more text-books on the subject.

Volume of Concrete.

The volume of a mass of concrete is much less than that of the separate ingredients, owing to the voids or interstices between the particles of coarse aggregate being occupied, in the concrete, by the sand and cement. Roughly,

Mixture.	Volume of coarse aggregate.	Volume of concrete.
1 : 2 : 4	1 cu. yd.	1·07 cu. yd.
1 : 2½ : 5	1 cu. yd.	1·02 cu. yd.
1 : 2 : 8	1 cu. yd.	1 cu. yd.

1 cu. ft. of loose Portland cement will make about :—

4 cu. ft. of 1 : 2 : 4 concrete.	6 cu. ft. of 1 : 3 : 6 concrete.
5 cu. ft. of 1 : 2½ : 5 „	7½ cu. ft. of 1 : 4 : 8 „

Weight of Concrete.

The weight of 1 cu. ft. of concrete varies with the proportion and nature of the aggregate used.

The average weight of 1 : 2 : 4 concrete, using sand as fine aggregate and one of the following coarse aggregates, is: coke breeze, 100 lbs. per cu. ft.; clinker, 110 lbs. per cu. ft.; sandstone, 120 lbs. per cu. ft.; bricks, 125 lbs. per cu. ft.; limestone, 135 lbs. per cu. ft.; shingle, 145 lbs. per cu. ft.; granite, 145–150 lbs. per cu. ft.

Strength of Concrete.

The proportion of water used in mixing concrete is much more important than is commonly realised, as it has a great influence on the strength of the concrete. According to D. A. Abrams,

$$\text{Compressive strength of concrete in lbs. per sq. in.} = \frac{14{,}000}{7x},$$

where x is the ratio (by volume) of water : cement. If this is the case, a comparatively small excess of water must have a very harmful effect. The American practice of using a very wet mixture is not to be recommended where great strength is required.

Too little water, as well as a large excess of water, are adverse to the production of strong concrete.

Concrete containing too much cement may be weaker than that containing less cement.

Badly mixed concrete is weak in some parts and strong in others.

The addition of 10 per cent. calcium chloride to the mixing water increases the strength of mass concrete, but cannot be used for reinforced concrete as it corrodes the reinforcement.

The compressive strength of most concretes, as commercially made, can be increased 25 to 100 per cent. or more by employing rigid inspection, which will ensure proper methods of fabrication of the materials.

For equal working consistency and equal cement, gravel concrete is as strong as stone concrete.

30–40 per cent. higher strengths are obtained with 3·16 in. cubes than with 6 in. cubes.

Small cubes are more uncertain and inconsistent in the strength values than larger cubes.

The requirements of the London County Council and the Specification drawn up by a Joint Committee of the Royal Institute of British Architects, District Surveyors' Association, Institute of Builders, Institute of Municipal and County Engineers, War Office, Admiralty, London County Council, and the Concrete Institute, call for a crushing strength of 1,800 lbs. per sq. in. at 28 days and 2,400 lbs. per sq. in. at 90 days for a 1 : 2 : 4 mixture.

The figures 1,400 at 28 days and 2,000 at 90 days more nearly represent the results obtained under ordinary working conditions, with an aggregate like Thames ballast.

The strength of concrete continues to increase long after it has been made, and is by no means at its maximum after 90 days.

According to the U.S.A. Bureau of Standards, if S_{28} be the strength of concrete at 28 days, and S_7 the strength at 7 days, then :

$$S_{28} = S_7 + 30\sqrt{S_7}.$$

Weather conditions have a marked effect on concrete work. Heat hastens the hardening process; cold delays it. The effect of cold becomes noticeable when temperatures fall below 50° F., and becomes more marked with lower temperatures. As a rule, concrete does not show any serious effects from having once been frozen if, after it thaws out, it is not again frozen until early hardening is complete. It is better, however, to protect the concrete from freezing for from forty-eight hours to four or five days, depending upon the degree of the cold, rather than to expose it to the possibility of freezing. Warmth and moisture are necessary to the proper hardening of concrete.

It is especially important to keep concrete thoroughly saturated with water for at least a week, as if it is allowed to dry too soon, it never develops its full strength.

Effect of Addition of Pigments.

Trials have recently (1927) been made by the British Portland Cement Association to test the effect on the strength of concrete produced by the addition of pigments. The tests were made at the age of seven days, on briquettes 2¾ in. cube. Red oxide of iron produced no effect; green chromium oxide, ultramarine blue, yellow ochre, and manganese dioxide slightly reduced the strength. Carbon black reduced the strength very noticeably.

Effect of Sea-water on Concrete.

The effect of sea-water on concrete depends on the permeability of the latter, dense, water-proof concrete being largely resistant to sea-water, whilst porous concrete corrodes readily. For exposure to sea-water, the concrete should contain a considerable proportion of trass, or equivalent, a suitable mixture consisting of 1 measure of trass, 1 of Portland cement, and 2 to 3 measures of aggregate. The aggregate should consist of coarse and moderately fine particles, in such proportions as to produce a concrete of maximum impermeability.

Condensation on Concrete.

Interior plastering will prevent condensation on any sort of concrete. A good method is to cover the interior of the concrete walls with ordinary plasterer's lime and sand mortar (about 3 of sand to 1 of lime), lightly keyed in the usual manner to receive the final setting coat. This coat must be left until strong pressure from the thumb makes no impression. It may be necessary to leave it for several days, according to the weather. The finishing coat of lime, putty, sand and plaster of Paris may then be applied with safety. Immediately before this latter coat sets it should be finished with a soft hair brush, which produces a granular surface, a further method of absorbing moisture.

The best and most easily obtainable finishing coat is the following :

3 parts of lime putty or chalk lime; 6 parts of washed sand; 1 part of plaster of Paris. This gives a good finish, sets well, and works quickly.

Instead of making dense concrete for walls, it is much cheaper and more hygienic to use a very porous concrete, and to render it with a cement waterproofed exterior coating, for the fiercest driving rain cannot penetrate a ¾-in. pudloed cement rendering. Porous concrete, like all porous materials, has also the quality of retaining the heat engendered in the room, thus giving a warmer dwelling. Therefore porous concrete has the dual advantage of assisting the absorption of condensation and of conserving heat.

Preventing Scaling and Cracking of Concrete.

The best method of preventing *scaling* is to keep the concrete thoroughly wet for a week or more after it has been placed, the surface being protected with wet cloths, sawdust, or other porous material. The surface may also be covered with about 2 in. of calcium chloride.

Cracking may be prevented in the same manner, except in those cases where insufficient allowance has been made for stresses due to load or to expansion.

Permeability of Concrete.

The Swiss Hydraulic Association Report (issued in 1922) states that only highly plastic loams of very fine grain can be recommended for making the concrete or gravel used in lining canal bottoms and rendering walls impermeable, and is in any case only likely to form a strong protective coating on surfaces which are always under water; layers which are exposed to the action of the sun rays, rain, and frost are apt to develop cracks. Rammed loam, even when mixed with sand or gravel, will crack in drying, and cannot be much improved by subsequent wetting. But loose gravel, suitably treated with loam water in such a way that the loam particles settle first in the lower gravel layers, will harden to a stony mass, not liable to cracking. The amount of water percolating per day through ordinary concrete under a pressure of 5 atmospheres was found to diminish gradually.

Colouring Concrete.

A method of producing colour in concrete has been introduced, in which coloured ground glass is mixed with the cement, which gives an unlimited variety of patterns and colour effects. It has been suggested that this concrete be used for brightening roads, pavements, and house fronts, and, since the colour will not fade, it will eliminate the drab appearance of buildings and highways so prevalent in big towns.

(See also p. 494.)

Rust Prevention in Reinforced Concrete.

Various methods have been proposed for preventing the reinforcement from rusting. Under ordinary circumstances, no special precautions are necessary, and if the corrosion is due to electric currents no application of chemicals can be satisfactory.

The use of galvanised reinforcement has been stated to prevent rusting, and also to secure greater adhesion between the metal and the concrete.

Steel cannot rust when embedded in a strongly alkaline substance. In the setting of Portland cement concrete a relatively large quantity of caustic lime (lime hydrate) is produced, and the concrete becomes saturated with it. This is strongly alkaline, and by decreasing the number of hydrogen ions present makes any corrosion of the steel impossible.

Treatment of Dusty Concrete Floors.

Various hardening solutions are sold for preventing concrete floors from being dusty, and to give a better wearing surface. The composition of most of these solutions is a trade secret.

Two excellent hardening solutions are the following:—

(1) Mix 1 part silicate of soda to 4 or 5 parts water. Brush or sprinkle the floor well with this solution, and allow to dry. Then, after 4 hours and within 24 hours, wash clean with clean water. Repeat the treatment three times.

(2) The following solution has been recommended by *Concrete*:—

To 10 gallons of cold water add 1 fluid ounce of sulphuric acid. Heat the liquid to boiling point and stir in 25 lbs. of sulphate of alumina. Let the solution cool and strain. Sweep and thoroughly wash the concrete surface. After drying, lay on the hardener in four applications of varying strength, ranging from 30 per cent. solution and 70 per cent. water, up to 100 per cent. solution. The above quantity suffices for the complete treatment of an area of from 50 square yards to 100 square yards, depending upon the porosity of the surface treated.

(See also p. 873.)

To Waterproof Concrete.

Concrete may be made waterproof by taking care to use such proportions of the various ingredients as will produce a dense and impermeable material.

As this is not always practicable, it is often preferable to add a waterproofing agent prior to mixing the various ingredients. The chief of these additions are:

(1) *Oil* or a solution of paraffin wax in benzoline or other cheap volatile solvent.

(2) *Insoluble soap* made by impregnating the concrete with a solution of alum, and afterwards with a solution of soap. Suitable proportions are:—

One part of cement, 2 parts of sand, ¾ lb. of dry powdered alum to each cubic foot of sand. These are mixed and dried, and to them is added water in which has been dissolved ¾ lb. soap to each gallon. This, it is said, is nearly as strong as ordinary cement, and is quite impervious to water, and does not effloresce. For a wash, a mixture of 1 lb. of lye and 2 lbs. of alum in 2 gallons of water is often used.

(3) *Water-glass* (silicate of soda) applied in the form of a wash or spray, several applications being necessary at suitable intervals.

(4) *Special mixtures* sold under various trade names, such as Pudlo, Prufitol, Bareau, Prufit, etc.

Building Products Ltd. (51 Columbia House, 44/46 King's Road, Chelsea, S.W. 3) supply a preparation called PRUFITOL for applying by brush or spraying machine to porous brick, stone, cement, or stucco work, which will keep out driving rains.

The integral system of incorporating a waterproofing agent with the cement and aggregate may be performed by mixing BAREAU cement waterproofing powder with the dry cement, or PRUFIT cement waterproofing paste with the gauging water.

'Cement Gun' Machine for Application of Hydraulic Materials.

In this machine, sand and cement, previously mixed dry, are placed in a hopper, from which the mixture is automatically fed through an air-locking device and hose to a nozzle, where water is automatically added, and by the aid of compressed air the 'Gunite' (as the mixture is called) is sprayed in a perfectly hydrated state on the surface to be coated.

The propelment of the material by the pneumatic pressure against the surface to be covered ensures a very dense, hard, and durable mortar. It also means the elimination of heavy and expensive forms, for the material builds up against the backing to a considerable thickness without losing its high quality.

Tests showed that the modulus of elasticity of 'Gunite' was at the end of ninety days, on one part cement to three parts sand mixture, 4,705,000; on one part cement to two-and-a-half parts sand mixture, 4,760,000.

On prisms made of mixtures consisting of one part cement and three parts sand, at the end of ninety days an average ultimate compressive strength of 4,000 lbs. per sq. in. was obtained on prisms consisting of mixtures containing one part cement to two-and-a-half sand, 4,600 lbs. per sq. in.

It was found that the adhesion between new and old surfaces was absolutely permanent. 'Gunite' has a very high resistance to salt water action.

The cement gun itself is supplied by the *Cement Gun (Great Britain), Ltd., Broadway Buildings, Westminster, S.W.* 1, whose firm also undertake constructional and repair work of a kind for which the cement gun is peculiarly suitable.

The cement gun is now used regularly in twenty-five collieries in this country, and many effective repairs to reservoirs, various concrete structures, and even to damaged factory chimneys have been made by its use, under conditions where no other method could have been so satisfactory.

CONCRETE BLOCKS, TILES, AND OTHER ARTICLES.

In addition to masses of concrete moulded *in situ*, large quantities of blocks, tiles, garden vases, fencing posts, troughs, and other articles made of concrete or of cement-sand mortar (p. 485) are in regular use, and afford clear proof of the manifold uses of this material.*

For *Concrete floors*, see p. 873.

* For further details see *Concrete and Constructional Engineering, Everyday Uses of Portland Cement*, and various text-books on concrete.

Asbestos Building Sheets.

The use of sheets composed of Portland cement, asbestos, and a neutral filler, has greatly increased during recent years. These sheets require costly plant for their production, so that it is usually necessary to buy them ready-made. They are usually sold under various trade names.

Plain sheets are used for walls and roofs ; corrugated sheets are largely used in place of those made of corrugated iron. Small sheets are used instead of roofing tiles (see p. 426).

See also pp. 425–427.

CEMENTS.

Cements are materials used for uniting other materials or articles so that they adhere, permanently. There are many kinds of cements, but the more important ones may be grouped, as follows :

(1) Mastic Cements.

Mastic cements, in which the chief ingredient is a gum (such as resin, shellac, wax, or rubber), boiled oil, or bituminous material to which is added a ' filler,' such as sand, rock dust, or other inert powder. If boiled oil is used red lead must usually be added as well as the filler. Useful mastic cements include :

A *strong general cement*, composed of 4 ozs. clear gum arabic, 3 ozs. fine starch, 2 ozs. white sugar. Dissolve gum in water ; then dissolve starch and sugar in gum solution ; boil mixture in a water-bath until starch becomes clear. Add a few drops of oil of cloves.

A cement for *fixing paper to metal*, composed of gum tragacanth, 30 grammes ; gum acacia, 120 grammes ; water, 500 cubic centimetres. Dissolve, filter, and add 2½ grammes of thymol in 120 cubic centimetres of glycerine. Add water to make up bulk of 1 litre.

A cement for *attaching rubber to metal*, made by soaking pulverised shellac in 10 times its weight of strong ammonia. The result will be a transparent mass, which becomes liquid in 3 to 4 weeks without the use of water. This fluid makes the rubber soft, but after the evaporation of the ammonia it becomes hard, and impermeable to gases and fluids.

A cement for *joining leather driving belts*, made by mixing 10 parts of bisulphide of carbon and 1 of oil of turpentine, and dissolving in it a sufficient quantity of gutta-percha to form a paste. The pieces of leather to be joined are cleansed from oil and grease by laying a rag upon their surfaces and placing a hot iron upon it. Both pieces are then spread with the cement, and subjected to pressure until the cement has become dry.

A cement for *joining wood to tin*, made by melting 1 part of yellow wax, and stirring in 2 parts gutta-percha chips until quite dissolved, then dissolving therein 2 parts shellac and $\frac{1}{10}$th part boiled linseed oil. Apply the melted cement to the dried surface of wood and tin, and press the two surfaces together for 24 hours.

A cement for *quickly closing leaks in barrels* is composed of tallow, 25 parts ; wax, 20 parts ; lard, 40 parts ; sifted wood ashes, 25 parts. Mix together by heating, and apply to the defective place by means of a heated knife-blade.

Cutlers' cements for fastening the blades of knives into the handles :

1. Rosin, 4 parts ; beeswax, 1 part ; brick dust, 1 part.
2. Rosin, 4 parts ; pitch, 4 parts ; tallow, 2 parts ; brick dust, 2 parts.

An *oil-resisting cement* which will withstand the action of paraffin or petroleum jelly can be made by boiling rosin with one-third its weight in caustic soda and one and two-thirds its weight of water. After cooling, the water separates and can be thrown away, the residue being then made into a plastic state with plaster of Paris.

A cement for *glass* is made (*a*) by dissolving 15 parts caoutchouc in 60 parts chloroform, adding about 35 parts mastic, and allowing to stand without heat for eight days. The cement is elastic and transparent ; additional caoutchouc increases its elasticity ; (*b*) of equal parts of wax and vaseline.

A cement for *marble* consists of four parts finely powdered gypsum and 1 part finely powdered gum arabic. Mix intimately, then with a cold solution of borax make into a mortar-like paste. Use the paste as a cement. Leave the cemented parts for several days undisturbed, so that the cement shall thoroughly set.

Strong cements for *stone*, having little body and applied in layers, consist of :

(*a*) Resin, 8 parts ; wax, 1 part ; turpentine, 1 part. For nitric and hydrochloric acid vapours.

(*b*) Resin, 1 part ; sulphur, 1 part ; fireclay, 2 parts. Sulphur gives great hardness and permanency in resin cements.

Good waterproofing cements are :

(*c*) Resin, 1 part ; wax, 1 part ; powdered stone, 2 parts.

(*d*) Shellac, 5 parts ; wax, 1 part ; turpentine, 1 part ; chalk, 8 to 10 parts.

A strong cement for *metals* (not copper), *porcelain, and glass*, is made of powdered shellac, 1 part ; ammonia water, 10 parts. Allow to stand until solution is effected.

A cement for *leather* may consist of : Asphalt, 1 part ; resin, 1 part ; gutta-percha, 4 parts ; carbon disulphide, 20 parts.

A cement resistant to *acid vapours* may consist of : Rubber, 1 part ; linseed oil, 2 parts ; fireclay, 3 parts.

A *rubber cement* may be made by cutting crude rubber in small pieces and then adding carbon disulphide or benzol, and allowing the rubber to dissolve. Corks and wood are made impervious to water by soaking them in the above solution.

Typical *oil cements*, *i.e.* cements rich in oil, are :

(*a*) A mixture of china clay and linseed oil, made into a stiff paste ; this is useful for sealing to prevent the escape of steam or other vapours.

(*b*) A mixture of lime and linseed oil—commonly known as *putty*.

(*c*) A mixture of red lead or white lead and linseed oil, made into a paste.

All the above become very strong when set, and may, for some purposes, be diluted with powdered glass, clay, graphite, or other inert filler.

(*d*) A mixture of oxide of iron and linseed oil is sometimes used to fill spaces between metals, or holes in metal.

(2) Fish-glues or Liquid Glues.

Fish-glues or liquid glues are made by treating fish bones with acetic acid. *Seccotine* is of this nature.

(3) Casein Cements.

Casein cements consist of casein (milk curd) and an alkali ; they are resistant to moderate heat, water, and oil vapours, but not to acid fumes.

(*a*) Finely powdered casein, 12 parts ; fresh slaked lime, 50 parts ; fine sand, 50 parts ; and enough water to make a thick mass.

(*b*) Casein in fine powder, 1 part ; rubbed with silicate of soda, 3 parts (useful for ground unions standing a moderate heat).

(*c*) White of egg made into a paste with slaked lime. This should be used immediately after being made up.

Unless properly compounded, casein cements deteriorate if kept. The ' First Report of the Adhesive Research Committee, 1922 ' (published by His Majesty's Stationery Office, Imperial House, Kingsway, London, W.C. 2 ; price 4*s.* net), gives the following as satisfactory :

Casein, 78 per cent. ; dry sodium carbonate, 4·5 per cent. ; sodium fluoride, 4·0 per cent. freshly slaked lime, 12·5 per cent. ; sodium arsenate, 1·0 per cent. All ingredients must be ground to pass through a 90-mesh sieve. For use, mix the cement with water ; if mixed with weak solution of gelatine glue the strength will be about 10 per cent. greater. Average breaking stress, about 1,000 lbs. per sq. in.

(4) Bituminous Cements.

Bituminous cements are those in which the chief ingredient is asphalt, tar, pitch, or bitumen (see also *Mastic cements*). Asphalt in benzol is useful as an adhesive for uniting glass for photographic and microscopical uses, also for coating wood, concrete, brick work, steel, etc., where the melted asphalt would be too thick to apply readily. Benzol is the cheapest and most satisfactory solvent. For waterproofing, melted asphalt with a small amount of paraffin added, and in particular cases boiled oil, is used :

(*a*) Refined lake asphalt.
(*b*) Asphalt, 4 parts ; paraffin, 1 part.
(*c*) Asphalt, 10 parts ; paraffin, 2 parts ; boiled oil, 1 part.
} Any of these may be thinned with hot benzol or toluol.

(*d*) Pitch, 8 parts ; resin, 6 parts ; wax, 1 part ; plaster, ¼ to ½ part.
(*e*) Pitch, 8 parts ; resin, 7 parts ; sulphur, 2 parts ; stone-powder, 1 part.
} Useful for uniting slate slabs and stoneware

The following are plastic cements for *caulking* :

(*f*) Pitch, 3 parts ; shellac, 2 parts ; pure crude rubber, 1 part.
(*g*) Pitch, 1 part ; shellac, 1 part ; rubber substitute, 1 part.
} Mix by melting.

(5) Water-glass or Silicate Cements.

Water-glass cements consist chiefly of an inert material mixed with water-glass (syrupy silicate of soda). Typical mixtures are :

(*a*) A paste made of silicate of soda and asbestos.
(*b*) A paste made of silicate of soda and fine sand.
(*c*) A paste made of silicate of soda and powdered glass.
(*d*) Equal parts of water-glass and zinc oxide, or iron oxide or litharge.

Sometimes lime is added to make the cement set more rapidly, a typical mixture being silicate of soda 50 parts, asbestos 15 parts, slaked lime 10 parts.

(6) Calcareous Cements.

Calcareous cements, such as hydraulic lime, Roman cement, the various natural cements, and Portland cement. *Hydraulic limes* are described on p. 486. *Roman cement* is a brown, quick-setting cement, made by calcining and grinding the septaria or calcareous claystones found in London clay. It is one of the natural cements.

Natural cements (so-called) are made by heating natural mixtures of clay and limestone to redness, so as to effect a combination between the lime and clay similar to that in Portland cement. Such natural cements are comparable to a mixture of Portland cement with either an excess of lime or clay, as the case may be. Their composition is irregular and uncertain so that they are inferior to Portland cement for all work of importance. They can be greatly improved by adjusting their composition by the addition of limestone or clay, as may be required, and heating until the mixture is clinkered. Such adjustment greatly increases the cost of production, but produces a Portland cement.

Portland cement is described on pp. 503–507.

Ciment Fondu or *Electric Cement* is composed of lime and alumina, heated to incipient fusion in an electric furnace and afterwards ground to powder ; it has a composition as follows : silica, 10 per cent. ; alumina, 42 per cent. ; lime, 42 per cent. ; iron, 6 per cent. ; as compared with Portland cement, which has an average analysis of silica, 23 per cent. ; alumina, 7 per cent. ; lime, 64 per cent. ; iron, 4 per cent. ; and 2 per cent. other matter ; in each case iron figures only as a non-deleterious impurity. The cement attains a high strength very much more quickly than Portland cement, and is said to be unaffected by sea-water. Its use is increasing rapidly, notwithstanding the results of investigations by German chemists, which seem to show that Portland cement can be made having similar properties, but far more cheaply.

(7) Gypsum Cements.

Gypsum cements include plaster of Paris, Keene's cement, Parian cement (see *Plasters*, p. 507).

(8) Oxychloride Cements.

Oxychloride cements, of which the best known is Sorel cement, are composed of dense magnesia and syrupy magnesia chloride, or zinc oxide and zinc phosphate. They depend very largely on the use of suitably calcined oxides and on the chloride or phosphate being of suitable density, so that it is wise to follow the manufacturers' instructions. Typical mixtures are :

(*a*) Magnesium oxide, 2 parts ; magnesium chloride, 1 part ; water to make a paste.
(*b*) Zinc oxide, 2 parts ; zinc chloride, 1 part ; water to make a paste.

Magnesium oxychloride cements may be diluted with fillers such as china clay, or may be coloured with mineral pigments such as ultramarine, ochre, etc. They are largely used for forming *floors*.

(9) Flour and Starch Pastes.

Pastes made of flour or starch are largely used for fastening papers to each other or to walls, and ceilings. A good paste for this kind is made :

(*a*) By dissolving ¾ oz. of alum in a quart of water, adding flour to make it the consistence of cream, then bring it to a boil, stirring it all the while, then add a teaspoonful of powdered resin, and also a few drops of oil of cloves. This paste will not turn sour by keeping.
(*b*) Flaxseed makes a very tough cement, but does not withstand water.
(*c*) Flour and molasses made into a stiff paste is sometimes used.
(*d*) A permanent cement for ordinary temperatures, impervious, but attacked by condensing steam and nitric vapours, consists of a mixture of stiff flour paste and concentrated zinc chloride solution.
(*e*) Dextrine and fine sand, made into a paste with water is sometimes used in foundries.
(*f*) A paste made by mixing dextrin with water is useful for fastening papers. The 'gum' on labels and stamps is of this nature.
(*g*) *Rice glue* is made by mixing rice flour into a paste with cold water and then heating it, with constant stirring, until it boils.

(10) Celluloid Cements.

For celluloid goods a cement may be made :

(*a*) By dissolving one part of camphor in four parts of alcohol, and adding an equal amount of shellac to the camphor solution. The cement must be applied hot. The celluloid goods must have the fractured surfaces kept pressed together until the cement has cooled.

(*b*) Dissolve celluloid in amylacetate to make a thick jelly. This cement may be used cold. It can also be used to cement china, silk or cotton fabrics, leather, etc. ; it is absolutely waterproof. A piece of paper smeared with the jelly makes an excellent sticking-plaster.

Celluloid cements for various purposes are on the market ; they are sometimes known as *dopes*, and are chiefly of the (*b*) class.

(11) Refractory and Fire-resisting Cements.

Refractory cements are those which are specially resistant to heat and are used in repairing furnaces, etc. (see pp. 530–535). Other refractory cements include :

(*a*) A mixture of fireclay and plumbago made into a paste with water ; it may also be used to coat glass to protect it from flame.

(*b*) Equal parts of flour and lime and half a part of fireclay are made into a paste with water ; white of egg is sometimes added. This is a fire-resistant cement and not highly refractory. It is sometimes used for patching retorts.

For patching *crucibles and melting pots* :

(*c*) Sift brickdust and mix with equal quantity of red lead : rub together with boiled linseed-oil, which has been mixed with sand to a stiffness of cement. In covering dishes apply the paste first, then apply sand and heat.

(*d*) Put freshly slaked lime with concentrated solution of borax, apply with a stiff brush and allow to dry. Upon heating, a fused glaze is obtained.

(*e*) Litharge, 6 parts ; fresh burnt lime, 4 parts ; china clay, 2 parts ; and mix with cold linseed-oil. This is only fire-resisting.

(*f*) Alumina, 1 part ; sand, 4 parts ; slaked lime, 1 part ; borax, ½ part ; water to make a stiff paste.

(*g*) A fire-resisting cement for *iron pipes* : Iron filings, 10 parts ; brick clay, 20 parts ; china clay or fireclay, 15 parts ; common salt, 8 parts. The salt is dissolved in water and mixed with the other ingredients.

(12) Glues.

Commercial glue is made by boiling animal flesh, bones, etc., in water, removing fat and other impurities and concentrating by evaporating the greater part of the water. It is usually sold in thin cakes or flakes, or in the powdered form, and should be kept in a dry place so that it will not mould. In whatever form it is purchased, the glue should, prior to use, be soaked in cold water for several hours before it is heated. The water used for this purpose ought to be distilled ; the drip from steam radiators may be utilised, if desired. The use of distilled water guards against chemical action due to impurities in the water, which may contain sulphur, lime, or iron, all of which are injurious to glue. If glue is soaked in hot water it quickly decomposes and its strength is impaired. The amount of water required should be stated by the makers.

Glue cake, ¼ to ½ in. thick, requires about twelve hours to dissolve ; it should be broken into small pieces before being put to soak. Flake glue requires from six to eight hours, according to the thickness of the flake. Pulverised glue may be dissolved in from three to three and a half hours. The soaking process should not be hurried.

After being heated, the glue may be diluted with hot water to the required consistency. Glue should never be heated sufficiently to make it boil. It is also bad practice to prepare large quantities of glue at a time, because it loses its strength rapidly after being under heat for about four hours.

A satisfactory glue-heater should have ample accommodations for all the glue that will be prepared at one time, say, six or more glue-kettles. The kettles in which the glue is heated should be made of aluminium, and their size and number should provide for handling glue of various consistencies in sufficient quantities to last not more than four hours. Aluminium is the most suitable metal for glue-pots, because the scum on the glue does not adhere to the inside of the pots, so that they are easily cleaned.

A thermometer should be part of the equipment of a glue-heater, for the temperature at the bottom of a pot 6 ins. deep should not be over 150° F., which will bring the temperature at the top to about 140° F. Higher temperatures than this destroy the adhesive power of glue. The pots should be thoroughly cleaned at least once each day The glue that has become cooled should never be reheated, as reheated glue loses about 50 per cent. of its strength. It is good practice to have a new lot of glue ready for use before the glue already prepared is consumed.

A little powdered *chalk* added to common glue is said to increase its strength.

Core Glues.

The following are largely used :

(*a*) Dextrine, 1 part ; sand, 10 parts ; water to form a thick paste.

(*b*) Anthracite coal powdered with molasses added to thick paste.

(*c*) Resin, partly saponified by soda lye, 1 part ; flour, 2 parts ; sand 4 parts ; with water as a diluent.

(*d*) Powdered glue, 1 part ; flour, 4 parts ; sand, 6 parts ; water.

Waterproof Glues.

(*a*) A very cheap waterproof glue is made by melting common glue with the smallest quantity of water possible. Add to this, by degrees, linseed oil made ' drying ' by boiling it with litharge. While the oil is added the ingredients must be well stirred so as to mix them thoroughly. Another plan : Take a very thick solution of glue 10 parts, linseed-oil varnish 5 parts, and litharge 1 part. Boil these together for ten minutes and use while hot. The additional ingredients have no effect whatever on the adhesive properties of the glue, which is rendered entirely waterproof.

(*b*) Gum shellac 3 parts and india-rubber 1 part by weight, these constituents being dissolved in separate vessels in ether, free from alcohol, subject to a gentle heat. When thoroughly dissolved, the two solutions are mixed and kept for some time in a vessel tightly sealed. This glue resists the action of water, both hot and cold, as well as most acids and alkalis If the glue is thinned by the admixture of ether, and applied as a varnish to leather along the seams where this has been sewn together, it renders the joint or seam water-tight, and almost impossible to separate.

(*c*) A formula for waterproof glue giving a degree of water resistance comparable with the best casein glues is as follows : A grade of animal glue suitable for woodworking is soaked in such a proportion of cold water as is required by its grade and is then ' melted ' in the glue-pot. Para-formaldehyde of 50-mesh fineness, and oxalic acid are then added in the proportions respectively of 10 per cent. and 5 per cent. on the weight of dry glue taken. As soon as the oxalic acid has dissolved, the glue is ready to use and will remain in a suitable condition for application for seven to nine hours at a temperature not exceeding 45° C.

Fire-resisting Glue.

Mix 4 parts linseed-oil and 1 part quicklime, then boil slowly until a paste. Spread the mixture on a plate and dry in the open air. It will become very hard, but can be dissolved over a fire, or in a glue-pot like common glue. This composition really is not glue at all, but a sort of waterproof cement that is extremely tenacious. (See also *Refractory Cements*.)

Liquid Glues.

(*a*) 1 part glue, 1 part water, 1 part vinegar. Dissolve by gentle heat, and then add 1 part alcohol.

(*b*) White glue, 16 ozs. ; dry white lead, 4 ozs. ; rain-water, 2 pints. Dissolve by gentle heat and then add alchohol, 4 ozs.

(*c*) Clear gelatine, 100 parts ; glue, 100 parts ; alcohol, 25 parts ; alum, 6 parts. Mix whole with 200 parts of 20 per cent. acetic acid, and heat in water-bath for 6 hours.

Marine Glues.

(*a*) India-rubber, 4 parts ; coal-tar naphtha, 34 parts ; powdered shellac, 64 parts.

(*b*) Glue, 12 parts ; dissolve in water ; add yellow resin, 3 parts. When dissolved, add turpentine, 4 parts. This glue is inferior in quality to (*a*).

Glue for Parchment.

Parchment shavings, 1 lb. ; water, 6 quarts. Boil until dissolved, then strain, and evaporate to consistency of ordinary glue.

Glue for Leather.

A little *tannin*, added in sufficient quantity to hot glue until it has the appearance of white of egg, is said to improve it when used for cementing two pieces of *leather* together.

Glue for Fastening Leather to Metal.

A recipe for fastening *leather to metal* is : Digest one part of coarsely crushed gall-nuts with 8 parts of distilled water about six hours, and filter through linen. Then pour 1 part of cold water over 1 part of glue, leave it to stand for twenty-four hours, and heat the whole, whereby a concentrated glue solution is obtained. Now coat the leather with the warm gall-nut extract, bring the glue solution on the roughened and warm metal, lay the leather on it, press it firmly, and allow it to dry in the air. The leather will adhere so firmly to the metal that it cannot be separated without tearing it.

To cement *leather to iron pulleys*, roughen the pulley with an old file ; glue the leather to the pulley with glue, 1 part ; glycerine, 1 part.

Glue for Fastening Cloth to Wood.

Equal parts of glue and isinglass made into a liquid like common glue, and then thickened with tannin, has been recommended for fastening *cloth to wood*.

(13) Metallic Cements.

Rust Joint Cements.

(*a*) *Quick setting.*—1 lb. sal-ammoniac in powder; 2 lbs. flowers of sulphur; 80 lbs. iron filings or borings. Mix to a paste with water.

(*b*) *Slow-setting.*—2 lbs. sal-ammoniac in powder; 1 lb. flowers of sulphur; 200 lbs. iron filings or borings. Mix to a paste with water. This cement is better than the quick-setting, if the joint is not required for immediate use.

Cements for Steam Boilers, Steam Pipes, etc.

(*a*) *Soft.*—Red or white lead in oil, 4 parts; iron borings, 2 to 3 parts.

(*b*) *Hard.*—Iron borings and salt water, and a small quantity of sal-ammoniac with fresh water.

(*c*) 5 lbs. Paris white, 5 lbs. yellow ochre, 10 lbs. litharge, 5 lbs. red lead, 4 lbs. black oxide of manganese. The whole is to be well mixed, and a little asbestos and boiled oil added. This soon becomes nearly as hard as the iron itself.

This cement is also excellent for making fluid-pressure joints.

(*d*) Take white lead ground in oil, and add dry red lead sufficient to make a stiff putty. Pound this on a block of iron or stone until it becomes soft, continuing to add red lead until the mass will no longer soften or stick to the fingers. Interpose this putty between the flanges of the steam-pipe joints. This will make the best joint known.

For Leaky Iron Pipes.

In cases where caulking, plugging, or other mechanical means of stopping leaks in iron pipes cannot be adopted, a cement made by mixing finely pulverised black manganese oxide and raw linseed-oil into a thick paste will usually be found effective. It should be thoroughly forced into the leak, and the pipe should be kept warm enough to absorb or remove the oil from the manganese. In about twenty-four hours the cement should be as hard as the iron, and should adhere thoroughly, so that leakage does not again occur.

For Iron Stove-pipes and for Filling Cracks in Stoves.

Pulverised brick clay, 1 part; wood ashes, 1 part. Add a little salt, and mix to consistence of syrup.

To Fasten Iron to Iron.

(*a*) Sulphur, 6 parts; white lead, 6 parts; borax, 1 part. When composition is to be applied, wet with strong sulphuric acid and smear on surfaces, which must be at once pressed together. Allow one week to dry.

(*b*) Equal parts of litharge, red lead, and sufficient glycerine to form a paste. This cement is said to be waterproof, fireproof, and to resist the action of alkalies.

For Holes in Castings.

Flowers of sulphur, 1 part; sal-ammoniac, 2 parts; iron filings or borings, 80 parts. Mix to a thick paste with water.

To Fasten Iron to Stone.

(*a*) Iron filings, 20 parts; plaster of Paris, 50 parts; sal-ammoniac, 3 parts. Mix to a thin paste with weak vinegar.

(*b*) Sulphur, 1 part; pitch, 1 part.

To Fasten Iron to Marble.

A cement for making repairs on switchboards when iron or other metal has to be fastened to marble may be made from 30 parts plaster of Paris, 10 parts iron filings, and ½-part sal-ammoniac. These, states the *American Machinist*, are mixed with acetic acid to form a thin paste. This cement must always be used immediately after being mixed.

(14) Miscellaneous Cements.

Cement for Mending Rubber Goods.

Bisulphide of carbon, 26 parts; gutta-percha, 2 parts; caoutchouc, 4 parts; fish glue, 1 part.

Composition to make Corks Impervious.

A composition for soaking corks, wood packing, etc., to render impervious to oil vapours, consists of: gelatine, 2 parts; glycerine, 1 part; water, 6 parts.

To Fasten Metal to Wood.

In order to fasten metal to wood without the use of nails or screws, the metal parts may be roughened by the use of dilute sulphuric acid. As soon as the metal has been wiped dry, it is glued on with the best joiner's glue to which a little glycerine has been added. This process is not only adapted for small plates or slabs, but also larger ones, but care must be taken that they touch the roughened wood surface evenly throughout.

To Fasten Metal Letters upon Glass, Marble, Wood, etc.

(*a*) Copal varnish, 15 parts; linseed-oil varnish, 5 parts; oil of turpentine, 5 parts; glue, 5 parts. The glue is dissolved by placing the mixture in a water-bath. When the solution is complete 10 parts of slaked lime are added to it.

(*b*) A good cement for brass and glass can be made by mixing together 2 parts litharge, 1 part white lead, 3 parts linseed-oil, and 1 part gum copal. Use at once.

Portland Cement.

(*Partly contributed by A. B. Searle, Author of 'Cement, Concrete, and Bricks, etc.*).

Portland cement is usually made from a mixture of chalk, or limestone, and clay ground together to an extreme degree of fineness, and subsequently dried, calcined, and ground to the fineness of flour. Pats or briquettes made from it should, when broken, exhibit a bluish-grey colour in the fracture.

Portland cement * may be obtained quick or slow setting. If there are no special reasons which make quick setting desirable, it is advisable to employ a cement which requires at least two hours to pass from the pasty state into the hard, solid one, as quick-setting cements require exceptional care and skill in gauging: otherwise they begin to set and to spoil before they have been placed in their proper position in the structure.

Most manufacturers add a little gypsum when grinding the cement clinker, and thereby adjust the rate of setting of the cement to suit the user's requirements. If required, the time taken for setting may be increased by exposing the cement to moist air before use, but this is not altogether satisfactory, and it is better to purchase a cement which sets at the desired rate.

Temperature has a very great effect upon the setting time of cement. A sample tested in a temperature of 61° Fahr. and gauged with water at the same temperature took six hours to set hard. The same sample gauged in a temperature of 90° Fahr. and gauged with water of equal temperature set hard in one hour fifty minutes. This is a point which is often lost sight of.

Testing Portland Cement.

The tests usually applied relate to its

Chemical composition.	Tensile strength. (Cement and sand.)
Specific gravity.	Time of setting.
Fineness.	Time of hardening.
Crushing or compression strength.	Soundness.
Tensile strength. (Neat cement.)	

The tests suggested by the British Standard Specification (p. 505) are usually regarded as sufficient, but the others are used for special purposes. The following notes indicate the purpose of the various tests:

Chemical Composition.—This test is for the detection of adulterants, or to determine whether certain constituents are present in amounts exceeding that believed to be safe.

Specific Gravity.—This test is designed to detect under-burning and adulteration, and should only be used in connection with the chemical analysis; low specific gravity is often caused by 'ageing' of the cement, so that to reject a cement because of a low specific gravity may be to reject it because it has been well seasoned.

Fineness.—The fineness of the cement is a measure of its cementing value; a fine cement will be much stronger when mixed into a mortar, or it can be mixed with a larger proportion of sand than a coarse one, and yet attain the same strength.

Crushing or Compression Strength.—The most generally comprehensive test of a Portland cement or of a mixture of it with sand would be a determination of the crushing strength of a cube of 4 in. side. Unfortunately, this requires a very costly machine, so that it is usual to substitute a tensile test which can be made much more cheaply.

Tensile Strength is determined in order to gain some idea of the cohesion between the particles. This property is not required in cement and concrete, but as it is roughly proportional to the crushing strength and the tensile strength is easier to determine, it is usually substituted for a crushing test.

A neat briquette rupture is practically a plane section.

* The composition of Portland cements is highly complex. Some further indications of it are given in 'Cement, Concrete, and Bricks,' by A. B. Searle (Constable & Co., Ltd., London).

Time of Setting.—This is determined in order to ascertain whether a cement sets at a rate suitable for a given piece of work. If a cement sets before it has been properly placed in position the work will be defective; hence where there is any doubt, a slow-setting cement should be used. There is no necessary relationship between the time of setting and that of hardening or attaining the maximum strength; a slow-setting cement may harden more rapidly than a quick-setting one, and *vice versâ*.

Time of Hardening.—This is sometimes determined to ascertain what is the minimum time which must elapse before a cement or concrete can be used, *e.g.* if a concrete road is being made, how long will it be before traffic can safely pass over it? The aluminous cements, such as *Ciment Fondu*, set slowly but harden very rapidly.

Soundness.—The object of this test is to hasten the rate at which a cement or concrete attains its maximum strength and to subject it to conditions more severe than are likely to occur in regular use. By thus exaggerating the conditions some idea is gained of the lasting properties of the material much more rapidly than would otherwise be the case. The soundness test is, in some respects, the most important of all, for if a sample passes all other tests satisfactorily yet fails in the soundness test, it is worthless as a constructional material. To pass the soundness test a cement or concrete must retain a *constant volume* under the conditions of the test; failure is revealed by the test-piece cracking, swelling, or disintegrating in any other way.

The actual testing of cement and concrete requires considerable skill. The methods described in the British Standard Specification for Portland Cement (see p. 505) are satisfactory, but require considerable practice before accurate results can be obtained.

Cement Testing Machines.

Tension tests of cement briquettes are generally made on special testing machines of various types, single and compound levers being used. The application of the load at a steady and definite rate is in some cases accomplished by running water or fine shot through a controllable opening into a vessel hanging from the end of the lever; in other cases a travelling poise is caused to move along a graduated lever at a steady speed.

A single-lever testing machine made by Mr. Adie, with a regulated travelling poise D, is shown in fig. 1. The briquette is placed in the clips B, C, and the hand-wheel R serves to tighten the screw attached to the lower clip C, so as to raise the lever F into a position of balance between the stops on the standard E. The poise D may be moved along the lever F, by means of the handle at the end of the beam. For loading at a uniform rate the traverse of the poise is accomplished by the pull of a suspended weight W, regulated by a dashpot cylinder below the pulley 5; the rate of traverse is regulated by adjusting a cock in the piston of the dashpot.

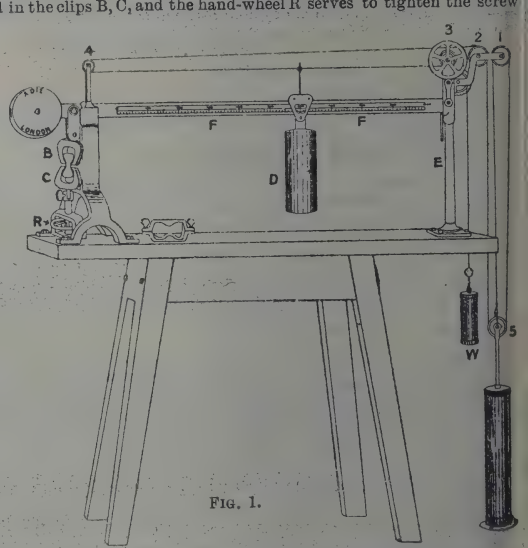
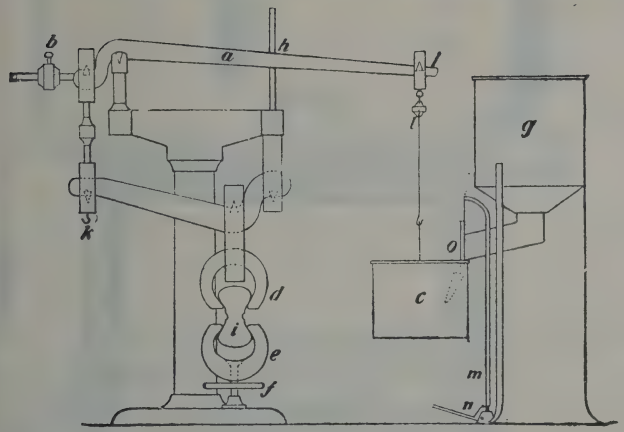


Fig. 1.

Fig. 2, p. 505, shows the form of another of Mr. Adie's cement-testing machines, designed by Dr. Michaelis. This machine, which is of the compound-lever type and is loaded by shot, may be taken as typical of German practice. The briquette *t* is held between clips *d* and *e*, the lower one of which is attached to a straining screw turned by the hand-wheel *f*. The pull on the briquette is balanced through two levers against the weight of shot in the vessel *c* at the end of the lever *a*, which also carries an adjustable balance weight *b*; the combined leverage of the two levers is 50 to 1. The shot runs into the vessel *c* from a reservoir

DR. MICHAELIS'S
Compound Lever
(Shot) Machine
FOR TESTING CEMENT.



Clips of above machine made to British Standard Specification.

For particulars of this and other Cement Testing Machines, and every Appliance used in the Testing of Cement, apply:

PATRICK ADIE

(Formerly BROADWAY WORKS),

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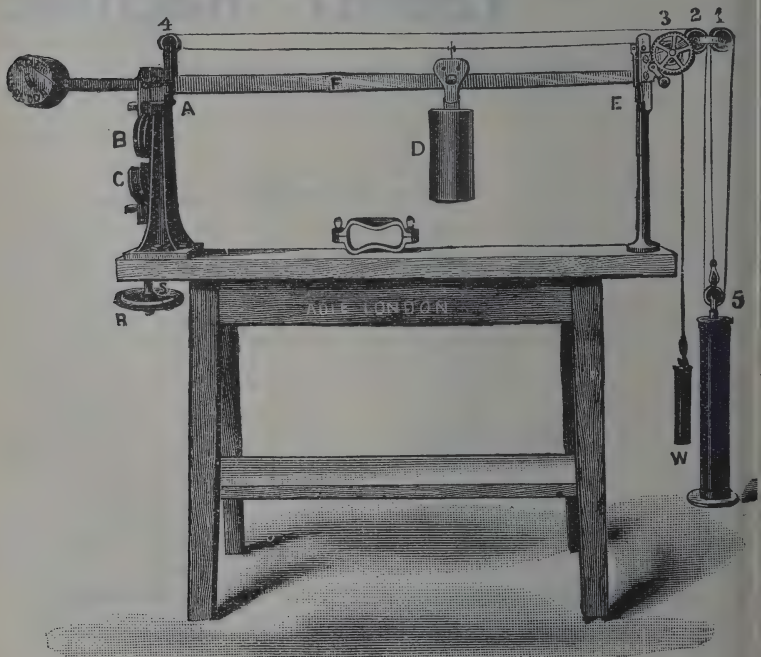

MOULDS, SIEVES, &c.,

Made according to the British Standard Specification for Portland Cement issued by the British Engineering Standards Association.

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F. 50

through a channel, which is regulated at *o* for any desired rate of loading by a lever *n*. The breaking of the briquette and consequent fall of the lever automatically shuts off the supply of shot, and 50 times the weight of shot in *c* gives the breaking load, this quantity being recorded by a spring balance at *l*.

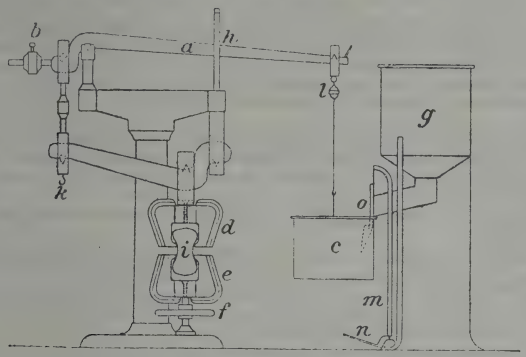

FIG. 2.

BRITISH STANDARD SPECIFICATION FOR PORTLAND CEMENT.*

(No. 12—1925.) (*Abstract.*)

1. The cement shall be manufactured by intimately mixing together calcareous and argillaceous or other silica and alumina bearing materials, burning them at a clinkering temperature and grinding the resulting clinker, so as to produce a cement capable of complying with the specification.

No addition of any material shall be made after burning other than calcium sulphate, or water, or both.

7. The sample or samples shall be tested for :—(*a*) fineness; (*b*) chemical composition; (*c*) tensile strength (neat cement); (*d*) tensile strength (cement and sand); (*e*) setting time; (*f*) soundness; and before any sample is submitted to tests (*c*), (*d*), and (*f*), it shall be spread out for a depth of 3 ins. for 24 hours in a temperature of from 58 to 64 degrees Fahrenheit.

8. The cement shall comply with the following conditions of fineness—100 grammes (or, say, 4 ozs.) of cement shall be continuously sifted for a period of 15 minutes on each of the undermentioned sieves and in the order of succession given below, with the following results :—

(1) The residue on a sieve 180 × 180 = 32,400 meshes per sq. in., shall not exceed 10 per cent.

(2) The residue on a sieve 76 × 76 = 5,776 meshes per sq. in., shall not exceed 1 per cent.

The sieves shall be prepared from wire-cloth, and the diameter of the wire for the 32,400 mesh shall be ·00171 in., and for the 5,776 mesh, ·0044 in. The wire-cloth shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

9. The cement shall comply with the following conditions as to its chemical composition. The proportion of lime, after deduction of the proportion necessary to combine with the sulphuric anhydride present, to silica and alumina, when calculated (in chemical equivalents) by the formula $\frac{CaO}{SiO_2 + Al_2O_3}$, shall be not greater than 2·90 nor less than 2·0. The percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 4 per cent.; and the total sulphur content calculated as sulphuric anhydride (SO_3) shall not exceed 2·75 per cent. The total loss on ignition shall not exceed 3 per cent.

10. The breaking strength of neat cement shall be ascertained from briquettes of the specified shape. The briquettes shall be prepared in the following manner :—

The cement shall be mixed with such a proportion of water that the mixture shall be plastic when filled into the moulds used for forming the briquettes. The cement, gauged as stated, shall be filled into moulds of the form required to produce briquettes of the specified shape, each mould resting upon a non-porous plate. In filling the moulds the operator's hands and the blade of the ordinary gauging trowel shall alone be used. The trowel shall weigh about 7½ ozs.

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No ramming or hammering in any form will be permitted, nor shall any other instrument or apparatus other than the trowel before described be employed for this operation. The moulds, after being filled, may be shaken to the extent necessary for expelling the air. Clean appliances shall be used for gauging, and the temperature of the water, and that of the test room at the time the above operations are being performed, shall be from 58 to 64 degrees Fahrenheit. The briquettes shall be kept in a damp atmosphere for 24 hours after gauging, when they shall be removed from the moulds and immediately submerged in clean fresh water and left there until taken out for breaking. The water in which they are submerged shall be maintained at a temperature of between 58 and 64 degrees Fahrenheit (in tropical climates any higher temperature up to 95 degrees Fahrenheit may be substituted). After they have been so taken out and until they are broken the briquettes shall not be allowed to become dry.

Six briquettes shall be tested for breaking strength at 7 days after gauging. The breaking strength shall be the average tensile breaking strength of the six briquettes. The briquettes to be tested shall be held in strong metal jaws of the specified shape, and the load shall be steadily and uniformly applied, starting from zero, and increased at the rate of 100 lbs. per sq. in. of section in 12 seconds.

The breaking strength of the briquettes at 7 days after gauging shall be not less than 600 lbs. per sq. in. of section.

11. The breaking strength of cement and sand shall be ascertained from briquettes of the specified shape. The briquettes shall be prepared in the following manner :—

A mixture of cement and sand in the proportion of one part by weight of cement to three parts by weight of the standard sand hereafter specified, shall be gauged with water, the percentage of water to be used being determined by the formula :—

$$\frac{1}{4} P + 2{\cdot}50,$$

where P is the percentage of water required for the preparation of the neat cement briquettes. The mixture thus gauged shall be evenly distributed in moulds of the form required to produce briquettes of the specified shape, each mould resting upon a non-porous plate. After filling a mould a small heap of the mixture shall be placed upon that in the mould and patted down with a standard spatula until the mixture is level with the top of the mould. This last operation shall be repeated on the other side and the mixture patted down until water appears on the surface ; the flat only of the standard spatula is to be used and no other instrument or apparatus is to be employed for this operation. The mould after being filled may be shaken to the extent necessary for expelling the air. No ramming or hammering in any form will be permitted during the preparation of the briquettes, which shall then be finished off in the moulds by smoothing the surface with the blade of a trowel. Clean appliances shall be employed for gauging, and the temperature of the water and that of the test room at the time the above operations are performed shall be from 58 to 64 degrees Fahrenheit (in tropical climates any higher temperature up to 95 degrees Fahrenheit may be substituted). The briquettes shall be kept in a damp atmosphere for 24 hours after gauging, when they shall be removed from the moulds and immediately submerged in clean fresh water, and left there until taken out for breaking. The water in which they are submerged shall be renewed every seven days, and maintained at a temperature of between 58 and 64 degrees Fahrenheit (in tropical climates any higher temperature up to 95 degrees Fahrenheit may be substituted). After they have been so taken out and until they are broken the briquettes shall not be allowed to become dry.

The briquettes shall be tested for breaking strength at 7 and 28 days respectively after gauging, six briquettes for each period. The breaking strength shall be the average tensile breaking strength of the six briquettes for each period. The briquettes to be tested shall be held in strong metal jaws of the specified shape, and the load steadily and uniformly applied, starting from zero, and increased at the rate of 100 lbs. per sq. in. of section in 12 seconds.

The breaking strength of the briquettes at 7 days after gauging shall be not less than 325 lbs. per sq. in. of section.

The breaking strength of the briquettes at 28 days after gauging shall show an increase on the breaking strength at 7 days and shall be not less than the number of lbs. per sq. in. of section arrived at from the following formula :—

$$\text{Breaking strength at 7 days} + \frac{10{,}000 \text{ lbs.}}{\text{Breaking strength at 7 days}}.$$

The standard sand shall be obtained from Leighton Buzzard, be thoroughly washed and dried, and shall pass through a sieve of 20 × 20 meshes per sq. in., and be retained on a sieve of 30 × 30 meshes per sq. in. The sieves shall be prepared from wire-cloth, the wires being ·0164 in. and ·0108 in. in diameter respectively. The wire-cloth shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

12. Unless a specially quick setting cement is specified or required, it shall have an initial setting time of not less than 30 minutes and a final setting time of not more than 10 hours.

If a special quick setting cememt is specified or required, it shall have an initial setting time of not less than 2 minutes, and a final setting time of not more than 30 minutes.

The initial and final setting times of cement gauged as above shall be determined by means of the Vicat needle apparatus, in the manner specified.

13. The cement shall be tested for soundness by the Le Chatelier method, in the manner specified.

British Standard Specification for Portland Blast-Furnace Cement.*

(*No.* 146—*Revised* 1926.) (*Abstract.*)

1. This cement shall consist of a mixture of Portland cement clinker and granulated blast-furnace slag in such proportions as the manufacturer may prefer, but in no case shall the proportion of slag exceed 65 per cent.

The Portland cement clinker and the granulated blast furnace slag shall be thoroughly and intimately mixed, and shall produce a cement capable of complying with the specification.

8. The cement shall comply with the following conditions of fineness :—100 grammes (or, say, 4 ozs.) of cement shall be continuously sifted for a period of 15 minutes on a 180 × 180 sieve and for a period of 5 minutes on a 76 × 76 sieve and in the order of succession given below with the following results :—

(1) The residue on a sieve 180 × 180 = 32,400 meshes per square inch (5,022 meshes per cm.^{2}) shall not exceed 10 per cent.

(2) The residue on a sieve 76 × 76 = 5,776 meshes per square inch (895 meshes per cm.^{2}) shall not exceed 1 per cent.

[The dimensions of the wires used for the sieves are fully detailed in the specification.]

9. The cement shall comply with the following conditions as to its chemical composition. The percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 5 per cent. Sulphur present as and calculated as sulphuric anhydride shall not exceed 2 per cent., and sulphur present as sulphide shall not exceed 1·2 per cent. sulphur, these being equivalent to a maximum total of 5·00 per cent. of sulphuric anhydride. The total loss on ignition shall not exceed 3 per cent.

10. The breaking strength of the testing briquettes of neat cement at 7 days after gauging shall be not less than 600 lb. per square inch of section (42·18 kg. per cm.^{2}).

The breaking strength of briquettes made of one part of cement to three parts of sand, with the proportion of water, shall

(*a*) be not less than 325 lbs. per sq. in. after 7 days;

(*b*) show an increase over (*a*) of not less than the number of lbs. per sq. in. arrived at from the formula :—

$$\text{Breaking strength at 7 days} + \frac{10{,}000}{\text{Breaking strength at 7 days.}}$$

The methods of making the tests are the same as for Portland cement (see p. 492).

Rapid Hardening Cements.

Concrete made with aluminous cement (*Ciment Fondu*) supplied by the Lafarge Aluminous Cement Co., Ltd., 296–302 High Holborn, W.C. 1, is as strong after 24 hours as ordinary Portland cement concrete which is 90 days old.

The 'Rapid Hardening Ferrocrete' cement (*The Cement Marketing Company, Limited, Portland House, Tothill Street, Westminster, S.W.* 1) gives in 3 to 4 days the same strength as concrete made with ordinary cement does in 28 days, while there is also a continuous growth of strength.

PLASTERS.

Plasters are pasty materials applied to walls, ceilings, etc., to give a hard, smooth finish. They resemble lime mortars in many respects but serve a different purpose. Common plaster is made of lime and sand, with or without ½ lb. of hair to each 1 cu. ft. of plaster. It is made harder and has smoother finish if 20 per cent. of plaster of Paris is added.

According to a tentative specification issued by the Department of Scientific and Industrial Research (*Building Research, Special Report, No.* 9, 1927) the lime to be used for plaster, fine and coarse stuff, should be *Quicklime, Class A*, or *High Magnesian Quicklime, Class A*, and, for coarse stuff only, *Quicklime, Class B* (see table in *Mortars*, p. 487).

For *floors*, a hard-burned plaster of Paris is used, or a mixture of ordinary plaster with a slight excess of lime is laid, and then treated with zinc sulphate (white), iron sulphate (red), boiled oil (mahogany), or copal varnish.

* By permission of the British Engineering Standards Association.

Stucco for external use consists of 1 part of hydraulic lime to 3 parts of sand, but for more durable work a cement mortar (p. 485) is often used.

Rough cast is sometimes made of the same materials as stucco, or of cement mortar (p. 485).

Plaster of Paris is made by calcining gypsum and grinding the product. The resulting powder, when mixed with water, forms a smooth paste which rapidly sets to a white, solid mass.

Hard Plasters.

Keene's, Martin's, and Parian cements are hard-setting forms of plaster of Paris. Keene's cement is made by soaking calcined gypsum in a solution of alum or borax and cream of tartar. For Martin's cement, a solution of potassium carbonate is used, and Parian cement is an intimate mixture of gypsum and borax which has been calcined and then ground to powder.

Another method of hardening plaster consists in intimately mixing 4 per cent. of powdered marsh mallow root and knead to a dough with 40 per cent. of water. The mass will harden in about one hour, and can be cut, filed, turned, or drilled. Eight per cent. of marsh mallow renders it still tougher.

Plaster of Paris articles may be hardened by means of a solution of borate of ammonia (ammonium borate), made by dissolving boracic acid in hot water, and then adding ammonia to it until the solution turns red litmus paper blue (or so that the solution smells faintly of ammonia). The best results are obtained when very little free ammonia is present. The borate of ammonia may be applied to the plaster of Paris article after it has been cast or before mixing. The most satistactory method is to treat the cast. The solution is applied to the dry plaster object and the absorption allowed to take place. The surface gradually hardens, and finally the interior. The plaster so hardened may be employed for a large number of uses.

The following process may be used for hardening plaster, so that it may be used for flooring:—About 6 parts of good-quality plaster are intimately mixed with 1 part of freshly slaked white lime, finely sifted. This mixture is then laid down as quickly as possible, care being taken that the trowel is not used on it for too long a time. The floor should then be allowed to become very dry, and afterwards be thoroughly saturated with sulphate of iron or zinc—the iron giving the strongest surface, the resistance to breaking being twenty times the strength of ordinary plaster. With sulphate of zinc the floor remains white, when iron is used it becomes the colour of rusted iron; but if linseed-oil, boiled with litharge, be applied to the surface, it becomes a beautiful mahogany colour; this is especially the case if a coat of copal varnish be added.

Artificial Stone.*

Artificial Building Stone, No. 1.—Mix 100 parts of hydraulic lime which has fallen to a powder with water to form a paste. To this add 250 parts of gravel and 50 of coal ashes or lixiviated wood ashes. The mass is then thoroughly mixed, and a sufficient quantity of water added to make the volume of the mass equal to 500 parts. It is then poured into moulds made of pine-boards, where it is allowed to remain until set.

No. 2.—125 parts of hydraulic lime which has fallen to a powder are mixed with a sufficient quantity of water to form a paste. To this are added 250 parts of ground oyster shells and 150 parts of ground peat ashes, and a sufficient quantity of water to make the bulk of the mass equal to 500 parts. It is then poured into moulds as in No. 1, and dried.

Artificial Stone from Quartz Sand and Plumbic Oxide.—Ground quartz sand is mixed with 2 to 10 per cent. of finely-ground plumbic oxide. The harder the stones are to be, the more plumbic oxide must be used. The mixture is moistened with water-glass, again thoroughly mixed, and then pressed firmly into moulds. The resulting stone is dried and then burned.

Victoria Stone.—The refuse of granite quarries is broken up into pieces of suitable size, and 4 parts of the fragments thus obtained are mixed with 1 part of Portland cement, and sufficient water added to bring the whole to the consistency of dough. The mass is run into moulds, in which it is allowed to remain for several days, or until it has set solid. The blocks are then immersed in a solution of silicate of soda.

Ransome's Artificial Stone.—Clean and dry sand and other suitable siliceous and earthy ingredients are thoroughly incorporated in a mixing mill with silicate of soda. The resulting pasty mass is then pressed into moulds of any required pattern or size, and when set sufficiently immersed in a solution of chloride of calcium. In the case of large pieces the saturation with chloride of calcium is facilitated by the use of an air-pump. The resulting reaction is the formation, by double decomposition of the ingredients of an insoluble calcium silicate out of

* The manufacture of artificial stones, *lime-sand* bricks and blocks, is dealt with at length i 'Bricks and Artificial Stones of Non-Plastic Materials,' by A. B. Searle (J.& A.Churchill, London

sodium chloride. The first-named forms a solid and indurate binding material for the stone, and the sodium chloride is removed by a subsequent thorough washing with water. This last operation is important, since, if the sodium chloride is not completely removed from the stone, it will make its appearance subsequently in the form of a white efflorescence on the surface.

To imitate Variegated Marble.—Mix hydraulic lime and ground marble and incorporate with the mixture a solution of alum and suitable colouring substances. Differently-coloured masses are then mixed together and cut into slabs.

Artificial Marble.—The following mixtures have been recommended for making artificial marble. Grind and thoroughly mix comminuted stone, 280 parts; limestone or chalk, 140 parts; burned calamine, 5 parts; calcined felspar, 3 parts; flourspar, 2 parts; calcium phosphate, 2 parts; water-glass, 40 parts.

On the addition of the water-glass the ingredients are quickly mixed, and thereupon pressed into moulds. The finished pieces are dried at a temperature gradually rising to 125° F.

Asphalt Flooring.

8 lbs. of asphalt composition (1 ton asphalt, 20 lbs. mineral tar) will cover 1 superficial foot ¾ in. thick. For goods warehouses thickness should be 1 in. For damp-course wall, ¾ in.

To Remedy Dampness in Walls.

1. If house shows damp on all sides just where walls rise from ground, cut out a course of bricks foot by foot, insert an asphalt damp-course, and re-brick up.

2. If wall becomes saturated by a stopped-up drain-pipe, remove plastering and re-point wall outside after wall has become dry. If it is inconvenient to renew plaster, the latter (although wet) may be varnished over with a solution of shellac in naphtha (4 ozs. shellac, 1 quart naphtha); this almost immediately hardens, and paper may be pasted over it.

3. A good coating of hot coal-tar laid on the exterior of a brick wall will prevent the entrance of damp, but should only be applied where its appearance is not objectionable.

4. Another plan for walls above-ground is to mix 1 part of Portland cement with 2 parts of fine sand, and add water enough to bring the ingredients to the consistency of thick cream. Cover the brickwork with two coats of the mixture, and when it is quite dry finish with a coat of paint.

5. Re-plaster the inside of the wall with sand and cement impregnated with one of the special waterproofing agents, such as 'Pudlo,' 'Bareau,' or 'Silicon Ester.'

6. Many special preparations for making damp walls waterproof are obtainable; the best of them consist essentially of: (*a*) a solution of water-glass (sodium, silicate), which is applied to the wall and is followed by a solution of calcium chloride, which forms an insoluble silicate; (*b*) a solution of various fluosilicates which with the mortar or with a subsequent application of calcium chloride form an insoluble calcium fluosilicate in the pores of the wall; or (*c*) various substances, dissolved in acetone, alcohol, or other volatile solvent, which remain in the pores when the solvent has evaporated.

Each of these methods is suitable for certain walls, but some walls appear to resist every kind of treatment yet applied to them.

SECTION IX

PART III

LATHING—PLASTERING—MOULDINGS—SLATING—TILING—GLAZING—PAINTING—PAPER-HANGING—PLUMBING—BOLT FIXING.

Lathing and Plastering.

LATHING

is the first operation for ceilings and partitions; ⅜-inch intervals are left between the laths, to key the plaster. Stronger for ceilings than for partitions.

One bundle of laths contains (nominally) 500 feet. Single fir laths are about $\frac{3}{16}$ in. thick; lath-and-a-half laths are full ¼ in. thick; double laths are about ⅜ thick. They are about 1½ in. broad. 1 bundle of 3-foot laths and 670 nails, or 1 bundle of 4-foot laths and 625 nails, will cover about 5 superficial yards.

Lath Nails are either wrought, cut, or cast; the latter, being cheapest, are generally used, 1 inch, ⅞ inch, or ¾ inch long, according as double, one-and-a-half, or single laths are used. ⅞-inch cut nails run about 380 to the pound.

PLASTERING.

Coarse stuff is mortar composed of 1 part lime (carefully-slaked fat or pure lime is generally used) and 1 or 2 of sharp fresh-water sand, with 1 lb. hair to 3 cubic ft. of mortar.

Hydrated lime is usually superior to lime which has been slaked by hand and can be used at once, whereas ordinary slaked lime must be kept in the form of a putty until slaking is complete.

Fine stuff is made of pure lime slaked with a little water, after which water is added to bring it to the consistency of cream; it is then left to settle, the superfluous water poured off, and the water evaporated until it is of proper thickness. In ceilings a small portion of white hair is mixed with it.

Bricklayers' and plasterers' putty is fine stuff brought to the proper consistency.

Gauged stuff is ¾ fine stuff mixed with ¼ plaster of Paris.

Common stucco is 1 lime to 3 or 4 clean-washed sand.

Bastard stucco is ⅝ fine stuff and ⅜ clean sand, with a little hair.

Lath-and-Plaster, or *One-Coat Work*.—A coat of coarse stuff, ½ inch to ⅝ inch thick, laid on the laths and smoothed off with the trowel.

Lath, Plaster, and Set, or *Two-coat Work*.—The first, or 'pricking-up' coat of coarse stuff is scored with a birch broom or undercut with a lath, and a thin finishing coat of fine stuff or gauged stuff added.

Lath, Plaster, Float, and Set, or *Three-coat Work*.—When the pricking-up coat is dry, the surface is scored, and divided into 8-foot squares by *screeds* of coarse stuff, 8 inches wide, carefully levelled. These are then filled in with coarse stuff, floated carefully level. The finishing coat is then put on as before.

Materials.	1 in. Thick.	¾ in. Thick.	½ in. Thick.
1 bushel of cement, or 1·28 cubic feet, will cover	1½ sq. yds.	1⅛ sq. yds.	2¼ sq. yds.
1 cement and 1 sand "	2½ "	3 "	4½ "
1 cement and 2 sand "	3⅜ "	4½ "	6¾ "

1 cubic yard of lime, 2 yards of sand, and 3 bushels of hair will cover 75 yards superficial, render and set, on brick, or 70 yards on lath.

Mouldings.

Mouldings are made of (*a*) plaster of Paris with or without fibrous material, etc., added to strengthen them and to save plaster; (*b*) burned clay or *terra cotta* (Section X.); or (*c*) wood. Mouldings of plaster may be bought ready for use, and are affixed with plaster of Paris or by means of nails. Wooden mouldings are supplied in various lengths and are sawn to the size of the job.

Nos. 1 to 32 (fig. 1) are forms of mouldings in general use:

Nos. 2, 17, 26.—For inner face of window-frames, and the outer and inner faces of door-frames.

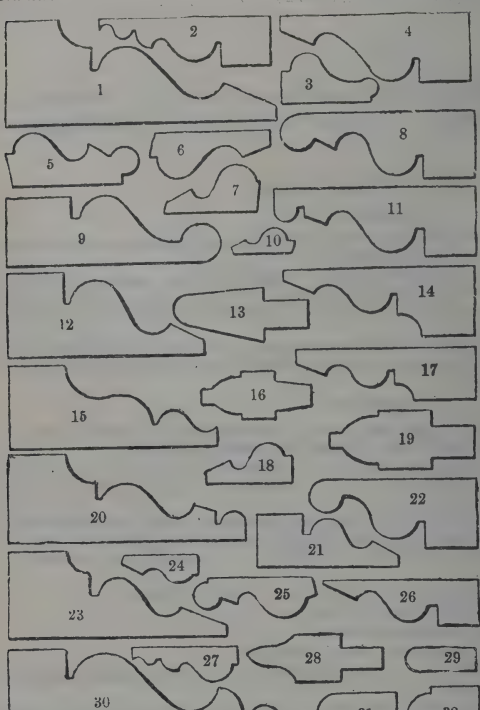

FIG. 1.—Mouldings.

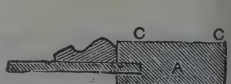

FIG. 2.—Moulding.

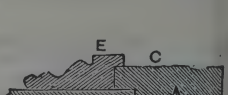

FIG. 3.—Bolection Moulding.

Nos. 18 and 24.—For edging the framing of panels of doors formed of styles and rails.

Nos. 13, 16, 19, 28.—Rebated mouldings for the reception of glass; may be used as sash-bars or for the bars of window-frames.

Nos. 31 and 32.—Beadings for capping matchboarding carried part way up a wall from the flooring.

No. 29.—Beading or slip for placing on either side of a window-frame, to confine the sashes in their proper place.

If the moulding does not project beyond the face, C, C, of the frame, A, as in fig. 2, it is simply described as a *moulding*.

If the moulding, fig. 3, projects beyond the face of the frame, A, making a narrow projecting framing, E, between the frame of the door and the curved part of the moulding, it is described as a *bolection* moulding.

Slating.

The following terms are used as in slaters' work :—

Head : the upper or edge top of slate. *Back* : the upper or exposed surface of slate when laid. *Red* : the lower or under surface of slate. *Tail* : the lower or bottom edge of slate. *Margin* : the part of each course of slates exposed to view (*a–b*, fig. 4). *Gauge* : the distance battens are apart from centre to centre : required to determine the position of battens to receive the nails by which the slates are secured. *Bond.*—When a joint of two adjacent slates is immediately in the centre of the slate, the tail end of which rests upon them, the slates are said to bond. *Lap* : the distance the tail of one slate overlaps the head of second course below, when slates are nailed near the centre, or the distance the tail of slate overlaps the nail-hole of second course below when slates are nailed near the head. The lap, in practice, ranges from 2½ inches to 4 inches, and averages as 3 inches. *Holeing* : the piercing of slates to receive nails. *Sorting.*—When roof is to be covered by slates of different lengths, they are regulated to proper dimensions, so that the largest slates may be nailed near the eaves, and the smallest at the ridge. *Eaves* : the lower part of slating hanging over a wall.

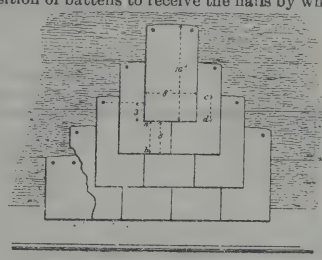

FIG 4.

Sizes of Slates.

The sizes of slates in common use are as follows :—'Duchess' slates, 24 inches by 12 inches, for moderate flat roofs of ⅛ pitch ; 'Countess' slates, 20 inches by 10 inches, for roofs of ¼ pitch ; and 'Ladies.' 16 inches by 8 inches, for roofs of ⅓ pitch, the rule being, the steeper the pitch, the smaller the slate, and the more exposed the building, the greater the pitch of the roof.

Slates are laid on *boards* (fig. 4) or *battens* (fig. 5), the latter being the cheapest. Boards, ¾ inch thick for Countess slates, and rafters not more than 18 inches in the clear, 1 inch or thicker, otherwise. Battens, 2 inches by ¾ inch for Countess, with rafters 12 inches interval : 3 inches by 1 inch for Duchess. Slates are often *holed* 1 inch or 1½ inch from the head, as in fig. 4, but are better centre-holed, i.e. just clear of head of slate below, as in fig. 5.

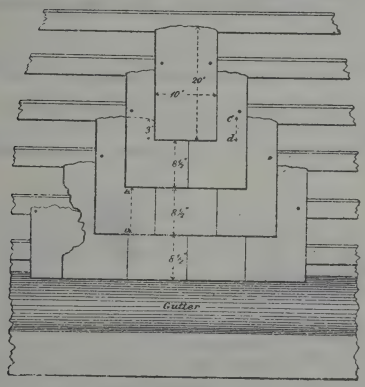

FIG. 5.

If a *good slate* is stood half its depth in water for several hours the moisture should not rise to the top.

Slating Nails.

Composition nails are recommended for all good work ; they are stiffer than copper or zinc, present a brassy appearance, and are cheaper than copper nails. If iron nails are used, they should be galvanised, or boiled in linseed oil. Two to each slate, 1⅝ inch long for small slates, 1½ inch long for Countess, and 1¾ for Duchess slates.

Zinc and Copper Clips.—When a slate gets broken that is nailed to boarding and has to be repaired, narrow clips, about ½ inch wide, are pushed between the slates to catch the head of slate below. The new slate is then inserted, and the end of clip turned as a hook over the tail of the slate. When slates are nailed to battens, and the interior is accessible, they may be repaired by means of a piece of copper wire which is pointed at one end and driven into the batten or boarding at the head of under slate, passed between the side-joints of slates immediately above it, and lapped over the tail of the next slate but one above it. A man under the battens will secure a piece of copper wire to the battens, and then push the wire between the slates for the man above to clip over the tail of the new slate.

Size and Weight of Slates.

A thousand slates means 1,200. A square is 100 super feet.

Name.	Size.	Gauge for 3-in. Lap Nailed in Centre.	No. of Squares covered by 1,000 of 1,200.	Weight per 1,000 of 1,200.	Weight* per Square.	No. to Cover One Square.	Nails required per Square.	
							Iron.	Copper.
	Ins.	Ins.		Cwts.	Cwts.		No.	Lbs.
Smalls	12 × 8	4½	2·8	17½	6¼	430	860	5
Doubles	13 × 6	5	2·5	18	6	480	960	6
Ladies	14 × 12	5½	5	31	6¼	240	480	3½
,,	16 × 8	6½	4·5	25	5·5	300	600	3½
Viscountesses	18 × 10	7½	6	36	6	200	400	2¾
Countesses	20 × 10	8½	7	40	5·7	171	342	4
Marchionesses	22 × 12	9½	9·4	55	6	130	260	3½
Duchesses	24 × 12	10½	10	63	6	125	250	3
Imperials	33 × 24	13½	25	..	..	48	96	3
Rags	36 × 24	16½	30	..	..	40	80	3½
Queens	36 × 24	16¼	30	..	..	40	80	2

* The weights are for first quality Penrhyn or Bangor; second quality weigh about one-third more. As the sizes of slates of the same name sometimes differ slightly, the size required should be given as well as the name, when of importance. This Table allows about $\frac{1}{20}$th for waste.

'Ægis' Asbestos-Cement Roofing Slates.

These slates are made in 'Honeycomb' and 'Diamond' patterns, figs. 6 and 7. In the figs. E and UE indicate the eaves and under-eaves portions respectively.

The slates can readily be cut to fit hips, valleys, verges, round chimneys, and roof lights.

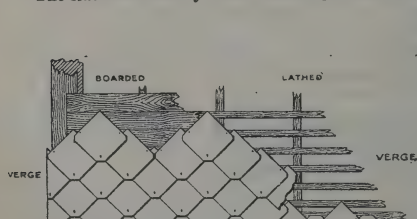

Fig. 6.

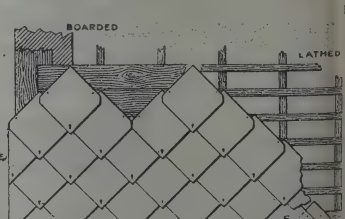

Fig. 7.

Both the 'Honeycomb' and the 'Diamond' pattern slates are made to the sizes 11¾ ins. b 11¾ ins., 15¼ ins. by 15¾ ins., and may be cut and holed for laying with a 2¾ ins. or 3½ ins. lap The lap to be given is determined by the pitch of roof, position of building, and the prevailin climatic conditions.

See also pp. 425-427.

Underlining.

Felt laid upon boarding under slates effectually keeps out the wet, and is a non-conductor of heat and sound; it should be battened over to preserve it.

Willesden Paper (*The Willesden Paper & Canvas Works, Ltd.*) is an excellent material for underlining. It is a good non-conductor, does not perish when shut up beneath slates or tiles, is waterproof, and will not allow rain or snow to penetrate, has no smell, even under the greatest heat, and lies very close on the roof.

Tiling.

Roofing tiles may be *plain* (i.e. rectangular and almost flat), or they may be wavy, as *pantiles*, or they may have grooves or other structures which enable them to *interlock* with on another. Interlocking tiles are much heavier, but form a more weatherproof roof.

For information respecting the materials of which roofing tiles are made see pp. 425 and 530.

The unit of measure for roofing tiles (when fixed) is a 'square' having an area of 100 sq. ft. Thus, if 4 in. is to be exposed on a *plain tile*, 600 such tiles will form a 'square,' but in flat roofing, where the overlap is much less, only 210 tiles will be required for a square. 1 square weighs about 15 cwt. 100 plain tile laths 5 ft. long = 1 bundle.

For *pantiles*, 180 to a 10-inch gauge, 164 to an 11-inch gauge, and 150 to a 12-inch gauge. The lap of the tile over the one below it will be just the difference between its length and the length of the gauge. 1 square weighs about 8 cwt. 12 pantile laths 10 feet long = 1 bundle. Fir tiling laths are $1\frac{1}{2}$ inch by 1 inch; and oak tiling laths, $1\frac{1}{4}$ inch by $\frac{1}{4}$ in. 1 square of tiling requires 1 bundle of laths, 150 nails, 1 peck of tile-pins, and 3 hods of mortar.

Wall and *Floor Tiles* are usually glazed; they are not very suitable for external use.

Glass and Glazing.

Sheet glass is that which is in ordinary use for windows, &c., and the usual glazing qualities are known as *best*, *seconds*, and *thirds*; a commoner quality, known as *fourths* or *coarse*, is also made, but is not much used.

The weights per foot super. are 15 oz., 21 oz., 26 oz., 36 oz., and 42 oz., the latter being nearly $\frac{1}{8}$ in. thick. As a rule, every $\frac{1}{16}$ in. may be taken as 13 oz. to the foot super.

In addition to the usual glazing qualities there are two others, called *picture qualities*, *A* and *B*, made in the 15 oz. and 21 oz., and one other, *C*, in the 26 oz. and 32 oz. thicknesses.

Sheet glass is sold by the foot super. of the required quality and weight, in *crates* of stock sizes for cutting up, or *squares* cut to order.

The ordinary stock sheets do not exceed in area 22 ft. super., in length 85 in., or in breadth 49 in., nor are they less than 11 ft. in area, 45 in. in length, or 34 in. in breadth.

The largest sizes that can be made in the various substances of sheet glass are as follows, *but the extreme limits of length and width cannot be combined in the same sheet* :—

	Extreme length.	Extreme width.	Extreme area.
15 oz.	60 in.	40 in.	15 ft.
21 „	90 „	50 „	26 „
26 „	90 „	50 „	25 „
32 „	85 „	48 „	21 „
36 „	70 „	44 „	17 „
42 „	70 „	44 „	15 „

The extreme area, taken in connection with the extreme length or width required in any particular case, will indicate approximately the corresponding limit of width or length.

Sheet glass obscured or frosted so as to appear like ground glass is made from any description of the third quality glass.

Sheet glass can be polished on face, bent to any required curve, or ground on the edges, as may be required.

Fluted sheet is glass rolled to form flutes or corrugations on both sides; which, while it secures privacy without obstructing the light, makes it much stronger than ordinary ground or obscured glass. It is made from 15 oz. to 32 oz. in weight, and in squares 60 in. in length and 38 in. in breadth. It can also be obscured if required.

White dappled is sheet glass about 21 oz. to the foot, the surfaces being mottled or undulatory as its name implies. *White muffled* sheet is somewhat similar.

Patent plate is merely a superior kind of sheet glass, and is now not much used. It can be distinguished from British polished plate, by a more wavy appearance of the surface, as well as by the air bubbles, which are *oval* in patent plate and *circular* in British plate. It is made in four thicknesses—viz. $\frac{1}{16}$, $\frac{1}{12}$, $\frac{1}{10}$, and $\frac{1}{8}$ in.—and three qualities—bests, seconds, thirds—in each. $\frac{1}{16}$ in. and $\frac{1}{12}$ in. are generally used for picture purposes, and $\frac{1}{10}$ in. and $\frac{1}{8}$ in. for coach plates. It can be supplied *smoothed* or *finely ground*, in sheets 50 in. in length or 36 in. in width.

Polished or *British polished plate* is the best article made, and is kept in stock sheets up to 100 ft. super., or 160 in. long or 104 in. wide, but can be made in larger sheets if specially ordered. The usual thickness is $\frac{1}{4}$ in., but it can be obtained $\frac{1}{8}$ in. thick, varying by $\frac{1}{16}$ in. up to 1 in. in thickness. It is manufactured in three qualities, known as *ordinary* and *best glazing*, for windows, etc., and *silvering quality*, for mirrors, etc. It can be bent to any desired curve, and the edges can be ground or polished. If scratched the surface can be repolished or resilvered at any glass works.

Rough cast plate is the cheapest quality of plate glass, and is made in plates even exceeding 100 ft. super., but the stock sizes run up to about 60 ft. superficial. Its thickness ranges from $\frac{1}{8}$ in to 1 in. It can be bent to any curve, or ground on one or both sides if required. From its strength it is very useful for risers to steps, glazing pavement lights, and similar rough work where light has to be transmitted.

Plain and *fluted rolled rough plate* is principally used for railway roofs, factories, workshops, etc., and other purposes where the object is to intercept the vision but not the light. The *plain* is rolled with fine lines on the surface; the *fluted* is either of the small pattern, with about 11 flutes to the inch, or the large pattern, with about 4 flutes to the inch. It is made from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. thick, in stock sizes not exceeding 25 ft. super., or 130 in. in length, or 46 in. in breadth. It can be bent to curves, or obscured on the rough side.

Diamond and *quarry rolled rough plate* is principally used for churches, chapels, schools, lecture halls, etc. The diamond rough plate has a bright and brilliant appearance. The pattern is of a lozenge shape, and in relief upon the body of the glass. The quarry rolled is in imitation of, and is used as a substitute for, leaded quarries, and is made in either *large* or *small* patterns. It is made from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. thick, in sheets from 20 in. to 34 in. wide and up to 100 in. long.

Chequered rolled plate is similar to *diamond*, but the pattern is square. It is principally used for screens, door panels, etc.

Rolled plate corrugated one side is about $\frac{1}{4}$ in. thick, and is made in sheets up to about 110 in. long and about 36 in. wide. It is used for glazing in any position where extra light is required and opaqueness a necessity, and is suitable, when silvered, for reflectors.

Figured rolled glass is made in a variety of patterns known by distinctive names, such as 'Muranese,' 'shell,' 'Arabesque,' etc., and is made either white or in various tints.

Patent wire rolled glass consists of a sheet of glass, about $\frac{1}{4}$ in. thick, having wire netting embedded in its centre. It is extremely useful for many purposes.

Rolled cathedral glass weighs about 21 oz. to 26 oz. to the foot super., but can be made thicker if required. It is made either in white, pot metal colours, or cathedral tints. This last term is applied to light tints of no positive colours, which are suitable for glazing the windows of churches throughout.

Coloured and *stained glass* is made from 15 oz. to 32 oz. in weight, and in sheets not above 48 in. long or 34 in. wide, in a variety of colours, which are known as *flashed*, in which the body is of ordinary sheet glass thinly covered on one surface only with coloured glass, or *pot metals* in which the glass is coloured throughout. This glass can also be *sanded* or *obscured*.

Constants of Labour for Glazier.

		Hours of a glazier.
Crown glass stopped in new sashes	per ft. super.	·20
" " old sashes	"	·60
Sheet glass stopped in large squares in new sashes	"	·15
" " " old sashes	"	·40
Hacking out glass, including painting putty	"	·30
Cleaning windows, both sides	"	·04

(*J. T. Rea.*)

Putty, Paint, and Solder.

Glazier's putty is composed of whiting and linseed oil (see p. 519).

In order to prevent the constant expansion and contraction of large panes of glass, especially in tap-lights, from loosening the putty, tallow may be mixed with it, forming *thermoplastic putty* which, by retaining its pliability, gives and takes with the glass.

The priming and paint used by the glazier are the same as used by the painter.

The solder used for lead glazing is the plumber's *fine solder*, consisting of equal parts of lead and tin.

To remove old putty, apply a hot iron, to soften it, or paint it with nitric acid or hydrochloric acid, and, after about an hour, remove the putty with a knife.

Painting.

All surfaces to be painted should be smooth, clean, and well dusted. The first operation in painting resinous woods, such as fir, is *killing the knots*, or treating them so as to prevent the resin or turpentine from exuding and ruining the paint. This may be done by painting the knots over with hot lime, and, when dry, ironing them with a hot iron, and then painting them smooth; or leaving the lime on for about 24 hours, scraping it off, and then painting with red and white lead and linseed oil, and, when dry, pumice-stoning the knots smooth. But these processes take time, to obviate which a liquid called *patent knotting*, chiefly shellac and naphtha, is much used. It forms a skin over the knots, and by drying in about 5 minutes allows of the painting going on at once. *Red-lead knotting*—made by grinding red lead in water mixed with strong glue size, and used warm—is, however, considered preferable to patent knotting, and dries in about 10 minutes.

The first coat of paint is called the *priming coat*. This in ordinary lead painting is composed of red lead, or red and a little white lead, mixed with raw linseed oil, a little litharge, and burnt copperas ground very fine in turpentine as a drier, the object being to fill the pores of the wood with oil before applying the colouring coats, which would otherwise be sucked up and wasted by the wood.

After the priming comes the stopping, or filling up all nail-holes, etc., with putty, which if applied before the priming, would become loose from the wood drawing the oil out of the putty, and allowing it to shrink.

After all defects have been made good, and the work has been rubbed smooth, the colouring coats are applied, the second coat, or first after priming, being diluted with about one-third turps, the third coat having the oil and turps in equal proportions, and the fourth coat one-third oil to two-thirds turps. If not to be painted white, the second coat should approximate to the required colour.

When, as in drawing-room work, it is desirable to avoid the glossy surface of oil paint, a fifth coat, for which all turps and no oil is used, is added, and is called a *flatting* coat, and should be laid on before the last coat has become hard. It will not admit of washing, as oil paint will, and therfore is not suitable for outdoor work.

Varnish adds greatly to both the appearance and durability of paint. A priming coat followed by a dark coat, such as a chocolate or purple-brown, and finished off with a coat of common varnish, is cheaper than, and as durable as, 4 coats of colour; it looks better, is more rapidly executed, and stands washing well. A single coat of gum-lac or good resin, dissolved in linseed oil to about the consistency of cream, and coloured as may be required, also forms a good and durable covering.

Walls may also be coloured and varnished thus: First, apply at boiling heat 2 coats of whiting mixed with strong glue size, then fill up defects with mastic in water, rule smooth with pumice stone, and cover with 2 coats of coloured varnish, the first coat mixed with one-fourth of the required colour, and the last coat with only half as much colour. The colour should be ground very fine, and the varnish should be white spirit varnish.

Plaster, being very absorbent, is often primed with glue size and then covered with 4 coats of colour (if the ordinary lead paints are used), and a flatting coat can be added if desired; but the best plan is to apply a priming coat of boiled oil quite warm, and when dry and hard add a thin coat of weak size tinged with red lead, in order to stop all absorption and give the work a uniform appearance, and finish off with 2 coats of oil paint, and a flatting coat if required; or 2 coats of coloured varnish can be applied as described above.

In painting on plaster, in order to guard against damp injuring the paint, it is safer to distemper the walls for the first two years, and then wash it off and paint, taking care that the walls are perfectly dry. If the distemper is not greasy or dirty, it is better to merely brush it well down with a dry brush, and paint over it without any washing.

With the ordinary paints, new wood or ironwork requires 4 coats, including the priming coat, but exclusive of any flatting coat, and old paint should have 2 coats for inside and 3 for outside work.

Painting Fresh Cemented Surfaces.

The McNicholl process seems to be the best treatment yet devised for coating a fresh cemented surface to enable it to be painted. It consists of zinc sulphate, 5 lbs. to the gallon of soft water. The zinc sulphate forms a chemical compound that prevents the alkali from attacking the paint coating, afterwards applied. This process is also good for interior walls, over Keene's or Portland cement. When it is dry apply a coat of either pure raw linseed oil or an oil paint, thinned out with benzene. (*Contract Record.*)

Value of Paints.

Details.	White lead.	Zinc white.	Red lead.	Red oxide.
Covering capacity in sq. yds. per cwt	806	1,411	594	1,083
Price per cwt. in shillings	32	36	32	28
Cost, in shillings, per 100 sq. ft.	·44	·28	·60	·28
Times painted in 20 years	5	5	3	7
Cost, in shillings, per 100 sq. ft. for 20 years	2·20	1·40	1·80	1·96
Relative economic value on 20 years' basis, the highest value being represented by 100	64	100	77	71

(*Cruickshank Smith.*)

Valuing and Estimating Painters' Work.

The rule in measuring painters' work is to take wherever the brush goes, by the *yard superficial* in the case of large surfaces, such as walls, doors, etc.; by the *foot run* in the case of narrow surfaces *cut-in* on both edges, as in skirtings, where the paint has to be run to a line both at top and bottom, to avoid painting the floor or wall; and by the *number* in the case of separate pieces, such as chimneypieces, newels, balusters, brackets, gratings, etc. In iron railings and other open work each side is measured by the yard superficial, as if it were a plain surface, and if ornamental each side is doubled, or a fair extra allowance made according to the nature of the work.

The outsides of ordinary-size frames, being *cut* to the wall, the insides, as well as when there are no linings, as in stores, riding-schools, etc., are taken by the number. In cases of sash-frames with mullions or transoms each division is taken as one side of a frame.

The sashes themselves are paid for by the *dozen squares*, the price being for one side only, the number being doubled if painted at the same cost on both sides.

Letters and figures are paid for by the *inch in height* as plain or ornamental.

Common colours include *lampblack*, *red* and *white lead*, *Venetian red*, *ambers*, and all other *common ochres*, such as *greys*, *buffs*, *stones*, *etc.* *Superior* or *ornamental colours* include *bright yellows*, *warm tints*, *blues*, *mineral greens*, *etc.* Some colours, such as *verditer*, *pea-greens*, *rich reds*, *pinks*, and *bright blues*, are charged at a higher rate still, as *delicate tints*.

The following are the yards super which a fixed amount of material will cover in each coat :—

First coat, or priming	10 lbs. white lead 1 oz. red lead	2 ozs. litharge* 4 pints linseed oil	63 superficial yards.
Second coat	10 lbs. white lead 2 ozs. litharge	2½ pints linseed oil* 1½ pint spirits of turpentine	100 superficial yards.
Third and fourth coats	10 lbs. white lead 2 ozs. litharge*	2 pints linseed oil 2 pints spirits of turpentine	113 superficial yards.

For outside work, when exposed to the sun, more turps should be used to prevent the paint from blistering, and only *boiled* linseed oil should be used. For inside work, raw linseed oil may be used, but the less oil the less gloss. For the flatting coat, the colour being ground in oil, only turps is added.

For coloured paints the last two coats have the colour added to the composition in the proportion of 1 to 2 lbs. for every 10 yards of surface to be painted; and the quantity of white lead is reduced in proportion.

One pint of varnish will cover about 16 yards with 1 coat.

For paints for various purposes see Section XLIII., 'Workshop Recipes.'

Spray Painting and Whitewashing.

Tests carried out on paint-spraying machines have shown that spraying requires approximately 10 per cent. more paint than brushing when the surface being treated is an iron roof, while brushing requires approximately 200 per cent. more labour than spraying. On exterior brick walls, spraying requires 7 per cent. more paint than brushing, while brushing requires 109 per cent. more labour than spraying. On interior ceilings and walls of plaster, spraying requires 40 per cent. more paint than brushing, but gives a better hiding in one coat. On similar work, brushing requires 160 per cent. more labour than spraying, and gives a poorer hiding in one coat. Although it has not been possible as yet to arrive at a definite conclusion confirming the relative durability of spraying as compared with hand-painting, it is claimed that the investigations so far made tend to support the belief that the spraying work will last longer.

* Or ½ oz. of burnt white vitriol and 1½ oz. of litharge.

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Stopping	,,	·05 ,,
First or priming coat on wood	,,	·16 ,,
Second and following coats, each	,,	·14 ,,
First coat on iron	,,	·25 ,,
Second and following coats, each	,,	·22 ,,
Add if painting done from a ladder	,,	·10 ,,
Iron bars, fillets, etc., one coat	,,	·06 ,,
Sash squares, each side, first coat	per dozen	·50 ,,
,, ,, ,, second coat	,,	·40 ,,
Tarring, first coat on wood	per yard super.	·25 labourer.
,, second and following coats	,,	·20 ,,
,, first coat on iron	,,	·28 ,,
,, second ,,	,,	·21 ,,

(J. T. Rea.)

PUTTY.

Mix 50 lbs. of whiting, 4 lbs. of white lead, and 1 gallon of raw linseed oil, preferably in a suitable mill, though hand-mixing is quite satisfactory, if well done. To make the putty set more quickly, add 2 lbs. of 'patent dryer,' or replace part of the raw oil by 'boiled' linseed oil. The white lead may be omitted if desired.

See also p. 516.

Distemper.

Distempers are wall-coverings which are intermediate in nature between paint and whitewash, being more adherent than the latter, but less impervious than the former. They are usually made of casein and alkali or lime, and are slightly cementitious in character, so that they 'set,' do not 'rub off,' and may be cleaned by washing with a sponge and water. Distempers may be in the form of a powder, or paste, which must be mixed with water (sometimes with a special 'petrifying liquid') so as to form a thick cream which is readily applied with a brush. Distempers may be obtained in various colours.

A good distemper produces a dull flat finish, but the surface may be stippled if desired. Most distempers are for interior work, but some of them can be used for outdoor work over brick, stucco, cement, stone, plaster, wood, iron, or other usual building material, provided a little pale boiled linseed oil is added before thinning as above.

One and a half pints of liquid to 14 lbs. of 'Deydol' Distemper (*Pinchin, Johnson & Co. Ltd.*) will make sufficient distemper to cover about 600 square feet of normal surface with one coat.

Where the underlying plaster or cement has a tendency to sweat it causes the colour to run; this can be prevented by a coat or two of 'Deydolene,' which also insulates lime action, stops suction, sweating, patches, spots, sheariness, discoloration, and other troubles. If desired, Deydol Distemper can be varnished, as an additional protection for surfaces that are subject to heavy wear.

Whitewash.

Whitewash is a mixture of whiting, water, and size, of the consistency of cream, which is used for covering walls and ceilings. It will not stand rain or rubbing, but it is cheap and effective in situations where it will not be disturbed.

The *whiting* should be bought ready made; it is usually prepared by purifying natural chalk, but some other forms of calcium carbonate, recovered as a by-product from various industrial processes, are equally suitable.

The *size* is powdered or flake glue, but the term is sometimes applied to a jelly made by soaking such glue in water overnight, so as to cause it to swell, and it is then melted by adding hot water and heating gently. About 1 lb. of glue should make a gallon of size. It is usually more satisfactory to buy the glue and produce the size than to purchase the size ready made. The size is added to make the particles of whiting adhere to each other and to the wall or ceiling.

A very good whitewash contains 10 lbs. of whiting, 1 lb. of flake or powdered glue, and 1 gallon of water, but this is regarded by some users as being too 'rich' and unnecessarily expensive. In that case it is diluted by adding more water.

LIMEWASH

is used for common walls or ceilings where for sanitary reasons a frequent application is necessary.

It will not stand rain, and adheres badly to very smooth or porous surfaces. It is cheap, and is made by slaking lump lime with about one-third of its weight of water, and then adding enough water to make a 'milk.' Hydrated lime is easier to use, and for most purposes is equally effective. The use of hot, freshly slaked lime is sometimes preferred, as it is supposed to have antiseptic and disinfectant properties. The proportions of lime and water are not important: about 5 lbs. of lime to 1 gallon are ample, and much less lime is often used. Some people consider that limewash is improved by adding 1 lb. of tallow (free from salt) to every bushel of lime.

Paperhanging.

APPROXIMATE NUMBER OF PIECES OF ENGLISH WALL-PAPER REQUIRED FOR ANY ROOM.

(Allowance to be made for doors and windows.)

Measurement in Feet Round the Walls.	Height of Room, in Feet, from Skirting to Cornice.									
	6	7	8	9	10	11	12	13	14	15
	Number of Pieces Required.									
32	4	4	5	5	6	6	7	7	8	8
36	4	5	5	6	6	7	7	8	9	9
40	4	5	6	6	7	8	8	9	9	10
44	5	5	6	7	8	8	9	10	10	11
48	5	6	7	7	8	9	10	10	11	12
52	6	6	7	8	9	10	10	11	12	13
56	6	7	8	8	9	10	11	12	13	14
60	6	7	8	9	10	11	12	13	14	15
64	7	8	9	10	11	12	13	14	15	16
68	7	8	9	10	11	12	13	15	16	17
72	7	9	10	11	12	13	14	15	17	18
76	8	9	10	11	13	14	15	16	17	19
80	8	9	11	11	13	15	16	17	18	20
84	9	10	11	12	14	15	17	18	19	21
88	9	10	12	12	14	16	17	19	20	22
92	9	11	12	13	15	17	18	19	21	22
96	10	11	13	13	16	17	19	20	22	23
100	10	12	13	15	16	18	20	21	24	24

Paper for wall decoration is sold by the *piece*. A piece of English paper is supposed to be 12 yds. long and 20 ins. wide when hung; therefore each yard run will contain 5 ft. super, and each piece 60 ft. super; consequently the feet super of surface to be papered divided by 60 will give the number of pieces of paper required, any odd number of yards being taken as a piece. With common patterns 1 piece in 10 should be added to make up for waste in cutting and fitting, the patterns in, whilst in large patterns 1 in 7 would not be too much. In all cases a liberal allowance should be made, as it is useful for repairs, the same pattern not being always procurable when required.

A gallon of paste will hang 5 pieces of English paper, a quart of flour being required for each gallon of paste; sometimes a little alum is used to increase its strength, but makes it harder and prevents it spreading so well. One gallon of boiling water to 2 lbs. of flour and 1 oz. of alum is a common proportion in making paste. The thinner the paste can be made, the better; and it should be well strained before using.

Before papering, the walls should be stopped, pumiced, and sized.

In paperhanging, the trimmed edges of the paper should face the light, to prevent any shadow marking the joints, and should be truly plumb; the pattern should accurately join.

In all cases of re-papering walls, the old paper should be stripped off and the walls scraped, washed, and stopped, previous to hanging the new paper. Papering-over old paper must never be allowed; many rooms which smell close and unhealthy owe it all to several thicknesses of old paper and paste decomposing on the walls. Disease and death have been clearly traced home to the omitting to strip off the old paper before re-papering.

Flock papers when old, instead of being stripped off, can be painted; they will absorb three or four coats of paint; but it produces a very good effect, from the embossed pattern standing out on the surface.

Plumbing.

Plumbing, as the word implies, is the art of working in lead—the principal operations being the covering of roofs and flats, laying gutters, covering hips, ridges, and valleys, fixing water pipes with all necessary taps, making and fixing certain cisterns and reservoirs, water-closets, washing appliances, etc. Plumbers also undertake fixing gas fittings and pipes related thereto

though this is really smith-work), and also work in sheet-zinc; they often fix rain-water pipes and sometimes drain-pipes, though these are really 'builder's work.'

The plumber's chief jointing material is solder, but in roofing its use should be avoided as far as possible, turned-over joints being far preferable.

Lead in gutters should turn up under slates, etc., from 7 ins. to 9 ins., according to pitch of roofs, and against walls from 5 ins. to 8 ins., and be covered with a flashing, or 'apron,' the upper edge of which is let into a mortar-joint a little above the gutter lead, the lower edge overlapping the latter at least 3 ins.

No sheet of lead should be laid in a greater length than 10 ft. or 12 ft. without a drip or vertical overlap at least 2 ins. deep, to allow of expansion.

Gutters should have a fall of at least 1 in. in 10 ft., better 1½ in. Flashings should have 3-in. laps, ridge and hip joints 4-in. laps, valley and roof joints 5-in. laps.

The thickness of the lead used for roofing should not be less than 7 lbs. per foot super for roofs, flats, gutters, bottoms of cisterns, and sinks; 6 lbs. per foot super for hips, ridges, small gutters, valleys, and sides of valleys; and 5 lbs. per foot super for flashings. For soil pipes it is well to use lead weighing 8 lbs. per foot super.

Zinc Roofing.

The gauges of zinc recommended for roofing purposes are Nos. 13, 14, 15, and 16, the weights per sq. ft. of each gauge being respectively 16 ozs. 15 drs., 18 ozs. 12 drs., 21 ozs. 12 drs., and 24 ozs. 12 drs. The sheets usually measure 8 ft. × 3 ft.

Rain-water Pipes.

These are made of cast iron, generally in 6-ft. lengths. The round pipes vary in diameter from 1½ in. to 8 ins. The square pipes are made from 2½ ins. × 2 ins., up to 6 ins. × 6 ins. The 3-in. round pipe is a size largely used.

'Everite' Rain-water Pipes.

(*Bell's Poilite and Everite Co., Ltd., Southwark St., London, and Peter St., Manchester.*)

Everite rain-water pipes (made of asbestos-cement), approved by the Ministry of Health for State-aided housing schemes, are stronger than cast iron and require no painting; their upkeep cost is insignificant. These consist of the following, all made to 2-in., 2½-in., 3-in., 3½-in., 4-in., 4½-in., 5-in., and 6-in. diameters:

Rain-water pipes; heads; shoes; bends or elbows, square or obtuse; plinth bends; offsets; swannecks; 'T' and 'Y' pieces; branch pieces, single and double.

'Everite' Eaves Gutters.

Everite rain-water gutters consist of the following, all made to 4-in., 4½-in., 5-in., and 6-in. diameters:

Half-round gutters; half-round nozzles, angles and 'T' pieces; half-round drop ends; half-round union clips; half-round stop ends.

Corrosion of Zinc and Lead Water Pipes.

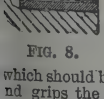
Zinc water pipes in contact with mortar containing gypsum become corroded and eaten through in places. The most active agent of destruction is sulphate of lime. Zinc is energetically attacked by mortar containing gypsum in the sand, but only feebly by mortar containing limestone and alone, or with an addition of gypsum. Lead, on the other hand, is energetically attacked by limestone containing gypsum, but only feebly by gypsum in sand. Both metals are strongly attacked by pure cement, but the destructive action is lessened in progressive measure by the addition of sand. Hence zinc should be put in contact only with limestone (carbonate) mortar, and lead only with clean sand. Lead is also attacked by acid soils, and should be protected from these by means of drain pipes or troughs.

Wall Plugs.

Rawlplugs.

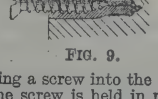
(*The Rawlplug Co., Ltd.*)

Rawlplugs are small patent tubes made of tough fibre, stiffened and treated by a special chemical process. A small hole is first made with a Rawlplug tool or a drill and the Rawlplug



Section showing plug in position ready for screw.

FIG. 8.



Screw entering, showing expansion of plug against sides of hole.

FIG. 9.

which should be an exact fit) inserted. On turning a screw into the Rawlplug the latter expands and grips the wall firmly, at the same time the screw is held in position by a perfect thread which is automatically formed in the fibre.

Figs. 8 and 9 show the arrangement.

The 'Metlex' Wall Plug.

(Metallic Wall Plugs, Ltd.)

The 'Metlex' Wall Plug is an all-metal wall plug for use with wood screws in very hard materials.

The arrangement, which consists of a metal wrap, is shown in fig. 10. One end, *a*, of the plug is coloured red to indicate that it is the outer end; at the opposite end, *b*, the longitudinal overlap of the wrap is depressed to facilitate its insertion into the plug hole. When the plug has been driven into the hole, this lip ensures a tight fit, and prevents it from rotating. The first turning motion of the screw enlarges the plug slightly, but powerfully, so as to provide the hole with what is virtually a solid metal lining, on which the screw now cuts its own thread, and develops a very strong grip.

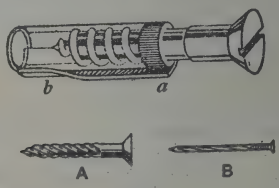


FIG. 10.

A and B show a 'Metlex' Drive Screw and a 'Metlex' Screw Nail. These can be driven into the plug by means of a hammer, no screw-driver being required. They may be hammered through wooden fixtures without previous drilling of the fixture.

Fixing Bolts.

(1)

A device for this purpose, fig. 11, comprises an expanding washer of curved and truncated conical form, with slots cut around its periphery, as shown at *A*. The washers are stamped cold from steel sheet, and as a result of the cold-working have considerable stiffness, while the slots around the periphery permit of easy expansion by drifting. With the aid of a drift and a few smar

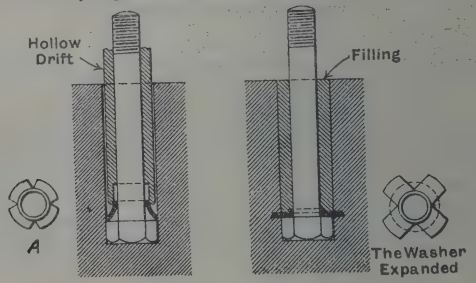


FIG. 11.

blows with a hammer the washer is easily expanded and flattened out to a sufficiently larg diameter as to form a substantial shoulder that is embedded, as shown. The excess space i the bolt hole may be caulked with oakum, gaskin, old lead pipe, or yarn. The arrangement wi sustain a load quite proportionate to the strength of the wall or floor in which it is fitted.

(J. T. Towlson, 'Machinery,' Nov. 8, 1923.)

(2)

The Rawlplug Bolt Anchor.

(The Rawlplug Co., Ltd.)

The 'Rawlplug Bolt Anchor' is constructed from specially chilled iron in combination wit lead.

Fig. 12 shows the arrangement. The lower end, A, of the anchor consists of a truncated cor of chilled iron, attached to a cylinder of lead; the iron cone is divided into segments, which a shaped in such a way that the edges are sharp at their greatest diameter.

The method of use is, first to prepare a hole with the aid of a 'Rawlplug Boring Tool,' then (place a bolt in the hole, head foremost, place a thick iron washer on the bolt, pressing it snug

against the bolt-head, and, finally, follow with the anchor, placed cone-shaped, head foremost, so that when in position it rests against the washer.

The space around the bolt is then caulked, which is carried out with the aid of the Rawlplug caulking tool and a heavy hammer.

The action of caulking has the effect of not only wedging the lead firmly against the bolt and the walls of the hole, but also of causing the hard iron cone to fracture at the segments and force the cutting edges into the wall of the hole.

The Rawlplug Bolt Anchor is made in sizes ranging from $\frac{3}{8}$ in. to $1\frac{1}{4}$ in., and the depth to which they should be fixed varies according to the kind of material in which the fixing is to be

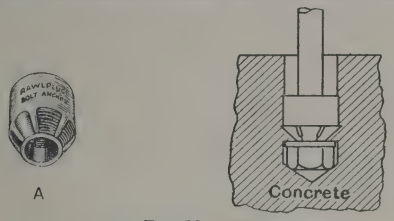


FIG. 12.

made. Should the material be hard and unyielding, a hole of lesser depth is required than when fixing in weak concrete. In good concrete for small sizes a depth of about 4 ins. is sufficient, whereas a depth of from 6 ins. to 9 ins. is recommended for the fixing of large size bolts. To facilitate caulking, and to enable this operation to be carried out more effectively, the lead cylinder of the larger size bolt anchors is furnished in two sections.

(3)

A (fig. 13) is an ordinary bolt, with head slightly tapered on both sides; B is a piece of ordinary gas barrel cut with a hack saw to the shape shown; C is the bolt in position inside the rube ready for fixing in position; and D is a 'jumper' for cutting the hole and is made out of a piece of the same barrel as B.

The teeth at F on D (as shown in the fig.) are V-shaped, roughly filed.

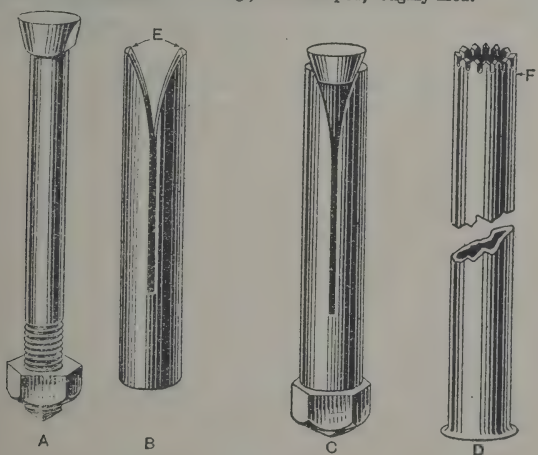


FIG. 13.

When the complete fitting C is placed inside the hole, and the work that it is desired to hold is inserted on the bolt underneath the nut, very great pressure can be exerted, as the tighter the nut is screwed down the further the jaws open at E (B) and the tighter the grip becomes.

Many thousand bolts with the fitting have stood the test of carrying loads under all conditions. At a large generating station the bolts, fixed in stone concrete and brickwork, have carried a 24-in. steam header subject to heat moisture and vibration.

(*London Association of Foremen Engineers' Magazine.*)

SECTION X

CLAYS AND ALLIED PRODUCTS USED BY ENGINEERS.

CLAYS AND EARTHS—PUDDLE—BRICKS—TILES—BLOCKS AND TERRA-COTTA—STONEWARE, SANITARY WARE, AND DRAIN PIPES — ELECTRICAL WARE — REFRACTORY MATERIALS — FIREBRICKS — FURNACE LININGS — RETORTS — CRUCIBLES — HEAT-INSULATING MATERIALS—FIRE-RESISTING CEMENTS.

Contributed by Alfred B. Searle
(Consulting Advisor on Clay Products)

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Contributed by Alfred B. Searle
(Consulting Advisor on Clay Products).

CLAYS AND EARTHS.

For engineering purposes, clays and earths may be regarded as (1) substances which must be excavated and transported from their present situation; (2) the raw materials from which earthwork, puddle, etc., are made; and (3) the raw materials used in the production of bricks, drain pipes and many other articles employed by engineers. The term 'clay' in the broadest possible sense is applied to a material which is tenacious and plastic when wet. Such clays may contain only a small proportion of true clay, together with a large proportion of inert material such as sand. For many engineering purposes a perfectly pure clay would be useless, as it might be of so fine a texture and so highly plastic that it would shrink excessively on drying, and it would be extremely difficult to make into bricks or other desired articles. When made, these articles would be deficient in certain important properties, such as resistance to crushing, impermeability to water, etc.

The term 'earth' is usually applied to a friable material partaking of the general properties of soil, though not necessarily of any agricultural value. It usually consists chiefly of inert material, the particles of which are united by a very variable proportion of clay, humus, or other adhesive. Hence the 'earths' are often regarded as 'clays' of low plasticity, but both these terms are used very loosely by many engineers and no really satisfactory definition of them has yet been formulated.

In selecting a 'clay' or 'earth' for any given purpose, the engineer must, therefore, decide what properties are essential to his requirements and must endeavour to find a natural material possessing these properties, or to prepare a mixture of two or more materials which suit his purpose.

The chemical and physical properties of 'clays' depend chiefly on the composition and plasticity of the material, it being obvious that a 'clay' containing 50 per cent. of quartz-grains must behave very differently from one which consists wholly of 'true clay.' The *plasticity* of clays varies with the nature of the clay and the amount of water present. Dry clays are friable and devoid of plasticity; on mixing clay with an equal weight of water a liquid slurry or slip is formed which is not really plastic, but becomes so when a suitable proportion of the water has been removed by evaporation or otherwise. No generally accepted explanation of the cause of plasticity has been published; this property may be due to the presence of colloidal particles which may be derived from the clay itself or from impurities which have become associated with it. The purest clays—e.g. 'china clay'—are very feebly plastic; the highly plastic ball clays which are supposed to have been derived from them are rich in carbonaceous matter, to which their plasticity is sometimes attributed. The clays commonly used for bricks, pipes, terra-cotta, etc., are never pure; they are naturally-occurring complex mixtures possessing the requisite properties to make them useful for specific purposes.

It is a great mistake to suppose that any plastic 'clay' can be made into bricks, or that any 'system' of manufacture is equally suitable for all 'clays.' On the contrary, the manufacture

of clay products is in reality so complex (notwithstanding its apparent simplicity) and the ordinary manufacturer depends on the simultaneous occurrence of so many fortuitous circumstances that it is not surprising that many firms fail to manufacture clay goods of uniform quality.

PUDDLE.

Puddle is a highly plastic paste made by mixing 'clay' with about one-fifth of its weight of water, the precise amount depending on the plasticity and dryness of the 'clay.' A perfectly pure 'clay' does not usually produce good puddle, as it is either deficient in plasticity (like china clay) or it shrinks excessively. The former defect can only be remedied by the use of a more highly plastic material; excessive shrinkage may be prevented by mixing a suitable proportion of sand with the clay. For the best results, a piece of puddle when dried should not shrink more than 1½ in. per linear foot; on the other hand, it should not shrink less than ¾ in per linear foot or it will probably not be sufficiently impermeable to water.

The materials used must be carefully selected and thoroughly well mixed; some contractors are very careless in this respect and will use anything which has been passed through a pug-mill. The correct consistency for good puddle is that at which that paste can be squeezed easily in the hand without any appreciable quantity adhering to the latter when the pressure is released. Puddle made of the consistency of porridge is much too soft for best work, though it is better than an over-dry or badly mixed stiff paste.

Where possible, the materials used for making puddle should, before being mixed with water, be passed between a pair of rollers placed not more than ¼ in. apart, so as to crush any stones or coarse gravel present. It is also desirable that all roots and large stones should be picked out before sending the 'clay' to the mixer.

BRICKS.

Many kinds of bricks are in use. The most important are: *Common Bricks*, used for ordinary building purposes; *Facing Bricks*, used for external work where appearance is important; *Paviours*, used for yards, footpaths and other locations where a hard-wearing and impervious brick is required (for *Road Bricks* see p. 839); *Blue Bricks*, which are similar in many respects to 'paviours' and are employed where exceptional strength and impermeability are important; *Stock Bricks*, which are practically the same as 'common bricks,' but have usually been burned in a clamp instead of in a kiln; they have proved exceptionally resistant to the climatic conditions of London, but are seldom, if ever, used in other large industrial centres (in some localities the term 'stock bricks' relates to 'facing bricks').

Bricks are also known according to the manner of their production. Thus, *Malms* contain a large proportion of chalk, either naturally or artificially mixed with the clay; *Wire-cut Bricks* are made by cutting up a column of clay issuing from a machine, by means of wires; *Pressed Bricks* have been made in presses; *Semi-plastic* or *Stiff Plastic Bricks* have been made from paste which is stiffer and less plastic than that used for hand-moulded or wire-cut bricks; *Semi-dry Bricks* are made by compressing the powdered clay in powerful presses instead of first converting it into a paste.* *Place Bricks*, *Grizzles*, and *Chuffs* are inferior bricks which are so through insufficient burning; *Crozzles* are excessively hard, misshapen bricks which have been partially melted and overheated. *Rubbers* and *Cutters* are soft, sandy bricks.

Glazed Bricks are used where a smooth and impervious surface is required (see 'Glazed Tiles').

Sand-lime Bricks † are made of sand mixed with about 6 per cent. of lime and matured in a atmosphere of steam under pressure. They have never become very popular, chiefly on account of the abundance of clay bricks and stone, but in localities where sand is plentiful and clay scarce they appear to be an excellent substitute for clay bricks.

Several attempts have been made by various Government officials to extend the use of sand-lime bricks, but such efforts have proved abortive, as such bricks are much more difficult to make at a profit, and there is a larger proportion of unsaleable waste than with clay bricks. Some of the statements respecting the speed of production and cost for manufacture of sand-lime bricks, published in certain Government publications, are by no means correct if applied to average conditions.

Cement-concrete Bricks.†—These bricks have attracted attention, but are not so suitable as larger blocks of concrete for general purposes, as the cost of production is relatively high. Such bricks are made in precisely the same manner as concrete blocks—i.e. from a mixture of Portland cement with six times its volume of one of the following aggregates:—sand, destructor furnace-, or boiler-clinker, ashes, quarry waste, and broken bricks or stone. The use of these bricks appears to be limited in practice to districts where clay bricks cannot be obtained at a reasonable price, and even then concrete blocks or mass concrete would be much cheaper, as the manufacture of such bricks is not nearly so simple as a description of the process may imply.

Engineering Bricks is the term usually applied to bricks of an exceptionally dense and vitreous character, of which the best known are the *Staffordshire* blue bricks. These owe their unusual strength and impermeability to the fact that they have been burned under such conditions that

* For further details respecting the manufacture of bricks see 'Modern Brickmaking,' by A. B. Searle (Scott, Greenwood & Son, London).

† See 'Bricks and Artificial Stones of Non-Plastic Materials,' by A. B. Searle (J. & A. Churchill, London).

the particles composing them are united very firmly by means of a film of clinker surrounding each. For purposes where a somewhat weaker brick has ample strength, well-made *pressed* or *stiff plastic* bricks are usually satisfactory and much less costly, but they are more porous and therefore less suitable for supporting heavy masses of material on a boggy or damp subsoil. Bricks for *boilers* should be accurate in size and shape so as to enable the thinnest possible joints to be used. In order to prevent undue leakage they should be glazed or painted with tar or other impervious material. For boiler *blocks* see Section XXX, Part II.

For *fireboxes*, *furnaces*, etc., firebricks and blocks are employed.

Colliery Bricks are usually of very poor quality, due to their being made from unsuitable material, or from good clay which has been spoiled by mixing it with rubbish.

There is serious need for great improvements in the manufacture of bricks in many collieries, and those firms who have called in a competent and independent advisor have found that it has paid them well to follow his advice. The services of unemployed foremen, machinery manufacturers, and kiln builders, in this connection, are seldom satisfactory, as their recommendations are unduly biassed.

Crushing Strength of Bricks.

Opinions differ greatly as to the respective values of different kinds of bricks, and as the crushing strength of bricks taken from the same works at different times varies 25 per cent. and even more, it is clear that no comparison of crushing strength tests can be of much value in deciding between various kinds of bricks. The chief use of the tests is in fixing a minimum crushing strength which shall ensure the safety of the structure, but as the strength of even the commonest bricks is much greater than that of average brickwork (the mortar being usually weak), it is difficult to stipulate any satisfactory minimum strength for bricks.

The following figures are the averages of a large number of bricks, but it must be clearly understood that bricks from any given works may be either much stronger or much weaker than the ones mentioned.

Description.	Crushing Commences.	Ultimate Crushing.
	Tons per square foot.	Tons per square foot.
Common stocks	40–60	80–120
London best stocks	80–140	100–180
Gault white, wire-cut	40–120	135–200
Aylesford, red pressed	70	140
Manchester, common red	75	120
,, wire-cut	85	260
Accrington, plastic *	690	1005
Leicester, wire-cut	115–250	230–340
Rugby, common red	160	190
Fletton	125–200	170–250
Notts.	60–300	120–400
Ruabon.	360	—
Staffordshire Bluebricks	250–450	400–750
Terra-cotta blocks	—	100–260
Glazed bricks	70–165	165–175
Stourbridge firebricks	90–160	110–210
Sand-lime Bricks	150–200	180–230

The crushing strength of brickwork is shown on pp. 285, 473.

Sizes of Bricks.

In many countries there is no official standard; the following are average sizes:—

Standard Sizes of Bricks in different Countries.†

Country.	Length, inches.	Breadth, inches.	Thickness, inches.
Great Britain	9	$4\frac{1}{2}$	$2\frac{1}{2}$ ‡
Germany	10	$4\frac{1}{2}$	$2\frac{1}{2}$
Austria	$11\frac{1}{2}$	$5\frac{1}{2}$	$2\frac{1}{2}$
France	$8\frac{1}{2}$	$4\frac{1}{2}$	$2\frac{1}{2}$
Italy	9	$5\frac{1}{2}$	$2\frac{1}{2}$
Holland and Belgium	$9\frac{1}{2}$	$4\frac{1}{2}$	$2\frac{1}{2}$
Switzerland	10	$4\frac{1}{2}$	$2\frac{1}{2}$
Russia (varies greatly)	$11\frac{1}{2}$	$5\frac{1}{2}$	$2\frac{1}{2}$
United States	8	4	$2\frac{1}{2}$

* These figures supplied by The Accrington Brick and Tile Co., 1926.

‡ In Scotland, $2\frac{1}{16}$ in. or 3 in.

† See also p. 468.

Specification for Bricks.

The sizes of bricks vary in different parts of Great Britain, but there are many advantages in adopting the Specification of the Royal Institute of British Architects as follows:

The Royal Institute of British Architects' standard size lies between—length, 8¾ ins. and 9 ins.; breadth, 4 $\frac{5}{16}$ ins. and 4⅜ ins.; thickness, 2⅜ ins. and 2 $\frac{1}{16}$ ins.

The method of measuring the bricks as set out in the standard specification is as follows:

(1) The length of the brick should be double the width plus the thickness of one vertical joint.

(2) Brickwork should measure four courses of bricks and four joints to a foot.

Joints should be ½ in. thick, and an extra $\frac{1}{16}$th, making $\frac{5}{16}$th, for the bed joints to cover irregularities in the bricks. This gives a standard length of 9¼ ins. centre to centre of joints.

The bricks, laid dry, to be measured in the following manner:

A. Eight stretchers laid square end and splay end in contact in a straight line, to measure 72 ins.

B. Eight headers laid side to side, frog upwards, in a straight line, to measure 35 ins.

C. Eight bricks, the first brick frog downwards and then alternately frog to frog and back to back, to measure 21½ ins.

A margin of 1 in. less will be allowed as to A and ½ in. less as to B and C.

Tests of Bricks.

All dry bricks should *ring clearly* when two, held in the hands, are struck sharply together. If a dull sound is emitted the bricks are either saturated with water or they have not been sufficiently well burned.

The *porosity* of bricks is usually tested by soaking them in water, wiping dry and noting the increase in weight. Whilst many good building bricks will absorb one-fifth of their weight of water, this is no criterion of the value from an engineering standpoint; on the contrary, engineers usually prefer bricks with low porosity on account of their greater strength.

Rattler Test.—In the United States, and to a much smaller extent in this country, engineering bricks are tested for toughness and resistance to abrasion by placing a weighed quantity of them in a cylinder with steel balls and rotating the cylinder a thousand times in about half-an-hour.* The contents of the cylinder are then removed, all pieces of brick larger than 1 in. diameter are picked out and reweighed. The loss in weight is regarded as a measure of the inferiority of the bricks. The rattler test is particularly applicable to bricks used for road making (Section XV) and for lining furnaces.

Lime-Sand Bricks.

Bricks made of sand with about 8 per cent. of lime and hardened by exposure to steam under pressure have long been used in Germany and in this country, though they are by no means well known. They are white, cream, or grey in colour, and have a crushing strength of 200 tons per sq. ft. They are, when properly made, as durable as good sandstone, but poorly made bricks are not suitable for damp situations. The cost is about the same as clay bricks.

Concrete Bricks.

Bricks made of 6 parts of sand and 1 part of Portland cement are cheap to produce when the sand is on the building site. Ordinarily they cost more than clay bricks. They are made in plain moulds, and must be kept wet for a fortnight. Concrete bricks are as durable as sandstone; they are suitably made in isolated places where sand is available and carriage is costly.

TILES.

Roofing Tiles are made of materials similar to those used for bricks, but of a somewhat finer texture. No official specifications have been published, but it is recognised that roofing tiles should be light, tough, and ring clearly when struck, be impervious to water in the sense that even under a continuous supply of water no dripping will occur from the underside of the tile when placed at the same angle as when in use on a roof. It is desirable that tiles should be moderately porous, so as to avoid undue condensation of their undersurfaces. (See also p. 515.)

Glazed Tiles are used partly for decorative purposes, but chiefly for sanitary reasons. The glaze should be sufficiently hard to resist all reasonable abrasion and it should not craze (forming hair-like cracks) after prolonged use. For chemical laboratories and other special purposes a felspathic glaze burned at about 1300° C. must be used in order that it may be sufficiently resistant to corrosive fluids, etc. (see 'Stoneware,' p. 531).

Paving Tiles, like paviour bricks, should be very hard and resistant to abrasion. To prevent animals slipping on them, the surface may be channelled with small grooves forming a diamond pattern.

Paving tiles are usually made of the same material and in the same manner as paving or engineering bricks.

* The weight of the balls, the number of revolutions, and the size of the rejected pieces, differ with various engineers.

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BLOCKS AND TERRA-COTTA.

The chief requirements of *blocks* made of clay and allied materials are accuracy in shape and size, and ample strength to carry the superimposed loads. For external work, appearance is also important.

Terra-cotta is largely used in conjunction with structural steel work, the latter taking the bulk of the stresses and the terra-cotta forming a sort of filler and cover of great resistance to climatic conditions and of pleasing appearance. There is no necessity to impose any conditions as to its strength, as in a properly designed structure it would not be exposed to any severe stresses.

Blocks for boilers are made of special shapes. They must be sufficiently heat-resisting not to be affected by the conditions to which they are subject when in use. They must be very accurate in shape and size or there will be a serious leakage into the side flues. (Section XXX., Part II.)

HOLLOW BLOCKS.

For many years in France and in some of the Colonies, but more recently in this country, the advantages which hollow blocks possess over building bricks have been realised. Such blocks are only one-third of the weight of the same number of bricks; they can be laid about four times as rapidly, and they are of ample strength for all purposes for which ordinary bricks are used. In addition, they automatically form a cavity wall, with all its advantages of warmth

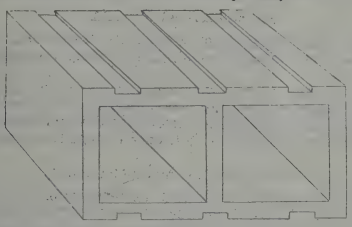

FIG. 1.

and soundproofness. Their great strength is really due to the fact that the bricks in a solid mass of brickwork have about ten times the crushing strength of the brickwork as a whole. Consequently a large proportion of the solid interior is quite useless and only adds to the cost of material, carriage, and labour; these costs are saved when hollow blocks are used.

Hollow building blocks are made in various shapes and sizes, according to the purposes for which they are to be used, and numerous patents have been granted in connection with them.

The *clays* used for making hollow blocks are the same as those employed in the manufacture of terra-cotta and roofing tiles. Such clays must vitrify sufficiently to form a strong, weather-resisting mass when fired. They must retain their shape perfectly at any temperature to which they may be exposed in the kiln, and whenever possible they should have a pleasing colour so as to avoid the necessity of 'rough casting.' Suitable clays and shales are found in various parts of the country, particularly in the Midlands. The lower grades of fireclays found in the various coalfields are also suitable, provided their buff colour is not regarded as objectionable.

The *process* of manufacture consists in preparing a clay paste of suitable consistency and extruding it through a die or mouthpiece, the interior of which is fitted with a number of cores, corresponding to the hollow portions of the blocks, fig. 1. The extruded column of clay is then cut by wires into suitable lengths, and the resulting blocks are dried and burned like bricks or architectural terra-cotta.

No standard specifications for hollow blocks have as yet been issued, but it is obvious that if the crushing strength of such blocks when they are laid in the same position as that in which they will be used, is greater than the normal strength of brickwork, such blocks will have ample strength. In most cases the blocks themselves have more than twice the strength of normal brickwork.

FOSALSIL.

This material (see p. 537) is used for the purpose of hollow blocks suitable for partitions; it possesses great mechanical strength and high fire resistance. It is supplied by *Messrs. J. H. Sankey & Son, Ltd.*, 7 & 8 Norfolk Street, Strand, London, W.C. 2.

STONEWARE, SANITARY WARE, AND DRAIN PIPES.

Stoneware, as used by engineers, is chiefly employed in chemical works in the construction of appliances for dealing with corrosive fluids both at low and high temperatures.

The conditions under which it is used are exceptionally severe and yet are so varied that no widely acceptable specifications have been found possible. For chemical and industrial purposes, stoneware should consist of an impervious body of great crushing strength and with a minimum sensitiveness to sudden changes in temperature. The ideal is closely approached by the porcelain crucibles used in chemical laboratories, but this is too costly and too fragile

for most commercial purposes and various coarser substitutes are therefore employed. To a very large extent the manufacturers of stoneware appliances may be relied upon to supply a satisfactory product if they are fully informed as to the conditions to which it will be subjected. Where troubles arise, they are often due to an engineer requiring a piece of stoneware of a design or shape which is incompatible with the nature of the material used.

Sanitary Ware is not subjected to the same conditions as stoneware, and may therefore consist of a porous body covered with a hard felspathic glaze, though an impervious body is preferable where expense is no object. It is highly important that the glaze should be of a suitable character, earthenware and lead glazes seldom being sufficiently durable. In designing sanitary ware it is desirable to work in close co-operation with the manufacturer, as in this way much delay in production and a considerable saving in cost may be effected, and the ware is likely to be more satisfactory. As far as possible, joints and sharp arrises or corners should be avoided.

Drain Pipes are frequently made of a porous body which is covered with a salt-glaze, but for the best work a vitreous or impervious body should be used. If the glaze is defective or damaged an impervious body will maintain the efficiency of the pipes, but a porous body may permit seepage of a disagreeable or even harmful character.

For 'The British Standard Specification for Salt-Glazed Pipes' see Section XXVI.

ELECTRICAL WARE.

Electrical Ware is chiefly used in the form of conduits, insulators, and fittings. The conduits are usually made of coarse stoneware and are similar in many respects to salt-glazed drain pipes (*supra*).

Other electrical ware is made of fine stoneware or porcelain. Insulators must have a fine and uniform texture and their fractured surface should be free from holes and fissures; they must be able to resist the passage of electric currents of the desired voltage without appreciable leakage, and should be tested at a considerably higher voltage to ensure this.

REFRACTORY MATERIALS.*

The term '*Refractory*' is applied to various heat-resisting materials, such as firebricks, crucibles, and furnace linings. There is no official definition of this term, but it is becoming increasingly customary to regard 1580° C. (2876° F.) as a minimum temperature, materials which suffer deformation when heated rather slowly to this temperature being excluded from what are generally regarded as refractory materials.

As the rate of heating has an important influence on the temperature at which deformation occurs, it is necessary, for comparative purposes, to specify the conditions of heating.

MELTING POINTS OF REFRACTORY MATERIALS.

	°C.
Alumina (pure)	2010†
Bauxite	1820†
Bauxite brick	1565 to 1785†
Bauxite clay	1795†
Chromite	2180†
Chromite brick	2050†
Fireclay brick—Highest grade	1843
General grade	1680 (average)
General grade (average of 41 samples)†	1649
Ganister	1700 to 1800
Kaolin	1835 to 1740†
Magnesia brick	2165
Silica—Pure	1750†
Pure (fine grains)	1650
Pure with 14·5 per cent. alumina	1690
Pure with 63·0 per cent. alumina	1790
Brick	1700 to 1750

The term 'melting point' is misleading when applied to refractory materials, as these are seldom, if ever, melted, and the term is generally used to indicate the temperature at which a small pyramid or 'cone' of the material bends over until its apex is on a level with its base, or, alternatively, at which the angular edges of the pyramid begin to lose their angularity.

FIREBRICKS.*

Fireclay bricks are made of clays derived chiefly from the coal measures. These clays are crushed to powder mixed with water and made into bricks either by hand-moulding or machines of the stiff-plastic or semi-dry type; the bricks are then dried and are afterwards burned in kilns. The temperature attained in burning should be at least as high as that to which the bricks will be subjected when in use, as otherwise shrinkage and other defects may occur. It is seldom that bricks burned at such high temperatures are obtained unless they are definitely specified; and for some purposes, such as lining steel-melting furnaces, users must be content with bricks fired at a lower temperature than that at which they will be employed. The highest temperature ordinarily attained in burning firebricks is about 1350° C.

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* See also *Refractory Materials, their Manufacture and Uses* (2nd edn.), by A. B. Searle (Griffin & Co., Ltd., London).

† Kanoit. The temperatures are those at which the materials were first seen to flow easily.

Firebricks are also made of silica (in which case they are known as *Ganister* or *Silica Bricks*), alumina (*Bauxite* or *Semi-bauxite Bricks*), magnesia (*Magnesia* or *Magnesite Bricks*), chrome iron ore (*Chromite Bricks*), sillimanite (*Sillimanite Bricks*), zirconia (*Zirconia Bricks*).

Firebricks made of clay or silica are acid in character and are readily attacked by the limestone used as a flux in steel furnaces.

The materials of which the bricks are made may be classified into three groups:

(*a*) Aluminous clays.
(*b*) Siliceous clays.
(*c*) Silica rock (sometimes erroneously termed 'silica clays').

The *Aluminous clays* include the Stourbridge, Yorkshire, Scotch, Welsh, and other Coal Measure fireclays, which contain, on an average, about 65 per cent. of silica. The *Siliceous clays* include those which contain 80–92 per cent. of silica, such as Ewell clay. *Silica rock* contains more than 92 per cent. of silica, such as Dinas rock and ganister. The composition of some of these materials is shown in the following table *:

	Stourbridge Clay.	Ewell Clay.	Dinas Clay.	Black Ganister.†
Silica	64·62	87.57	97.60	98·5
Alumina	21·65	3·60	0·50	0·3
Ferric oxide	1·48	4·80	1·50	1·3
Lime	1·88	0·74	0·20	0·2
Magnesia	0·62	0·41	—	—
Potash	—	0·69	0·09	trace
Soda	—	0·10	0·03	trace
Moisture	9·62	—	—	—
Combined water	—	2·09	—	—

Ordinary fireclays contain 58 to 75 per cent. of silica, 25 to 36 per cent. of alumina, and ½ to 2 per cent. of iron oxide. Good silica bricks contain upwards of 95 per cent. of silica, little or no alumina, and under 2 per cent. of lime. Ganister bricks contain about 90 per cent. of silica, 5 per cent. of alumina, and less than 2 per cent. of iron oxide. Magnesia bricks consist almost wholly of magnesia, unless about 5 per cent. of clay or iron oxide has been used to bind the particles together.

Basic Bricks are made of magnesia, whilst *Neutral Bricks* are made of bauxite, sillimanite, zirconia, chromite, or carbon; the two latter are chiefly used as an intermediate course between acid and basic bricks in furnace linings. The materials used for silica and neutral firebricks usually need a 'binder' such as fireclay or lime, but the clays are self-binding. Firebricks made of sillimanite appear to be specially suitable for use at very high temperatures. As natural sillimanite ($Al_2O_3.SiO_2$) is a rare mineral which has to be imported from Northern India, an artificial material made by heating fireclay and bauxite in a blast-furnace is frequently used instead; the artificial product is not true sillimanite, but more closely resembles millite ($3Al_2O_3.2SiO_2$). Those made of zirconia have proved disappointing—chiefly on account of the impurities in the zirconia used.

The impurities in fireclays, i.e. those constituents other than the silica and alumina, have a most harmful effect on the refractoriness of the material owing to their low fusing point. These constituents should, if possible, never be allowed to exceed more than 4 to 5 per cent. Much must, of course, depend upon the type of clay, and it is possible to point to certain substances containing so much as 4 per cent. of iron alone, and yet they are highly refractory. Green clay when fired is subject to considerable shrinkage, and it is for this reason that chamotte, or 'grog,' is added in varying proportions before the article is placed in the kiln. This 'grog' is usually prepared from a clay which originated in the same seam as the clay with which it is mixed. It should be prepared specially for the purpose, and should not consist of the crushings from defective and broken articles which have passed through the kiln. The quantity of 'grog' added varies, of course, with the material required and the kind of clay made use of. For firebricks and smaller articles it is usually added in a proportion of 15 to 20 per cent. For larger articles, such as retorts, the amount is increased to 30 to 40 per cent.

The deformation or softening points of firebricks vary considerably. The following are fairly typical:—

Fireclay bricks, 1610°–1770° C.; Silica bricks, 1670°–1790° C.; Magnesia bricks, 1730°–2000° C.

* Analyses of these and other heat-resisting materials will be found in *Refractory Materials*, by A. B. Searle (Griffin & Co., Ltd., London).

† The Dinas material is not a true clay, but a silica rock composed of almost pure quartz; ganister is similar, but consists of much smaller particles.

Specification for Fireclay Bricks.

The following paragraphs contain the salient features of the Specifications for Firebricks issued by the Institution of Gas Engineers (1911, revised 1912).

(1) *Refractoriness.*—Two grades of material are covered by the specification :—

(*i*) The material which shows no sign of fusion when heated to a temperature of not less than Seger Cone 30 (about 1670°C.).

(*ii*) Material which shows no sign of fusion when heated to a temperature of not less than Seger Cone 26 (about 1580°C.).

(2) *Surfaces and Texture.*—The material shall be evenly burnt throughout and the texture regular, containing no holes or flaws. All surfaces shall be reasonably true and free from flaws or winding.

(3) *Contraction or Expansion.*—A test piece, when heated to a temperature of Seger Cone 14 for two hours, shall not show more than the following linear contraction or expansion :—

No. 1 grade, 1 per cent. ; No. 2 grade, 1·25 per cent.

After the test temperature has been reached, the furnace shall be maintained constant at that temperature throughout the testing period.

The test piece shall be 4½ inches long and 4½ inches wide, the ends being ground flat, and the contraction being measured by means of vernier calipers reading to 0·1 mm., a suitable mark being made on the test piece, so that the calipers may be placed in the same position before and after firing.

(4) *Variations from Specified Measurements.*—In the case of ordinary bricks, 9 inches by 4½ inches by 3 inches or 2½ inches thick, there shall not be more than ± 1½ per cent. variation in length, nor more than ± 2½ per cent. variation in width or thickness, and in all cases the bricks shall work out their own bond, with not more than ½ inch allowance for joint. In the case of special bricks, blocks or tiles, there shall not be more than ± 2 per cent. variation from any of the specified dimensions.

(5) *Crushing Strength.*—The material shall be capable of withstanding a crushing strain of not less than 1,800 lbs. per square inch when applied to whole bricks placed with their long side vertical between the jaws of the machine, giving a vertical thrust.

Specification for Silica Bricks.

(Institution of Gas Engineers, 1912.)

The material covered by this specification is divided into two classes :—

(*i*) That containing 92 per cent. and upwards of silica, and hereinafter called 'silica' material.

(*ii*) That containing from 80 to 92 per cent. of silica, and hereinafter called 'siliceous.'

(1) *Refractoriness.*—Test pieces of the material shall show no sign of fusion when heated to the following temperatures :—

'Silica' material not less than Seger Cone 32 (about 1710°C.).

'Siliceous' material not less than Seger Cone 29 (about 1650°C.).

The test shall be carried out in an oxidising atmosphere, the temperature of the furnace being increased at the rate of about 50°C. per five minutes.

(2) *Surface and Texture.*—The material should be evenly burned throughout, and the texture regular, with no holes or flaws. All surfaces shall be reasonably true and free from flaws or winding.

(3) *Contraction and Expansion.*—A test piece, when heated in a gas muffle or electric furnace to a temperature of Seger Cone 14 for two hours, shall not show on cooling more than 0·75 per cent. linear contraction or expansion. The test piece shall be at least 4½ inches long by 4½ inches wide, the ends being ground flat, and the contraction or expansion measured by means of vernier calipers reading to 0·1 mm., a suitable mark being made on the test piece, so that the calipers may be placed in the same position before and after firing. The test samples shall not be taken out of the middle of a brick or tile, but shall be representative of the whole.

(4) *Variations from Measurements.*—In the case of ordinary bricks, 9 inches by 4½ inches by 3 inches or 2½ inches thick, there shall not be more than ± 1½ per cent. variation in length, nor more than ± 2½ per cent. variation in width or thickness ; and in all cases the bricks shall work out their own bond. Special bricks, blocks, or tiles shall not have more than ± 2 per cent. variation from any of the specified dimensions.

Specifications for Refractory Mortar or Cement.

(Institution of Gas Engineers, 1911; revised 1912.)

Cementing clay or fireclay mortar shall be machine-ground, and, at the discretion of the manufacturer, may contain a suitable percentage of fine grog ; but in all cases the cement-clay shall be quite suitable for the purpose of binding together the bricks, blocks or tiles for which it is supplied, and shall be capable of withstanding the same test for refractoriness.

This specification applies equally to cement or mortar used for bricks made of either fireclay or silica.

Firebricks used in Gasworks.

The firebricks used in gasworks should conform to the specifications of the Institution of Gas Engineers (p. 534). They are usually, but by no means invariably, made of the materials mentioned on p. 533.

BRICKS OR BLOCKS FOR FURNACE LININGS.*

The bricks or blocks used for lining furnaces should be selected according to the conditions to which they will be subjected. It is almost impossible to obtain a material which is wholly efficient in every respect, and some compromise is essential. Thus, great resistance to abrasion can only be obtained by increasing the amount of vitreous material and thereby lowering the refractoriness of the bricks. Answers to the following questions will usually provide most of the information required :—

(*a*) What is the highest temperature to which the brick will be exposed (excessive or only moderate), and will it be constant or fluctuating? (*b*) Will the material come into contact with any flame, and will the latter be of an 'oxidising' or 'reducing' character? (*c*) Is mechanical strength required? (*d*) Is heat to be conducted or retained? (*e*) Is the brick expected to withstand sudden and repeated changes in temperature? (*f*) Will the brick come into contact with fluid slags or glass, or with flue-dust, cement or other fluxes? (*g*) Must the brick resist blows, shocks and other unavoidable strains? (*h*) What is the nature of the fuel used and is it fed by hand or mechanically? (*i*) Is the electrical conductivity important?

To meet (*a*), refractoriness is of much importance, but, in most cases, other factors deserve even greater attention. For (*b*) and (*c*) the texture of the surface of the brick must be right or the brick will not be durable, no matter how great its refractoriness. If mechanical strength is needed, the brick cannot be as refractory as otherwise, for great strength is dependent on the presence of a large amount of bond, which is necessarily less refractory than the particles to be bound together. For (*d*), it will be found that the conduction of heat depends chiefly on the density of the material if made of clay or silica and on its chemical composition if made of graphite, plumbago or other carbonaceous material. Graphite, fused alumina and zirconia are good heat conductors, whilst clay, silica and magnesia are good heat retainers. For (*e*) a lean, coarse and porous material should be used, whilst for (*f*) a fat, close material is required, i.e. exactly opposite to that for (*e*), and for (*g*) a hard-burned material which has not been heated more than once is preferable; broken bricks and other refractory articles should not be used as grog in this case, and the mass should not be either too lean or too fine-grained.

Consideration of the above points will show that there is some difficulty in deciding upon the correct description of the material for use in the ordinary type of industrial furnace. Where bricks of high refractoriness are required to withstand the temperature employed, heat must be retained and radiation reduced to a minimum, though most of these requirements are satisfied by using an open-grained, porous material. Still greater difficulty arises in dealing with furnaces in which fluxes are brought into contact with the firebricks, and in these the material must be close-grained, even if this is accompanied by the loss of some heat resistance.

Where great resistance to fluxes (flue-dust, lime and other bases) is required, the refractoriness of the brick is of secondary importance to the closeness of texture. Under such conditions, a porous, highly refractory brick will be far less durable than a dense brick of much lower fusing point. The fluxes act less rapidly on a comparatively smooth, dense surface than on a more porous one, so that the 'life' of the former brick will be longer than the latter, notwithstanding the fact that its actual heat resistance may be lower. For this reason, many fireclays which are of No. 2 quality as regards heat resistance are preferable for use in some furnaces and for flue work generally.

In some heating appliances, the draught and the atmosphere to which the refractory material is exposed have a far greater influence on the durability of the latter than is generally supposed. Unless properly managed, such furnaces may cause firebricks to be destroyed in a few weeks, whereas under proper conditions of draught they would last almost as many years. This is a matter of which firebrick manufacturers have no special knowledge and most builders and users of furnaces are equally ignorant. It is, in fact, one which can only be properly investigated by a specialist in refractory materials.

RAMMED FURNACE LININGS.

Furnaces are sometimes lined with a stiff paste which is rammed into position. The composition of such rammed linings varies with the purpose for which the furnace is used; a well-known material consists of ganister to which a little lime has been added and the mixture then made into a very stiff paste with water.

Various kinds of sand, with or without sufficient clay or other binding agent to make the mass adhesive, are largely used for lining and repairing furnaces. (See also 'Refractory Cements,' p. 537.)

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* For a much fuller description of the properties required in bricks and blocks used for various furnaces, kilns, etc., see *Refractory Materials*, by A. B. Searle (Griffin & Co., Ltd., London).

GAS RETORTS.

The chief forms of gas retorts are briefly described in Section XXXVII. They are usually made of a mixture of fireclay and 'grog,' the latter consisting of fireclay which has previously been burned and reduced to a very coarse powder. The grog should not consist of particles of uniform size, but should be graded so as to produce a material capable of withstanding sudden changes in temperature. The proportions of grog and clay must be adapted to the nature of the clay and the size and shape of the retort. The retorts require to be dried very slowly and carefully, and to be burned at a sufficiently high temperature to prevent them shrinking unduly when in use.

The following paragraphs contain the salient features of the Specification for Gas Retorts issued by the Institution of Gas Engineers in 1911, revised 1912.

SPECIFICATION FOR GAS RETORTS.

(Institution of Gas Engineers, 1911; revised 1912.)

(1) *Constituents.*—The retorts or retort tiles shall be made of sufficiently seasoned raw clay and clean-burnt 'grog.' No 'grog' shall be used which will pass through a test sieve having 16 meshes to the linear inch.

Standard sieves* to be used.

(2) *Refractoriness.*—A piece of the material shall show no signs of fusion when heated to a temperature not less than Seger Cone 28 (about 1630°C.), the heat being increased at a rate of about 50°C. per five minutes in an oxidising atmosphere.

The material is to be chipped to the form and size of a Seger Cone, and tested against standard Seger Cones (small size).

(3) *Surfaces and Texture.*—All surfaces shall be reasonably true and free from flaws or winding, and after burning no 'washing' shall be done without the consent of the engineer (or purchaser). The texture throughout shall be even and regular, containing no holes or flaws, and the 'apparent porosity' shall not be less than 18 per cent. by volume.

(4) *Contraction.*—The material shall be evenly burnt throughout and contain no black core. A test piece, when heated to a temperature of Seger Cone 14 for two hours, shall not show, when cold, more than 1½ per cent. contraction or expansion. The test piece shall be 4½ inches by 4½ inches, the ends being ground flat, and the contraction being measured by means of vernier calipers, reading to 0·1 mm., a suitable mark being made on the test piece, so that the calipers may be placed in the same position before and after firing.

Retorts made of *silica bricks and blocks* have, in recent years, achieved great success, as they transmit the heat better than fireclay. For these the Specification for Silica Bricks (p. 534) is suitable.

CRUCIBLES.

Crucibles are made of (*i*) fireclay to which a suitable proportion of sand has been added, (*ii*) graphite or plumbago with a sufficient amount of clay or other binder, and (*iii*) various other materials of a special character such as magnesia, zirconia, etc. Crucibles must be sufficiently refractory to withstand the heat to which they are subjected, and whilst at the highest temperature at which they are used they must be sufficiently strong to be lifted out of the furnace, with their contents. Equally important is the resistance offered to the action of their contents, and as no crucible is equally suitable for all purposes careful selection is necessary.

A common test for the ability of a crucible to withstand corrosion is to half fill it with copper and to add a little borax. As the copper melts, part of it will be oxidised, the borax will absorb the oxide and will rapidly corrode the crucible, unless the latter is of excellent quality.

Another useful test consists in melting red lead and copper oxide in the crucible to be tested. Most crucibles will be perforated by the fused mixture after a few minutes' heating, but a satisfactory crucible will stand prolonged heating.

Silica is more readily corroded than clay or grog, but graphite is not affected at all. Hence, for highly corrosive contents, grog or graphite crucibles and not siliceous ones should be used.

Resistance to sudden changes in temperature is an essential property of a good crucible. How necessary is this resistance may be realised from the fact that a crucible may be withdrawn from a furnace at 1800°C., with its contents of 80 lbs. of steel at 1500°C. The steel is at once poured out and replaced by air at a temperature of only 20°C. Yet, notwithstanding the severity of such conditions, crucibles are regularly used for this purpose. On the other hand, many clay crucibles which have been used once and allowed to become cold cannot be used again, as they crack when reheated.

Further information will be found in *Refractory Materials*, by A. B. Searle (Griffin & Co. Ltd., London).

* It is necessary to observe that in the standard 16-mesh sieve the wires and spaces are of equal diameter, so that such a sieve only allows pieces less than $\frac{1}{32}$ inch linear dimension to pass through it. Sieves with spaces and wires of any other dimensions will not give results in conformity with the specification.

ABRASIVE WHEELS AND BLOCKS.

The vitrified bonds used in the manufacture of some abrasive wheels, blocks, etc., are largely composed of clay. For further details see Section XXI., Part II.

HEAT-INSULATING MATERIALS.

Attention is being increasingly paid to the saving of fuel by retaining heat in structures from which it ordinarily escapes very rapidly. Thus the loss of steam and of heat in hot gases passing through pipes, cylinders, etc., may be greatly reduced by coating the pipes or cylinders with a highly porous material, such as Kieselguhr, light magnesia, felt, cork, or various fibrous materials. The choice of a material must depend partly on the temperatures to which it will be raised when in use; for instance, felt and fibrous vegetable materials should not be raised to more than 220° F., but Kieselguhr can be used at a bright red heat.

A considerable saving in fuel may be effected in kilns, furnaces, and the like by inserting a wall' of insulating bricks between the firebrick lining and the exterior. Such bricks should not be placed where their temperature will exceed 2000° F., or they will not long remain effective. They are most efficient at temperatures below 1800° F. They must be protected from damp, which would fill the pores, and so are not suitable for exterior work which is exposed to the weather.

These porous materials depend for their efficacy on air being a valuable thermal insulator, especially if it is quite stationary.

The difference between the thermal conductivity of diatomaceous earth, cork, and charcoal is small, but the earth can be used at much higher temperatures.

Heat-insulating bricks for kilns, furnaces, etc., are supplied by Newell's Ltd., Newcastle-upon-Tyne, and by J. H. Sankey & Son, 7 & 8 Norfolk Street, Strand, London, W.C. 2; in addition to bricks, the latter supply the loose material and also slabs of all sizes.

'FOSALSIL.'

(Moler.)

(*J. H. Sankey & Son, Ltd., 7 & 8, Norfolk Street, Strand, London, W.C.* 2.)

For the conservation of heat, still air—after a vacuum—is the best heat insulator, and there occurs in nature a material composed of minute cells, each separately sealed, that makes the theory of 'still air' practical. This material is known as 'Moler,' 'Fossil Meal,' 'Kieselguhr,' and 'Diatomaceous Earth,' and is utilised in the material (of English manufacture) known as 'Fosalsil' (Moler).

The difference between the thermal conductivity of diatomaceous earth and cork or charcoal is very small, but owing to the fact that diatomaceous earth has very great mechanical strength and a high fire resistance, it can be used where cork would be useless.

'Fosalsil' is supplied by Messrs. Sankey as clay—both raw and calcined—and in bricks and slabs of all sizes.

CEMENTS.

Many cements are clay products of a more or less definite character. Thus, *Portland cement* is made by heating a carefully proportioned mixture of clay and limestone or chalk until they combine and the mass sinters. *Roman cement* and hydraulic lime are crude materials of the same character, in which a natural material is used containing the clay and lime compounds in suitable proportions.

FIRE-RESISTING OR REFRACTORY CEMENTS.

These cements—usually sold under a fancy name—are used for patching furnaces, and other appliances subjected to heat. The precise nature of most of these cements is regarded as a trade secret, but many of them are composed of fireclay, ground firebricks, and Portland cement or water-glass. These materials, when properly selected and mixed in the proper proportions, form a paste which adheres readily to cold brickwork, and when the latter is heated the nature of the cement is changed and a strong heat-resisting material is produced.

The commonest cements for use with various bricks consist of a slip made from the same material as that of the bricks. Thus, a mixture of fireclay and brick-dust (grog) is used with fireclay bricks, whilst a mixture of sand and sodium silicate is often used for bonding silica bricks.

Ground ganister or a mixture of silica rock and fireclay is largely used for lining furnaces.

Special cements are used in certain cases; fused alumina and carborundum cements are sometimes used in retorts and muffles, a small proportion of clay being used as a bonding agent. Powdered zirconia, ground so as to pass through a 200-mesh sieve, is very effective at exceptionally high temperatures, whilst other special mixtures may also be employed where a mixture of unusual composition is needed.

SECTION XI

REINFORCED CONCRETE CONSTRUCTION

(Contributed by Alexander Drew, M.I.Mech.E.)

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SECTION XI

REINFORCED CONCRETE CONSTRUCTION.

(Contributed by Alexander Drew, M.I.Mech.E.)

REPORT OF JOINT COMMITTEE OF ROYAL INSTITUTE OF BRITISH ARCHITECTS.*

(*Abstract.*)

Good workmanship and materials are essential in reinforced concrete.

It is essential that the workmen employed should be skilled in this class of construction.

Very careful superintendence is required during the execution of the work in regard to—

(*a*) The quality, testing, and mixing of the materials.

(*b*) The sizes and positions of the reinforcements.

(*c*) The construction and removal of centering.

(*d*) The laying of the material in place, and the thorough punning of the concrete to ensure solidity and freedom from voids.

If the metal skeleton is properly coated with cement, and the concrete is solid and free from voids, there is no reason to fear decay of the reinforcement in concrete of stone, gravel, cinder, coke-breeze, etc., made with clean, fresh water.

Fire Resistance.

Experiment and actual experience of fires show that concrete in which limestone is used for the aggregate is disintegrated, crumbles and loses coherence when subjected to very fierce fires, and that concretes of gravel or sandstones also suffer, but in a rather less degree. The metal reinforcement in such cases generally retains the mass in position, but the strength of the part is so much diminished that it must be renewed. Concrete in which coke-breeze, cinders, or slag forms the aggregate is only superficially injured, does not lose its strength, and in general may be repaired. Concrete of broken brick suffers more than cinder concrete and less than gravel or stone concrete.

Rigidly attached web members, loose stirrups, bent-up rods, or similar means of connecting the metal in the lower or tension sides of beams or floor slabs (which sides suffer most injury in case of fire) with the upper or compression sides of beams or slabs not usually injured are very desirable.

In all ordinary cases a cover of $\frac{1}{2}$ inch on slabs and 1 inch on beams is sufficient. It is undesirable to make the covering thicker. All angles should be rounded or splayed to prevent spalling off under heat.

More perfect protection to the structure is required under very high temperature, and in the most severe conditions it is desirable to cover the concrete structure with fire-resisting plastering which may be easily renewed. Columns may be covered with coke-breeze concrete, terra-cotta, or other fire-resisting facing.

Materials.

Cement.—Only Portland cement complying with the requirements of the specification adopted by the British Engineering Standards Committee should be employed; in general the slow-setting quality should be used.

Sand.—The sand should be composed of hard grains of various sizes up to particles which will pass a $\frac{1}{4}$-inch square mesh, but of which at least 75 per cent. should pass $\frac{1}{8}$-inch square mesh.

* By permission.

R.I.B.A. JOINT COMMITTEE'S REPORT—*continued.*

Fine sand alone is not so suitable, but the finer the sand the greater is the quantity of cement required for equal strength of mortar. It should be clean and free from ligneous, organic, or earthy matter.

Aggregate.—The aggregate, consisting of gravel, hard stone, or other suitable material,* should be clean and angular, varied in size as much as possible between the limits of size allowed for the work. In all cases material which passes a sieve of ¼-inch square mesh should be reckoned as sand. The maximum allowable size is usually ¾ inch. The maximum limit must always be such that the aggregate can pass between the reinforcing bars and between these and the centering. The sand should be separated from the gravel or broken stone by screening before the materials are measured.

Proportions of the Concrete.—For ordinary work a proportion of 1 part cement to 2 parts sand will be found to give a strong, practically watertight mortar, but where special watertightness or strength is required the proportion of cement must be increased.

The weight of a cubic foot of cement for the purpose of proportioning the amount of cement to be added may be taken at 90 lbs.

Metal.—The metal used should be steel having the following qualities :—

(*a*) An ultimate strength of not less than 60,000 lbs. per square inch.

(*b*) A yield point of not less than 32,000 lbs. per square inch.

(*c*) It must stand bending cold 180° to a diameter of the thickness of pieces tested without fracture on outside of bent portion.

(*d*) In the case of round bars the elongation should not be less than 22 per cent., measured on a gauge-length of eight diameters. In the case of bars over one inch in diameter the elongation may be measured on a gauge-length of four diameters, and should then be not less than 27 per cent.

For other sectional material the tensile and elongation tests should be those prescribed in the British Standard Specification for Structural Steel. If hard or special steel is used, it must be on the architect's or engineer's responsibility and to his specification.

Before use in the work the metal must be clean and free from scale or loose rust. It should not be oiled or painted.

Welding should in general be forbidden ; if it is found necessary, it should be at points where the metal is least stressed, and it should never be allowed without the special sanction of the architect or engineer responsible for the design.

The reinforcement ought to be placed and kept exactly in the positions marked on the drawings, and, apart from any consideration of fire resistance, ought not to be nearer the surface of the concrete at any point than 1 in. in beams and pillars, and ½ in. in floor slabs or other thin structures.

Mixing.—When the materials are mixed by hand they are to be turned over and thoroughly mixed on a clean platform until the colour of the cement is uniformly distributed over the aggregate. Whenever practicable the concrete should be mixed by machinery.

Laying.—The thickness of loose concrete that is to be punned should not exceed 3 ins. before punning, especially in the vicinity of the reinforcing metal. Special care is to be taken to ensure perfect contact between the concrete and the reinforcement, and the punning is to be continued till the concrete is thoroughly consolidated. Each section of concreting should be as far as possible completed in one operation† ; when this is impracticable, and work has to be recommenced on a recently laid surface, it is necessary to wet the surface ; and where it has hardened it must be hacked off, swept clean, and covered with a layer of cement mortar ½ in. thick, composed of equal parts of cement and sand. Work should not be carried on when the temperature is below 34° Fahr. The concrete when laid should be protected from the action of frost, and shielded against too rapid drying from exposure to the sun's rays or winds, and kept well wetted. All shaking and jarring must be avoided after setting has begun. The efficiency of the structure depends chiefly on the care with which the laying is done.

Centering or Casing.—The centering must be of such dimensions, and so constructed, as to remain rigid and unyielding during the laying and punning of the concrete. It must be so arranged as to permit of easing and removal without jarring the concrete. Provision should be made wherever practicable for splaying or rounding the angles of the concrete. Timber when used for centering may be advantageously limewashed before the concrete is deposited.

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* Coke-breeze, pan-breeze or boiler-ashes ought not to be used for reinforced concrete. It is advisable not to use clinker or slag, unless the material is selected with great care.

† In particular the full thickness of floor slab should be laid in one operation.

R.I.B.A. JOINT COMMITTEE'S REPORT—*continued.*

Striking of Centres.—The casing for columns, for the sides of beams, and for the soffits of floor slabs not more than 4 ft. span must not be removed under eight days; soffits of beams and of floors of greater span should remain up for at least fourteen days, and for large span arches for at least twenty-eight days.

Testing.—In the case of concrete made in proportions of 1 cement, 2 sand, 4 hard stone, the strength should not be less than 1,800 lbs. per square inch in compression after 28 days.

Loading tests on the structure itself should not be made until at least two months have elapsed since the laying of the concrete. The test load should not exceed one and a half times the accidental load. Consideration must also be given to the action of the adjoining parts of the structure in cases of partial loading. In no case should any test load be allowed which would cause the stress in any part of the reinforcement to exceed two-thirds of that at which the steel reaches its elastic limit.

Methods of Calculation.

DATA.

Loads.—The weight of the concrete and steel structure may be taken at 150 lbs. per cubic foot.

In structures subjected to very varying loads and more or less vibration and shock, as, for instance, the floors of public halls, factories, or workshops, the allowance for shock may be taken equal to half the accidental load. In structures subjected to considerable vibration and shock, such as floors carrying machinery, the roofs of vaults under passage ways and courtyards, the allowance for shock may be taken equal to the accidental load.

In the case of columns or piers in buildings, which support three or more floors, the load at different levels may be estimated in this way:—For the part of the roof or top floor supported, the full accidental load assumed for the floor and roof is to be taken. For the next floor below the top floor 10 per cent. less than the accidental load assumed for that floor. For the next floor 20 per cent. less, and so on to the floor at which the reduction amounts to 50 per cent. of the assumed load on the floor. For all lower floors the accidental load on the columns may be taken at 50 per cent. of the loads assumed in calculating those floors.

In the case of many warehouses and buildings containing heavy machinery it is desirable not to make any reduction of the actual loads.

Stresses in Beams.

(*a*) The coefficient of elasticity in compression of stone or gravel concrete, not weaker than 1 : 2 : 4, is treated as constant and taken at one-fifteenth of the coefficient of elasticity of steel.

	Lbs. per Sq. In.
Coefficient for concrete	$E_c = 2{,}000{,}000$
„ „ steel	$E_s = 30{,}000{,}000$
$\frac{E_s}{E_c}$	$= 15.$

It follows that at any given distance from the neutral axis, the stress per square inch on steel will be fifteen times as great as on concrete.

(*b*) The resistance of concrete to tension is neglected, and the steel reinforcement is assumed to carry all the tension.

(*c*) The stress on the steel reinforcement is taken as uniform on a cross-section, and that on the concrete as uniformly varying.

Working Stresses.

If the concrete is of such a quality that its crushing strength is 1,800 lbs. per square inch after twenty-eight days, and the steel has a tenacity of not less than 60,000 lbs. per square inch, the following stresses may be allowed:—

	Lbs. per Sq. In.
Concrete in compression in beams subjected to bending	600
Concrete in columns under simple compression	600
Concrete in shear in beams	60
Adhesion * of concrete to metal	100
Steel in tension	16,000
Steel in shear	12,000
Steel in compression	15 times the stress in the surrounding concrete.

* It is desirable that the reinforcing rods should be so designed that the adhesion is sufficient to resist the shear between the metal and concrete. Precautions should in every case be taken by splitting or bending the rod ends, or otherwise to provide additional security against the sliding of the rods in the concrete.

R.I.B.A. JOINT COMMITTEE'S REPORT—*continued.*

When the proportions of the concrete differ from those stated above, the stress allowed in compression on the concrete may be taken at one-third the crushing stress of the cubes at twenty-eight days as determined above.

If stronger steel is used, the allowable tensile stress may be taken at one-half the stress at the yield point of the steel, but in no case should it exceed 20,000 lbs. per square inch.

Beams of Rectangular and T Section.

In the calculation of all beams the area upon which the ratio of tensile reinforcement is taken is considered as a rectangle of breadth equal to the greatest breadth of the beam and of depth equal to the greatest effective depth of the beam.

In designing beams where the rib is monolithic with a slab, the beam may be considered to be of T form. The slab must first be calculated and designed, having its own reinforcing bars transverse to the rib. The whole of the slab cannot in general be considered to form part of the upper flange of the T beams. The width b_s of the upper flange may be assumed to be not greater than one-third the span of the beams, or more than three-fourths of the distance from centre to centre of the reinforcing ribs or more than fifteen times the thickness of slab. The width b_r of the rib should not be less than one-sixth of the width b_s of the flange.

Shear Reinforcement.

It is always desirable to provide reinforcement to resist the shearing and diagonal tension stresses in reinforced concrete beams. The diagonal tension stresses depend on the vertical and horizontal shear and also on the longitudinal tension at the point considered. As the longitudinal tension in the concrete at any given point is very uncertain, the amount and direction of the diagonal tension cannot be exactly determined.

It is the general practice to determine the necessary reinforcement by taking the vertical and horizontal shearing only into consideration.

Experience shows that:

(*a*) In general, floor slabs require no special reinforcement against shearing and that the bending up of alternate bars near the end is sufficient.

(*b*) In beams, especially in T beams, shearing reinforcement should be provided at distances apart not exceeding the depth of the beam.

(*c*) It is desirable to bend up one or more of the bars of the tension reinforcement near the supports. When bent at an angle of about 45° the effect of this may be taken into account in the manner set out above; when bent at a small angle to the horizontal the effect is very indeterminate.

(*d*) As the resistance of the shear members to the pull depends on the adhesion, and the anchorage at the ends, it is desirable to use bars of small diameter, and to anchor the stirrups at both their ends. In all cases the stirrups must be taken well beyond the centre of compression.

Slabs Supported or Fixed on more than Two Sides.

It does not appear that there is either a satisfactory theory or trustworthy experiment from which the strength of rectangular slabs supported or fixed on all four edges can be determined.

Pillars and Pieces under Direct Thrust.

DEFINITIONS.

The length is to be measured between lateral supports (neglecting ordinary bracketing).

The effective diameter of a pillar means the least width and should be measured to the outside of the outermost vertical reinforcement.

The effective area of a pillar means the area contained by the outermost lateral reinforcement, and should be measured to the outside of the outermost vertical reinforcement.

Loading and Length of Pillars.

If the load is strictly axial the stress is uniform on all cross-sections.

Lateral bending of the pillar as a whole is not to be feared, provided—

(*a*) That the ratio of length to least outside diameter does not exceed 18.

(*b*) That the stress on the concrete does not exceed the permissible working stress for the given pillar.

(*c*) That the load be central.

(*d*) That the pillar be laterally supported at the top and base.

Construction.

Lateral reinforcement properly disposed raises the ultimate strength and increases the security against sudden failure, by preventing the lateral expansion of the concrete and the sudden disruption of the pillar.

R.I.B.A. JOINT COMMITTEE'S REPORT—*continued.*

Practical considerations lead to the addition of longitudinal bars, and the formation of an enveloping network of steel.

The total cross-sectional area of the vertical reinforcement should never be less than 0·8 per cent. of the area of the hooped core.

There should be at least six vertical bars when curvilinear laterals are used, and four for square pillars having rectilinear laterals.

In the case of rectangular pillars in which the ratio between the greater and the lesser width measured to the outside of the vertical bars) exceeds one and a half, the cross-section of the pillars should be subdivided by cross ties; and the number of vertical bars should be such that the distance between the vertical bars along the longer side of the rectangle should not exceed the distance between the bars along the shorter side of the rectangle.

The most efficient disposition of the lateral reinforcement would appear to be in the form of a cylindrical helix, the pitch or distance between the coils being small enough to resist the lateral expansion of the concrete.

Jointed circular hoops as ordinarily made are apparently not quite so efficient.

Rectilinear ties are still less adapted to resist the lateral or radial expansion of a highly stressed core.

The volume of curvilinear laterals should never be less than 0·5 per cent. of the volume of hooped core.

The diameter of rectilinear laterals should not be less than $\frac{3}{16}$ inch.

Pillars Eccentrically Loaded.

If a pillar, initially straight, is loaded eccentrically, as when a beam rests on a bracket attached to the pillar, it may be regarded as fixed at the base and free at the loaded end.

It is desirable in pillars that there should be no tension, and generally when the vertical load is considerable there is none. Cases in which the eccentricity is so great that there is tension must be treated by the methods applicable to beams if it is made a condition that the steel carries all the tension.

Long Pillars Axially Loaded.

For columns more than 18 diameters in length there is risk of lateral buckling of the column as a whole. The strength of such pillars would be best calculated by the Gordon-Rankine formulæ.

LONDON COUNTY COUNCIL (GENERAL POWERS) ACT, 1909.

REINFORCED CONCRETE REGULATIONS—(MADE JULY 1915).*

The following brief summary is intended merely to indicate the scope, and give the principal approved data.

Nothing in these Regulations interferes with the application of the formulæ, etc., for the designing of reinforced concrete structures given in the following pages.

Part I. defines reinforced concrete and indicates the application of the same to buildings whose skeleton framework, together with any party walls, is capable of safely and independently sustaining the whole of the dead and superimposed loads.

Floors, main stairs, and landings must be of incombustible material; internal stairs and landings may be of fire-resisting materials; and roofs may be of wood framing, boards, and battens.

No part of the reinforcing metal is to be used for conducting electrical currents.

Notices to be served on, and plans and calculations to be provided to, the District Surveyor are detailed.

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* Where fuller information is desired, the complete Regulations should be referred to. A reprint of the Regulations, with useful notes, illustrations, and worked examples, has been published by B. T. Batsford, Ltd., 94 High Holborn, London.

Part II.—Superimposed Loads.

On Floors: Equivalent dead loads.

For a floor intended to be used for the purpose of	Equiv. dead load in lbs. per sq. ft.	For a floor intended to be used for the purpose of	Equiv. dead load in lbs. per sq. ft.
Domestic buildings not hereinafter specified Other similar purposes	70	Music halls Public assembly Public concert rooms Public library reading rooms Retail shops	112
Asylum wards Common lodging-house bedrooms Hospital wards Hotel bedrooms Workhouse wards Other similar purposes	84	Theatres Workshops Other similar purposes	
Counting houses Offices Other similar purposes	100	Ball rooms Drill rooms Other similar purposes Similar floors subject to vibration	150
Art galleries Chapels Churches Classrooms in school buildings, not being dwelling houses so used Lecture rooms Meeting rooms	112	Book stores at libraries Museums For every floor in a building of the warehouse class, except such floors as are intended to be used for any of the purposes aforesaid—not less than	224

On Stairs and Landings: Minimum to be equal to a distributed dead load of 120 lbs. per square foot, but each step must be capable of safely supporting a concentrated load of 300 lbs. at any point.

On Roofs of greater upward inclination than 20° with the horizontal, a superimposed load (including wind pressure and weight of ice) of '28 lbs. per square foot of sloping surface, normal to such sloping surface, on either side of such roof.' On all other roofs, '56 lbs. per square foot measured on a horizontal plane.'

On floors, stairs, landings, or roofs, other than those indicated, the actual superimposed load must be provided for, 'with an equivalent margin of safety.'

For Rolling Loads actuated by mechanical power, take an equivalent static load equal to 1½ times the actual rolling load and provide for the stresses due to every position of such load.

Partitions and other Structures on floors or roofs whose weight exceeds the superimposed load must be specially provided for.

For calculating the **Resistance Moment**, the angle of dispersion of a point load through hard filling and concrete may be taken at not more than 45° from the vertical.

For Buildings of more than two storeys in height the loads on foundations, pillars, and walls may be reduced, as in Steel Regulations (para. 19, page 476).

Wind Pressure to be equal to a static horizontal pressure of not less than 20 lbs. per square foot of the whole projected surface normal to the wind direction. On **panels of external walls** allow for not less than 30 lbs. per square foot 'assumed as acting uniformly over the area of one panel from either side.'

For all structures or attachments to buildings (including towers or other parts extending above the roof, etc.), allow for not less than 40 lbs. per square foot of whole projected surface normal to direction of every wind.

Weight of Reinforced Concrete to be taken at not less than 144 lbs. per cubic foot measured over finished surfaces.

The span of a beam shall not be greater than twenty times its effective depth, unless the maximum tensile or compression stresses are correspondingly reduced below the maximum stresses recognised in these regulations.

The length of a Cantilever shall not exceed five times its effective depth at the bearing.

Bending Moments.—For the purpose of calculation the effective span of a beam or slab shall be taken as the clear span plus the effective depth, or the span to centres of bearings, whichever is the lesser.

[The values for the **bending moments due to various loadings** may be obtained graphically by means of the diagrams on pp. 318, 319, except for type loading (*h*), where these

regulations call for equal maximum moments at centre and at ends (to obtain the former by diagram, make value of $A=\frac{1}{8}$ Wl).]

For Continuous Beams or Slabs the maximum positive and negative bending moments in each span may be calculated for all necessary arrangements of loading to same and to adjoining spans. Or the approximate maximum bending moments may be taken as follows :— Near middle of end span, at support next to end support, and at other interior supports, $=\frac{1}{10}$ total load × effective span ; at middle of interior spans, $=\frac{1}{12}$ total load × effective span.

For Slabs reinforced with mesh reinforcement, or reinforced in two directions at right angles to each other, the bending moments in each direction may be obtained from the table on page 561 (Reinforced Concrete Construction Section), the accepted values being those marked ' Grashof and Rankine.'

For all loadings other than those indicated, the actual bending moments shall be calculated ' so as to give an equivalent margin of safety.'

The permissible working stresses in concrete, except as further provided for in pillars, shall not exceed the following :—

Stresses in Concrete.	Proportion by Volume.											
	Cement.	Sand.	Coarse Material.	Cement.	Sand.	Coarse Material.	Cement.	Sand.	Coarse Material.	Cement.	Sand.	Coarse Material.
	1	2	4	1·2	2	4	1·5	2	4	2	2	4
	V=6			V=5			V=4			V=3		
	Lbs. per Sq. In.			Lbs. per Sq. In.			Lbs. per Sq. In.			Lbs. per Sq. In.		
Direct compressive stress.	600			650			700			750		
Extreme flexural compressive stress in beams .	600			650			700			750		
Shearing stress . . .	60			65			70			75		
Grip or adhesion between concrete and steel bars hooked at both ends .	100			100			100			100		
Grip or adhesion between concrete and steel bars otherwise effectively anchored at the ends .	60			60			60			60		
Tensile stress . . .	Nil			Nil			Nil			Nil		

If V is less than 3 the stresses in the last column shall not be exceeded.

The permissible working stress in steel shall not exceed the following :—

Stress in mild steel complying with the British Standards Specification . . .	Pounds per square inch.
Compressive stress	m times the stress in the concrete immediately surrounding the steel.
Tensile stress	16,000.

Eccentric loading stresses must be provided for.

For Hooks or Anchors to ends of tensile and shear reinforcement, and for Grip Lengths, refer to Regulations.

The elastic modulus of steel in tension or compression shall be taken at 30,000,000 lbs. per square inch.

The modular ratio for steel and concrete shall be taken as follows :—

For beams . . . . . $mc=9{,}000$ or $m=\frac{9{,}000}{c}$

For pillars with the minimum of hooping or binding . $mc=9{,}000$ or $m=\frac{9{,}000}{c}$

For pillars with more than the minimum of hooping or binding . . . . . $mi = 9{,}000$ or $m = \frac{9{,}000}{i}$,

where

c = permissible *compressive* working stress given in preceding table;

i = *increased* stress allowed in pillars with more than the minimum of hooping or binding (see PART IV.).

Part III.

The term 'beam' shall include any beam, girder, lintel, bressummer, or cantilever, or any other similar member carrying transverse loads.

Longitudinal bars must be at least ¼ inch in diameter, all other reinforcing bars being not less than ¼ inch in diameter.

Distance apart of bars at least 1 inch horizontally and ½ inch vertically, except at joints or crossings of bars.

Tensile reinforcement to be not more than 6 inches apart.

Compression reinforcement must not be stressed to more than m times the stress in the immediately surrounding concrete, and be anchored by bars extending through a depth at least equal to the resistance moment arm, and spaced not further apart than this resistance moment arm or than sixteen times the least diameter of the anchored bar.

Where all compression stress is taken by steel rods, these may be stressed to 16,000 lbs. per square inch, and be anchored laterally and vertically not further apart than 6 inches or than eight times the diameter of the anchored bars; the anchors to be passed round or hooked over both the compressive and the tensile reinforcement.

If hooping is adopted, the compression stress for ¼ span from each end may be taken as that for the core of a similarly hooped pillar; the concrete outside the hooping must not be taken into account.

Shear and Web Reinforcement.—Regulations are provided as to the value of concrete alone, and with the addition of rods; and as to spacing, and anchoring of shear rods to the main reinforcing bars, etc.

Splays at ends of beams intended to increase the resistance moment must not be calculated at a greater angle than 30° from the horizontal.

Brackets acting as cantilevers must be suitably reinforced.

Slabs.—The effective depth must not be less than 3 inches, and ¼ inch to be the least diameter or thickness of reinforcing bars. Any tension cross wires, in mesh or similar reinforcement, to be at least $\frac{1}{10}$ inch in diameter or thickness. Tension bars to be at least 1 inch apart, except at joints or crossings. Mesh reinforcement to be of such dimensions as to allow the concrete to freely pass through the same.

Tension bars or strands to be not further apart than 12 inches, or more than twice the effective depth. When reinforced in one direction only, distributing bars must be provided on top and at right angles to the main bars; these distributing bars to be not more than 18 inches apart, and have an aggregate cross-section of at least 0·08 per cent. of effective cross-section of the slab; or the diameter of each distributing bar must be at least $\frac{1}{5}$th of the effective depth of the slab, and spaced not more than four times the effective depth apart. Wiring or binding shall not be regarded as reinforcement.

Resistance Moments.—Tee beams.—The breadth of the flange shall not be more than ¼ of the effective span, or the distance between the centres of the ribs of the tee beams, or twelve times the thickness of the slab, whichever is the least.

Ell beams.—The breadth of flange shall not be more than four times the thickness of the slab, except where the moments due to the eccentricity of the compression are provided for, when six times the slab thickness is permitted.

The breadth of the rib of a tee or ell beam shall be not less than ⅓ depth of rib below the slab.

Buckling in rectangular beams to be provided for when length exceeds twenty times the least width, or thirty times the least width over the outermost longitudinal reinforcement.

A beam supported at its end by a transverse beam must have special provision made as to connecting together, and resisting shear and torsion.

Notes must be added to drawings or diagrams of beams or pillars showing the loads which have been provided for.

Complete formulæ are given for rectangular and tee beams, but these are similar to the data given on pp. 557, 558, 559 (Reinforced Concrete Construction), to which reference may be made.

Part IV.

Pillars shall include piers, posts, columns, detached supports, or any other vertical compression member; struts any compression member at any angle.

In calculations for strength, the maximum ratio of length to gyration radius, or of length to effective diameter, shall be taken, the length being measured between the lateral supports irrespective of any splays other than allowed for beams, and the effective diameter to be that over the outermost vertical rods.

Vertical and lateral reinforcement must be provided to all pillars, four full length verticals for rectangular laterals (binding) not less than $\frac{3}{16}$ inch in diameter, and six verticals to curvilinear laterals not less than $\frac{1}{8}$ inch diameter.

Pitch of laterals (binding) shall not exceed $\frac{6}{10}$ effective diameter at any part in length, or sixteen times the diameter of the least vertical. For a length of one and a half times effective diameter at each end, laterals to be spaced not more than $\frac{3}{10}$ effective diameter. All laterals to be firmly secured at each end. The volume of laterals to be not less than 0·5 per cent. of the volume of the hooped core.

Verticals to be not less than $\frac{1}{2}$ inch or more than 2 inches in diameter, and have a minimum total cross-section of 1·0 per cent. of the volume of the hooped core. Joints in verticals to be made at or adjacent to points of lateral support, and lapped at least twenty-four times the diameter of the upper rod.

In Rectangular Pillars, where the ratio between the greater and the lesser diameter exceeds $1\frac{1}{2}$, the cross-section shall be subdivided by cross ties, and the distance apart of verticals in the longer side be not greater than that in the shorter side.

(*As the rules and tables given for calculating the strength of pillars are largely empirical, they are included here in full.*)

Notation for pillars, struts and other compression members.

113.—

A=effective *area* of the pillar, *i.e.* the *area* bounded by the lateral reinforcement (binding) measured to the inside of the hooping.

A_b=cross-sectional *area* of one bar of the *binding* or lateral reinforcement.

A_v=*area* of the *vertical* reinforcement.

c=permissible direct *compressive* stress.

d=effective *diameter*.

f=*form* factor, depending upon form or type of binding or laterals (para. 118).

g=*gyration* radius of the area $[A + (m-1)\ A_v]$ about an axis passing through the centroid of the area.

i=*increased* stress permissible in the core of a pillar suitably hooped.

l=actual *length* of the pillar.

m=*modular* ratio $= \frac{E_s}{E_c}$.

P=*permissible* load or *pressure* on pillars with both ends fixed and with a ratio of virtual length to gyration radius not exceeding 45 (para. 122).

p=*percentage* of volume of binding or lateral reinforcement with respect to the volume of hooped core in any given length of pillar $= 100\ V_v$.

p_b=*pitch* of the *binding* or lateral reinforcement.

s=*spacing* factor depending upon the spacing or pitch of the binding or laterals (para. 118).

V_v=*volume* ratio or *ratio* of the *volume* of binding or lateral reinforcement to the volume of the hooped core in any given length of pillar (paras. 116, 117).

v=*virtual* length of the pillar, strut or other compression member for different conditions of the ends (paras. 122, 124).

114.—A pillar, or other strut, shall be deemed to have fixed ends when the ends are sufficiently secured to other parts of the construction having such rigidity as will maintain the axis at the ends in its original position and direction under all loads less than the crippling load.

115.—In a pillar with fixed ends the stress in the concrete in the area bounded by the lateral reinforcement shall not exceed

c, in a pillar with the minimum of hooping or binding,

i, in a pillar with more than the minimum of hooping or binding, where

$$i = c\,[1 + f\,s\,V_v]$$

116.—The required ratio of the volume of binding or lateral reinforcement to the volume of the hooped core may be obtained from the equation—

$$V_v = \frac{i-c}{c\,f\,s}.$$

117.—The value of V_v actually provided, in either round or square pillars, may be ascertained by direct measurement or from the equation—

$$V_v = \frac{4\,A}{d\,p_b}.$$

118.—

Table showing the value of fs.

Form of Lateral Reinforcement or Binding.	Form Factor *f*.	Spacing of Laterals throughout the length of the Pillar (in terms of diam. of hooped core).	Spacing Factor *s*.	Value of *fs*.
Helical (curvilinear on plan)	1·0	0·2*d*. or less	32	32
Ditto ditto	1·0	0·3*d*.	24	24
Ditto ditto	1·0	0·4*d*.	16	16
Circular hoops	0·75	0·2*d*. or less	32	24
Ditto	0·75	0·3*d*.	24	18
Ditto	0·75	0·4*d*.	16	12
Rectilinear	0·5	0·2*d*. or less	32	16
Ditto	0·5	0·3*d*.	24	12
Ditto	0·5	0·4*d*.	16	8
Ditto	0·5	0·5*d*.	8	4
Ditto	0·5	0·6*d*.	0	0

119.—Notwithstanding any other provision in these regulations the increased stress in the concrete of pillars shall not exceed one-third of the ultimate compressive resistance at four months as given in subsequent table.

120.—The working stress in the vertical reinforcement shall not exceed m times the stress in the concrete.

121.—The permissible load or pressure on pillars with both ends fixed and with ratios not exceeding those in the first column of figures in table below shall be obtained from either of the equations—

For pillars with the minimum of hooping or binding

$$P = c\,[A + (m-1)\,A_v]$$

For pillars with more than the minimum of hooping or binding—

$$P = i\,[A + (m-1)\,A_v]$$

122.—For pillars the permissible load or pressure shall be obtained from the following table :

For the maximum ratio of *virtual* length to *gyration* radius	$\frac{v}{g}$ =	45	54	63	72	81	90
For the maximum ratio of *virtual* length to effective *diameter* for square pillars	$\frac{v}{d}$ =	15	18	21	24	27	30
For the maximum ratio of *virtual* length to effective *diameter* for round pillars	$\frac{v}{d}$ =	12	15	18	21	24	27
Permissible load		P	0·8 P	0·6 P	0·4 P	0·2 P	Nil

For other ratios higher than those in the first column of figures the stress shall be proportional to the above.

123.—Struts shall be subject to all the rules applying to pillars, and the combined stresses at any part shall not exceed the permissible stresses for pillars of like ratios.

124.—For the different conditions of the ends of pillars and other struts mentioned in th

llowing table, the permissible load shall be ascertained by using the corresponding value of ıe virtual length in such table in conjunction with paras. 121 and 122:

Condition of Axis at Ends.	Virtual Length, v.
Both ends fixed in position and direction	$v=l$
One end fixed in position and direction and One end fixed in position but not in direction	$v=1{\cdot}4l$
Both ends fixed in position but not in direction	$v=2l$
One end fixed in position and direction and One end not fixed in position and direction	$v=4l$

125.—In the case of arches or other similar constructions the combined stresses at any part ıall not exceed the permissible stresses set out in Table of Working Stresses for Beams.

Part V.

External enclosure walls of reinforced concrete formed between reinforced oncrete framework must be designed for any loads they may have to carry, but must not e less than 4 inches thick. Where they support vertical loads or resist lateral pressures hey must be of the necessary thickness to keep the stresses within the prescribed limits. For nclosure walls of brickwork, stonework, or plain concrete, the topmost 0 feet of their height must be not less than 8½ inches thick, and 13 inches thick for all lower ortions. If the walls are formed of hollow blocks, the following minimum imensions are required. Aggregate thickness, including any cavity, 8½ inches; sides, 2 inches; nds and any interior partitions, 1 inch; clear unsupported span of any part of side, end, r interior partition, four times the least thickness of such part; and aggregate thickness of ıaterial, measured at right angles to face of wall, 6 inches.

Any less thickness of walls prescribed under the London Building Act, 1894, may be adopted; ut any external wall or portion of same, not supported or secured by the reinforced concrete ramework, must comply with the requirements of the above Act.

All walls and facing materials shall be incombustible, and securely connected o the reinforced concrete framework.

Each panel in any external wall must be designed to safely resist a horizontal ressure equal to a static pressure of at least 30 lbs. per square foot, assumed to act uniformly ver the area of one panel from either side.

The aggregate area of openings in external walls shall not exceed in a wall f any storey above the ground storey two-thirds of the whole area of such wall, nor the aggregate ridth three-fourths of the whole length of such wall.

Party and division walls in reinforced concrete shall be not less than 8 inches hick, but party walls between a reinforced concrete building and a steel framed building, or a uilding constructed in accordance with rules of the London Building Act, 1894, shall in no part ıe less than 13 inches thick.

All brickwork, stonework, and plain concrete shall be executed in Portland cement mortar.

The pressure on any brickwork supporting reinforced concrete work shall not xceed the values given under Steel Regulations, page 478.

The height of such brickwork with proper lateral supports must not exceed welve times its least thickness; if without proper lateral supports, six times its least thickness. This thickness must in no case be less than 13½ inches.

Part VI.

The pressure of foundations on the natural soil, or on plain concrete, hall not exceed the values given under Steel Regulations, page 477.

Part VII.

Protection (measured from outer surface of concrete to outer surface of reinforcement) hall not be less than the following values:—Beyond the anchored ends of hooked or upward ient bars, 2 inches, or twice the normal diameter of the bar; vertical bars in pillars, 1½ inches, or the diameter of the vertical bar; longitudinal bars in beams, 1 inch, or the diameter of the ongitudinal bar; tensile, compressive, shear, or any other slab reinforcement, ½ inch, or the liameter of bar to be covered; and any reinforcement in any other member, 1 inch, or the liameter of the bar to be covered.

Part VIII.

Materials.—The **Cement** shall be Portland cement of slow setting quality and to British Standard Specification, and one cubic foot of same shall be assumed as weighing 90 lbs. The **Sand** shall be clean and gritty, of hard silicious grains, and free from clay, animal, vegetable, or bituminous matter. It must be capable of passing through a mesh $\frac{3}{16}$ inch square, measured in the clear, and must be separated from the coarse materials before measuring. The **coarse material** (which includes all the ingredients in the concrete except the sand, cement, and water) shall consist of clean Thames or pit ballast or gravel, hard stone, such as granite, basalt, trap rock, or other hard and equally suitable material, and free from clay or any animal, vegetable or bituminous matter. If necessary this material shall be thoroughly washed.

The following materials shall not be used with the sand or coarse material in the composition of concrete:

(*a*) Coal residues, including clinkers, cinders, ashes, coke breeze, pan breeze, slag, and other similar material.
(*b*) Blast furnace slag, copper slag, forge breeze, dross, and other similar material.
(*c*) Sulphates, including plaster of Paris, and other similar material.
(*d*) Limestones, magnesian limestones, marbles, and other calcium carbonates.

The coarse material must pass through a mesh $\frac{3}{4}$ inch square, measured in the clear, and be retained on a mesh $\frac{3}{16}$ inch square, measured in the clear; it shall be varied as much as possible between these limits. If the material is of a porous nature, it must be thoroughly wetted before mixing with the other materials.

The **volume** of mortar shall be in excess of that required to fill the voids in the coarse material. The volume of sand shall not be more than twice the volume of cement, nor the coarse material twice that of the sand.

The **concrete** shall be composed of cement, sand and coarse material in one of the following or intermediate proportions, and the ultimate compressive resistance shall not be less than that specified for the proportion adopted:

Proportion by volume.			V	*Ultimate* compressive resistance in pounds per square inch.		Value of one-fourth of u_4
Cement.	Sand.	Coarse material.		1 month after mixing, $=u_1$	or, 4 months after mixing, $=u_4$	
1	2	4	6	1,600	2,400	600
1·2	2	4	5	1,800	2,600	650
1·5	2	4	4	2,000	2,800	700
2	2	4	3	2,200	3,000	750

Test cubes shall be not less than 4 inches each way in dimensions, or **test cylinders** not less than 6 inches each way; the preparing, setting, maturing, and testing of such pieces should, as far as possible, conform to the actual conditions under which the work would be carried out.

All three materials shall be thoroughly mixed dry in batches, and again mixed after wetting. Salt water shall not be used for the concrete.

The concrete shall be placed in its final position before initial set has taken place. For beams, pillars and walls the thickness of the layers of loose concrete shall not exceed three inches before ramming.

As soon as possible after mixing, the concrete shall be properly rammed into the moulds so as to secure a compact mass, without voids and of the greatest possible density for the proportions used.

All metal reinforcement shall be of steel to the British Standard Specification for structural steel for bridges and general building construction (see page 295).

All reinforcement metal shall be cleaned of all scale, dust and loose rust, immediately before depositing the concrete.

No welding shall be employed in any tensile reinforcement.

The builder or other person directing the work shall furnish the District Surveyor with reasonable proof as to the quality of materials to be used in such construction, and shall make any tests which shall be reasonably necessary.

If testing during the construction or within two months after the completion of the reinforced concrete construction is found necessary by reason of any sign of weakness or faulty work

appearing, the builder or other person directing the work shall make such tests, and, if these show faulty work, it shall be reconstructed and reinstated in accordance with these regulations.

The total deflection of beams or slabs freely supported and carrying the uniformly distributed working load shall not exceed 1/600th of the span, when the span is twenty times the effective depth, and shall be in proportion for other ratios of span to depth, and for other conditions of ends and stress and loading.

The superimposed test load shall be one and a half times the superimposed load.

Loading tests shall not be made earlier than 90 days after laying the concrete.

Part IX.

The formwork or centering shall be of such dimensions and so constructed as to remain rigid during the laying, ramming, and setting of the concrete.

The vertical strutting shall be maintained continuous through the lower storeys to the foundations or to other floors or beams which are sufficiently set to afford the required safe support, and all formwork or centering shall be removed without shock or vibration.

Before the formwork or centering under any beam or floor slab is removed, the pillars below such beam or floor slab shall be partially stripped to allow of complete examination on all sides.

Part X.

All reinforcement shall be placed and maintained in the position shown on the drawings, and the concreting in any member shall be carried out as continuously as possible.

Where work has to be recommenced on a surface which has hardened, such surface shall be well hacked, swept clean, thoroughly wetted, and covered with mortar composed of equal volumes of cement and sand.

Concrete laid during dry weather shall be protected against too rapid drying. During the first week of hardening it shall be kept damp by wet sacking or other methods, or by watering daily (Sundays and holidays included).

Concrete shall not be laid when the temperature is below 4° C. (39° F.), and shall be protected when necessary.

Concrete or mortar which has been frozen shall not be used.

The concrete or mortar in any member which has been exposed to frost during the first week of hardening shall be removed, or such members shall be tested as previously provided.

No cutting for piping or any other purpose shall be done which would reduce the strength of any part of the structure below the standard required by these regulations.

Blocks or strips of hard wood, coke breeze, or other equally fire-resisting material may be embedded in the concrete and used solely for fixing purposes, provided that they do not reduce the strength of any part of the structure below the standard required by these regulations, and the area of such blocks or strips at any given cross-section is not included in the calculated compression area of any beam, slab, pillar, or other constructional member.

Soft wood or other equally combustible material shall not be embedded in the concrete.

Wood or other combustible material may be placed on or over the surface of the concrete, provided that any voids or hollow spaces between the combustible and incombustible materials be filled up with incombustible materials.

SYSTEMS OF REINFORCED CONCRETE CONSTRUCTION.

Although there exists a considerable number of so-called independent systems of reinforced concrete construction, the principles underlying the same are in every way similar, and it is only in the manner in which these principles are carried out that any difference arises. The several systems can be readily divided into groups, and the following notes will be sufficient here to indicate wherein one differs from another :—

Systems which make use of Plain Steel Rod Reinforcing Bars.

In the Hennebique system, the main bars are set parallel to the lower or tension face of the beam, some being, where necessary, bent or cranked upwards towards the upper face (as where the beam is continuous over a support). In addition to these bars, flat stirrups are hooked at intervals over the lower bars, and carried upwards towards the upper part of the beam ; these bind the concrete and steels securely together, and assist largely in resisting the shearing stresses. For columns or piles, the rods are grouped symmetrically about the centre of the pile, and are tied together at intervals by means of straps or wire lacing.

The Coignet system is in many respects very similar to the Hennebique, except that generally a number of smaller rods are used, these being in turn bent upwards as they approach the ends of the beam. A continuous top bar is also provided, to which the bent-up members are securely tied or laced. Any additional stirrups or binding ties which are necessary are formed of small

section round bars, varying from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. diameter; these are laced or tied between the lower or main tension bars and the upper bar.

In the Considère system, the portions of any structure under compression are provided with a close-set spiral of steel wire or small-section steel rod, which, by surrounding the concrete and preventing its displacement, enables the enclosed portion to resist safely very high compressive stresses.

A number of other systems in which plain bars are used have recently appeared, the difference between them being in the manner in which the several bars are connected together, and the method of providing for shearing stresses, and for connecting the shear bars to the main bars. Of these might be mentioned the types supplied by the British Reinforced Concrete Engineering Company, the Lewis Construction Company, etc.

Systems in which Bars of Special Sections are utilised.

The Trussed Concrete Steel Company own the 'Kahn' bar and the 'Rib' bar. The former consists of a square or other section bar provided with two projecting wings which can be sheared and bent up to form stirrups or shear members. As these members form part of the main bar there is no possibility of displacement or slipping occurring between the shear and the main bars. From this method of construction it will be obvious, however, that the length and spacing of these shear bars are limited, but in practice it is very seldom that this is in any way objectionable. The rib bar is of round section provided with four ribs or projections running the full length of the bar; cross ribs are set at frequent intervals between the longitudinal ribs, so as to form pockets or recesses into which the concrete can key.

The Indented Bar and Concrete Engineering Company, Ltd., possess a square and a round bar provided throughout their full length with a series of depressions and ridges all round; it is claimed that by arranging the depressions and ridges on opposite sides of the bar the full section of the bar is retained throughout its length. By this formation a mechanical bond or key with the concrete is provided which it is claimed greatly increases the key between the bar and the concrete.

In the Perfector System a round bar with a continuous rib or fin is used, this fin being provided with perforations through which the shear members, etc., are passed.

Other bars providing a mechanical bond are sometimes used, notably some American patents such as the 'Ransome,' which consists of a twisted square rod, etc.

Systems in which the Reinforcement consists of a Metallic Meshwork.

The Expanded Metal Company supply sheets formed from steel sheets of various thickness which, by special machinery, have been slit or slotted and expanded to form a metallic network. By embedding this network in the correct position in a concrete beam or floor slab the necessary metal to resist the tension stresses is provided in a satisfactory and simple manner. For detailed information regarding this material and system, see p. 436.

The Lock Woven Mesh System consists of a mechanically woven fabric made of steel wire crossing at right angles and secured at the intersections.

Reinforced Concrete or Fire-Resisting Floors.

Numerous systems of these are on the market, but they can be grouped together into types, to which the following may be noted:—

(1) A series of hollow or solid blocks of fireclay, concrete, or other material are laid at short distances apart, and the space between same filled up with concrete or cement grouting, with steel rods embedded in same. In this way a series of reinforced concrete beams are formed surrounding the blocks. Where the area to be covered is approximately square, or the proportion of length to breadth does not much exceed 2 to 3, these reinforced concrete beams can be formed on all four sides of the blocks; but where hollow blocks are used, the open ends must be closed up, or provision made to prevent the concrete finding access into the hollows which are intended to lighten the weight of the floor. Of this type may be mentioned the 'Kleine,' the 'Fram,' Diespeker 'Bigspan,' etc.

(2) Hollow blocks, usually of arched formation, and of a width or span of from 2 to 3 feet, over, are laid between and supported by lines of rolled steel beams, or of reinforced concrete beams, these latter being made either at works, and delivered and erected complete, or formed *situ* during the construction of the floor. A level floor surface is obtained by a light filling breeze concrete over the blocks. Where steel beams or finished reinforced concrete beams are used, the floor can be erected without the use of centering. The dispensing with large masses wet concrete minimises all trouble due to dripping from the new floor, and allows it to be used immediately after it has been erected. Floors of this nature are manufactured by Messrs. D. Somerville & Co., the Armoured Tubular Floor Company, etc.

A modification of this floor consists in the use of half-arch shaped blocks, which are set into the webs of steel beams, and brought together at the centre where they are lightly grouted at their meeting edges. A levelling-up covering of breeze concrete completes the floor. This type is represented by the 'Fram' arched floor, the 'Carlisle' tubular arch floor, etc.

(3) Concrete tubes of various sections and of considerable lengths may be formed, and reinforced where necessary with steel rods or wire. By placing these close together, it is only necessary to grout in between the joints in the several tubes to complete the floor ready for any top finish; the advantage of a dry laid floor is thus secured. The 'Siegwart,' etc., provide this type of floor.

(4) Floors may be formed of solid concrete slabbing reinforced with plain or special section bars as required, and supported by rolled-steel beams or reinforced concrete beams. Such types are supplied by any reinforced concrete contractor.

(5) Floors provided with a continuous mesh reinforcement :—The floors provided by the Expanded Metal Company and by the Lock Woven Mesh Company may be taken as examples of this class.

Other types of floors are to be met with, each possessing some particular qualification or arrangement peculiar to itself.

DESIGNING REINFORCED CONCRETE STRUCTURES.

Concrete is very strong under compression, but weak under tension. Good average concrete will safely resist a compressive stress of from 600 to 700 lbs. per square inch of section; its tensile strength does not exceed about one-tenth of this value, and may altogether disappear through the formation of minute cracks.

Concrete and steel possess practically the same coefficient of expansion, and therefore expand and contract together under changes of temperature, without developing internal stresses.

Concrete adheres strongly to a clean surface of steel; the average safe adhesion can generally be taken as about 100 lbs. per super. inch. It is thus possible to form a practical and economical combination of concrete and steel, the former material being utilised to resist the compressive stresses, with the necessary steel bars embedded at the points where tensile stresses occur. In certain cases, where the concrete alone cannot provide all the necessary compressive resistance, steel rods are added to assist the concrete; but from an economical point of view this should be avoided whenever possible, for the following reason :—

Steel possesses, on an average, about fifteen times the elasticity of concrete; where steel bars are embedded in concrete to assist in resisting compression, it follows that when the concrete around the bars has been stressed up to its limit, the steel has been compressed to fifteen times that of the concrete only, and is still far from its limit. Notwithstanding this want of economy, it is frequently necessary to utilise steel in this way, as, for instance, in the case of columns arches, etc., and in beams when sufficient depth, or area of concrete in the compression flange, cannot be obtained.

Steel is very perfectly protected from deterioration by a covering of concrete, and many instances could be quoted to show that a covering of less than 1 inch of good concrete is sufficient to preserve steel almost indefinitely.

In many cases reinforced concrete forms an almost ideal method of construction, particularly where great strength and durability are essential. The strength of the concrete increases with age, and there is no cost of upkeep, as in the case of steelwork, which requires regular inspection, painting, etc.

All structures can have their several members resolved into three types or into combinations of these three types—namely, beams or girders, struts or stanchions, and ties. Beams or girders support loads which act at right angles to their length, and tend to cause bending or deflection of the member. In struts or stanchions the loads act in the direction of the length, and tend to compress the members; in long and slim compression members, however, stresses similar to those in beams may also arise, through bending or side-yielding when the load exceeds a particular value. In ties the load acts in the direction of their length, as in struts, but here the tendency is to produce tension or stretching in the member.

Composite members may be represented by struts or ties which are not placed vertically, and consequently tend to bend by their own weight, and to this latter extent act as beams. Arches also are generally subjected to bending stresses in addition to that of compression.

Beams or Girders.

The bending moment and shearing force values are calculated exactly as in the case of ordinary beams, and reference may be made to pages 318 and 319 for information on this point. Owing to the composite nature of a reinforced concrete beam, however, the determination of the

internal stresses, or of the scantlings of any beam necessary to limit the tension and compression stresses to some specific maximum, are distinctly more complex than in the case of beams formed of a homogeneous material.

The following assumptions, which are practically correct within the usual limits of safe stress and ordinary conditions, are generally admitted, and form the basis on which the formulæ are built up :—

(*a*) The coefficient of elasticity in compression of good concrete is constant throughout the working limit of stress, and for an average 1 : 2 : 4 mixture may be taken as $\frac{1}{15}$ that of the steel reinforcement. For any distance from the neutral axis, therefore, the stress per square inch on the steel is fifteen times that on the concrete.

(*b*) The tensional resistance of concrete is ignored.

(*c*) The stress on the concrete varies uniformly from zero at the neutral axis to a maximum at outer edge ; the stress on the area of the steel is constant.

(*d*) The bond, or adhesion, between the concrete and the steel is sufficient to transmit any stress arising between these two materials.

Considering, in the first instance, a beam formed of some homogeneous material, supported at each end, and loaded so that it tends to deflect, the compressive stress at the upper edge of the beam will be exactly equal to the tensile stress at the lower edge, and these values will gradually diminish towards the centre of the depth, where they will altogether disappear ; this plane of no stress is called the neutral axis.

Assuming that the stresses vary uniformly, fig. 1 may be taken to represent the stresses in any section of the beam, the horizontal distance between the vertical line and the inclined line at any point above the neutral axis will be proportionate to the compressive stresses at the given point; similarly, the horizontal lengths below the neutral axis will be proportionate to the tensile stress.

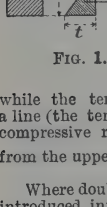


FIG. 1.

The total resistance to compression or extension would be represented by the area of either triangle. The resultant of either of these stresses would act through the centre of gravity of these triangles, or at a distance equal to $\frac{1}{3}$ the perpendicular depth from the base, giving the distance between the two resultants, or the lever arm of the resistance couples, as equal to $\frac{2}{3}d$.

The corresponding diagram for a simple reinforced concrete beam would be that of fig. 2. Here the compressive resistance, which occurs above the neutral axis, is represented, as before, by a triangle while the tensile resistance, being that of the steel reinforcement only, is represented by a line (the tensile strength of the concrete is ignored). The position of the resultant of the compressive resistance would pass through the centre of gravity of the triangle, or at $\frac{2}{3}$ from the upper surface ; the lever arm in this case would equal $d - \frac{n}{3}$.

Where double reinforcement is adopted—that is to say, where a certain amount of steel is introduced into the upper or compression area of the beam to assist the concrete (fig. 3)—the total compressive resistance would, in addition to that of the concrete, include the compressive resistance of the steel ; the combined resultant of these two resistances would equal the sum of the two, and would act at some point between the two independent resistances, the exact position depending on the relative values of these two resistances.

In the case of T beams, or those in which the upper or compression flange is formed in part of the flooring slabs with which the beam proper is combined, two cases arise : the one in which the distance from the neutral axis to top of beam (n) is *not greater* than the thickness of the floor slab (d_s), and the other in which this value (n) is *greater* than the thickness of the slab (d_s). Since the compressive stress is assumed as being resisted by the concrete alone, the first case naturally falls under the same condition as that of a simple beam (fig. 2), except that the breadth of the beam must now be taken, not as the breadth of the reinforced beam only (b_r), but must include a certain portion of the slab at each side of the main beam, or b_s.

The difference between the first and second cases referred to will be obvious by a comparison between figs. 4 and 5. In the former the compression resistance is represented by a triangle with a resultant acting $\frac{1}{3}n$ from the upper surface; while in the latter case the compressive resistance is represented by the area of a trapezoid, the point of action being through the centre of gravity of this figure. It should be noted that in this latter case the compressive value of the concrete in the main beam between the bottom of slab and the neutral axis is ignored, as its value is very slight, and the formulæ are much simplified by doing this.

Two extensions of the above two cases are shown in figs. 6 and 7, where double reinforcement is adopted ; the treatment in these two cases is modified generally, as previously noted when referring to figs. 2 and 3 for rectangular beams.

The following series of formulæ for the several types of single and double reinforced beams just referred to will enable the scantlings for any such members to be readily calculated and the designs for these checked with the minimum of trouble.

Rectangular Beams with Single Reinforcement.

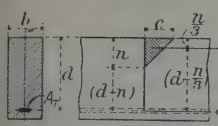


FIG. 2.

$$n=\frac{1}{1+\frac{t}{cm}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$r=\frac{1}{\frac{2t}{c}\left(1+\frac{t}{cm}\right)} \quad . \quad . \quad . \quad . \quad (2)$$

$$t=c\frac{(1-n)m}{n} \quad . \quad . \quad . \quad . \quad (3)$$

$$c=t\frac{n}{(1-n)m} \quad . \quad . \quad . \quad . \quad (4)$$

$$A_T=\frac{B}{td\left(1-\frac{n}{3}\right)} \quad . \quad . \quad . \quad (5)$$

$$n=\sqrt{(mr)^2+2mr}-mr \quad . \quad . \quad (6)$$

$$R=bd^2\left[tr\left(1-\frac{n}{3}\right)\right] \quad . \quad . \quad (7)$$

$$R=bd^2\left[\tfrac{1}{2}cn\left(1-\frac{n}{3}\right)\right] \quad . \quad . \quad (8)$$

Symbols.

n = Ratio of distance of neutral axis from compression edge of beam to effective depth.
r = Ratio of area of steel to area of concrete = A_T/bd.
t = Tensile stress intensity on steel.
c = Compressive stress intensity on concrete.
m = Modulus ratio = E_s/E_c.
A_T = Area of tensile reinforcement.
B = Bending moment of external forces.
R = Resistance moment of internal stresses.
b = Breadth of beam.
d = Effective depth of beam.

DESIGNING.—Decide values for m, t, c, and trial dimensions for b and d. Calculate n by (1) and r by (2); then value of A_T by (5). R is got from (7) or (8). If any other value of r is used than is given by (2), calculate n by (6) and R by (7) and (8), the lesser of these two values being adopted.

CHECKING A DESIGN.—Calculate r ($=A_T/bd$), and with this determine n from (6); test t and c by (3) and (4). If t exceeds the safe stress, get R from (7); if c exceeds the safe stress, get R from (8), in each case using the maximum safe stress for t or c.

Note.—Where more than one bar is used to form the reinforcement, measure d to the centre of gravity of the group.

Usual Dimensions.—d = one-twelfth to one-sixteenth of span; b = one-half to two-thirds d.

Rectangular Beams with Double Reinforcement.

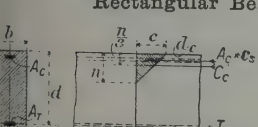


FIG. 3.

$$c_s=\frac{(n-d_c)}{n}m\times c \quad . \quad . \quad . \quad (9)$$

$$c_s=\frac{(n-d_c)}{(1-n)}t \quad . \quad . \quad . \quad (10)$$

$$A_c=\frac{B-\left[\tfrac{1}{2}cnbd^2\left(1-\frac{n}{3}\right)\right]}{c_sd(1-d_c)} \quad . \quad . \quad (11)$$

$$A_T=\frac{B-\left[A_cc_sd\left(\frac{n}{3}-d_c\right)\right]}{dt\left(1-\frac{n}{3}\right)} \quad . \quad . \quad (12)$$

$$n=\sqrt{m^2(r_t+r_c)^2+2m(r_t+r_cd_c)}-m(r_t+r_c) \quad (13)$$

$$R=bd^2\left[tr_t\left(1-\frac{n}{3}\right)+c_sr_c\left(\frac{n}{3}-d_c\right)\right] \quad (14)$$

$$R=bd^2\left[\tfrac{1}{2}cn\left(1-\frac{n}{3}\right)+c_sr_c(1-d_c)\right] \quad 15)$$

Additional Symbols.

c_s = Compressive stress intensity on steel.
d_c = Ratio of depth to centre of compression reinforcement to effective depth.
A_c = Area of compression reinforcement.
r_t = Ratio of area of steel in tension to area bd.
r_c = Ratio of area of steel in compression to area bd.

DESIGNING.—Calculate n by (1), then c_s by (9) or (10); the area of Compression Steel is got from (11), and the area of Tension Steel from (12). The Resistance Moment is got from (14) or (15).

CHECKING A DESIGN.—Calculate r and r_c from scantlings given, and n from (13). c_s is got from (9) and (10), the smaller value being adopted. R is obtained from (14) and (15), the former assuming the concrete, and the latter the steel as stressed to their respective safe limits; the least value of R from (14) and (15) must consequently be taken as the maximum safe R.

See Diagrams on pages 562-563.

T Beams with Single Reinforcement.

Class I.—n not greater than d_s.

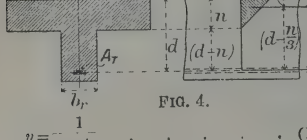


FIG. 4.

$$n=\frac{1}{1+\frac{t}{cm}} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$r=\frac{b_s}{\frac{2t}{c}\left(1+\frac{t}{cm}\right)b_r} \quad . \quad . \quad . \quad . \quad (17)$$

$$t=c\frac{(1-n)m}{n} \quad . \quad . \quad . \quad . \quad (18)$$

$$c=t\frac{n}{(1-n)m} \quad . \quad . \quad . \quad . \quad (19)$$

$$A_T=\frac{B}{td\left(1-\frac{n}{3}\right)} \quad . \quad . \quad . \quad . \quad (20)$$

$$n=\sqrt{\left(mr\frac{b_r}{b_s}\right)^2+2mr\frac{b_r}{b_s}}-mr\frac{b_r}{b_s} \quad . \quad (21)$$

$$R=b_rd^2\left[tr\left(1-\frac{n}{3}\right)\right] \quad . \quad . \quad . \quad (22)$$

$$R=b_sd^2\left[\tfrac{1}{2}cn\left(1-\frac{n}{3}\right)\right] \quad . \quad . \quad . \quad (23)$$

SYMBOLS.

n = Ratio of distance of neutral axis from compression edge of beam to effective depth.
r = Ratio of area of steel to area (b_rd).
t = Tensile stress intensity on steel.
c = Compressive stress intensity on concrete.
m = Modulus ratio $=E_s/E_c$.
A_T = Area of tensile reinforcement.
B = Bending moment of external forces.
R = Resistance moment of internal stresses.
b_s = Breadth of T slab.
b_r = Breadth of rib.
d = Effective depth of beam.

DESIGNING.—Decide values for m, t, c, and tri dimensions for b_r, b_s, and d. Calculate n by (1 and r by (17), then value of A_T by (20). R is g from (22) or (23). If any other value of r is us than is given by (17), calculate n by (21) and R t (22) and (23), the lesser of these two values bei adopted.

CHECKING A DESIGN.—Calculate r $(=A/b_rd$ and with this determine n from (21). Test t and by (18) and (19). If t exceeds the safe stress, g R from (22), if c exceeds the safe stress get R fro (23), in each case using the maximum safe stre for c or t.

T Beams with Single Reinforcement.

Class II.—n greater than d_s.

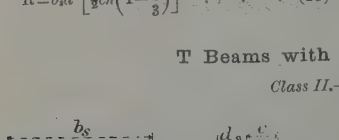


FIG. 5.

$$r=\frac{nd_s\left(1-\frac{d_s}{2n}\right)b_s}{(1-n)mb_r} \quad . \quad . \quad . \quad . \quad (24)$$

$$A_T=\frac{B}{td\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)} \quad . \quad . \quad (25)$$

$$=\frac{a^2.\frac{b_s}{b_r}+2mr}{\frac{b_s}{b_r}+2mr} \quad . \quad . \quad . \quad . \quad (26)$$

$$R=bd^2\left[\left(1-\frac{d_s}{2n}\right)cd_s\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)\right] \quad (27)$$

$$R=b_rd^2\left[tr\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)\right] \quad . \quad (28)$$

ADDITIONAL SYMBOL.

d_s = Ratio of depth or thickness of slab to effecti depth of beam.

DESIGNING.—Decide values for m, t, c, and tr dimensions for b_r, b_s, and d. Calculate n by (1 and r by (24), then value of A_T by (25). R is g from (27) or (28). If any other value of r is us than is given by (24), calculate n by (26), and by (27) and (28), the lesser of these two valu being adopted.

CHECKING A DESIGN.—Calculate r $(=A_T/b_r$ and with this determine n from (26). Test t a c by (18) and (19). If t exceeds the safe stress g R from (28), if c exceeds the safe stress get R fr (27), in each case using the maximum safe str for c or t.

T Beams with Double Reinforcement.

Class I.—n not greater than d_s.

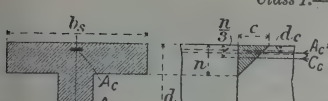


FIG. 6.

$$n = \frac{1}{1+\frac{t}{cm}} \quad . \quad . \quad . \quad . \quad . \quad (29)$$

$$t = c\frac{(1-n)m}{n} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

$$c = t\frac{n}{(1-n)m} \quad . \quad . \quad . \quad . \quad . \quad (31)$$

$$c_s = \frac{(n-d_c)}{n}m \times c \quad . \quad . \quad . \quad . \quad (32)$$

$$c_s = \frac{(n-d_c)}{(1-n)}t \quad . \quad . \quad . \quad . \quad (33)$$

$$A_c = \frac{B-\left[\frac{1}{2}cnb_sd^2\left(1-\frac{n}{3}\right)\right]}{c_sd(1-d_c)} \quad . \quad . \quad (34)$$

$$A_t = \frac{B-\left[A_cc_sd\left(\frac{n}{3}-d_c\right)\right]}{td\left(1-\frac{n}{3}\right)} \quad . \quad . \quad (35)$$

$$n = \sqrt{\left[\frac{m(r_t+r_c)b_r}{b_s}\right]^2+\left[\frac{2m(r_t+r_cd_c)b_r}{b_s}\right]} - \left[\frac{m(r_t+r_c)b_r}{b_s}\right] \quad (36)$$

$$R = b_rd^2\left[tr_t\left(1-\frac{n}{3}\right)+c_sr_c\left(\frac{n}{3}-d_c\right)\right] \quad . \quad (37)$$

$$R = d^2\left[\frac{1}{2}cnb_s\left(1-\frac{n}{3}\right)+c_sr_cb_r(1-d_c)\right] \quad (38)$$

SYMBOLS.

n = Ratio of distance of neutral axis from compression edge of beam to effective depth.
t = Tensile stress intensity on steel.
c = Compressive stress intensity on concrete.
c_s = Compressive stress intensity on steel.
m = Modulus ratio = E_s/E_c.
A_T = Area of tensile reinforcement.
A_c = Area of compression reinforcement.
b_s = Breadth of T slab.
b_r = Breadth of rib.
d = Effective depth of beam.
d_c = Ratio of depth to centre of compression reinforcement to effective depth of beam.
r_t = Ratio of area of steel in tension to area b_rd.
r_c = Ratio of area of steel in compression to area b_rd.
B = Bending moment of external forces.
R = Resistance moment of internal stresses.

DESIGNING.—Calculate n by (29), then c_s by (32) or (33), the area of Compression Steel is got from (34), and the area of Tension Steel from (35). The Resistance Moment is got from (37) or (38).

CHECKING A DESIGN.—Calculate r_t and r_c from scantlings given, and n from (36). c_s is got from (32) and (33), the smaller value being adopted. R is obtained from (37) and (38), the former assuming the Steel and the latter the Concrete as stressed to their respective safe limits. The least value of R from (37) and (38) must consequently be taken as the maximum safe R.

T Beams with Double Reinforcement.

Class II.—n greater than d_s.

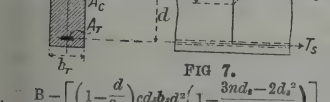


FIG 7.

$$A_c = \frac{B-\left[\left(1-\frac{d}{2n}\right)cd_sb_sd^2\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)\right]}{c_sd(1-d_c)} \quad (39)$$

$$A = \frac{B-\left[A_cc_sd\left(\frac{3nd_s-2d_s^2}{6n-3d_s}-d_c\right)\right]}{td\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)} \quad . \quad . \quad (40)$$

$$n = \frac{d_s^2b_s+2m(r_t+r_cd_c)b_r}{2d_sb_s+2m(r_t+r)b} \quad . \quad . \quad (41)$$

$$R = d^2\left[\left(1-\frac{d_s}{2n}\right)cd_sb_s\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)+c_sr_c(1-d_c)r\right] \quad . \quad (42)$$

$$R = b_rd^2\left[tr_t\left(1-\frac{3nd_s-2d_s^2}{6n-3d_s}\right)+cr_c\left(\frac{3nd_s-2d_s^2}{6n-3d_s}-d_c\right)\right] \quad . \quad (43)$$

ADDITIONAL SYMBOL.

d_s = Ratio of depth or thickness of slab to effective depth of beam.

DESIGNING.—Calculate n from (29), then c_s by (32) or (33), the area of Compression Steel is got from (39), and the area of Tension Steel from (40). The Resistance Moment is got from (42) or (43).

CHECKING A DESIGN.—Calculate r_t and r_c from scantlings given, and n from (41), c_s is got from (32) and (33), the smaller value being adopted. R is obtained from (42) and (43), the former assuming the Concrete and the latter the Steel as stressed to their respective safe limits. The least value of R from (42) and (43) must consequently be taken as the maximum safe R.

Note.—In many cases of double reinforcement the compression reinforcement can be placed at the centre of gravity of the compression area; the formula for R could then be somewhat simplified.

Shearing Stresses and Diagonal Tension in Beams.

These stresses and the methods of resisting them require careful consideration in all cases. At any point in a beam, the horizontal and vertical shearing stresses are of equal value, and these stresses may be looked upon as the connecting link between successive increments of tension in the reinforcement and corresponding increment of compression in the concrete; also, in the case of double reinforcement, in connecting up the increments of tension and compression in the two forms of reinforcement. The tendency of the longitudinal shearing stress is to destroy the adhesion between the concrete and steel, and it is necessary to calculate this value to ensure that no slipping or failure takes place from this cause.

If S represents the total vertical shear, which is equal to the rate of change of the bending moment from point to point along the beam; s_b the shearing stress between concrete and steel O the periphery of reinforcement, whether one bar or a number of bars; the shearing stress round the bars per unit surface of reinforcement is approximately equal to :—

$$s_b = \frac{S}{O \times 0{\cdot}86d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51),$$

and this same stress per unit length may be written—

$$s_b O = \frac{S}{0{\cdot}86d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52).$$

The fraction $0{\cdot}86d$ in the above equations represents the approximate average length of the lever arm, or distance between the centre of tension in the steel and the centre of compression in the concrete; and these equations may therefore be used to give practical values for rectangular or T beams, either with single or double reinforcement.

If s represents the unit horizontal shearing stress in the concrete, the shearing stress per unit length on any width b of a beam is as follows :—

$$s \times b = \frac{S}{0{\cdot}86d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53).$$

This last formula not only gives the value of the horizontal shearing stress, but also that of the vertical shearing stress at the same point, since both these stresses are always of equal value.

Failure by *diagonal tension* is the cause of numerous mishaps, which are frequently attributed to shear. The maximum diagonal tension in a reinforced concrete beam is largely governed by the amount of the horizontal tension in the concrete as well as that of the shearing stress at the same point. From practical experiments and data it would appear that, with average concrete beams with no web reinforcement are liable to fail by diagonal shear when the vertical shearing stress intensity, at point of failure, averages about 120 lbs. per square inch. Accepting a factor of safety of 4, the shearing stress intensity given by formula (53) should not exceed 30 lbs. per square inch. With the same factor of safety, the shearing stress calculated by this formula in beams with web reinforcement may be taken at 120 lbs. per square inch.

Web Reinforcement.

This generally consists either of vertical or diagonal stirrups, alone or in conjunction with inclined bars, these latter generally consisting of a portion of the main reinforcing bars bent upwards as required.

The sectional area of steel to withstand the total shearing force at any vertical section, when the shear bar is inclined at an angle ϕ with the horizontal, should be as follows :—

$$\text{Sectional area required} = \frac{S}{t \times \sin \phi} \quad . \quad . \quad . \quad . \quad (54),$$

t being the tensile strength per square inch of the steel.

The resistance to shear and to diagonal tension in a T beam is practically similar to that for rectangular beams, if the breadth in the former be taken as the breadth of the rib (b_r), this value being compared with the breadth (b) of the rectangular beam.

The breadth of rib in T beams (b_r) will usually be found sufficient to resist any horizontal shear when of a size to give sufficient practical space for embedding the steel reinforcing bars but to allow for any excessive shear, and for diagonal tension, it is well to keep this breadth of ample size.

Inverted Beams.

Where a beam is continuous over one or more intermediate supports, or where a single span beam is securely fixed or built in at its ends, the effect on the continuous beam over the support or at the ends of the single span beam is to produce reverse bending, and consequently an inversion of the stresses; the upper portion now being in tension, while the lower portion is in compression. To meet this change in stress, it is usual to bend up a number of the lower reinforcing bars as they approach the ends, and for partial fixing this may be sufficient, but it will generally be found that additional reverse stress bars (sometimes called 'continuity bars') must be added to provide the full area of reinforcement necessary at the upper portion of the beam.

In the case of inverted T beams, it will usually be found that the neutral axis falls outside the slab, and it may therefore be calculated as for an ordinary rectangular beam, of a breadth (b) equal to the breadth of rib (b_r).

Floor Slabs.

By imagining any slab to be broken up into a series of parallel strips, each say 12 ins. wide, it is only necessary to treat each strip as an independent beam, and determine the thickness and the amount of reinforcement according to the particular conditions of loading, etc. The amount of reinforcement thus found will give that required per 12 ins. of width, and may be arranged in the form of a series of small rods set at the required spacing to give this calculated area.

When slabs are reinforced in one direction only, it is generally assumed that the two beams upon which the ends of the reinforcing bars rest will carry the complete load, but should the slab be of approximately square shape, and the reinforcement arranged in two directions, all four beams upon which the slab rests are assumed as taking a share of the total load. In the case of a square slab supported on all four sides, it will be sufficiently accurate to calculate the total load as distributed equally over all four girders. If the slab is of rectangular form, the short or end girders may be calculated as each supporting a triangular area formed by the beam and by lines drawn at 45° from its corners; the long or side girders each supporting one-half the remainder of the slab. This will be obvious from an examination of figs. 8 and 9, where an indication is given of the manner in which two plain concrete slabs failed when tested to destruction.

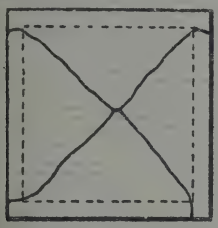


FIG. 8.

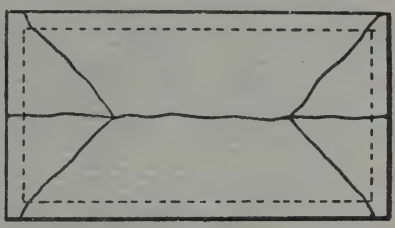


FIG. 9.

There is no satisfactory theory as to the stresses in slabs supported on all sides, nor does there seem to be any single generally accepted rule for determining these stresses. The table below gives a series of multipliers for adjusting the bending moment stresses for a slab as calculated in the direction of its length and its breadth; these multipliers are based respectively on the theory developed by Professors Grashof and Rankine, and on the instructions issued by the French Government to the Ingénieurs des Ponts et Chaussées. A comparison of the two series will show a marked divergence of opinion. It is recommended that for ordinary requirements the first rule be adopted, but where the work is carried out under very careful supervision, and first-class material and workmanship are ensured, the second rule may be applied.

Rectangular Slabs supported on four sides.

Value of $\frac{L}{B}$	Grashof and Rankine. $s=\frac{L^4}{L^4+B^4}$	Grashof and Rankine. $l=\frac{B^4}{L^4+B^4}$	French Government. $s=\frac{1}{1+2\frac{B^4}{L^4}}$	French Government. $l=\frac{1}{1+2\frac{L^4}{B^4}}$
1-1	·500	·500	·333	·333
1-1·1	·594	·406	·423	·254
1-1·2	·675	·325	·509	·194
1-1·3	·741	·259	·588	·149
1-1·4	·793	·206	·658	·115
1-1·5	·835	·165	·717	·090
1-1·6	·868	·132	·766	·071
1-1·7	·893	·107	·807	·056
1-1·8	·913	·087	·840	·045
1-1·9	·929	·071	·867	·037
1-2·0	·941	·059	·889	·030

A glance at this table will show that when the proportion of length to breadth approaches that of 1 to 2, the effect of the end supporting becomes negligible, and beyond this limit slabs should

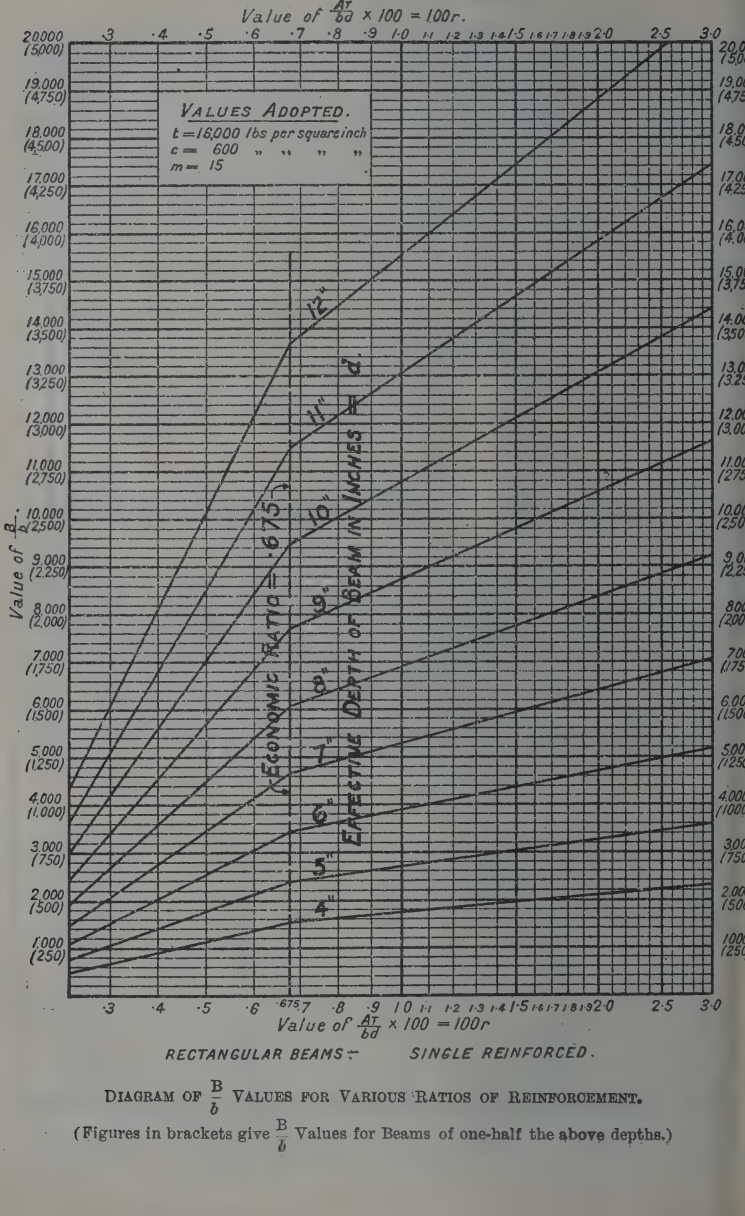
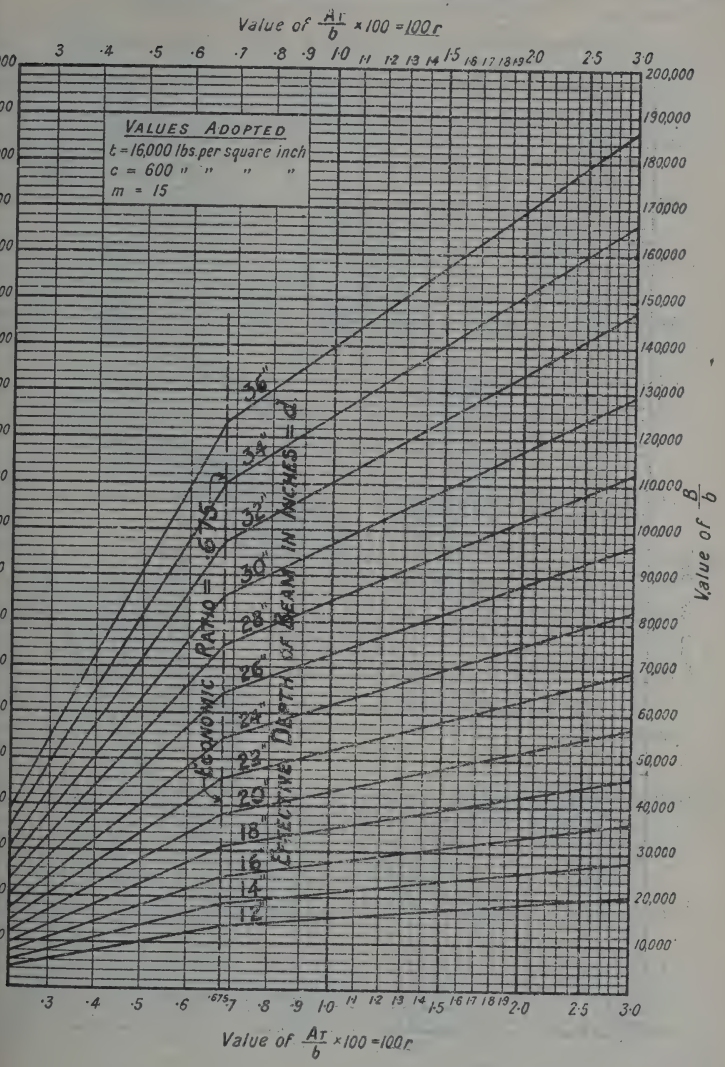


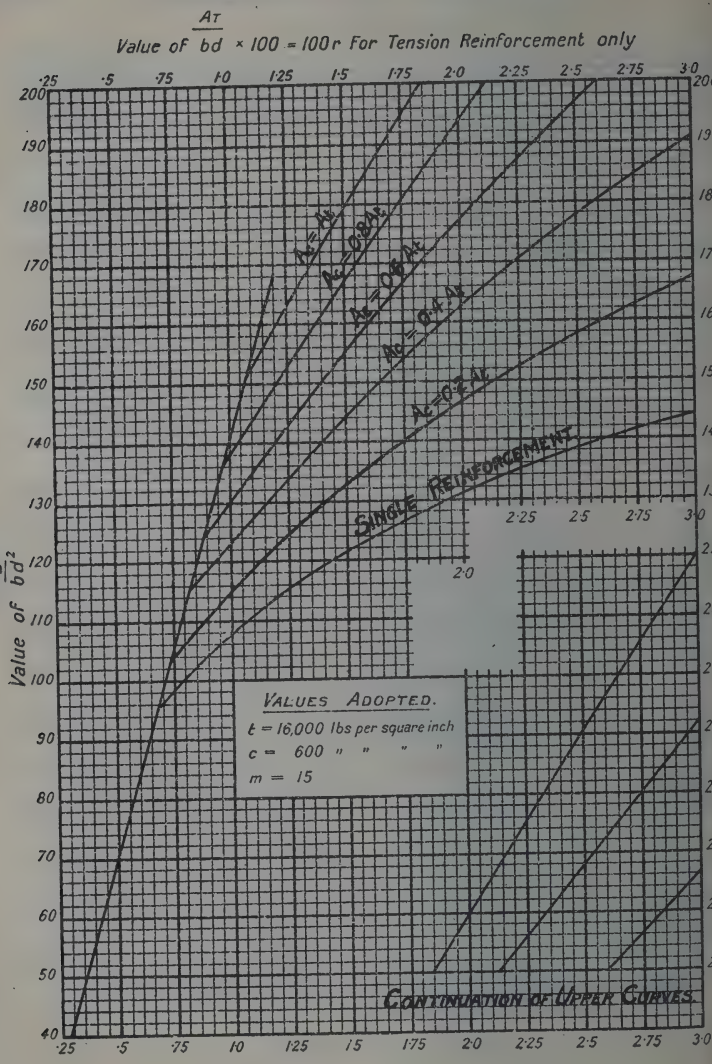
DIAGRAM OF $\frac{B}{b}$ VALUES FOR VARIOUS RATIOS OF REINFORCEMENT.

(Figures in brackets give $\frac{B}{b}$ Values for Beams of one-half the above depths.)



RECTANGULAR BEAMS- SINGLE REINFORCED.

DIAGRAM OF $\frac{B}{b}$ VALUES FOR VARIOUS RATIOS OF REINFORCEMENT.



RECTANGULAR BEAMS —— SINGLE & DOUBLE REINFORCED.

DIAGRAM OF $\frac{B}{bd^2}$ VALUES FOR VARIOUS RATIOS OF TENSION AND COMPRESSION REINFORCEMENT.

be single reinforced, and treated as if supported on two sides only. The use of the foregoing table is as follows :—

In any floor slab of length L and breadth B, calculate the bending moment first for a beam of span B under the total load from the slab, and as supported or fixed at the sides only. Multiply the bending moment thus found by the multiplier s in the table corresponding to the value L/B to determine the actual bending moment on the long axis of the slab. By a similar operation, with a span L, and the use of the multiplier l, determine the actual bending moment on the short axis. By means of the formulæ already given for rectangular beams, the necessary thickness and amount of reinforcement can be determined, and it remains only to distribute this total area of reinforcement in the form of small bars arranged at the necessary spacing throughout the full length and breadth of the slab.

Deflection of Reinforced Concrete Beams.

An ingenious method of calculating the approximate deflection of a reinforced concrete beam or slab was suggested by Mr. Eli White in the 'Engineering Record' for November 9, 1907. The following explanations are based on this method :—

The deflection of a reinforced concrete beam being proportionate to the elongation of the steel tensile reinforcement, this deflection will be similar in amount, for similar tensile stress intensities, to that of a symmetrical beam, whose flanges are each of an area equal to the tensile reinforcement in the reinforced concrete beam, and are placed at a distance apart equal to twice that of

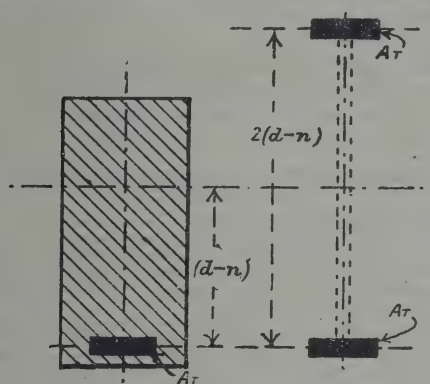


FIG. 10.

the distance between the tensile steel and the neutral axis in the reinforced concrete beam Fig. 10 indicates to the left a sketch section of a reinforced concrete beam, with tensile reinforcement equal to A_T, and the sketch to the right indicates the section of an imaginary symmetrical steel beam, whose two flanges are each equal in area to A_T and are placed at $2(d-n)$ apart. If t = tensile stress intensity on steel, the

$$\text{Resistance Moment of this symmetrical beam} = 2(d-n) \times A_T \times t. \quad . \quad (55).$$

When any beam is carrying a load, it is obvious that the resistance moment must be equal to the bending moment of the external force acting on the beam.

For this symmetrical beam, the

$$\text{Approximate Moment of Inertia value} = 2A_T \times (d-n)^2 \quad . \quad . \quad . \quad . \quad (56),$$

and taking E at 30,000,000 lbs., the deflection formulæ given in the tables on pages 318 and 319 can be applied to calculate the approximate deflection in any single or double reinforced concrete beam, the correct value for $(d-n)$ being used in the above formulæ.

It should be noted that in the above formulæ the tensile resistance of the concrete has been entirely neglected, and that the formulæ for deflection on pages 318 and 319 are those for beams of uniform section (reinforced concrete beams only more or less approach this condition) ; for these reasons the calculated deflection will generally be distinctly higher than the actual values which may at times be found as much as 10 to 15 per cent. less than given by these calculations.

The tables on pages 318 and 319 may prove of service in determining *graphically* the bending moment and shearing stress values for various types of loading ; and since these diagrams show clearly the *change of values* they can frequently be used in arranging the main reinforcement and the points where these bars may be bent up to resist shear ; independent shear members can also be set out by the same means.

COLUMNS, PILES, AND WALLS.

SYMBOLS USED IN THE FOLLOWING FORMULÆ.

A = Sectional Area of Concrete in Column.
A_E = Equivalent Area of Concrete to that of Concrete and Steel Longitudinals.
A_L = Sectional Area of Steel Longitudinal Reinforcement.
A_H = „ „ „ Hooping.
W = Safe Load on Short Column.
W_I = „ „ Long „
C_u = Ultimate Compressive Stress on Concrete at 90 days.
c = Safe Stress per square inch on Concrete.
p = Percentage of Longitudinals to Concrete = $A_L \div A$.
l = Length of Column in inches.
I_c = Moment of Inertia of Concrete about Neutral Axis of Column.
I_L = „ „ of Longitudinals „ „ „
G_E = Radius of Gyration of A_E.
b = Smaller Side of Rectangle, or Side of Square.
b_y = Larger „ „
d = Diameter of Round Column, or of Round Rods.
y = Distance of Longitudinal from Neutral Axis, in inches.
x = „ Eccentric Load from Centre of Column.
r_h = Ratio of Volume of Hooping to Volume of Concrete.

Short Columns Reinforced with Longitudinal Bars and Cross Ties.

Load Applied at Centre.

In ordinary cases, the Longitudinal Reinforcement takes the form of round or square steel rods of comparatively small area placed symmetrically about the cross-section of the column; these Longitudinals are held or tied securely together by Horizontal Bindings, which should not be set further apart than twenty to twenty-four times the least diameter of the Longitudinals. This spacing of Bindings should, as a rule, be reduced towards the end of the columns, where in the majority of cases failure first occurs.

When the length does not exceed about 18 times the least diameter or width, and the Maximum Stress per sq. in. on the concrete is limited to 600 lbs., the column may be expected to yield by crushing. Since the Modulus of Elasticity of the Steel Longitudinals is assumed as 15 times that of the concrete, the Maximum Stress on the steel will be 15 times that of the concrete only: 1 sq. in. of steel is, therefore, equal to 15 sq. ins. of concrete. It is sometimes convenient to consider a reinforced column as consisting of concrete only; in which case the sectional area of the concrete would be increased by 14 times the sectional area of the steel reinforcement to give this equivalent area. This may be written:—

$$A_E = A + 14A_L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

Thus, the Safe Load for a short column would be as follows:—

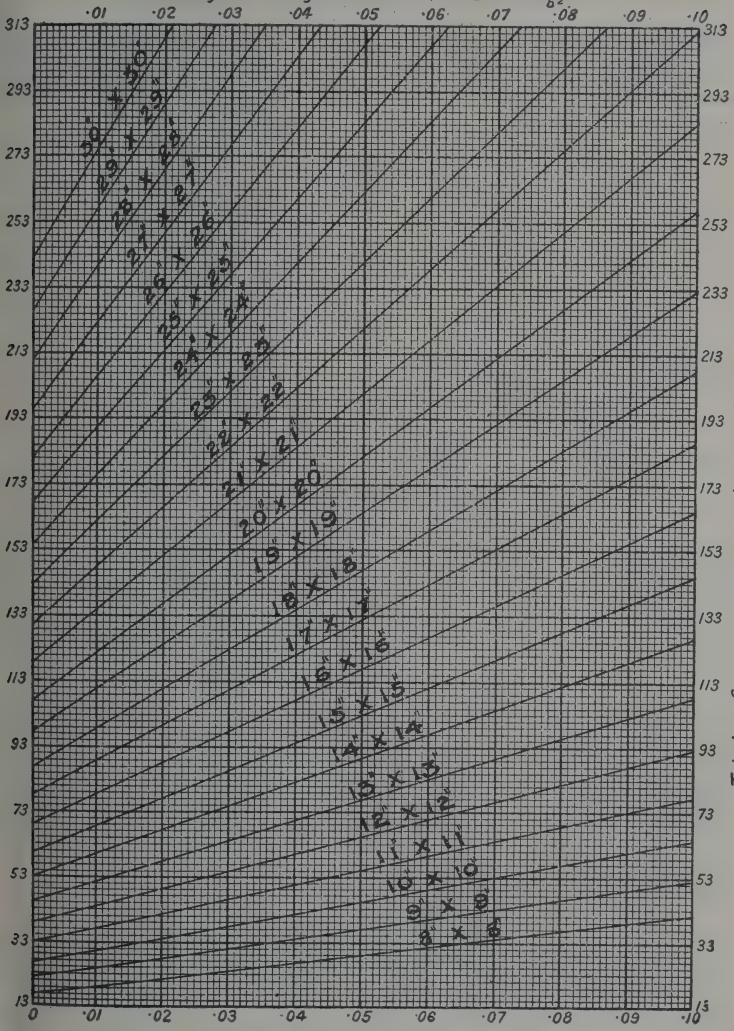
$$W = c\,(A + 14A_L) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (58)$$

It is sometimes convenient to consider the area of the steel longitudinals as a certain percentage of the total area of the concrete, and when this is done, we have the following equation:—

$$\text{Safe Compressive Stress per square inch} = c\,(1 + 14p) \quad . \quad . \quad . \quad (59)$$

The following table gives the Safe Stress Values for varying percentages of Steel, and may be used directly when designing Short Columns:—

Percentage of Reinforcement.	Safe Stress, when $c = 600$.	Percentage of Reinforcement.	Safe Stress, when $c = 600$.
½	642 lbs. per sq. in.	4	936 lbs. per sq. in.
¾	663 „ „	5	1,020 „ „
1	684 „ „	6	1,104 „ „
1½	726 „ „	7	1,188 „ „
2	768 „ „	8	1,272 „ „
2½	801 „ „	9	1,356 „ „
3	852 „ „	10	1,440 „ „



TOTAL SAFE LOADS FOR SQUARE COLUMNS, WITH LONGITUDINAL REINFORCEMENT ONLY

High Columns Reinforced with Longitudinal Bars and Cross Ties.

Load applied at Centre.

When the length exceeds about 18 times the least diameter or width there is a risk of Deflection or Lateral Buckling of the column as a whole. It is necessary, therefore, to take into account this tendency, and what is known as Rankine's formula may be used for this purpose. Here the strength calculated as for a short column is reduced in proportion to the ratio of length of the column to its least Radius of Gyration. The formulæ for three forms of end fixings are as under :—

Fixed Ends . . . . . $W_1 = \dfrac{W}{1 + \dfrac{l^2}{34000\,(G_E{}^2)}}$ . . . . (60)

One End fixed, the other free . $W_1 = \dfrac{W}{1 + \dfrac{l^2}{25500\,(G_E{}^2)}}$ . . . . (61)

Free Ends . . . . . $W_1 = \dfrac{W}{1 + \dfrac{l^2}{17000\,(G_E{}^2)}}$ . . . . (62)

Where $G_E{}^2 = \dfrac{I_c + 1{\cdot}4\,I_L}{A_E}$ . . . . . (63)

The values for I_c may be taken as follows :—

Any Rectangular Section (b = small side) . . . . $= {\cdot}0833b^3b_y$. (64)
,, Hexagonal Section (b_x = rad. of circumscribed circle) = ${\cdot}5413b_x{}^4$. (65)
,, Octagonal Section (,, ,, ,,) = ${\cdot}6381b_x{}^4$. (66)
,, Circular Section (d = diameter) . . . . . = ${\cdot}0491d^4$. (67)

If all Longitudinals are of small size and the same section,

$$I_L = \frac{A_L\,\Sigma y^2}{\text{Number of Longitudinals}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

Piles, Walls, etc.

In the case of Piles, the formula given for short columns may be utilised, but it would be well to reduce the Maximum Compressive Stress to 400 lbs. per sq. in., or under, and to close up the spacing of the Cross Ties, particularly towards the ends, owing to the heavy stress which arises during driving. For unsupported lengths of Piles, where they exceed in length 18 times their diameter, the formula for High Columns would be adopted.

In the case of walls, these may be assumed as broken up into a series of independent columns set close together, and their strength calculated as for short or long columns, the particular formula depending on the relation between height and the thickness of wall.

Columns with Eccentric Loads.

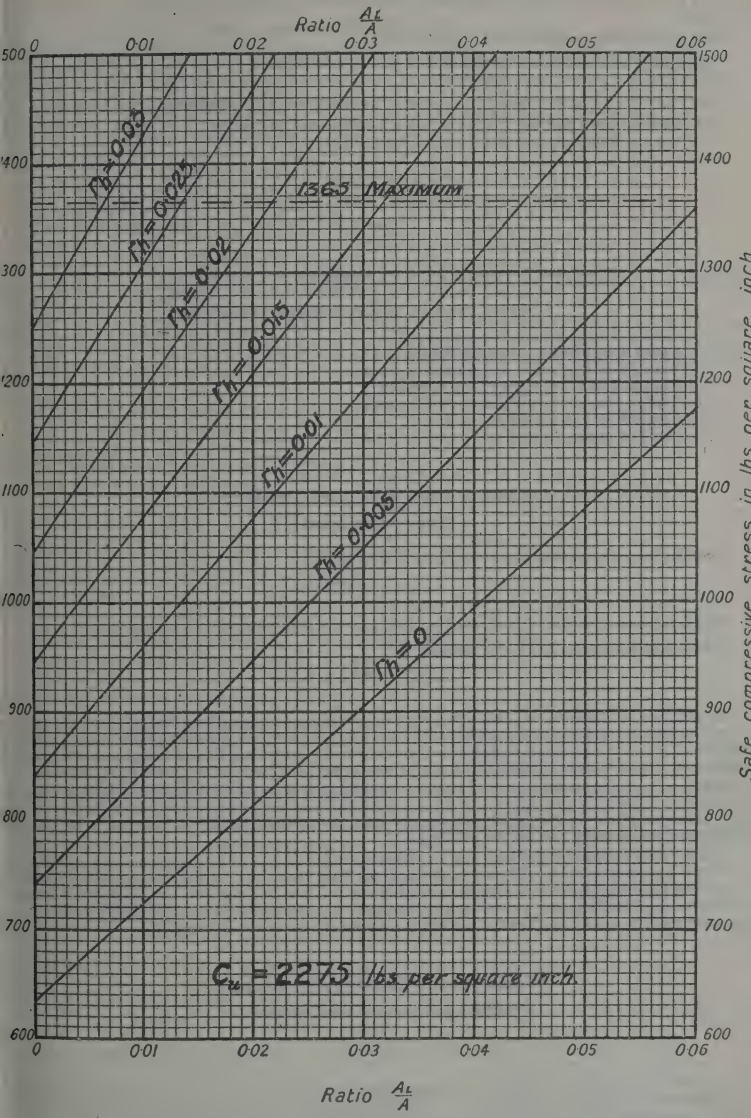
When a load is applied at a distance 'x' from the centre of a column, the stress produced may be considered as that due to two independent actions : *first*, a load equal to the Total Eccentric Load applied at the centre of the column, and giving rise to a Uniformly Distributed Compressive Stress, and *second*, a Couple, with a Moment equal to the Eccentric Load × x. This gives rise to a bending tendency, the effect of which may be calculated by considering the column as a Double Reinforced Beam, acted on by a Bending Moment equal in value to this couple. The Maximum Compressive Stress per sq. in. got by this calculation must be added to the Uniform Compressive Stress first got, to arrive at the Maximum Compressive Stress on column at edge nearest the load. At edge furthest from the load the Stress will equal the difference between the Tensile Stress per sq. in. got when calculating as for a beam, and the Uniform Compressive Stress. When the Eccentricity is considerable, the compression at furthest edge may be changed into tension. To resist any such tension, the Steel Longitudinals at that side should alone be calculated on.

Columns with Longitudinal Bars and Steel Hooping.

This type of column was carefully investigated by M. Considère, who showed that by confining the Concrete within a close set Steel Hooping, so as to prevent it bulging, its resistance to Compression was very greatly increased. From experiments made, this Engineer recommended that the hooping should in all cases be circular, that the Longitudinal Rods should be not less than 6 in number, and that the total volume of the Longitudinals should not be less than $\frac{1}{100}$th of the volume of the Concrete. It will be noted that these proportions are given in volumes, not in areas so as to take into account any necessary pitch of the spiral hooping.

The diameter of the column should be assumed as that within the spiral hooping, and, taking as a unit a length equal to the diameter, we have :—

Unit Volume of Concrete = ${\cdot}7854d^2$ . . . . . (69)
Unit Volume of Longitudinals = total area of Longitudinals × d . . . . . (70)
Unit Volume of Hooping = Sectional area of coil × $3{\cdot}14d \times \dfrac{d}{\text{pitch}}$ . . . . (71)



SAFE STRESS PER SQUARE INCH FOR CIRCULAR HOOPED COLUMNS.

The following is the formulæ adopted by the French Government Commission on Reinforced Concrete :—

Safe compressive resistance $= c(0{\cdot}7854d^2 + 14A_L)$ . . . . . (72)

For pitches of hooping between $\frac{1}{2}d$ and $\frac{1}{8}d$, $c = 0{\cdot}28\ C_u\ (1 + 32r_h)$ . . . (73)

The value of c should not exceed $0{\cdot}6\ C_u$.

The value of C_u for the usual 1 : 2 : 4 mixture of Concrete may be taken as 2,275 lbs. per sq. in.

The approximate diameters for the hooping may be taken as follows :—

For a pitch of $\frac{1}{2}d$ diameter $= {\cdot}030d$ . . . . . (74)

" " $\frac{1}{4}d$ " $= {\cdot}028d$ . . . . . (75)

" " $\frac{1}{6}d$ " $= {\cdot}026d$ . . . . . (76)

" " $\frac{1}{8}d$ " $= {\cdot}024d$ . . . . . (77)

PIPES, CIRCULAR RESERVOIRS OR BINS, etc.

SYMBOLS USED IN THE FOLLOWING FORMULÆ.

A_h = Sectional area of hoop reinforcement.
C = Direct compressive stress on the shell.
b_r = Breadth of ring under consideration, in inches.
d = Diameter of pipe or reservoir, in inches.
t = Tensile stress in lbs. on steel reinforcement.
p_1 = Pressure in lbs. per sq. in. on shell.
H_w = Head of water, in feet.

When under Internal Pressure.

(Concrete neglected.)

Consider any circumferential strip or ring, then :—

$$A_h = \frac{p_1 \times d \times b_r}{2t} \quad . \quad . \quad . \quad . \quad (78)$$

The total area thus found is divided up into any suitable number of hoops or rings.

Where water pressure has to be resisted :—

$$A_h = \frac{0{\cdot}216H_w \times d \times b_r}{t} \quad . \quad . \quad . \quad (79)$$

In addition to the hoop or spiral reinforcement determined above, longitudinal bars are necessary to strengthen the concrete shell between each hoop to resist the pressure they have to sustain ; the shell here acts as a fixed ended beam or slab of a span equal to the distance between the hoops, and the scantlings calculated by the formulæ previously given for such a type of beam.

Practical considerations generally decide the thickness of the concrete shell, which is usually 1½ to 2 ins. thick for pipes up to 9 or 10 ins. diameter, and seldom exceeds 3 to 3½ ins. even for large diameter pipes. In vertical reservoirs or bins the thickness towards the base must also be such as will safely carry the weight of the shell.

NOTE.—The required reinforcement for circular bins or silos may be determined by calculating 'p' from formulæ (82) or (83) on next page, for two levels say 12 ins. apart ; the difference of the two values thus got will give the pressure per lin. foot and per one foot in height between these levels. Dividing this value by 12×12 (144) will give the average pressure per sq. in., and formula (78) above will at once decide the necessary hoop reinforcement.

When under External Pressure.

(Concrete and hooping both effective.)

$$C = \frac{p_1 d}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (80)$$

The safe stress which the shell will sustain depends on the proportion of the steel hooping, and is given in table at foot of page 566. A few trials with varying thicknesses and proportions, of reinforcements may be required. The minimum practical thickness of shell is that necessary to give complete protection to the steel rods, and to permit of safe transport and handling.

Longitudinal reinforcement is provided under the same conditions as in the last case.

STORAGE BINS OR SILOS.

SYMBOLS USED IN THE FOLLOWING FORMULÆ.

h = Depth of bin in feet, or height of material above any point.
b = Breadth of rectangular bin, in feet.
l = Length of rectangular bin, in feet.
d = Diameter of circular bin, in feet.
p = Pressure against sides of bin in lbs. per lin. foot of horizontal perimeter.
w = Weight per cubic foot of material in bin.
μ = Coefficient of friction within the material stored.
μ_1 = Coefficient of friction between material and sides of bin.
(For values of the last three items, see table below.)

Bins can be conveniently divided into two classes, as follows :—

First.—Shallow Bins, where the plane of rupture (or the plane along which the material would tend to slide if the sides yielded) passes out through the material itself before it meets the opposite side of the bin, and

Second.—Deep Bins, where the plane of rupture meets the opposite side of the bin within the mass of the contained material.

The particular depth forming the dividing point between the above two classes is obtained by the following formula.

$$h = b \times \left[\mu + \sqrt{\mu \frac{1+\mu^2}{\mu+\mu_1}}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (81)$$

All depths less than the above value would indicate shallow bins, all greater depths would be classed as deep bins.

For square bins :—

$$\textit{First Class.}—p = \tfrac{1}{2} w h^2 \left[\frac{1}{\sqrt{\mu(\mu+\mu_1)} + \sqrt{1+\mu^2}}\right]^2 \quad . \quad . \quad . \quad . \quad . \quad (82)$$

$$\textit{Second Class.}—p = \tfrac{1}{2} w b^2 \left[\frac{\sqrt{\frac{2h}{b}(\mu+\mu_1) + (1-\mu\mu_1)} - \sqrt{1+\mu^2}}{\mu+\mu_1}\right]^2 \quad . \quad (83)$$

The total pressure on bottom of bin =

(Total weight of material) $- (\mu_1 \times p \times$ perimeter of bin in feet) . . (84)

The maximum pressure on the bottom of a bin occurs when

$$h = \frac{b}{2}\left[\frac{1+\mu^2}{\mu+\mu_1}\left(\frac{4\mu_1}{3\mu_1-\mu}\right)^2 - \frac{1-\mu\mu_1}{\mu+\mu_1}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (85)$$

For Rectangular Bins the values given by formulæ (82) and (83) will be different for the sides and the ends, since in the latter case the value l would replace that of b.

For Circular Bins substitute d for b in formulæ (81), (83), and (85).

These formulæ are not applicable to the inclined sides of Hopper bins, nor to the conical or spherical bottoms of shallow bins.

Nature of Grain, etc.	Weight per Cubic Foot in Pounds.	Coefficients of Friction.	
		Grain on Grain.	Grain on Cement.
Wheat	53	0·466	0·444
Barley	43	0·509	0·452
Oats	32	0·532	0·466
Maize	48	0·521	0·423
Beans	50	0·613	0·442
Peas	54	0·477	0·296
Tares	53	0·554	0·394
Linseed	45	0·456	0·414
Cement	100	0·554	0·316
Sand	90	0·674	0·577
Bituminous Coal	50	0·700	0·700
Anthracite Coal (small)	52	0·510	0·510
Ashes	40	0·839	0·839
Coke	28	0·839	0·839

DOMES AND CONICAL COVERINGS.

The following graphic method of determining the stresses in domes is only correct for thin coverings of true spherical or conical section, and formed of a material of uniform weight per unit of surface, and capable of resisting both tension and compression. The majority of reinforced concrete domes approximate to these conditions.

For a detailed explanation of the following statements and formulæ, &c., a reference may be made to a Paper by Mr. W. Dunn, A.M.Inst.C.E., F.R.I.B.A., published in the 'Transactions of the Royal Institute of British Architects,' May 21, 1904.

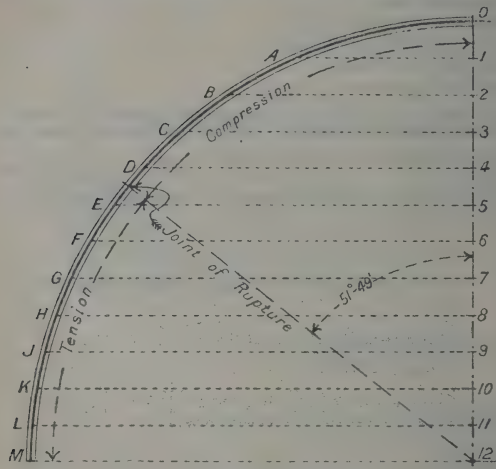


FIG. 11.

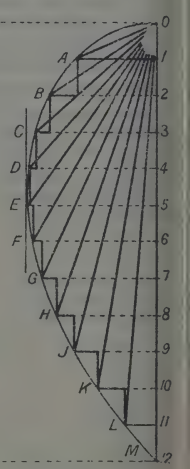


FIG. 12.

To construct figs. 11 and 12. Divide centre line of dome (fig. 11) into any convenient number of parts, and draw the horizontal lines to shell, as 1A, 2B, &c. Draw load line 0–12 (fig. 12) and from O draw radial lines parallel to tangents on the curve at points A, B, &c., till they meet the corresponding horizontal lines; from these meeting points verticals are drawn to the adjacent horizontal lines to complete the zigzag line shown. If correctly set out, the outer meeting points will lie on a regular curve as shown.

Select a scale such that the length 0–12 corresponds with the total weight of the dome; then the several heights between any two horizontal lines can be scaled off direct to give the weight of the portion between these two lines. To same scale, the radial lengths from O (fig. 12) to any point A, B, C, &c., indicate the total pressure on any horizontal section; the horizontal lengths A1, B2, &c., to same scale, give the total horizontal, or radial thrust; the shorter full lines drawn from A, B, &c., give the variation in the radial thrust between the adjoining section lines.

To determine the hoop stress, or that acting at the vertical face of any section, the radial thrust must be divided by $6{\cdot}28 \left(= \frac{\text{Radius}}{\text{Circumference}}\right)$, or by choosing a scale such that the height $0\text{–}12 = \frac{1}{6{\cdot}28} \times$ total weight of dome, the horizontal lengths to this scale will give the radial thrust direct.

The pressure per lineal unit on any horizontal section is equal to the length of the radial line from O to the particular section measured by the modified scale just mentioned, divided by the radius length at this section.

The position of the joint of rupture is at an angle of about 51½° with the vertical, or where the tangent to the curve in fig. 12 is parallel to the loadline 0–12; this is also the point of no hoop stress.

The addition of a lantern, or other load, at apex of dome will raise the point O in load line, and also the joint of rupture; the formation of a central opening will depress the point O to level of edge of opening, and lower the joint of rupture.

This graphic method will similarly apply to conical coverings.

ARCHES.

The designing of concrete arched bridges as a rule should be undertaken only by experts, as the accurate determination of the stresses, and the economical arrangement of concrete and steel to resist those stresses, calls for a large amount of skill and experience. The following diagrams and brief explanations will serve to indicate the manner in which such arches can be designed, or the strength of existing arches calculated.

Arched bridges may be divided into three general types :—

1. That in which a continuous arch is provided, without joints or hinges, and connected rigidly to the abutments.

2. Where the arch is hinged or jointed at each abutment, but is continuous between these two points.

3. Where the arch is hinged or jointed not only at the abutments, but also at the centre.

The existence of a hinge or joint implies that any stress in the arch ring must pass through the centre of the joint, and it is necessary to keep this in view when drawing the equilibrium polygon, and to arrange that this polygon passes through the centre of all joints.

Fig. 13 indicates an arched bridge of the first type, viz., that in which no joints occur, and consequently the position of the stresses in the ring is not restricted, as it would be by the introduction of joints or hinges. The complete width of the bridge may be considered as divided up into a series of strips, each say 12 inches wide, and attention given to one strip only. In the event of any irregularity in the loading of one strip more than the other, as for instance the outer edge of the arch which carries the parapet wall, such a strip would be considered independently. The complete span would be divided into a number of sections as indicated by dotted lines, and the weight or load on each section carefully calculated ; these weights can be taken as acting each through the centre of gravity of the section.

Assuming in the first place that the total dead load is practically uniformly distributed over the length of the bridge, so that the weight or load at each section is equal, the shorter line of loads A, B, . . . K, to the right of the illustration can be set up, and a polar point, or pole, V, chosen. Since the load is uniformly distributed, the vertical reaction at each abutment will be equal to one half the total load, and as the closing line of the equilibrium polygon must be in the same line as that joining the two points in the abutments where it is desired that the resultant pressures should occur, and in this case these two points are on the same horizontal line, a horizontal line would be drawn from the centre of the line of loads and the point V chosen on this line, at such a distance from the load line as to limit the height or rise of the equilibrium polygon drawn on the arch ring, so that it may coincide, as nearly as possible, with the centre line of the arch. The approach of this polar point to the load line tends to raise the centre of the equilibrium polygon, while a movement in the opposite direction will depress the centre.

If the loading is not uniform, as for example where the live load covers half the length of the bridge, the load line would take the form somewhat as that indicated by the longer line A, B . . . K, and to determine in the first place the vertical reaction at each abutment, a focal point W is chosen at random. and an equilibrium polygon drawn, as shown below the arch ; the closing line of this latter, marked *a*, gives the direction in which a line must be drawn from the point W in the polar diagram, so that its intersection with the load line will divide this latter into two portions, the vertical height, A O, giving to scale the vertical reaction at the left abutment, or the A end of arch, while the lower length, O K, gives the corresponding value for the opposite abutment. Having found this point O, a horizontal line is drawn from O on which the new focal point X must lie, to ensure the starting and finishing point of polar diagram occurring at the required points on the abutments. The position of X must be chosen, by one or two trials if necessary, so that the equilibrium polygon line, as before, is as near as possible to the centre line of the arch ring.

If the ring is formed of stone or brick, and no tension can be resisted, it is essential that all equilibrium polygons, for any possible combination of loads, should lie within the middle third of the depth of the arch ring ; if a line of any of the polygons extends beyond this limit, tension stresses are likely to develop.

The length of the outer rays or lines on the polar diagram will give the values of the total resultant pressures at each abutment, and assuming that the abutments are of sufficient strength and stability to give this required resistance, the values calculated for the stresses in the arch ring by this method are correct. Should, however, the abutments tend to yield, the amount of horizontal reaction is limited in value, and the distance of the point X from the load line must not indicate a horizontal stress greater than the abutments can offer ; the equilibrium polygon drawn under these conditions would in all probability pass above the centre of the arch ring, and thereby indicate that excessive bending stresses arise in the ring, tending to cause failure or collapse through the arch sinking downwards. If by any means the abutments are forced together, or if the ring of the arch tends to increase in length, as by a rise of temperature, the polar point would tend to move further from the load line, and the equilibrium polygon would tend to fall below the centre of the arch ring, indicating the tendency of the ring to be forced upwards, heavy stresses being again produced.

In the case of types Nos. 2 and 3 the positions of the centre of the hinges or joints limit the position at these points of the equilibrium polygon, and in fig. 14 a diagram is shown of a

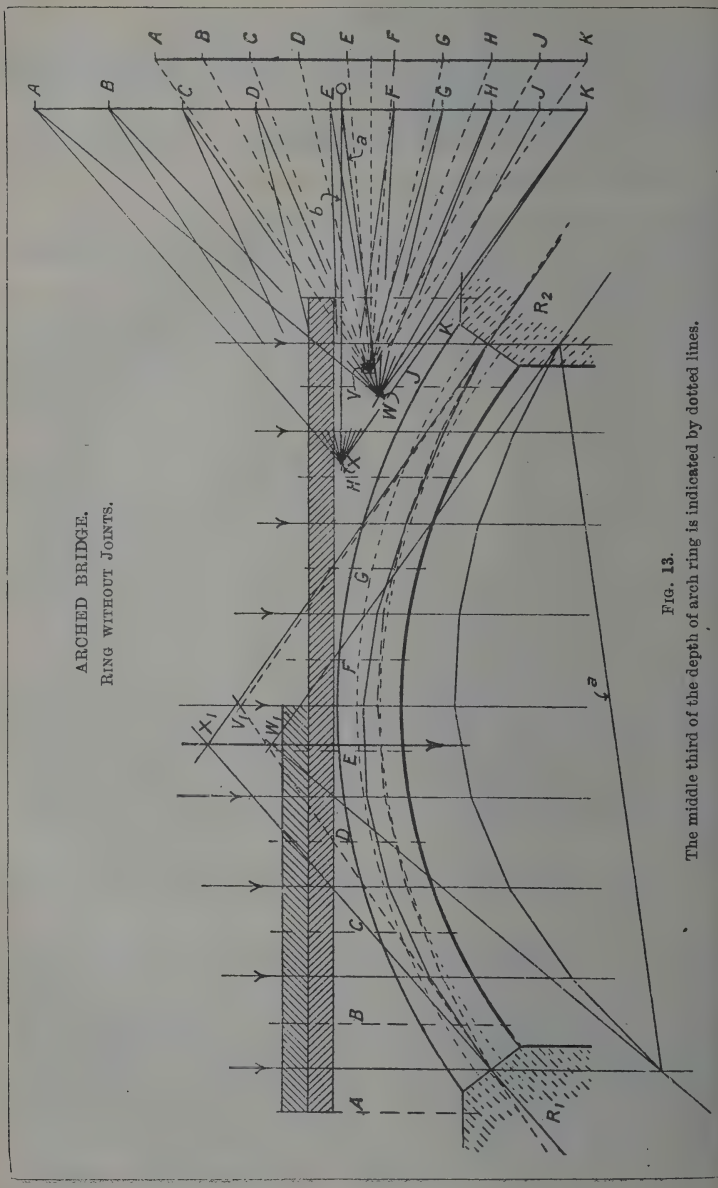
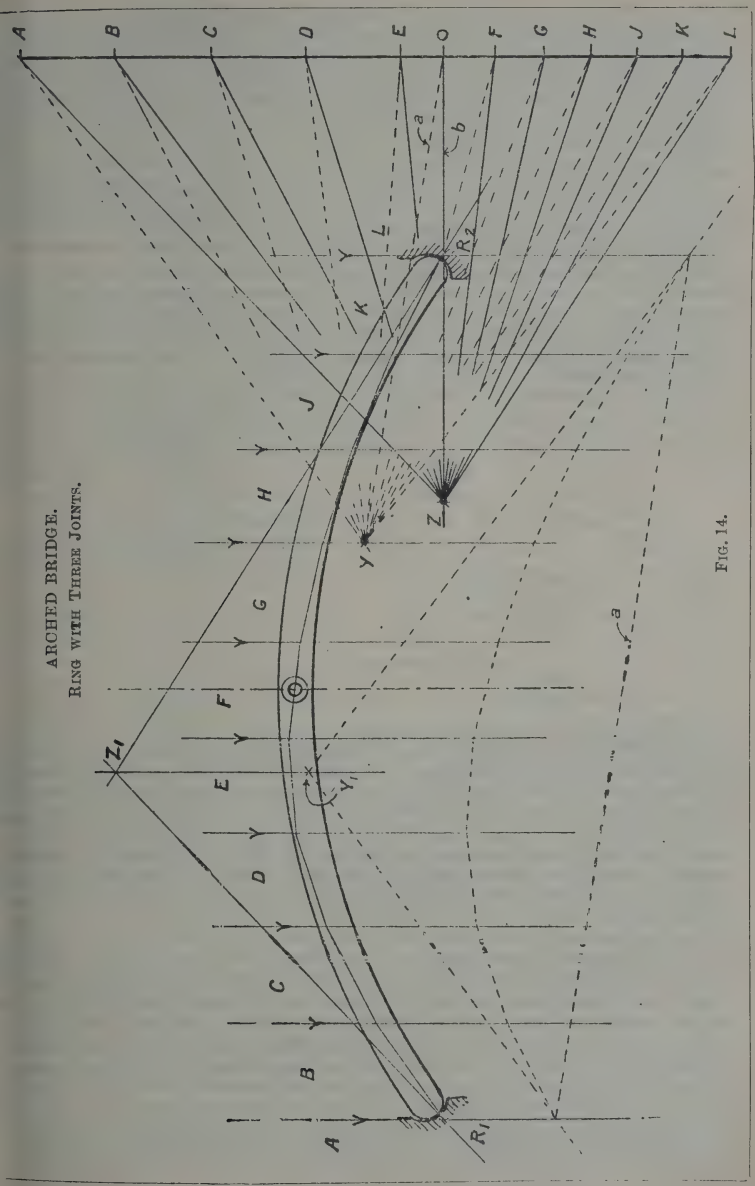


FIG. 13.

The middle third of the depth of arch ring is indicated by dotted lines.



ARCHED BRIDGE.
RING WITH THREE JOINTS.

FIG. 14.

three-hinge arch sustaining an unequally distributed load. After drawing the load line A, B. . . . L, a polar point Y is chosen, and the equilibrium polygon, shown in dotted lines, is completed, the closing line *a* determining the point O in the line of loads which divides this line into two sections, giving the vertical loads on the two abutments. A line from this point O drawn parallel to a line joining the centres of the hinges at the abutments, will give the line *b*, and on this line a point Z is chosen, such that the equilibrium polygon shown in full lines on diagram will pass through the centre hinge. If this centre hinge does not exist, as in type No. 2, the same process would be gone through, but here the aim would be to keep the equilibrium line as near the centre of the depth of the arch ring as possible.

The value of hinges or joints in the arch ring is that definite points are determined at the abutments through which the total thrust must pass, as also does a hinge in the centre of the rib; another marked advantage of a centre hinge is that a slight yielding of the abutment would imply only a drop in the centre of the ring, but would not induce the excessive bending stress such as would arise in the case of a ring without a centre hinge. Again, a slight lengthening in the arch due to a rise of temperature would not produce excessive stress, owing to the fact that the arch would be enabled to rise more or less freely in the centre.

In addition to drawing equilibrium polygons for the total dead load only, it is advisable in the majority of cases to draw similar polygons for live loads extending over say $\frac{1}{3}$, $\frac{1}{2}$, and $\frac{2}{3}$ of the complete span, and also for the live load confined to the centre of the bridge, and extending for one-fourth of the span on each side of the centre. No other arrangement of the live load is likely to give higher maximum stresses than got from these positions.

The next step necessary is to determine the actual stresses in the arch ring itself, and this may be done as follows :—

Figs. 15 and 16 indicate to a larger scale a portion of the arch shown in fig. 14 about

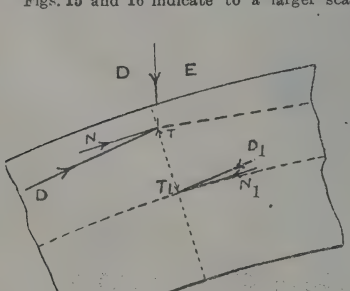


FIG. 15.

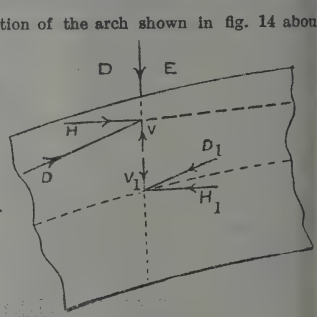


FIG. 16.

the point of application of the load D E. Taking in the first instance fig. 15, the value of the force or thrust, represented by the equilibrium polygon line 'D,' can be obtained by scaling the length of the line Z D in the polar diagram ; the effect of this eccentric load on the cross-section of the rib is equal to that of a single load of this value acting at the centre of gravity of the section (and producing a uniformly distributed compressive stress over the whole section), along with a couple value equal to the load or thrust, multiplied by its normal distance from the neutral axis of rib ; this couple produces a bending tendency, and gives rise to tensile stress at the distant edge and compressive stress at the near edge of the section. The combined result is an increase of compressive stress at the near edge, and a reduction at the far edge. As previously mentioned should the force act without the middle third of the depth of the ring, the tensile stress due to the couple will be in excess of the uniformly distributed compressive stress, and tension at the distant edge will arise.

Considering the bending moment effect of the couple referred to above, D, D_1, fig. 15, indicate the two forces forming the couple ; these are of value equal to the thrust indicated by the equilibrium polygon, the one acting along the polygon line, and the other at the neutral axis of the arch ring. Each of these forces may be resolved into two forces without altering the effect on the rib ; thus D may be resolved into a force N acting normal to the radius line (shown by a dotted line), and a small force T acting in the direction of the radius line. Similarly D_1 can be resolved into two forces N_1 and T_1, and as T and T_1 are of equal value, but act in opposite directions, these will neutralise or balance one another, with the result that the two forces N, N_1, acting normal to the radius line, will produce the same effect as the two original forces D, D_1. It may be pointed out that the normal force N alone serves to produce direct stress in the arch rib, the smaller resolved force T producing shearing stress : this shearing stress, however, is always very small and may frequently be neglected.

In calculating the bending moment by means of these resolved forces it is necessary to determine the value of N for each point under consideration ; these calculations, however, can be simplified by modifying this treatment, as indicated in fig. 16. Since the effect of the force

not altered by resolving it into any two forces, a vertical line may be chosen, and D resolved into force H acting horizontally, and V acting vertically ; D_1 would be similarly resolved into H_1 and V_1. A glance at the polar diagram will show that at any point in the equilibrium polygon the horizontal component of the thrust is constant, and can be determined by scaling the length O ; from this it will be evident that the values H, H_1 in fig. 16 will be constant for any section of the arch, and since V, V_1 neutralise one another, the constant forces H, H_1 remain. For any section of the ring, therefore, it is only necessary to carefully measure or calculate the vertical distance between polygon line and centre of gravity of the arch ring, and to multiply this by the constant horizontal thrust H, to determine the bending moment value at the point under consideration ; the addition of the uniformly distributed load value will give the complete stress throughout this section.

Thus, if the thrust H, fig. 16, is 40,000 lbs., the vertical distance between H and the neutral axis 8 ins., and the dimensions of the arch ring under consideration are 20 ins. deep × 12 ins. wide ; the uniformly distributed compressive stress throughout the section will be $\frac{40,000}{20 \times 12} = 167$ lbs. per sq. ft. ; the B M $= 40,000 \times 8 = 320,000$ inch lbs., and the maximum compression and tension stresses at upper and lower edges of the section $= \frac{320,000 \times 10 \times 12}{12 \times 20^3} = 400$ lbs. This gives the total maximum compression at the upper edge $= 167 + 400 = 567$ lbs. per sq. in., and the total tension at lower edge $= 400 - 167 = 233$ lbs. per sq. in., necessitating the addition of steel reinforcement at the tension portion.

Temperature stresses due to variations in the temperature of the arch may be considerable, and should be carefully examined ; a rise of temperature (by causing expansion) tends to increase the compression stress, while a fall has the opposite effect. The result is very similar to that of increasing or reducing the horizontal thrust (or the distance Z O in the polar diagram) throughout the arch. Owing to the mass of the materials, and its non-conducting nature, the range of temperature in concrete arches will probably not exceed 15° to 20° Fahr. between summer and winter seasons.

Specification for Reinforced Concrete Work.

The following sketch specification may be of assistance. It can be modified to any required extent to meet special conditions.

(Date) ..... Specification for Reinforced Concrete Work to be executed in erecting New Premises at ..... for Messrs. .....

Engineer.

Architect.

General Description and Conditions.—The Structure will be erected in strict accordance with the Engineer's Drawings Nos. ..... and ..... and to any further Detail Drawings to be afterwards provided.

The Structure will consist of (*give general description*). The Foundations shall be taken out to *the clay, ballast ?*). The Maximum Load at this point must not exceed ..... tons per square foot. The average depth of foundations may be assumed as ..... below datum level.

The whole of the work included in this Contract shall be constructed of the best materials and workmanship, and shall be carried out to the entire approval of the Consulting Engineer, and be completed to his satisfaction.

No variations or alterations from Specification or Drawings shall be permitted unless same are approved in writing by the Consulting Engineer.

Immediately on acceptance of his tender, the Contractor must provide a complete and detailed Bill of Quantities (priced in ink) for this work. Should any variations or alterations occur during the carrying out of the work, the variations shall be measured up and priced according to the Bill of Quantities, and any necessary additions or deductions thereafter made from the quoted lump sum price. Any materials or labour required during the progress of the work which are not indicated in the Bill of Quantities shall be paid for at Rates or Prices to be agreed with the Engineer.

The Contractor will be responsible for meeting all requirements of the London County Council, or other Local Authorities, with regard to the mode of construction or the carrying out of same, and shall at once notify the Consulting Engineer should such requirements necessitate any modification in his designs or details.

The Contractor will be held responsible for setting out the Works, and for amending any errors due to inaccuracy, or other cause, at his own cost.

The Contractor must provide for these Works all labour, tools, tackle, boards, horsing, centering, scaffolding, cartage, water, etc.

The Contractor must provide and maintain proper sheds, latrines, and other accommodation for the use of workmen, and proper sheds and shelters for the protection of materials.

The Contractor will be held responsible for all losses, accidents, and damages that may happen to the works, adjoining properties, or persons during the progress, and caused by the execution of the Works.

The Contractor will be bound to complete all the Works contained in this Specification, etc. within ..... months of the date of signing the Contract or obtaining possession of site under the penalty of ..... per week or part of a week as liquidated and agreed damages, except the delay in the opinion of the Engineer arises from causes beyond the control o the Contractors, in which case the Engineer shall grant an extension of time in writing.

The Contractor must allow for making good at his own expense any defect or defects which may become noticeable in the Works during a period of twelve months after certified completion

Samples.—Samples of all materials must be submitted to the Consulting Engineer, and approved by him in writing before same are used. All materials rejected must be removed immediately from the vicinity of the Works.

Cement.—The Cement used must be the best quality of British Portland Cement, of a approved make, and guaranteed to conform to the Specification of the British Standards Com mittee for slow-setting cement. Before being used all Cement must be tested, as required by th Engineer, at the Contractor's expense. The Cement should be delivered to the Site in sealed bag bearing the maker's name and the weight of the cement contained.

Cement shall be stored on the Site in such a manner as to permit of easy access for proper inspection and identification. The building used for same must be raised from the ground, an properly weatherproofed to protect the cement.

Sand.—The Sand used shall be clean, sharp, and coarse, composed of grains of various sizes u to particles which shall pass a $\frac{1}{4}$-inch square mesh, but of which at least 75 per cent. shall pas a $\frac{1}{8}$-inch square mesh. It shall be free from all ligneous, organic, or earthy matter.

Aggregate.—This must be composed of Thames ballast; screened, broken stone of a har close-grained quality; or gravel, cleaned free from organic matter, and angular, varied in size a much as possible, and to pass through a $\frac{3}{4}$-inch ring, but not through a $\frac{1}{4}$-inch ring.

Proportions of Concrete.—(*Here specify the composition of concrete, which for usual requirement may be* 1 *part cement*, 2 *sand*, 4 *aggregate. Foundations are frequently made of a weaker mixtur say* 1 : 3 : 6.) These proportions are approximately correct, but in all cases sufficient sand must b added to fill the interstices. The proportioning should be done in an approved manner, as b means of a bottomless box, to insure each of the materials being accurately measured.

Mixing of Concrete.—The concrete must be thoroughly well mixed in a suitable machin sufficient clean water being added to convert the whole into a semi-liquid mass, which will quive under the blows of the rammer. The water for each batch of concrete must be measured in small tank, so as to insure the same amount being used each time. When consent is given to mi any of the concrete by hand, it shall be done as follows:—The necessary quantity of the thre materials—coarse aggregate, sand, and cement—shall be measured separately, 5 per cent. mor cement being added in addition to the above specified amount. The materials should first b thoroughly mixed dry, then the necessary amount of water added, and the mixing continued till th concrete shows a uniform colour. As far as possible, the mixture shall always be brought to the sam degree of wetness. A competent foreman must be in constant attendance at the mixer, to give hi approval of every batch which leaves the machine.

Allowable Working Stresses.—(*Here specify maximum stresses desired, or state requirements t be those embodied in Report of R.I.B.A. Joint Committee.*)

Steel Reinforcement.—All steel used should have a tensile strength of not less than 60,000 lb per square inch of section, and an elastic limit of not less than 50 per cent., nor more than 60 pe cent. of the ultimate tensile strength, with an elongation of not less than 20 per cent. in a lengt of 8 ins. Any bar must stand bending cold round a bar of its own diameter, through an angle o 180°, and should close down upon itself without fracture on the outside of the bent portion. A welding will be prohibited, unless where absolutely necessary, and must be done only with th sanction of the Consulting Engineer.

All bars shall be free from scale, flaws, or other imperfections, and from oil, but a slig coating of rust is not objectionable. Wherever cinder concrete is used, the bars before bein placed in position should receive a coating of neat cement grouting.

Any temporarily protruding bars which shall be exposed to the weather for any period mus be protected from rusting by a thin coat of cement grout.

Centering.—All centering must be of dressed timber with close joints, and must be true to lin and sufficiently braced and strutted to be rigid and free from measurable deflection when carryin the dead load of the concrete which is to be placed upon it. A slight camber of $\frac{1}{4}$ in. per 10 ft. span should be given to all beams, &c. It must also be without appreciable deflection when me are working upon it, and barrows, &c., are being wheeled over it. The joints must be tight, so a to prevent leakage of the liquid cement. The centering shall be arranged so that the sides of th columns can first be removed, then that at the side of beams, and below floor slabs, and final that below the beams themselves. The time of removal of these several portions shall be arrange with the Consulting Engineer.

Placing of Reinforcement.—All bars must be accurately placed in the exact position shown o the detail drawings, and great care must be taken that they are not displaced during the proce of packing the concrete around them. Where, for unavoidable reasons, it is necessary to stop th concreting work, care must be taken to place in position all the bars which will be embedded i the portion of the concrete work which is being executed.

Placing of Concrete.—Before any concrete is put in position a careful inspection of the centering must be made, to ascertain that no dirt, shavings, loose stones, etc., have been allowed to remain in or about the centering, and the woodwork should be well watered to avoid any danger of its sucking up too much moisture from the concrete.

All concrete shall be placed in its final position in the work as soon as possible after mixing. In no case must more than half-an-hour be allowed to elapse before this is done. The concrete must be placed gently into position, in layers not exceeding 6 inches thick, and must not be tipped or dropped from a height. It must then be thoroughly rammed into position, great care being taken to see that the steel reinforcement is thoroughly surrounded by the liquid cement, and that no voids or cavities are left. This can be insured only by repeated ramming with a suitable tool.

In hot weather the concrete shall be continually moistened for at least a week after placing in position.

In beams and slabs, if any difficulty is found in getting the concrete to pass through the bars which have been placed in position in the bottom of the timber centering, the concrete at the bottom of the beam should be made of finer and more liquid consistency than that used elsewhere, so that it may freely pass between the bars.

Cessation and Recommencement of Work.—Stoppage of work in laying concrete in slabs, beams, etc., will be allowed only at the centre of the span of the slab, or a beam, and the joint with the new concrete should be a vertical plane at right angles to the direction of the span of beam or slab. No joint must be made towards the ends of beams or slabs, or close to a concentrated load.

Wherever a stop has been made in concreting, before recommencing the work, the surface of the existing concrete must be carefully washed with a stiff brush to remove loose particles and dust, and a thick grout of neat cement must be poured over it before the concrete is rammed against it.

Frosty Weather.—No concreting work should be done when the temperature is near or below freezing point. If a frost comes on shortly after any concreting work has been completed, this should be very carefully covered over with sawdust, straw, or sacking, and the centering must be allowed to remain up for at least as long a time after the complete disappearance of the frost as it would have been left in position if no frost had occurred.

Finish.—All concrete roofs and gutters must be laid with the necessary fall, and finished for asphalte, all as may be directed.

All floors shall be finished. (*Here state whether cement, granolithic, preparation for wood blocking, or other covering is desired.*)

The top surface of all outside walls to be weathered.

Tests.—The Maker's Certificate must be provided, when required, with each lot of steel reinforcing bars supplied, but in addition to this the Consulting Engineer shall choose whatever test pieces he may desire from the material delivered, and shall have same tested by Messrs. Kirkaldy, or other firm, and should the result not comply with Specification the right is reserved to condemn all bars included in same consignment.

The cement shall be tested as required, and must comply with the Specification. Cubes of concrete from the material used shall be made as and when directed, and these shall be tested for crushing strength by Messrs. Kirkaldy, or other firm.

The Consulting Engineer shall select at least one bay in each floor, or the equivalent, and these bays shall be tested to $1\frac{1}{2}$ times the safe superimposed load, by means of bricks, cement bags, or in such other manner as the Engineer may decide. Should the deflection under this test exceed $\frac{1}{360}$th part of the span, or should the beam or floor slab fail to regain its normal position after the removal of the load, or show any indication whatever of weakness, the building shall be considered unsafe, and the contractor shall carry out at his own expense such additional work as the Engineer may consider necessary to make the building secure.

The cost of all such testing shall be borne by the Contractor.

Practical Notes.

Wood Strips.

Particularly long lengths of wood for nailing strips in concrete beams should be avoided; they have been known to absorb the moisture from the concrete, and cause serious cracks in the beams. Short plugs are the safest, and where a nailing strip must be used flush with beams, a moulded impress of the wood strip should be made and the strip then removed, and only fixed when the concrete beam is thoroughly dry, it being then secured by means of the plugs. (*Horobin.*)

Durability.

Reinforced concrete will last as long as plain concrete in any situation provided that certain special precautions are taken during its construction. The precautions to be taken are as follows: The materials (cement, sand, and stone) must be of good quality. They must be most carefully and thoroughly mixed and scientifically proportioned, so as to be practically water-proof and air-proof. The mixture must be fairly wet, and must be well punned into position so as to minimise voids. The aggregate should be as non-porous as possible, and any aggregate which

is known to have a chemical action on steel should be avoided. The aggregate should all pass through a $\frac{3}{4}$ in. mesh. The concrete covering should in no case be less than $\frac{1}{2}$ in., and it is suggested that if round or square bars be used the covering should not be less than the diameter of the bar. In structures exposed to the action of water or damp air the thickness of covering should be increased at least 50 per cent., or the size of the aggregate should be reduced so as to ensure a dense skin. In the case of structures exposed to very severe conditions the concrete might be covered with some impervious coating as an extra precaution. The reinforcement should be so arranged that there shall be sufficient space between one piece and its neighbour to allow the concrete to pass and to completely surround every part of the steel. All steel should be firmly supported during the ramming of the concrete, so as to avoid displacement. It should not be oiled or painted, and thick rust should be scraped and brushed off before placing. The scantling of the various members of the structure should be sufficient to prevent excessive deflection. If electric mains are laid down very great care must be taken that no current is allowed to pass through the reinforced concrete. Fresh water should be used in mixing, and aggregates charged with salt should be washed. These recommendations have regard only to the prevention of corrosion of steel and not to fire-resistance or any other property of reinforced concrete. (*Committee of the Concrete Institute.*)

Causes of Failures in Concrete Structures.

Owing to the failure of several reinforced concrete floors in the United States within ten or a dozen years of their construction, Prof. H. J. M. Creighton, of Swarthmore College, examined a large number of reinforced concrete structures in which cracks were developing, and found that in every case the cracks ran along the reinforcing rods, due to the deteriorating action of salt and brine on the concrete. Solutions of the chlorides reacted with the lime and the silicates in the concrete, and penetrating to the iron of the reinforcement converted it into oxide and hydrate, which occupy more space than the metal and force the concrete apart. It was therefore necessary to waterproof reinforced concrete structures which will be in contact with brine, to cease to use in the concrete beach gravel which has not been thoroughly washed with fresh water, and never to add salt to the concrete to prevent it freezing during building operations in cold weather.

Cracking.

According to a recent report, the cracking of reinforced concrete structures is markedly prevalent in the Philippine Islands. A study of this trouble has shown that not a single structure showing rusted steel has been free from salt, the percentage of which varies considerably. In view of this, engineers in the Philippines have been advised that not only is the use of salt water dangerous in concrete structures, but that beach sand and beach gravel should be employed only after having been thoroughly washed with fresh water. The foregoing, and many other similar pieces of evidence, indicate that salt and brine exert a deteriorating action on concrete.

Specification Notes.

Specifications governing concrete construction generally require that 1–2–4 concrete be used in the best class of reinforced concrete construction. In other reinforced concrete work, and in some mass concrete work, 1–3–5 concrete is specified, while in other mass work, such as dams, gravity retaining walls, etc., 1–3–6 concrete is generally required.

TABLE GIVING THE SECTIONAL AREAS OF **Round and Square Rods** AT VARIOUS DISTANCES APART, IN 12-INCH WIDTH OF SLAB.

Diameter in Ins.	Circumference in Ins.	Area in Sq. Ins.	Distance in Inches from Centre to Centre of **Round** Rods.										
			2½	3	4	5	6	7	8	9	10	11	12
¼	0·785	0·049	0·24	0·20	0·15	0·12	0·10	0·08	0·07	0·06	0·06	0·05	0·05
5/16	0·982	0·077	0·37	0·31	0·23	0·18	0·15	0·13	0·11	0·10	0·09	0·08	0·08
⅜	1·178	0·110	0·53	0·44	0·33	0·26	0·22	0·19	0·16	0·15	0·13	0·12	0·11
7/16	1·374	0·150	0·72	0·60	0·45	0·36	0·30	0·25	0·22	0·20	0·18	0·16	0·15
½	1·571	0·196	0·94	0·78	0·59	0·47	0·39	0·33	0·29	0·26	0·23	0·21	0·20
9/16	1·767	0·248	1·19	0·99	0·74	0·59	0·50	0·42	0·37	0·33	0·30	0·27	0·25
⅝	1·964	0·307	1·47	1·23	0·92	0·74	0·61	0·52	0·46	0·41	0·37	0·33	0·31
11/16	2·160	0·371	1·78	1·48	1·11	0·89	0·74	0·63	0·56	0·49	0·44	0·40	0·37
¾	2·356	0·442	2·12	1·77	1·32	1·06	0·88	0·75	0·66	0·59	0·53	0·48	0·44
13/16	2·552	0·518	2·49	2·07	1·55	1·24	1·04	0·88	0·78	0·69	0·62	0·56	0·52

TABLE GIVING THE SECTIONAL AREAS OF **Round and Square Rods** AT VARIOUS DISTANCES APART, IN 12-INCH WIDTH OF SLAB—*continued.*

Diameter in Ins.	Circumference in Ins.	Area in Sq. Ins.	Distance in Inches from Centre to Centre of **Round** Rods—*continued.*										
			2½	3	4	5	6	7	8	9	10	11	12
7/16	2·743	0·601	2·89	2·40	1·80	1·44	1·20	1·02	0·90	0·80	0·72	0·65	0·60
15/32	2·945	0·690	3·31	2·76	2·07	1·66	1·38	1·17	1·03	0·92	0·83	0·75	0·69
1	3 142	0·785	3·77	3·14	2·36	1·88	1·57	1·33	1·18	1·05	0·94	0·86	0·78
1 1/16	3·338	0·887	—	3·55	2·66	2·13	1·77	1·51	1·33	1·18	1·06	0·97	0·89
1 1/8	3·534	0·994	—	3·98	2·97	2·39	1·99	1·69	1·49	1·32	1·19	1·08	0·99
1 3/16	3·731	1·107	—	—	3·32	2·66	2·21	1·88	1·66	1·48	1·33	1·21	1·11
1 1/4	3·927	1·227	—	—	3·68	2·94	2·45	2·09	1·84	1·64	1·47	1·34	1·23
1 5/16	4·123	1·353	—	—	—	3·25	2·71	2·30	2·03	1·80	1·62	1·47	1·35
1 3/8	4·320	1·485	—	—	—	3·56	2·97	2·52	2·23	1·98	1·78	1·62	1·48
1 7/16	4·516	1·623	—	—	—	—	3·25	2·76	2·43	2·16	1·95	1·77	1·62
1½	4·712	1·767	—	—	—	—	3·53	3·00	2·65	2·36	2·12	1·93	1·77

Side in Ins.	Perimeter in Ins.	Area in Sq. Ins.	Distance in Inches from Centre to Centre of **Square** Rods.										
			2½	3	4	5	6	7	8	9	10	11	12
1/4	1·00	0·063	0·30	0·25	0·19	0·15	0·13	0·11	0·09	0·08	0·07	0·07	0·06
5/16	1·25	0·098	0·47	0·39	0·29	0·23	0·20	0·17	0·15	0 13	0·12	0·11	0·10
3/8	1·50	0·141	0·68	0·56	0·42	0·34	0·28	0·24	0·21	0·19	0·17	0·15	0·14
7/16	1·75	0·192	0·92	0·77	0·58	0·46	0·38	0·33	0·29	0 26	0·23	0·21	0·19
½	2·00	0·250	1·20	1·00	0·75	0·60	0·50	0·43	0·37	0·33	0·30	0·27	0·25
9/16	2·25	0·317	1·52	1·27	0·95	0·76	0·63	0·54	0·47	0·42	0·38	0·34	0·32
5/8	2·50	0·392	1·88	1·57	1·77	0·94	0·78	0·67	0·59	0·52	0·47	0·43	0·39
11/16	2·75	0·474	2·27	1·90	1·42	1·14	0·95	0·81	0·71	0·63	0 57	0·52	0·47
¾	3·00	0·564	2·71	2·26	1·69	1·35	1·13	0·96	0·84	0·75	0·68	0·61	0·56
13/16	3 25	0·661	3·17	2·64	1·98	1·59	1·32	1·13	0·99	0·88	0·79	0·72	0·66
7/8	3·50	0·767	3·68	3·07	2·30	1·84	1·53	1·31	1·15	1·02	0·92	0·84	0·77
15/16	3·75	0·881	4·23	3·52	2·64	2·11	1·76	1·51	1·32	1·17	1·03	0·96	0·88
1	4·00	1·000	4·80	4·00	3·00	2·40	2·00	1·71	1·50	1·33	1·20	1·09	1·00
1 1/16	4·50	1·266	6·08	5·06	3·80	3·04	2·53	2·16	1·90	1·69	1·52	1·38	1·27
1 1/8	5·00	1·575	7·56	6·30	4·72	3·78	3·15	2·69	2·36	2·10	1·89	1·72	1·57
1 3/16	5·50	1·905	9·14	7·62	5·71	4·57	3·81	3·26	2·86	2·54	2·29	2·08	1·90
1¼	6·00	2·253	10·81	9·01	6·76	5·41	4·51	3·85	3·38	3·00	2·70	2·45	2·25

REINFORCED CONCRETE FOR FACTORY WORK.

One of the objections to the employment of reinforced concrete for factory work has been e difficulty experienced in attaching shaft hangers, pipe lays, and other fixtures, because of e hardness of the material. *Building Products Ltd.* (51 Columbia House, 44/46 King's Road, elsea, S.W. 3) claim to have solved the problem by employing standard pressed steel fittings led RIGIFIX bolt-hanger sockets and slotted inserts. These are embedded in the beams and umns of the building during course of construction. The bolt-hanger sockets are placed at ed points to receive a ⅜-in. or ⅝-in. bolt. The inserts are supplied in 12 in., 18 in., and 36 in. gths, the runway being provided with a slot to receive a ⅜-in. or ⅝-in. bolt, which can be moved any point on the length. Many modern factories have adopted these fitments.

SECTION XII

EARTHWORK — EXCAVATION — FOUNDATIONS — PILING — SCAFFOLDING — STAGINGS — SHORING — DAMS — RETAINING-WALLS — CHIMNEYS — STONE AND BRICK ARCHES — PIERS — BRIDGES

(With contributions by Reginald Ryves, A.M.Inst.C.E.)

SECTION XII

EARTHWORK — EXCAVATION — FOUNDATIONS — PILING — SCAFFOLDING — STAGINGS — SHORING — DAMS — RETAINING-WALLS — CHIMNEYS — STONE AND BRICK ARCHES—PIERS—BRIDGES.

EARTHWORK.

To determine the Volume of Earth in a Railway Cutting.

First Method.

Divide the length of the cutting into an *even* number of equal parts, and take the areas of the transverse sections at the points of division. Add together the areas of the extreme sections, twice the sum of the areas of all the intermediate sections of an *odd* order, and four times the sum of the areas of all the intermediate sections of an *even* order, and multiply by the distance between two consecutive sections; the product will be three times the volume.

Second Method.

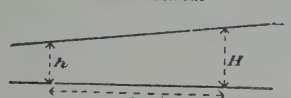


FIG. 124.

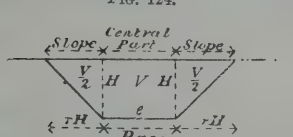


FIG. 125.

H, h = heights of section, in feet, at each end of a length, l, in feet (fig. 124).

rH breadth of each slope at one end (fig. 125).

rh breadth of each slope at other end.

(r ratio of breadth of each slope to height = $\frac{\text{breadth}}{\text{height}}$).

e = base.

$\frac{A}{2}$ = area of each slope at one end.

$\frac{a}{2}$ = area of each slope at other end.

V = cubic contents of both slopes = $\frac{1}{2}(A + \sqrt{Aa} + a) \times l = \frac{1}{2}r(H^2 + Hh + h^2) \times l$.

V = cubic contents of centre = $\frac{1}{2}(H + h)e \times l$.

Q = cubic contents of length, l, in feet = V + V.

Third Method.

If the transverse section is on an incline, instead of horizontal, as in figs. 126 and 127, then, if A, A′, a, and a' are the respective areas of the ends of the slopes,

$$V = \tfrac{1}{3}(A + \sqrt{Aa} + a) \times l + \tfrac{1}{3}(A' + \sqrt{A'a'} + a') \times l. \qquad V = \tfrac{1}{2}(H + h)e \times l.$$

The longitudinal section of the line of railway, road, or canal, having been drawn, and the gradients laid off, the quantities of earthwork may be calculated as follows :—

If the ground is tolerably even, record the heights (or depths in cuttings) on the section at every 100 feet, or some other convenient distance. The sectional areas at each of these recorded heights (or depths) may then be calculated.

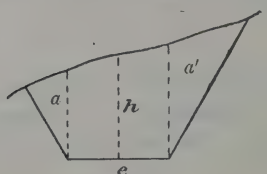


FIG. 126.

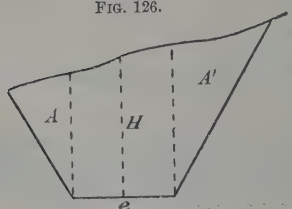


FIG. 127.

Let
A = area of section, $s = s$ to 1 slope,
h = height or depth of section,
F = width at formation-level,

all expressed in feet ; then, if the slopes on both sides are the same, as is usually the case,

$$A = h(sh + F).$$

By this formula the areas of the first three sections of a series increasing in height regularly are calculated, and from them the remainder are at once written down by the method of second differences, as follows :

Assume heights to be 1, 2, 3, 4, 5 feet,

$$F = 10, \quad s = 2 \text{ to } 1.$$

Then

		Difference.	Second Difference.
A for 1 ft. =	12		
		16	
„ 2 „ =	28		4
		20	
„ 3 „ =	48		
		$\frac{4}{2\cdot4}$	—
„ 4 „ =	72..		
		$\frac{4}{2\cdot5}$	—
„ 5 „ =	100..		

and so on.

If the cross-slope of the ground is not much, and the areas of the sections do not differ very widely, the quantity of earthwork may be found by taking the mean of the two areas and multiplying by the distance between them, thus :

A′ = area of first section ; A″ = area of second section ; d = distance apart.

$$\text{Cubic contents} = d \frac{A' + A''}{2} \text{ feet.}$$

When the cross-slope is considerable, and the heights of the section differ widely, cross-sections must be taken at each place, and their areas calculated independently, and the cubic contents should then be calculated by the *First Method.*

Earthwork Tables.*

(H. R. Kempe.)

The tables on pages 589 to 594 are for the purpose of facilitating the calculation of the volumes of earthwork.

V = cubic contents, in *yards*, of both slopes.
V = cubic contents, in *yards*, of centre part.

V is calculated from the formula

$$V = \tfrac{1}{3}r(H^2 + Hh + h^2) \times l,$$

r being = 1, l = 1 chain = 66 feet, and H and h being in *feet* ; so that

$$V = \tfrac{1}{3}(H^2 + Hh + h^2)\,66 \div 27 = \cdot 814815\,(H^2 + Hh + h^2) \text{ cubic yards.}$$

V is calculated from the formula

$$V = \tfrac{1}{2}(H + h)e \times l,$$

e being = 1 foot ; so that

$$V = \tfrac{1}{2}(H + h)\,66 \div 27 = 1\cdot 22222\,(H + h) \text{ cubic yards.}$$

For any slope other than 1 to 1 the values of V in Table I. must be multiplied by r, that is by $\frac{\text{breadth of slope}}{\text{height of slope}}$. Table II. gives the values of V and V for slopes of 1 to 1½.

* Revised 1920.

EXAMPLE.—The length of a cutting is 3 chains, the width 10 feet, the $\frac{\text{breadth of slope}}{\text{height of slope}} = 2$, the height at one end 20 feet, and at the other end 15 feet; what is the cubic content of the cutting?

From table (page 590), $V = 753{\cdot}70$, $V = 42{\cdot}78$: then,

total cubic content $= (753{\cdot}70 \times 2 + 42{\cdot}78 \times 10)3 = 5805{\cdot}60$ cubic yards.

Excavation.

A good excavator will dig and throw into a barrow in a day of 10 hours:

In common ground, from 8 to 10 cubic yards. In stiff clay or firm gravel, 6 cubic yards. In hard ground, where picking is required, from 3 to 5 cubic yards.

One excavator to 5 or 6 feet breadth of face of a cutting is as near as they should be.

A shoveller will throw each shovelful of earth from 6 to 10 feet horizontally, or from 4 to 5 feet vertically upwards.

PROPORTION OF EXCAVATORS, SHOVELLERS, AND WHEELERS (100 to 120 ft.).

Material.	Excavators.	Shovellers.	Wheelers.
Loose sand and vegetable moulds	0	1	1
Compact earth	$\frac{1}{2}$	1	1
Ordinary clay	$\frac{1}{2}$ to 1	1	1
Hard clay	$1\frac{1}{2}$ to 2	1	1

The rate at which a cutting may be expected to advance will be, for each line of wheelers or for each shoveller, in one rank:

20 cubic yards of loose sand or mould a day. 16 cubic yards of clay or compact earth a day.

Excavating Machinery.

Dry land excavating machinery may be divided into two principal types, namely power shovels—sometimes known as power navvies—and dragline excavators, the essential difference being that the former is equipped with a rigid handle carrying a bucket, which is forced upwards through the soil by a positive control, the motion being, therefore, upwards and away from the machine, while the dragline excavator, on the contrary, has its bucket suspended from a wire rope at the end of a long jib, and drags this bucket through the earth towards the machine by means of another wire rope. Thus the shovel is principally used for excavation against a bank or face of material, while the dragline digs from below its own level, and is therefore much used on canal excavation, very frequently excavating from below water level.

Modern steam shovels and dragline excavators range in size from machines of some 20 tons, with $\frac{1}{2}$ cubic yard bucket, to immense excavators weighing up to 350 tons, and equipped with an 8 cubic yard bucket.

The larger types of shovel and dragline may be driven by steam or electricity, and the smaller types—up to about $1\frac{3}{4}$ cubic yard capacity bucket—by steam, electric, petrol, or Diesel engine.

Modern practice is to equip all the smaller and some of the larger types with caterpillar traction in place of the old railway or road wheels.

Particulars of several sizes of shovels and draglines are given below.

RUSTON EXCAVATORS.

(*Ruston & Hornsby, Ltd., Lincoln.*)

These excavators are divided into three groups or types:

(1) Crane Navvies. (2) Dragline Excavators. (3) Railroad type Shovels.

Items Nos. 1 and 2 are of the full circle type, and in the case of No. 3, the swing of the jib is restricted to approximately 180°.

CRANE NAVVIES.

Size of Machine.	Jib Centres.	Bucket Capacity.	Nett Weight.		Approximate Output per Day of 10 Working Hours.
			Rail Wheels.	Caterpillars.	
	Ft. Ins.	Cu. Yds.	Tons.	Tons.	Cu. Yds.
No. 4	16 9	$\frac{1}{2}$	$11\frac{3}{4}$	14	300 to 400
No. 6	20 0	$\frac{5}{8}$	21	25	400 to 600
No. 10	29 0	$1\frac{1}{4}$	36	46	800 to 900
No. 15	28 0	$2\frac{1}{4}$	48	62	1,200 to 1,400
No. 20	31 0	$2\frac{3}{4}$	61	82	1,500 to 1,700
No. 135	60 0	$2\frac{3}{4}$	150	—	1,400 to 1,600
No. 300	80 0	6	320	—	3,000 to 4,000

DRAGLINES.

Size of Machine.	Jib Centres.	Bucket Capacity.	Nett Weight.		Approximate Output per Day of 10 Working Hours.
			Rail Wheels.	Caterpillars.	
	Ft. Ins.	Cu. Yds.	Tons.	Tons.	Cu. Yds.
No. 4 . .	22 0	$\frac{1}{2}$	$11\frac{3}{4}$	14	200 to 300
No. 6 . .	30 0	$\frac{3}{4}$	$20\frac{1}{2}$	$25\frac{1}{2}$	360 to 550
No. 10 . .	40 0	$1\frac{1}{4}$	$34\frac{1}{2}$	$44\frac{1}{2}$	700 to 800
	60 0	$2\frac{1}{4}$			
No. 75 .	70 0	$1\frac{3}{4}$	75	93	600 to 1,100
	80 0	$1\frac{1}{2}$			
	70 0	4			
No. 135 .	80 0	$3\frac{1}{2}$	142	—	1,000 to 2,000
	90 0	3			
	100 0	$2\frac{3}{4}$			
	90 0	6			
No. 180 .	100 0	5	195	—	1,100 to 3,000
	120 0	4			
	140 0	3			
No. 300 . .	100 to 160 ft.	10 to 5	316	—	1,700 to 4,000

The railroad shovels are made in two sizes, Nos. 30 and 40, with buckets of $3\frac{1}{2}$ and $4\frac{1}{2}$ cubic yards capacity.

Output.—The output figures given represent average outputs when machines are working in easy material such as sand, loose earth, etc., with skilled operating crew and adequate wagon service.

When working in medium clay, the output will be reduced by approximately 20 per cent. and when excavating stone, outputs can only be determined after an inspection of the actual conditions.

Varying jib lengths and bucket capacities can be fitted to the Nos. 20, 135, and 300 crane navvies and Nos. 75, 135, 180, and 300 draglines, *e.g.* on the No. 300 dragline machine, in place of the 120 ft. jib with 8 cubic yard bucket there can be supplied a 160 ft. jib and a 5 cubic yard bucket.

Sizes Nos. 6 and 10 are universal machines, *i.e.* convertible from crane navvies into dragline excavators and grabbing cranes, or from dragline excavators into crane navvies and grabbing cranes. These machines can also be used as travelling cranes and pile drivers.

Costs.—The cost of excavation per cubic yard varies according to the output, nature of material, depth of face, local fuel and labour costs.

The saving possible by mechanical excavation over hand excavation is definite in most cases, and it is possible to get excavation costs down to $1\frac{1}{2}$d. per cubic yard, when working in easy material and where the disposal arrangements can handle the full output of the machine.

With moderate outputs and working in clay, the cost per cubic yard, including full depreciation and maintenance charges, would range from 3*d.* to 6*d.*

Operating Crew.—The crew required to operate 'Ruston' excavators comprise one driver and a youth as fireman; and in the case of caterpillar machines, one or two men in the bottom. With rail wheel machines up to the No. 20, two to four men in the bottom are called for, and on the larger machines, six men in the bottom.

The dragline excavator can be used for under-water excavation, and has successfully carried out the cutting of new waterways and the cleaning out of existing waterways. In India, 'Ruston' No. 300 draglines are now engaged in excavating waterways having a bottom width of 280 ft.

In addition to steam operation, 'Ruston' excavators can be supplied for electrical and internal combustion engine drive.

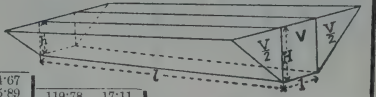
See also Excavating (Mechanical)—'Cost of Engineering Works,' Section XLV.

Shrinkage of Materials.

In estimating the relative amounts of excavation and embankment required, allowance must be made for difference in the spaces occupied by the material before excavation and after it is settled in embankment. The shrinkage of the different materials is about as follows:—

Gravel	8 per cent.	Loam and light sandy earths .	12 per cent.
Gravel and sand . . .	9 per cent.	Loose vegetable soil . .	15 per cent.
Clay and clay earths .	10 per cent.	Puddled clay	25 per cent.

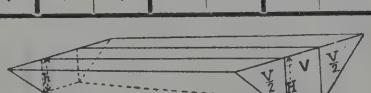
Rock, on the other hand, increases in volume by being broken up, and does not settle again into less than its original bulk. The increase may be taken at 50 per cent. Thus, an excavation of loam measuring 1,000 cubic yards will form only about 880 cubic yards of embankment, or an embankment of 1,000 cubic yards will require about 1,120 cubic yards measured in excavation to make it. A rock excavation measuring 1,000 cubic yards will make from 1,500 to 1,700 cubic yards of embankment, depending upon the size of the fragments.



H	h = 0		1		2		3		4		5		6		7		8		9	
	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**
1	·81	1·22	2·44	2·44																
2	3·26	2·44	5·70	3·67	9·78	4·89														
3	7·33	3·67	10·59	4·89	15·48	6·11	22·00	7·33												
4	13·04	4·89	17·11	6·11	22·81	7·33	30·15	8·56	39·11	9·78										
5	20·37	6·11	25·26	7·33	31·78	8·56	39·92	9·78	49·70	11·00	61·11	12·22								
6	29·33	7·33	35·04	8·56	42·37	9·78	51·33	11·00	61·92	12·22	74·15	13·44	88·00	14·67						
7	39·93	8·56	46·45	9·78	54·59	11·00	64·37	12·22	75·78	13·44	88·81	14·67	103·48	15·89	119·78	17·11				
8	52·15	9·78	59·48	11·00	68·44	12·22	79·04	13·44	91·26	14·67	105·11	15·89	120·59	17·11	137·70	18·33	156·44	19·56		
9	66·00	11·00	74·15	12·22	83·93	13·44	95·33	14·67	108·37	15·89	123·04	17·11	139·33	18·33	157·26	19·56	176·81	20·78	198·00	22·00
10	81·48	12·22	90·44	13·44	101·04	14·67	118·26	15·89	127·11	17·11	142·59	18·33	159·70	19·56	178·44	20·78	198·81	22·00	220·81	23·22
11	98·59	13·44	108·37	14·67	119·78	15·89	132·81	17·11	147·48	18·33	163·78	19·56	181·70	20·78	201·26	22·00	222·44	23·22	245·26	24·44
12	117·33	14·67	127·98	15·89	140·15	17·11	154·00	18·33	169·48	19·56	186·59	20·78	205·33	22·00	225·70	23·22	247·70	24·44	271·33	25·67
13	137·70	15·89	149·11	17·11	162·15	18·33	176·81	19·56	193·11	20·78	211·04	22·00	230·59	23·22	251·78	24·44	274·59	25·67	299·04	26·89
14	159·70	17·11	171·98	18·33	185·78	19·56	201·26	20·78	218·37	22·00	237·11	23·22	257·48	24·44	279·48	25·67	303·11	26·89	328·37	28·11	
15	183·33	18·33	196·87	19·56	211·04	20·78	227·33	22·00	245·26	23·22	264·81	24·44	286·00	25·67	308·81	26·89	333·26	28·11	359·33	29·33
16	208·59	19·56	222·44	20·78	237·93	22·00	255·04	23·22	273·78	24·44	294·15	25·67	316·15	26·89	339·78	28·11	365·03	29·33	391·92	30·56
17	235·48	20·78	250·15	22·00	266·44	23·22	284·37	24·44	303·92	25·67	325·11	26·89	347·92	28·11	372·37	29·33	398·44	30·56	426·15	31·78
18	264·00	22·00	279·48	23·22	296·59	24·44	315·33	25·67	335·70	26·89	357·70	28·11	381·33	29·33	406·59	30·56	433·48	31·78	462·00	33·00
19	294·15	23·22	310·45	24·44	328·37	25·67	347·92	26·89	369·11	28·11	391·92	29·33	416·37	30·56	442·44	31·78	470·15	33·00	499·48	34·22
20	325·93	24·44	343·04	25·67	361·78	26·89	382·15	28·11	404·15	29·33	427·78	30·56	453·04	31·78	479·92	33·00	508·44	34·22	538·59	35·44
21	359·33	25·67	377·26	26·89	396·81	28·11	418·00	29·33	440·81	30·56	465·26	31·78	491·33	33·00	519·04	34·22	548·37	35·44	579·33	36·67
22	394·37	26·89	413·11	28·11	433·48	29·33	455·48	30·56	479·11	31·78	504·37	33·00	531·26	34·22	559·78	35·44	589·92	36·67	621·70	37·89
23	431·04	28·11	450·59	29·33	471·78	30·56	494·59	31·78	519·04	33·00	545·11	34·22	572·81	35·44	602·15	36·67	633·11	37·89	665·70	39·11
24	469·33	29·33	489·70	30·56	511·70	31·78	535·33	33·00	560·59	34·22	587·48	35·44	616·00	36·67	646·15	37·89	677·92	39·11	711·33	40·33
25	509·26	30·56	530·45	31·78	553·26	33·00	577·70	34·22	603·78	35·44	631·48	36·67	660·81	37·89	691·78	39·11	724·37	40·33	758·59	41·56
26	550·81	31·78	572·81	33·00	596·44	34·22	621·70	35·44	648·59	36·67	677·11	37·89	707·26	39·11	739·04	40·33	772·44	41·56	807·48	42·78
27	594·00	33·00	616·81	34·22	641·26	35·44	667·33	36·67	695·04	37·89	724·37	39·11	755·33	40·33	787·92	41·56	822·15	42·78	858·00	44·00
28	638·81	34·22	662·45	35·44	687·70	36·67	714·59	37·89	743·11	39·11	773·26	40·33	805·04	41·56	838·44	42·78	873·48	44·00	910·15	45·22
29	685·26	35·44	709·70	36·67	735·78	37·89	763·48	39·11	792·81	40·33	823·78	41·56	856·37	42·78	890·59	44·00	926·44	45·22	963·92	46·44
30	733·33	36·67	758·59	37·89	785·48	39·11	814·00	40·33	844·15	41·56	875·92	42·78	909·33	44·00	944·37	45·22	981·04	46·44	1019·33	47·67
31	783·04	37·89	809·11	39·11	836·81	40·33	866·15	41·56	897·11	42·78	929·70	44·00	963·92	45·22	999·78	46·44	1037·26	47·67	1076·37	48·89
32	834·37	39·11	861·26	40·33	889·78	41·56	919·92	42·78	951·70	44·00	985·11	45·22	1020·15	46·44	1056·82	47·67	1095·11	48·89	1135·04	50·11
33	887·33	40·33	915·04	41·56	944·37	42·78	975·33	44·00	1007·92	45·22	1042·15	46·44	1078·00	47·67	1115·48	48·89	1154·59	50·11	1195·33	51·33
34	941·98	41·56	970·45	42·78	1000·59	44·00	1032·37	45·22	1065·78	46·44	1100·81	47·67	1137·48	48·89	1175·78	50·11	1215·70	51·33	1257·26	52·56
35	998·15	42·78	1027·48	44·00	1058·44	45·22	1091·04	46·44	1125·26	47·67	1161·11	48·89	1198·59	50·11	1237·70	51·33	1278·44	52·56	1320·81	53·78
36	1056·00	44·00	1086·15	45·22	1117·93	46·44	1151·33	47·67	1186·37	48·89	1223·04	50·11	1261·33	51·33	1301·26	52·56	1342·82	53·78	1386·00	55·00
37	1115·48	45·22	1146·45	46·44	1179·04	47·67	1213·26	48·89	1249·11	50·11	1286·59	51·33	1325·70	52·56	1366·44	53·78	1408·82	55·00	1452·81	56·22
38	1176·59	46·44	1208·37	47·67	1241·78	48·89	1276·81	50·11	1313·48	51·33	1357·78	52·56	1391·70	53·78	1433·26	55·00	1476·44	56·22	1521·26	57·44
39	1239·33	47·67	1271·93	48·89	1306·15	50·11	1342·00	51·33	1379·48	52·56	1418·59	53·78	1459·33	55·00	1501·70	56·22	1545·70	57·44	1591·33	58·67
40	1303·70	48·89	1337·11	50·11	1372·15	51·33	1408·81	52·56	1447·11	53·78	1487·04	55·00	1528·59	56·22	1571·78	57·44	1616·59	58·67	1663·03	59·89

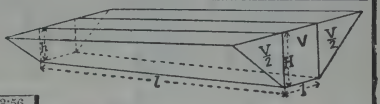
TABLE I. FOR CALCULATING EARTHWORK—(*continued*).

Slopes 1 to 1. Base = 1 foot. l = 66 feet = 1 chain. H and h in feet. V and V in cubic yards.

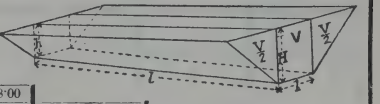


H	h = 10		11		12		13		14		15		16		17		18		19	
	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
10	244·44	24·44																		
11	269·70	25·67	295·78	26·89																
12	296·59	26·89	328·48	28·11	352·00	29·33														
13	325·11	28·11	352·81	29·33	382·15	30·56	418·11	31·78												
14	355·26	29·33	388·78	30·56	413·92	31·78	445·70	33·00	479·11	34·22										
15	387·04	30·56	416·37	31·78	447·33	33·00	479·92	34·22	514·15	35·44	550·00	36·67								
16	420·44	31·78	450·59	33·00	482·37	34·22	515·78	35·44	550·82	36·67	587·48	37·89	625·78	39·11						
17	455·48	33·00	486·44	34·22	519·04	35·44	553·26	36·67	589·11	37·89	626·59	39·11	665·70	40·33	706·44	41·56				
18	492·15	34·22	523·92	35·44	557·33	36·67	592·37	37·89	629·04	39·11	667·33	40·33	707·26	41·56	748·81	42·78	792·00	44·00		
19	530·44	35·44	563·04	36·67	597·26	37·89	633·11	39·11	670·59	40·33	709·70	41·56	750·44	42·78	792·81	44·00	836·81	45·22	882·44	46·44
20	570·37	36·67	603·78	37·89	638·81	39·11	675·48	40·33	713·78	41·56	753·70	42·78	795·26	44·00	838·44	45·22	883·26	46·44	929·70	47·67
21	611·92	37·89	646·15	39·11	682·00	40·33	719·48	41·56	758·59	42·78	799·33	44·00	841·70	45·22	885·70	46·44	931·38	47·67	978·59	48·89
22	655·11	39·11	690·15	40·33	726·81	41·56	765·11	42·78	805·04	44·00	846·59	45·22	889·78	46·44	934·59	47·67	981·04	48·89	1029·11	50·11
23	699·92	40·33	735·78	41·56	773·26	42·78	812·37	44·00	853·11	45·22	895·48	46·44	939·48	47·67	985·11	48·89	1032·37	50·11	1081·26	51·33
24	746·37	41·56	783·04	42·78	821·33	44·00	861·26	45·22	902·81	46·44	946·00	47·67	990·81	48·89	1037·26	50·11	1085·33	51·33	1135·04	52·56
25	794·44	42·78	831·92	44·00	871·04	45·22	911·78	46·44	954·15	47·67	998·15	48·89	1043·78	50·11	1091·04	51·33	1139·92	52·56	1190·44	53·78
26	844·15	44·00	882·44	45·22	922·37	46·44	963·22	47·67	1007·11	48·89	1051·92	50·11	1098·37	51·33	1146·44	52·56	1196·15	53·78	1247·48	55·00
27	895·48	45·22	934·59	46·44	975·33	47·67	1017·70	48·89	1061·70	50·11	1107·33	51·33	1154·59	52·56	1203·48	53·78	1254·00	55·00	1306·15	56·22
28	948·44	46·44	988·37	47·67	1029·92	48·89	1073·11	50·11	1117·92	51·33	1164·37	52·56	1212·44	53·78	1262·15	55·00	1313·48	56·22	1366·44	57·44
29	1003·04	47·67	1043·78	48·89	1086·15	50·11	1130·15	51·33	1175·78	52·56	1223·04	53·78	1271·92	55·00	1322·44	56·22	1374·59	57·44	1428·37	58·67
30	1059·26	48·89	1100·82	50·11	1144·00	51·33	1188·82	52·56	1235·26	53·78	1283·33	55·00	1333·04	56·22	1384·37	57·44	1437·33	58·67	1491·92	59·89
31	1117·11	50·11	1159·48	51·33	1203·48	52·56	1249·11	53·78	1296·37	55·00	1345·26	56·22	1395·78	57·44	1447·92	58·67	1501·70	59·89	1557·11	61·11
32	1176·59	51·33	1219·78	52·56	1264·59	53·78	1311·04	55·00	1359·11	56·22	1408·82	57·44	1460·15	58·67	1513·11	59·89	1567·70	61·11	1623·92	62·33
33	1237·70	52·56	1281·70	53·78	1327·33	55·00	1374·59	56·22	1423·48	57·44	1474·00	58·67	1526·15	59·89	1579·92	61·11	1635·33	62·33	1692·37	63·56
34	1300·44	53·78	1345·26	55·00	1391·70	56·22	1439·78	57·44	1489·48	58·67	1540·82	59·89	1593·78	61·11	1648·37	62·33	1704·59	63·56	1762·44	64·78
35	1364·82	55·00	1410·44	56·22	1457·70	57·44	1506·59	58·67	1557·11	59·89	1609·26	61·11	1663·04	62·33	1718·44	63·56	1775·48	64·78	1834·15	66·00
36	1430·82	56·22	1477·26	57·44	1525·33	58·67	1575·04	59·89	1626·37	61·11	1679·33	62·33	1733·92	63·56	1790·15	64·78	1848·00	66·00	1907·48	67·22
37	1498·44	57·44	1545·70	58·67	1594·59	59·89	1645·11	61·11	1697·26	62·33	1751·04	63·56	1806·44	64·78	1863·48	66·00	1922·15	67·22	1982·44	68·44
38	1567·70	58·67	1615·78	59·89	1666·48	61·11	1716·82	62·33	1769·78	63·56	1824·37	64·78	1880·59	66·00	1938·44	67·22	1997·92	68·44	2059·04	69·67
39	1638·59	59·89	1687·48	61·11	1738·00	62·33	1790·15	63·56	1843·92	64·78	1899·33	66·00	1956·37	67·22	2015·04	68·44	2075·33	69·67	2137·26	70·89
40	1711·11	61·11	1760·82	62·33	1812·15	63·56	1865·11	64·78	1919·70	66·00	1975·92	67·22	2033·78	68·44	2093·26	69·67	2154·37	70·89	2217·11	72·11

Slopes 1 to 1. Base = 1 foot. l = 66 feet = 1 chain. H and h in feet. V and V in cubic yards.



H	h = 20		21		22		23		24		25		26		27		28		29	
	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
20	977·78	48·89																		
21	1027·48	50·11	1078·00	51·33																
22	1078·82	51·33	1130·15	52·56	1183·11	53·78														
23	1131·78	52·56	1183·92	53·78	1237·70	55·00	1293·11	56·22												
24	1186·37	53·78	1239·33	55·00	1293·92	56·22	1350·15	57·44	1408·00	58·67										
25	1242·59	55·00	1296·37	56·22	1351·78	57·44	1408·82	58·67	1467·48	59·89	1527·78	61·11								
26	1300·44	56·22	1355·04	57·44	1411·26	58·67	1469·11	59·89	1528·59	61·11	1589·70	62·33	1652·44	63·56						
27	1359·92	57·44	1415·33	58·67	1472·37	59·89	1531·04	61·11	1591·33	62·33	1653·26	63·56	1716·82	64·78	1782·00	66·00				
28	1421·04	58·67	1477·26	59·89	1535·11	61·11	1594·59	62·33	1655·70	63·56	1718·44	64·78	1782·82	66·00	1848·82	67·22	1916·44	68·44		
29	1483·78	59·89	1540·81	61·11	1599·48	62·33	1659·78	63·56	1721·70	64·78	1785·26	66·00	1850·44	67·22	1917·26	68·44	1985·70	69·67	2055·78	70·89
30	1548·15	61·11	1606·00	62·33	1665·48	63·56	1726·59	64·78	1789·33	66·00	1853·70	67·22	1919·70	68·44	1987·33	69·67	2056·59	70·89	2127·48	72·11
31	1614·15	62·33	1672·82	63·56	1733·11	64·78	1795·04	66·00	1858·59	67·22	1923·78	68·44	1990·59	69·67	2059·04	70·89	2129·11	72·11	2200·82	73·33
32	1681·78	63·56	1741·26	64·78	1802·37	66·00	1865·11	67·22	1929·48	68·44	1995·48	69·67	2063·11	70·89	2132·37	72·11	2203·26	73·33	2275·78	74·56
33	1751·04	64·78	1811·33	66·00	1873·26	67·22	1936·82	68·44	2002·00	69·67	2068·82	70·89	2137·26	72·11	2207·33	73·33	2279·04	74·56	2352·37	75·78
34	1821·92	66·00	1883·04	67·22	1945·78	68·44	2010·15	69·67	2076·15	70·89	2143·78	72·11	2213·04	73·33	2283·93	74·56	2356·44	75·78	2430·59	77·00
35	1894·44	67·22	1956·37	68·44	2019·92	69·67	2085·11	70·89	2151·93	72·11	2220·37	73·33	2290·44	74·56	2362·15	75·78	2435·48	77·00	2510·45	78·22
36	1968·59	68·44	2031·33	69·67	2095·70	70·89	2161·70	72·11	2229·33	73·33	2298·59	74·56	2369·48	75·78	2442·00	77·00	2516·15	78·22	2591·93	79·44
37	2044·37	69·67	2107·92	70·89	2173·11	72·11	2239·93	73·33	2308·37	74·56	2378·44	75·78	2450·15	77·00	2523·48	78·22	2598·45	79·44	2675·04	80·67
38	2121·78	70·89	2186·15	72·11	2252·15	73·33	2319·78	74·56	2389·04	75·78	2459·93	77·00	2532·45	78·22	2606·59	79·44	2682·37	80·67	2759·78	81·89
39	2200·82	72·11	2266·00	73·33	2332·82	74·56	2401·26	75·78	2471·33	77·00	2543·04	78·22	2616·37	79·44	2691·33	80·67	2767·93	81·89	2846·15	83·11
40	2281·48	73·33	2347·48	74·56	2415·11	75·78	2484·37	77·00	2555·26	78·22	2627·78	79·44	2701·93	80·67	2777·70	81·89	2855·11	83·11	2934·15	84·33



H	h = 30		31		32		33		34		35		36		37		38		39	
	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
30	2200·00	73·33																		
31	2274·15	74·56	2349·11	75·78																
32	2349·93	75·78	2425·70	77·00	2503·11	78·22														
33	2427·33	77·00	2503·93	78·22	2582·15	79·44	2662·00	80·67												
34	2506·37	78·22	2583·78	79·44	2662·82	80·67	2743·48	81·89	2825·78	83·11										
35	2587·04	79·44	2665·26	80·67	2745·11	81·89	2826·59	83·11	2909·70	84·33	2994·45	85·56								
36	2669·33	80·67	2748·37	81·89	2829·04	83·11	2911·33	84·33	2995·26	85·56	3080·82	86·78	3168·00	88·00						
37	2753·26	81·89	2833·11	83·11	2914·59	84·33	2997·70	85·56	3082·45	86·78	3168·82	88·00	3256·82	89·22	3346·45	90·44				
38	2838·81	83·11	2919·48	84·33	3001·78	85·56	3085·70	86·78	3171·26	88·00	3258·45	89·22	3347·26	90·44	3437·70	91·67	3529·78	92·89		
39	2926·00	84·33	3007·48	85·56	3090·59	86·78	3175·33	88·00	3261·70	89·22	3349·70	90·44	3439·33	91·67	3530·59	92·89	3623·48	94·11	3718·00	95·33
40	3014·81	85·56	3097·11	86·78	3181·04	88·00	3266·59	89·22	3353·78	90·44	3442·59	91·67	3533·04	92·89	3625·11	94·11	3718·81	95·33	3814·15	96·56

TABLE II. FOR CALCULATING EARTHWORK.

Slopes $1\frac{1}{2}$ to 1. Base = 1 foot. l = 66 feet = 1 chain. H and h in feet. V and V in cubic yards.

H	h = 0		1		2		3		4		5		6		7		8		9	
	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
1	1·22	1·22	3·67	2·44																
2	4·89	2·44	8·56	3·67	14·67	4·89														
3	11·00	3·67	15·89	4·89	23·22	6·11	33·00	7·33												
4	19·56	4·89	25·67	6·11	34·22	7·33	45·22	8·56	58·67	9·78										
5	30·56	6·11	37·89	7·33	47·67	8·56	59·89	9·78	74·56	11·00	91·67	12·22								
6	44·00	7·33	52·56	8·56	63·56	9·78	77·00	11·00	92·89	12·22	111·22	13·44	132·00	14·67						
7	59·89	8·56	69·67	9·78	81·89	11·00	95·56	12·22	113·67	13·44	133·22	14·67	155·22	15·89	179·67	17·11				
8	78·22	9·78	89·22	11·00	102·67	12·22	118·56	13·44	136·89	14·67	157·67	15·89	180·89	17·11	206·56	18·33	234·67	19·56		
9	99·00	11·00	111·22	12·22	125·89	13·44	143·00	14·67	162·56	15·89	184·56	17·11	209·00	18·33	235·89	19·56	265·22	20·78	297·00	22·00
10	122·22	12·22	135·67	13·44	151·56	14·67	169·89	15·89	190·67	17·11	213·89	18·33	239·56	19·56	267·67	20·78	298·22	22·00	331·22	23·22
11	147·89	13·44	162·56	14·67	179·67	15·89	199·22	17·11	221·22	18·33	245·67	19·56	272·56	20·78	301·89	22·00	333·67	23·22	367·89	24·44
12	176·00	14·67	191·89	15·89	210·22	17·11	231·00	18·33	254·22	19·56	279·89	20·78	308·00	22·00	338·56	23·22	371·56	24·44	407·00	25·67
13	206·56	15·89	223·67	17·11	243·22	18·33	265·22	19·56	289·67	20·78	316·56	22·00	345·89	23·22	377·67	24·44	411·89	25·67	448·56	26·89
14	239·56	17·11	257·89	18·33	278·67	19·56	301·89	20·78	327·56	22·00	355·67	23·22	386·22	24·44	419·22	25·67	454·67	26·89	492·56	28·11
15	275·00	18·33	294·56	19·56	316·56	20·78	341·00	22·00	367·89	23·22	397·22	24·44	429·00	25·67	463·22	26·89	499·89	28·11	539·0	29·33
16	312·89	19·56	333·67	20·78	356·89	22·00	382·56	23·22	410·67	24·44	441·22	25·67	474·22	26·89	509·67	28·11	547·54	29·33	587·89	30·56
17	353·22	20·78	375·22	22·00	399·67	23·22	426·56	24·44	455·89	25·67	487·67	26·89	521·88	28·11	558·56	29·33	597·67	30·56	639·22	31·78
18	396·00	22·00	419·22	23·22	444·89	24·44	473·00	25·67	503·56	26·89	536·56	28·11	572·00	29·33	609·89	30·56	650·22	31·78	693·00	33·00
19	441·22	23·22	465·67	24·44	492·56	25·67	521·89	26·89	553·67	28·11	587·89	29·33	624·56	30·56	663·67	31·78	705·22	33·00	749·22	34·22
20	488·89	24·44	514·56	25·67	542·67	26·89	573·22	28·11	606·22	29·33	641·67	30·56	679·56	31·78	719·89	33·00	762·67	34·22	807·89	35·44
21	539·00	25·67	565·89	26·89	595·22	28·11	627·00	29·33	661·22	30·56	697·89	31·78	737·00	33·00	778·56	34·22	822·56	35·44	869·00	36·67
22	591·56	26·89	619·67	28·11	650·22	29·33	683·22	30·56	718·67	31·78	756·56	33·00	796·89	34·22	839·67	35·44	884·88	36·67	932·56	37·89
23	646·56	28·11	675·89	29·33	707·67	30·56	741·89	31·78	778·56	33·00	817·67	34·22	859·22	35·44	903·22	36·67	949·67	37·89	998·56	39·11
24	704·00	29·33	734·56	30·56	767·56	31·78	803·00	33·00	840·89	34·22	881·22	35·44	924·00	36·67	969·22	37·89	1016·88	39·11	1067·00	40·33
25	763·89	30·56	795·67	31·78	829·89	33·00	866·56	34·22	905·67	35·44	947·22	36·67	991·22	37·89	1037·67	39·11	1086·56	40·33	1137·89	41·56
26	826·22	31·78	859·22	33·00	894·67	34·22	932·56	35·44	972·89	36·67	1015·67	37·89	1060·89	39·11	1108·22	40·33	1158·67	41·56	1211·22	42·78
27	891·00	33·00	925·22	34·22	961·89	35·44	1001·00	36·67	1042·56	37·89	1086·56	39·11	1133·00	40·33	1181·88	41·56	1233·22	42·78	1287·00	44·00
28	958·22	34·22	993·67	35·44	1031·56	36·67	1071·89	37·89	1114·67	39·11	1159·89	40·33	1207·56	41·56	1257·67	42·78	1310·22	44·00	1365·22	45·22
29	1027·89	35·44	1064·56	36·67	1103·67	37·89	1145·22	39·11	1189·22	40·33	1235·67	41·56	1284·56	42·78	1335·89	44·00	1389·67	45·22	1445·89	46·44
30	1100·00	36·67	1137·89	37·89	1178·22	39·11	1221·00	40·33	1266·22	41·56	1313·89	42·78	1364·00	44·00	1416·56	45·22	1471·56	46·44	1529·00	47·67
31	1174·56	37·89	1213·67	39·11	1255·22	40·33	1299·22	41·56	1345·67	42·78	1394·56	44·00	1445·89	45·22	1499·67	46·44	1555·89	47·67	1614·56	48·89
32	1251·56	39·11	1291·89	40·33	1334·67	41·56	1379·89	42·78	1427·55	44·00	1477·67	45·22	1530·22	46·44	1585·22	47·67	1642·67	48·89	1697·56	50·11
33	1331·00	40·33	1372·56	41·56	1416·56	42·78	1463·00	44·00	1511·89	45·22	1563·22	46·44	1617·00	47·67	1673·22	48·89	1731·89	50·11	1793·00	51·33
34	1412·89	41·56	1455·67	42·78	1500·89	44·00	1548·56	45·22	1598·67	46·44	1651·22	47·67	1701·22	48·89	1763·67	50·11	1823·56	51·33	1885·89	52·56
35	1497·22	42·78	1541·22	44·00	1587·67	45·22	1636·56	46·44	1687·89	47·67	1741·67	48·89	1797·89	50·11	1856·58	51·33	1917·67	52·56	1981·22	53·78
36	1584·00	44·00	1629·22	45·22	1676·89	46·44	1727·00	47·67	1779·56	48·89	1834·56	50·11	1892·00	51·33	1951·89	52·56	2014·22	53·78	2079·00	55·00
37	1672·22	45·22	1719·67	46·44	1768·56	47·67	1819·89	48·89	1873·67	50·11	1929·89	51·33	1988·56	52·56	2049·67	53·78	2113·22	55·00	2179·22	56·22
38	1764·89	46·44	1812·56	47·67	1862·67	48·89	1915·22	50·11	1970·22	51·33	2027·66	52·56	2087·56	53·78	2149·89	55·00	2214·67	56·22	2281·89	57·44
39	1859·00	47·67	1907·89	48·89	1959·22	50·11	2013·00	51·33	2069·22	52·56	2127·89	53·78	2189·00	55·00	2252·56	56·22	2318·56	57·44	2387·00	58·67
40	1955·56	48·89	2005·67	50·11	2058·22	51·33	2113·22	52·56	2170·67	53·78	2230·56	55·00	2292·89	56·22	2357·67	57·44	2424·89	58·67	2494·56	59·89

Slopes 1½ to 1. Base=1 foot. l=66 feet=1 chain. H and h in feet. V and **V** in cubic yards.

H	h = 10		11		12		13		14		15		16		17		18		19	
	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**
10	366·67	24·44																		
11	404·56	25·67	443·67	26·89																
12	444·89	26·89	485·22	28·11	528·00	29·33														
13	487·67	28·11	529·22	29·33	574·22	30·56	619·67	31·78												
14	532·89	29·33	575·67	30·56	620·89	31·78	668·56	33·00	718·67	34·22										
15	580·56	30·56	624·56	31·78	671·00	33·00	719·89	34·22	771·22	35·44	825·00	36·67								
16	630·67	31·78	675·89	33·00	723·56	34·22	773·67	35·44	826·22	36·67	881·22	37·89	938·67	39·11						
17	683·22	33·00	729·67	34·22	778·56	35·44	829·89	36·67	883·67	37·89	939·88	39·11	998·56	40·33	1059·67	41·56				
18	738·22	34·22	785·89	35·44	838·00	36·67	888·56	37·89	943·56	39·11	1001·00	40·33	1060·89	41·56	1123·22	42·78	1188·00	44·00		
19	795·67	35·44	844·56	36·67	895·89	37·89	948·67	39·11	1005·89	40·33	1064·56	41·56	1125·67	42·78	1189·22	44·00	1255·22	45·22	1323·67	46·44
20	855·56	36·67	905·67	37·89	958·22	39·11	1013·22	40·33	1070·67	41·56	1130·56	42·78	1192·89	44·00	1257·67	45·22	1324·89	46·44	1394·56	47·67
21	917·89	37·89	969·22	39·11	1023·00	40·33	1079·22	41·56	1137·89	42·78	1199·00	44·00	1262·56	45·22	1328·56	46·44	1397·00	47·67	1467·89	48·89
22	982·67	39·11	1035·22	40·33	1090·22	41·56	1147·67	42·78	1207·56	44·00	1269·89	45·22	1334·67	46·44	1401·89	47·67	1471·56	48·89	1543·67	50·11
23	1049·89	40·33	1103·67	41·56	1159·89	42·78	1218·56	44·00	1279·67	45·22	1343·22	46·44	1409·22	47·67	1477·67	48·89	1548·56	50·11	1721·89	51·33
24	1119·56	41·56	1174·56	42·78	1232·00	44·00	1291·89	45·22	1354·22	46·44	1419·00	47·67	1486·22	48·89	1555·89	50·11	1628·00	51·33	1802·56	52·56
25	1191·67	42·78	1247·89	44·00	1306·56	45·22	1367·67	46·44	1431·22	47·67	1497·22	48·89	1565·67	50·11	1636·56	51·33	1708·89	52·56	1885·67	53·78
26	1266·22	44·00	1323·67	45·22	1383·56	46·44	1445·89	47·67	1510·67	48·89	1577·89	50·11	1647·56	51·33	1719·67	52·56	1794·22	53·78	1971·22	55·00
27	1343·22	45·22	1401·89	46·44	1463·00	47·67	1525·56	48·89	1592·56	50·11	1661·00	51·33	1731·89	52·56	1805·22	53·78	1881·00	55·00	2059·22	56·22
28	1422·67	46·44	1482·56	47·67	1544·89	48·89	1609·67	50·11	1676·89	51·33	1746·56	52·56	1818·67	53·78	1893·22	55·00	1970·22	56·22	2149·67	57·44
29	1504·56	47·67	1565·67	48·89	1629·22	50·11	1695·22	51·33	1763·67	52·56	1834·56	53·78	1907·89	55·00	1983·67	56·22	2061·89	57·44	2242·56	58·67
30	1588·89	48·89	1651·22	50·11	1716·00	51·33	1783·22	52·56	1852·89	53·78	1925·00	55·00	1999·56	56·22	2076·56	57·44	2156·00	58·67	2337·89	59·89
31	1675·67	50·11	1739·22	51·33	1805·22	52·56	1873·67	53·78	1944·56	55·00	2017·89	56·22	2093·67	57·44	2171·89	58·61	2252·56	59·89	2435·67	61·11
32	1764·89	51·33	1829·67	52·56	1896·89	53·78	1966·56	55·00	2038·67	56·22	2113·22	57·44	2190·22	58·67	2269·67	59·89	2351·56	61·11	2535·89	62·33
33	1856·56	52·56	1922·56	53·78	1991·00	55·00	2061·89	56·22	2135·22	57·44	2211·00	58·67	2289·22	59·89	2369·89	61·11	2453·00	62·33	2638·56	63·56
34	1950·67	53·78	2017·89	55·00	2087·56	56·22	2159·67	57·44	2234·22	58·67	2311·22	59·89	2390·67	61·11	2472·56	62·33	2556·89	63·56	2743·67	64·78
35	2047·22	55·00	2115·67	56·22	2186·56	57·44	2259·89	58·67	2335·67	59·89	2413·89	61·11	2494·56	62·33	2577·67	63·56	2663·22	64·78	2851·22	66·00
36	2146·22	56·22	2215·89	57·44	2288·00	58·67	2362·56	59·89	2442·00	61·11	2519·00	62·33	2600·98	63·56	2685·22	64·78	2772·00	66·00	2961·22	67·22
37	2247·67	57·44	2318·56	58·67	2391·89	59·89	2467·67	61·11	2545·89	62·33	2626·56	63·56	2709·67	64·78	2795·22	66·00	2883·22	67·22	3073·67	68·44
38	2351·56	58·67	2423·67	59·89	2498·22	61·11	2575·22	62·33	2654·66	63·56	2736·56	64·78	2820·89	66·00	2907·67	67·22	2996·89	68·44	3189·56	69·67
39	2457·89	59·89	2531·22	61·11	2607·00	62·33	2685·22	63·56	2765·89	64·78	2849·00	66·00	2934·56	67·22	3022·56	68·44	3113·00	69·67	3305·89	70·89
40	2566·67	61·11	2641·22	62·33	2718·22	63·56	2797·67	64·78	2879·56	66·00	2963·89	67·22	3050·67	68·44	3139·89	69·67	3231·56	70·89	3425·67	72·11

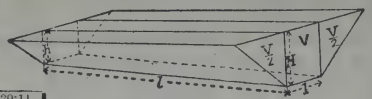
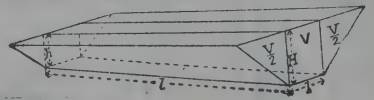
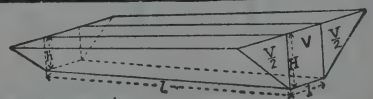


TABLE II. FOR CALCULATING EARTHWORK—(*continued*).

Slopes $1\frac{1}{2}$ to 1. Base=1 foot. l=66 feet=1 chain. H and h in feet. V and **V** in cubic yards.



H	h = 20		21		22		23		24		25		26		27		28		29	
	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**
20	1466·67	48·89																		
21	1541·22	50·11	1617·00	51·33																
22	1618·22	51·33	1695·22	52·56	1774·67	53·78														
23	1697·67	52·56	1775·89	53·78	1856·56	55·00	1939·67	56·22												
24	1779·56	53·78	1859·00	55·00	1940·89	56·22	2025·22	57·44	2112·00	58·67										
25	1863·89	55·00	1944·56	56·22	2027·67	57·44	2113·22	58·67	2201·22	59·89	2291·67	61·11								
26	1950·67	56·22	2032·56	57·44	2116·89	58·67	2203·67	59·89	2292·89	61·11	2384·56	62·33	2478·67	63·56						
27	2039·89	57·44	2123·00	58·67	2208·56	59·89	2296·56	61·11	2387·00	62·33	2479·89	63·56	2575·22	64·78	2673·00	66·00				
28	2131·56	58·67	2215·89	59·89	2302·67	61·11	2391·89	62·33	2483·56	63·56	2577·67	64·78	2674·22	66·00	2773·22	67·22	2874·66	68·44		
29	2225·67	59·89	2311·22	61·11	2399·22	62·33	2489·67	63·56	2582·56	64·78	2677·89	66·00	2775·67	67·22	2875·88	68·44	2978·55	69·67	3088·66	70·89
30	2322·22	61·11	2409·00	62·33	2498·22	63·56	2589·89	64·78	2684·00	66·00	2780·56	67·22	2879·56	68·44	2980·99	69·67	3084·88	70·89	3191·22	72·11
31	2421·22	62·33	2509·22	63·56	2599·67	64·78	2692·56	66·00	2787·89	67·22	2885·67	68·44	2985·89	69·67	3088·55	70·89	3193·66	72·11	3301·22	73·33
32	2522·67	63·56	2611·89	64·78	2703·56	66·00	2797·67	67·22	2894·22	68·44	2993·22	69·67	3094·67	70·89	3198·55	72·11	3304·88	73·33	3413·66	74·56
33	2626·56	64·78	2717·00	66·00	2809·89	67·22	2905·22	68·44	3003·00	69·67	3103·22	70·89	3205·89	72·11	3310·99	73·33	3418·55	74·56	3528·55	75·78
34	2732·89	66·00	2824·56	67·22	2916·67	68·44	3015·22	69·67	3114·22	70·89	3215·67	72·11	3319·55	73·33	3425·88	74·56	3534·66	75·78	3645·88	77·00
35	2841·67	67·22	2934·56	68·44	3029·89	69·67	3127·67	70·89	3227·89	72·11	3330·55	73·33	3435·67	74·56	3543·22	75·78	3653·22	77·00	3765·66	78·22
36	2952·89	68·44	3047·00	69·67	3143·56	70·89	3242·55	72·11	3344·00	73·33	3447·89	74·56	3554·22	75·78	3662·99	77·00	3774·22	78·22	3887·88	79·44
37	3066·56	69·67	3161·89	70·89	3259·67	72·11	3359·89	73·33	3462·56	74·56	3567·66	75·78	3675·22	77·00	3785·22	78·22	3897·66	79·44	4012·55	80·67
38	3182·67	70·89	3269·22	72·11	3378·22	73·33	3479·67	74·56	3583·56	75·78	3689·88	77·00	3798·67	78·22	3909·88	79·44	4023·55	80·67	4139·66	81·89
39	3301·22	72·11	3399·00	73·33	3499·22	74·56	3600·89	75·78	3707·00	77·00	3814·55	78·22	3924·55	79·44	4036·99	80·67	4151·88	81·89	4269·21	83·11
40	3422·22	73·33	3521·22	74·56	3622·67	75·78	3725·55	77·00	3832·89	78·22	3941·66	79·44	4052·89	80·67	4166·55	81·89	4282·66	83·11	4401·21	84·33



H	h = 30		31		32		33		34		35		36		37		38		39	
	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**	V	**V**
30	3300·00	73·33																		
31	3411·22	74·56	3523·67	75·78																
32	3524·89	75·78	3638·55	77·00	3754·67	78·22														
33	3640·99	77·00	3755·89	78·22	3873·22	79·44	3993·00	80·67												
34	3759·75	78·22	3875·67	79·44	3994·22	80·67	4115·22	81·89	4238·67	83·11										
35	3880·55	79·44	3997·89	80·67	4117·67	81·89	4239·89	83·11	4364·55	84·33	4491·67	85·56								
36	4003·99	80·67	4122·55	81·89	4243·55	83·11	4367·00	84·33	4492·89	85·56	4621·22	86·78	4752·00	88·00						
37	4129·89	81·89	4249·67	83·11	4371·89	84·33	4495·55	85·56	4623·67	86·78	4753·22	88·00	4885·22	89·22	5019·67	90·44				
38	4258·22	83·11	4379·22	84·33	4502·67	85·56	4628·55	86·78	4756·89	88·00	4887·67	89·22	5020·89	90·44	5156·55	91·67	5294·67	92·89		
39	4388·99	84·33	4511·22	85·56	4635·89	86·78	4763·00	88·00	4892·55	89·22	5024·55	90·44	5159·00	91·67	5295·89	92·89	5435·22	94·11	5577·00	95·33
40	4522·22	85·56	4645·67	86·78	4771·55	88·00	4899·89	89·22	5030·67	90·44	5163·89	91·67	5299·55	92·89	5437·67	94·11	5578·22	95·33	5721·22	96·56

Methods of getting Earth.

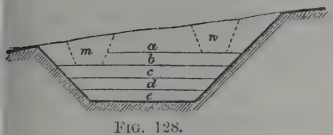


FIG. 128.

1. *Ordinary Method* (fig. 128).—Excavations carried out in layers, *a*, *b*, *c*, &c., each layer being opened out by cuts, as *m* and *n*, into which temporary ways or dobbin carts are brought. Suitable for easily-won earth and long cuttings, allowing the employment of many workmen, carts, and waggons at the same time.

2. *Method of Terracing.*—Figs. 129 and 130 show, in longitudinal section, the terraces, each of which has a transport-way, on a bench, on one or both sides of cutting, which is only removed on the completion of its terrace. Very great advantage, especially on sidelong ground, is often got by placing the temporary way alongside the cutting.

FIG. 129.

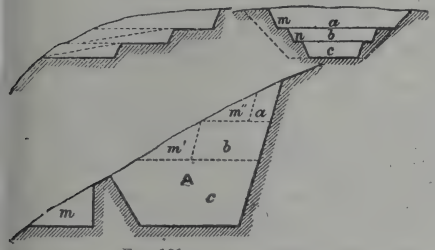


FIG. 131.

FIG. 130.

3. *Sidelong System.*—For cuttings on sidelong ground the principal temporary way runs parallel to the centre line, but at the side of cutting, which can be attacked at numerous points, and eventually along its whole length. In fig. 131, *m* represents the position of temporary way, and A the cutting. Different stages, *a*, *b*, *c*, with separate temporary ways, *m''*, *m'*, *m*, may often be advantageously employed, in which case it approximates to terracing. Steep sidelong cuttings chiefly occur in rock, where this system gives great advantages.

4. *Long-face System.*—A deep, narrow cutting, *g*, *z*, *n*, *m*, taken down to formation-level, if possible, is formed for the principal transport-way and drainage. This system is advantageous in rock strata sloping across the line, in which case the cutting will be on one side, as *m*, *n*, *p*, *o*, in fig. 132. In cases where a central cutting can be made the faces can be attacked on both sides, at different points, along the whole length, drainage and blasting being easily performed.

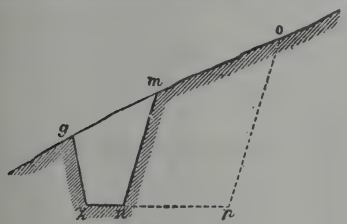


FIG. 132.

Central Lift, or English System.—A drift, *a*, *a* (figs. 133 and 134), is driven at formation-level about centre line of cutting, and a temporary way laid down in it; at the same time one or more shafts, *m*, *n*, *o*, *p*, are sunk down to it from above, and cut away in a funnel-shape, through which the stuff is shot direct into waggons standing below in the drift. This method is now widely used, with best results, both as regards time and cost. A deep cutting in lava, 500′ long × 60′ deep, containing over 124,000 cubic yards, with three shafts, was run to bank, 700′ distant, within six months, *i.e.*, at about 800 cubic yards a day. Compared with other methods it is quicker; the formation-level is at once defined; the temporary ways are shorter, and require less shifting; it is cheaper in loading waggons into which stuff falls; there is no up-throwing; and the drainage is readily done, and with the least disturbance of the work. The drift and shafts are the only source of expense, but their cost can be closely estimated.

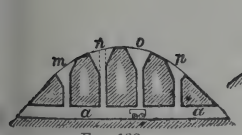


FIG. 133.

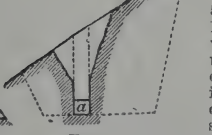


FIG. 134.

Transporting Earth.

The systems adopted comprise *barrow runs*, *horse and cart*, and *rail transport*; the latter include *hand trollies*, *horse waggons*, and *trucks drawn by locomotives or by ropes worked by stationary engines.*

Gradients in transport ways increase cost. The practical limits are: for barrows, 1 in 30; for horse and cart, 1 in 40; for temporary ways, 1 in 100.

Leading Material.

A higher up-throw, an unfavourable lifting, a repeated throwing or unnecessary moving of earth, add to cost. Good tools, well-formed barrows, carts, tip waggons, good temporary ways of rails, or planks for barrow runs, are essential. A barrow carrying 2 cubic feet without a plank run will carry 3 cubic feet with one. A tip cart carrying 8 to 10 cubic feet without, will carry 15 to 18 cubic feet with, a good temporary way.

Slopes of Excavations and Embankments.

Heights at which different soils will retain a vertical face in excavations for a short time without falling in :

	ft. ft.		ft. ft.
Clean dry sand and gravel from . .	0 to 1	Loamy soil, well drained . . .	5 to 10
Moist sand and ordinary surface mould	1 „ 3	Ordinary clay	9 „ 12

Slopes of railway cuttings are often—

In gravel, 1 to 1 when not more than 20′ deep	In clay, 2 to 1 when well drained
„ 1½ „ 1 when of greater depth	„ 3 or 4 to 1 when wet

Slopes of railway embankments are often—

In gravel, 1½ to 1 when not more than 30′ high	In clay, 2 to 1 when not more than 40′ high
„ 2 „ 1 when of greater height	„ 2½ „ 1 when of greater height

Chalk and rock will stand perpendicular, or with a slope of about ¼ base to 1 height.

In roads it is often better to make the sides of cuttings, especially on the south side, with greater slope than that they will stand at, to admit sun.

Earth in embankments should be laid in regular horizontal courses not more than 4′ thick. In high embankments they should be rather concave, to avoid slipping.

Form of Side Slopes.

The natural, strongest, and ultimate form of earth slopes is a concave curve, in which the flattest portion is at the bottom. This form is very rarely given to the slopes in constructing them ; in fact, the reverse is often the case, the slopes being made convex, thus saving excavation for the contractor, and inviting slips.

In cuttings exceeding 10 feet in depth the formation of concave slopes will materially aid in preventing slips, and in any case it will reduce the amount of material which will eventually have to be removed when cleaning up. Straight or convex slopes will continue to slip until the natural form is attained.

Table of Angles and Lengths of Slopes.

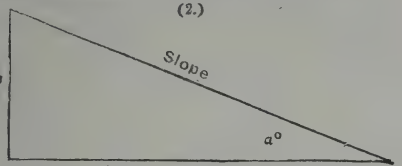
(1.)

Base of Slope is given in terms of the Height ; Length of Slope, in terms of the Base.

Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).	Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).	Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).	Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).
° ′			° ′			° ′			° ′		
45 0	1	1·414	8 0	7·1	1·009	2 52	20	1·0012	0 43	80	1·0000
40 0	1·2	1·305	7 7	8	1·007	2 18	25	1·0008	0 40	86	„
38 40	1¼	1·280	7 0	8·1	1·007	2 12	26	1·0007	0 38	90	„
35 0	1·4	1·220	6 20	9	1·006	2 7	27	1·0007	0 36	95	„
33 41	1½	1·201	6 0	9·5	1·005	2 3	28	1·0006	0 34	101	„
30 0	1·7	1·154	5 42	10	1·005	2 0	28·6	1·0006	0 23	150	„
29 44	1¾	1·151	5 11	11	1·0041	1 59	29	1·0006	0 17	202	„
26 34	2	1·118	5 0	11·4	1·0038	1 54	30	1·0005	0 14	245	„
25 0	2·1	1·103	4 46	12	1·0034	1 38	35	1·0004	0 12	286	„
20 0	2·7	1·064	4 23	13	1·0029	1 26	40	1·0003	0 10	343	„
18 26	3	1·054	4 5	14	1·0025	1 16	45	1·0002	0 9	381	„
15 0	3·7	1·035	4 0	14·3	1·0024	1 9	50	1·0002	0 8	429	„
14 2	4	1·030	3 49	15	1·0022	1 2	55	1·0001	0 7	491	„
11 18	5	1·019	3 34	16	1·0019	1 0	57·3	1·0001	0 6	572	„
10 0	5·7	1·015	3 22	17	1·0017	0 57	60	1·0001	0 4	859	„
9 27	6	1·013	3 11	18	1·0015	0 53	65	1·0001	0 2	1718	„
9 0	6·3	1·012	3 1	19	1·0013	0 49	70	1·0001	0 1	3437	„
8 8	7	1·010	3 0	19	1·0013	0 46	75	1·0000	—	—	„

Table of Angles and Lengths of Slopes.

(2.)



f Height = 1, then

Base = $\cot a^\circ$ (see table, page 73); Slope = $\sec a^\circ = \frac{1}{\cos a^\circ}$.

Base and Slope in Terms of Angle.			Angle in Terms of Base and Slope.					
Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).	Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).	Angle.	Base of Slope (Height = 1).	Length of Slope (Base = 1).
°			°			° ′		
90	·000	∞	45	1·000	1·414	89 25	·01	98·223	17 21	3·2	1·048
89	·017	57·299	44	1·036	1·390	88 17	·03	33·381	16 52	3·3	1·045
88	·035	28·654	43	1·072	1·367	87 8	·05	19·995	16 23	3·4	1·042
87	·052	19·107	42	1·111	1·346	86	·07	14·336	15 57	3·5	1·040
86	·070	14·336	41	1·150	1·325	84 51	·09	11·110	15 31	3·6	1·038
85	·087	11·474	40	1·192	1·305	84 17	·1	10·039	15 8	3·7	1·036
84	·105	9·567	39	1·235	1·287	81 28	·15	6·739	14 45	3·8	1·034
83	·123	8·206	38	1·280	1·269	78 41	·2	5·096	14 23	3·9	1·032
82	·141	7·185	37	1·327	1·252	75 58	·25	4·124	14 2	4·0	1·031
81	·158	6·392	36	1·376	1·236	73 18	·3	3·480	13 42	4·1	1·030
80	·176	5·759	35	1·428	1·221	70 43	·35	3·028	13 24	4·2	1·028
79	·194	5·241	34	1·483	1·206	68 12	·4	2·693	13 6	4·3	1 027
78	·213	4·810	33	1·540	1·192	65 47	·45	2·438	12 49	4·4	1·026
77	·231	4·445	32	1·600	1·179	63 26	·5	2·236	12 32	4·5	1·024
76	·249	4·134	31	1·664	1·167	61 11	·55	2·075	12 16	4·6	1·023
75	·268	3·864	30	1·732	1·155	59 2	·6	1·943	12 1	4·7	1·022
74	·287	3·628	29	1 804	1·143	56 59	·65	1·835	11 46	4·8	1·021
73	·306	3·420	28	1·881	1·133	55 1	·7	1·744	11 32	4·9	1·021
72	·325	3·236	27	1·963	1·122	53 8	·75	1·667	11 19	5	1·020
71	·344	3·072	26	2·050	1·113	51 20	·8	1·601	10 19	5·5	1·016
70	·364	2·924	25	2·145	1·103	49 38	·85	1·544	9 28	6	1·014
69	·384	2·790	24	2·246	1·095	48 1	·9	1·495	8 45	6·5	1·012
68	·404	2·669	23	2·356	1·086	46 28	·95	1·452	8 8	7	1·010
67	·424	2·559	22	2·475	1·079	45 0	1	1·414	7 8	8	1·008
66	·445	2·459	21	2·605	1·071	42 16	1·1	1·351	6 20	9	1·006
65	·466	2 366	20	2·747	1·064	39 48	1·2	1·302	5 43	10	1·005
64	·488	2·281	19	2·904	1·058	37 34	1·3	1·262	5 12	11	1·004
63	·510	2·203	18	3·078	1·051	35 32	1·4	1·229	4 46	12	1·003
62	·532	2·130	17	3·271	1·046	33 41	1·5	1·202	4 24	13	1·003
61	·554	2·063	16	3·487	1·040	32	1·6	1·179	4 5	14	1·003
60	·577	2·000	15	3·732	1·036	30 28	1·7	1·160	3 49	15	1·002
59	·601	1·942	14	4·011	1·031	29 3	1·8	1·144	3 35	16	1 002
58	·625	1·887	13	4·331	1 026	27 46	1·9	1·130	3 22	17	1·002
57	·649	1·836	12	4·705	1·022	26 33	2	1·118	3 11	18	1·002
56	·675	1·788	11	5·145	1·019	25 28	2·1	1·108	3 1	19	1·001
55	·700	1·743	10	5·671	1·015	24 27	2·2	1·099	2 52	20	1·001
54	·727	1·701	9	6·314	1·012	23 30	2·3	1·090	2 18	25	1·001
53	·754	1·662	8	7·115	1·010	22 37	2·4	1·083	1 55	30	1·001
52	·781	1·624	7	8·144	1·008	21 48	2·5	1 077	1 38	35	1·000
51	·810	1·589	6	9·514	1·006	21 2	2·6	1·071	1 26	40	1·000
50	·839	1·556	5	11·430	1·004	20 19	2·7	1·066	1 9	50	1·000
49	·869	1·524	4	14·301	1·002	19 39	2·8	1·062	58	60	1·000
48	·900	1·494	3	19·081	1·001	19 2	2·9	1·058	49	70	1·000
47	·933	1·466	2	28·636	1 001	18 26	3	1·054	43	80	1·000
46	·966	1·440	1	57·290	1·000	17 53	3·1	1·051	38	90	1·000

-(*H. R. Kempe.*)

Angles of Repose of Soils.

Material.	Angle.	Ratio of Base of Slope to Height.
	°	
Clay, dry	29	1·8 to 1
„ damp, well drained	45	1 to 1
„ wet	16	3·5 to 1
Earth, dry	29	1·8 to 1
„ moist	45 to 49	1 to 1 to ·87 to 1
„ very wet	17	3·27 to 1
„ punned	66 to 74	·45 to 1 to ·28 to 1
Gravel, clean	48	·9 to 1
„ with sand	26	2 to 1
Sand, fine dry	37 to 31	1·3 to 1 to 1·6 to 1
„ wet	26	2 to 1
„ very wet	32	1·6 to 1
Shingle, loose	39	1·2 to 1
Peat	14 to 45	4 to 1 to 1 to 1

Weight of a Cubic Yard of different Soils.

	cwts.		cwts.		cwts.		cwts.
Dry peat	7½	Common earth	24	Common gravel	27	Grey chalk	36
Wet peat	15	Sandy loam	24	Wet sand	28	Sandstone	37
Top soil	20	Marl	26	Gravelly clay	30	Shale	39
Dry sand	22	Clay	27	Rough water gravel	34	Limestone	48

Loads of Carts and Waggons.

An ordinary cart, 6′ × 3¼′ × 2½′ deep, holds 1⅜ cubic yards, equal 2½ tons of earth.

A dobbin cart	„	¾	„	„ 1	„
An earth waggon	„	2	„	„ 3½	„
„ „ large	„	3	„	„ 4½	„
A wheelbarrow, navvy	„	1/10	„	„ 3/20	„
„ ordinary	„	1/20	„	„ 3/40	„

Carting is estimated at so much per cubic yard, by the run of 1 furlong (220 yards).

Equivalents of a Load of Different Materials.

A single load of sand, earth, rubbish	= 1 cub. yd.
„ „ lime (a measure or hundred)	= 1 cub. yd. = 21 striked bushels.
„ „ „ „ „	= 22 bushels.
„ „ squared or hewn timber, deals, &c.	= 50 cub. ft.
„ „ unhewn timber	= 40 „
„ „ bricks	= 500 bricks.
„ „ tiles	= 1,000 tiles.
„ „ water	= 1 butt of 108 gallons.
„ „ light, bulky materials	= 80 cub. ft.

Barrow and Cart Runs.

The barrows used usually hold about one-tenth cubic yard, and are mostly run on planks, which should not be narrower than 11″, and 3″ thick, nor, as a rule, have a greater inclination than 1 in 12, unless aided by ropes or winding machinery. Box-horses (fig. 135) are the best supports on an incline, either singly or resting one on another; they are mostly from 1½′ to 3′ square, made out of 11″ × 3″ planks. If a considerable height is required, trestles (fig. 136) are used, but boxhorses are stronger, and less likely to get out of repair.

A barrow run is 20 or 25 yards. Each foot of rise is considered equal to 6′ to 9′ additional run.

Wheeling is more economical than carting for distances under 100 yards.

An earth waggon holds as much as 20 or 30 wheelbarrows, and goes one-fifth faster—equal, therefore, to 24 or 36 barrows.

If loaded waggons have to be drawn up an ascent, and the temporary rails are in moderately good order, each foot of ascent may be considered equivalent to about 150 feet of additional horizontal distance.

BOXHORSE.

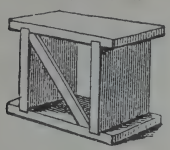


FIG. 135.

TRESTLE.

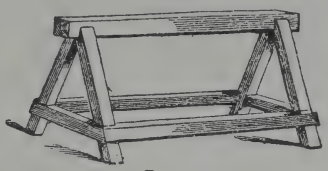


FIG. 136.

When the height exceeds 12 feet, a horse lift is better than wheeling.

For railway embankments and cuttings, locomotives are better than carting for distances over 1¼ miles.

Tip Waggons.

End Tip Waggons (figs. 137 and 138) will hold 2 yds. filled up to top of sides, as with gravel, 2½ yds. when heaped up with clay, &c., the most economical size. The lowness of sides is of great advantage in filling.

The sides, one end, and bottom of body are of elm 1½″ thick (the earth being confined at other end by movable tailboard), bound together with iron straps at angles, and with upright

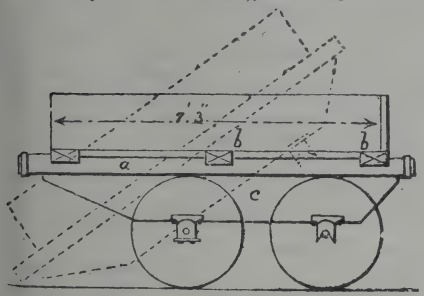


FIG. 137. Side Elevation.

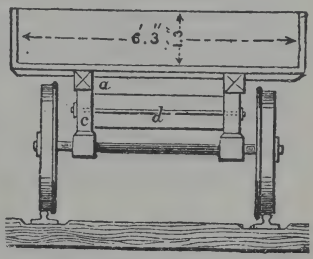


FIG. 138. Cross Section.

straps at sides and one end, all bolted through. The sole is the longitudinal piece, *a*, at each side, of elm, 5″ × 5″, upon which the bottom boards rest. At each end, and in middle of body, is a cross-piece of elm, *b*, 6″ × 3″, bolted down to the soles. The under soles, *c*, are of Memel, 12″ × 3″, between which from side to side are two distance-pieces, *a*, each 9″ × 3″, and alongside of each is a ¾″ bolt. The wheels are of cast iron, 2′ 6″ diam., with wrought-iron axles.

Weight of body of waggon, ¾ ton, of load, 3¼ tons; total load on axles, 4 tons. With well-greased axles, resistance will be about 10 lbs. per ton, but may be as high as 20. Resistance, 80 lbs. per waggon. A horse can draw 150 lbs. 2½ miles an hour for eight hours; a horse can therefore draw two waggons.

Temporary contractor's rails weigh from 25 lbs. to 30 lbs. per yard.

It is generally better to throw earth away than to lead it three miles.

FOUNDATIONS.

In cases where there is any doubt as to the ground being of too soft a nature to bear the weight of the proposed structure, a trial pit should be sunk, or borings made with boring-rods; samples of the underlying strata may thus be brought up and examined.

Where a soft stratum overlies firm ground, the foundation should, if possible, be carried down to the firm ground; if this is not possible, piles may be driven to the solid ground and the building supported on them, or a number of piers of brickwork, masonry, or iron cylinders sunk.

Where ground is soft to a great depth, a wide trench filled with concrete may distribute the weight over a sufficiently large area to support it, or the trench may be filled with carefully rammed sand, prevented, by sheet piling or some other means, from escaping laterally. Another method is to drive a number of piles, which, by the friction of their sides, would bear the weight of the building.

Foundations on different Soils.

In any structure begun at different levels larger blocks should be used for the deeper parts, if the material admits of it, so as to reduce the number of mortar joints and the risks of unequal settlement.

With Sand or Gravel Foundation overlying Clay on a Slope, intercept water by drain on upper side of building.

Least Depth to escape Effects of Heat and Frost, from 3′ to 6′, according to climate. Not less than 3′ in England for ordinary soils, and 4′ for clay.

Rock.—Good foundation, but must be level; should be levelled, if necessary, in steps. The uneven parts should be filled up with large stones, firmly built with strong cement, or with concrete.

Gravel.—The best foundation.

Sand.—Good foundation, if dry and not liable to be washed away, but this easily occurs; drains with leaky joints may cause a subsidence, or any disturbance of the water-level in the stratum, whether by natural or artificial means, such as pumping operations connected with deep foundations, even at a great distance.

Clay.—Generally very treacherous and damp; the foundation must be deep.

Hard overlying Soft Ground.—If care is taken that the pressure per unit of area is not greater than the firm layer will bear, it may be wiser to build on it, sinking into it as little as possible.

Soft Ground overlying Hard Ground.—If the stratum of soft ground does not exceed 15′ to 20′ it will generally be cheaper to sink down to the firm ground; if not more than about 30′, drive piles or sink wells of masonry. If of indefinite depth, the platform must be supported by friction against the sides, and be therefore of considerable thickness.

Made Ground should never be trusted for the support of much weight, even though it may have lain undisturbed for years.

Load which Foundations will Bear.

Safe Load on Ordinary Foundations.

	Tons per sq. ft.
1. Rock, moderately hard, strong as the strongest red brick	9·0
2. Rock of the strength of good concrete	3·0
3. Rock very soft	1·8
4. Moist clay and sand	1·36
5. Coarse sand and dry clay	2·25
6. Firm stone on dry clay	3·18
7. Loose beds with piling	1·82
8. „ „ „ concrete	2·75
9. Brick, stock, mortar	2·5
10. „ „ Portland cement, 1 to 1	8·0
11. Concrete, Portland cement, 1 to 6	15
12. Rubble on lias	4

Intensity of pressure on a rock foundation should at no point exceed one-eighth pressure which would crush the rock.

Buildings seldom press with a weight of more than 1 ton per square foot on foundations.

Safe Load on Materials.

	Cwts. per sq. in.	Tons per sq. ft.		Cwts. per sq. in.	Tons per sq. ft.
Portland cement, concrete, 5 to 1	2·0	15	Brick in cement	·8	5·75
Portland cement, concrete, 10 to 1	1·0	7·5	Granite	10·0	72
Mortar, ordinary	·5	3·5	Limestone	9·0	65
Brick in mortar	·5	3·5	Sandstone	5·0	38
			Rubble	·6	3·5

Safe Load on Bearing Surface for end of Girders.

	Tons per sq. ft.		Tons per sq. ft.		Tons per sq. ft.
Granite	15	Brick, blue, in cement	9	Brick, stock, in lime	4
Portland stone	12	Brick, stock, in cement	6	Earth, compact	2
Limestone	9	Brick, stock, in lias	5	„ made	1

Safe Load on Chimney Foundations.

	Tons per sq. ft.		Tons per sq. ft.
Granite	45	Concrete, 6 to 1	10
Brick, blue Staff., in cement	20	Clay	4

Safe Load on Stone Walls and Columns.

	Ashlar Walls, single bedstones. Columns, diameter = ⅛ height. Lbs. per sq. in.	Block in course. Columns, diameter = $\frac{1}{12}$ height. Lbs. per sq. in.
Granite	712	570
Hard stone	356	280
Medium	214	142

Safe Load on Brick Walls and Columns.

	Walls not less than 18 ins. Columns, diameter $< \frac{1}{8}$ height.	Walls under 18 ins. Columns, diameter $< \frac{1}{8}$ height.	Columns, diameter $= \frac{1}{8}$ to $\frac{1}{12}$ height.
	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.
ick in mortar	72	36	—
,, ,, cement	108	72	—
,, ,, Portland cement	142	108	44
bble mortar	58	—	—
,, cement	72	—	—
ssed bricks in mortar	128	114	103
,, ,, ,, cement	172	142	114
,, ,, ,, Portland cement	100	—	—

Safe Loads on Floors.

	Lbs. per sq. ft.		Lbs. per sq. ft.
tics	31	Stairs	82
velling-rooms	51	Workrooms	82
rary	72	Hay lofts	102
ncing	72	Warehouses	112

Piled Foundations

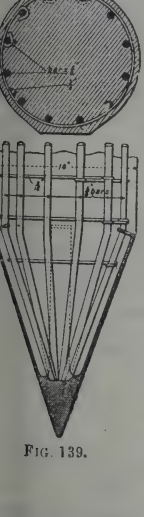


FIG. 139.

There are two kinds of piled foundations.

1. *When the soil is soft to a great depth*, area should be enclosed with sheet piling before main piles are driven, to consolidate the ground better. When the tops of the piles are connected by timber, cross-pieces (12″ × 9″ for 12″ piles) running across breadth of foundation are first notched on to heads of piles, and longitudinals, or *string pieces*, 12″ × 9″, running parallel to length of foundation, over them. On these latter, 3″ or 4″ planking (better diagonal) is laid to carry masonry. When upper stratum of ground is very soft, upper part of ground should be taken off, and filled in with stones or concrete or regular masonry. When of concrete, it should be 3′ thick for large buildings not excessively heavy.

2. *When there is hard ground below.*—In this case, as each pile resists partly by resistance to buckling as a column, the cross section should be greater in proportion to the depth. Maximum depth may be put at 30 feet. The number of piles must be proportional to weight carried.

PILES.

Timber piles may be made of oak, elm, beech, larch, pine, or teak. Timber in sea-water is rapidly attacked by the wood borers *Teredo navalis* and *Limnoria terebrans*; creosoting will prevent their attack for a considerable time; it has also been suggested to cover piles with sheet copper or flat-headed copper nails. The head of the pile may be protected by a wrought-iron hoop, about 3″ × 1″, to prevent splitting when being driven. The lower end should be pointed, the length of the point being from 1½ to twice the diameter, and where the ground is hard, protected with an iron shoe. Piles protected by shoes should have a blunt end 4 to six inches in diameter. The shoes should have a solid point; the base being properly fitted to the blunt end of the pile prevents splitting by bolts which secure the shoes.

Concrete Piles.

Fig. 139 shows a 'Coignet' reinforced concrete pile. The reinforcement consists of longi-dinal bars encircled by rings of round steel, with overlapping joints, spaced about 4 ins. apart.

For modern requirements concrete piles having a section less than 14 ins. square or equivalent rea should never be used if over 30 ft. long; 12-in. square piles in many cases are quite large nough, but when it comes to actual practice it will be found that the extra cost of 14-in. piles more than compensated for by the extra convenience of handling. The pile shoe should be of niform taper, the faces being at an angle of about 16° to the centre-line of the pile, with nose ightly blunted. The length of the cast-iron portion to be about half the total length of the per, the area at the top of the cast-iron point being about 40 per cent. of the sectional area the pile in the case of the 14-in. square piles. The vertical rods to rest on the cast-iron point id to be kept in place by the recess. The straight portions of the wrought-iron arms always to e embedded in the concrete of the pile and not kept flush or project from the body.

Piles made with a steel pipe driven to refusal and lined with concrete can develop not only the very considerable strength of the steel shell alone as an independent column, but the strength of the concrete core is materially increased by the shell acting as a continuous hooping, beside which there is an almost unlimited additional strength that can be obtained by the addition of vertical reinforcement bars. Such piles, says *Contract Record*, can endure very hard driving, can be thoroughly inspected inside, can have satisfactory bearing assured at the bottom, and can be reinforced to a high degree of strength comparable with massive structural steel columns. This reduces the number of piles and the cost of driving, and gives freedom from all uncertainty or possible deterioration from subterranean obstructions. The large factor of safety in the shell permits the safe application of working loads before the concrete filling is hard, which is often an important advantage.

The 'Simplex' System of Piling.

A cast-iron point is first driven to the required depth by means of a 16-in. steel pipe, ¾ in. or ½ in. in thickness, stiffened with a collar at the top. The pipe is then filled with concrete and afterwards withdrawn slowly, the concrete filling adapting itself to irregularities in the ground. When more than one length of pipe is needed, welded joints may be preferred to riveted joints with cover plates. Instead of the permanent point or shoe an 'alligator' pile point may be used, consisting of a sleeve of annealed cast steel, about 17 ins. in diameter, and a pair of toothed jaws hinged to the sleeve in such a manner that when closed they form a flat cutting edge which penetrates the ground. When the pipe is drawn up a foot or more the jaws open, allowing the concrete to pass through to the bottom of the hole.

Moulded-in-Place Concrete Piles.

The Macarthur Compressed-Concrete Piles.

The moulded-in-place concrete pile has not to withstand handling before driving and, as it is formed in a mould which has taken the 'punishment' incidental to placing, does not require reinforcement, unless the pile is to be subjected to lateral stress, in which case only the minimum necessary to withstand such stresses need be placed.

Fig 139A.

The Macarthur piles are made in three different types, as shown by figs. 139A–139C.

In the first of these, fig. 139A, the core and casing are driven into the ground; the core then being removed and the casing filled with concrete. The core is then replaced to compress the concrete and the casing withdrawn, the core and hammer, weighing 7 tons or 8 tons, remaining on the concrete and forcing it into the space occupied by the casing and into any voids in the ground. Finally, a solid homogeneous mass of concrete is left in position in the ground.

The second type of pile employed is known as the compressed-concrete pedestal pile, and the method of placing piles of this type is shown in fig. 139B. The core and casing are driven into the ground as shown on the left of fig. 139A, and, after removing the core, a charge of concrete is deposited in the bottom of the casing. After replacing the core, with the hammer above it, on the concrete, the casing is withdrawn a distance of 18 in. to 3 ft., and the charge of concrete is rammed out into the ground as shown. The core is then again removed, and the casing filled up with concrete, the casing being completely withdrawn as before with the core and hammer in position on the concrete. In this way a pile with an enlarged base is left in position, as shown on the right of fig. 139B.

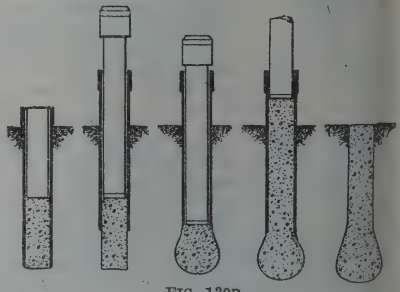


Fig. 139B.

Where a fair stratum, insufficient to support an ordinary pile, lies between poor upper and lower strata, the compressed-concrete pedestal pile is used, but, under these conditions, one or more

iles should be load-tested to determine their carrying capacity. The piles, in such cases, are rbitrarily stopped in the fair stratum and the pedestal formed in the upper portion.

Another condition in which the pedestal proves aluable, is when the pile comes on to hard rock of shelving formation. In such cases, the pedestal ives a full cross-section bearing on the rock, and lso provides a very efficient means of eliminating ny danger of side slip.

A further important field for the pedestal pile xists where it is necessary to hold down as well as o hold up a structure.

The third class of pile, of the composite compressed-concrete and timber type, is used for lengths xceeding 40 ft., and the method of placing these iles is shown in fig. 1390. As before, the core and asing are first driven into the ground, and after withdrawing the core a 10-in. square timber pile is laced in the casing. This pile is then driven to the equired depth, the casing acting as a guide. When his has been done the core is again withdrawn, and batch of concrete is deposited in the casing, which s then withdrawn a certain distance after the core as been replaced on the concrete. The latter is hen rammed so as to form a pedestal joint around he top of the timber pile as shown in the figure, and he pile is completed in a similar manner to that escribed above.

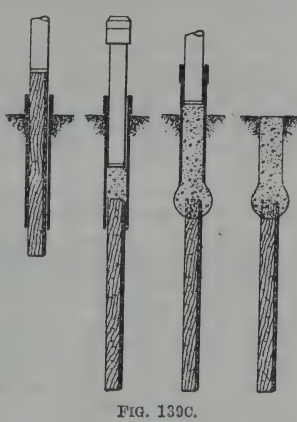


FIG. 1390.

Loads Carried by Piles.

A timber or steel pile is usually of the same section throughout its length, and it is then only ecessary to calculate the load borne by the greatest unbraced length of the pile, regarded as a trut or column. The part below ground may be regarded as held firmly or as quite free, accordg to the nature of the strata. Piles are often driven so closely together, or have to be of such trength for driving purposes, that they are more than strong enough for their loads. This also pplies to piles which support their loads by skin friction only and are of ample section, or umerous, in order that the area subjected to skin friction may be great enough to support the oads. But it is often necessary for the sake of economy, especially when the piles are very long, o load them up to the safe limit.

The calculations of strength may then be made as follows :

(1) If the pile is unbraced above the ground, the length measured from a few feet below the rface of the ground to the head of the pile is treated as a long column, and the section at the id-point must be sufficient (see Column formulæ and ' Reinforced Concrete ').

(2) If it is braced, the length taken is, in the case of a uniform pile, the longest unbraced length; iat is, from a few feet below the ground to the point of bracing, or from the point of bracing to ie head of the pile.

(3) If the pile is not uniform, the strength of the section at the mid-point of each of these ngths may have to be calculated separately, each length being treated as a long column.

(4) Bracing must not be considered effective unless it is effective in both directions, except in ie following case :

(5) When the dimension of the pile is greater at right angles to the bracing than it is in the irection of the bracing, the two part lengths must be calculated as struts liable to cripple in the irection of the smaller diameter, and the whole length as a strut liable to cripple only in the irection of the larger diameter. If the formula for a square section of a reinforced concrete pile e used, the permissible load, expressed as a proportion of the short column load, may be thus odified. In each case modify the factor with l^2 in it, by multiplying by $\frac{r^2}{r_1^2}$ for the smaller imension, and by $\frac{r^2}{r_2^2}$ for the larger dimension ; where r = radius of gyration of a square section f the same area, r_1 = the smaller actual radius of gyration, and r_2 the larger actual radius of yration. In the case of reinforced concrete piles, use the sums of the squares of the radii of yration of the concrete and of the steel as in the formula (see ' Reinforced Concrete '). In this ase the outside dimension might be the same, but the reinforcement stronger in one direction han in the other.

(6) For the portion of the pile below the ground :—

If the pile is in firm ground, or passes through a sufficient number of firm layers so that it is ffectively steadied, any section of the pile should have sufficient strength, calculated as a short

column; that is, it should take a load equal to the safe stress multiplied by the area. The load will be the whole load *less* an amount equal to the area of the pile above the section in question multiplied by the coefficient of friction. This will usually range from about 1 to 4 cwts. per square foot.

If the ground into which the pile is driven is soft and yielding, and is not regarded as effectively steadying the pile, the strengths at mid-points of each length $l_1, l_2, \ldots$ must be calculated as those of the mid-section of a long strut or column of that length. These lengths are measured from the head of the pile, or from the point of effective bracing, to successive points in the length of the pile, the last being measured to the tip. The load in each case is the whole load less the load carried by friction on the length of pile above the point in question. Unless the tip of the pile rests on a hard stratum, or is driven some way into a very firm stratum, the load vanishes before the point is reached, and very few calculations will actually be required.

(7) If the pile so rests upon a firm stratum that a large part of the load is carried from the ower end, the same procedure may be adopted, but the loads will, of course, be greater.

If the length of the pile below ground is small, and it is driven into or rests on a hard stratum, the whole length may have to be calculated as a strut carrying the whole load. Such length as is actually in firm ground should, however, be subtracted from the length for calculation.

In some cases the support given by the ground may not be regarded as equivalent to effective bracing, but may be considerable. The strength of any section may then be calculated in the first place as though the soil were quite firm and hard, giving a load W_1, and next as though the soil, though exerting the effect of skin friction, had no bracing effect, giving a load W_2. The actual load will be something between W_1 and W_2, depending upon the estimated value of the soil as a steadier of the pile. Even soft silt must be regarded as exerting a considerable steadying effect; but if there be progressive movement of silt, sand, or peaty ground, no steadying effect can be counted upon. Considerable movement, of course, demands the provision of special bracing, or, with short piles driven into a firm stratum, the calculation of a cantilever effect based upon the observed pressure as recorded by a torsion pressure meter or otherwise estimated.

Generally: to find the necessary strength at any section S, measure the distance upwards to the head or bracing, at A, and an equal distance downwards to a point B. Calculate the load P carried by skin friction above B, and (W − P) is the load carried by AB as a strut. The strength at S will be calculated as that of a short strut if most of the length BS be effectively steadied by the ground; if there be no such steadying the calculation will be that for a strut of length AB (but in no case any greater length). If the lower half of SB is in firm ground, or all of it in weak ground, the section may be calculated for a stress somewhere between that allowable as a short strut and that allowable on the length AB as a free strut.

The strength of the cross-sections of a pile does not change suddenly, and very few calculations need be made in actual practice; but any of the above may be necessary in a particular case.

The two most probable errors are, first, to calculate as free struts lengths which are really steadied by the ground, and, secondly, to neglect making for each section the reduction of load (regarding the section as the mid-point of a strut) due to skin friction from the surface of the ground to a point which is as far below the section as the bracing or head of the pile is above it. The load which the length in question itself carries by skin friction is imposed, upwards, upon some other mid-section nearer the head of the pile.

Loads on Reinforced Concrete Piles.

A well-designed reinforced concrete pile, 14 ins. by 14 ins. in section, will carry a load up to 100 tons (calculated). In actual practice such piles are carrying loads of 60 to 70 tons (at Bristol up to 65 tons; in the Thames, 15-in. × 15-in. piles, 70 tons).

Pile-sinking with the Water Jet.

In sinking piles the work may sometimes be much facilitated by the use of a water jet. In the case of hollow piles, the usual shoe may be replaced by a funnel-shaped end-piece, and the water pumped through the pile. In sinking cast-iron piles for bridge piers in New South Wales (*E. M. de Burgh*) it was found that a central nozzle with an aperture of 2 ins., and four holes of ½ in. diameter in the conical portion, gave good results in sand and soft clay, the piles being sunk through 14 ft. of sand in an average time of 6 minutes, and the actual rate of movement was about 8 ft. a minute. For sinking in sand not under water it was found expedient to flood the surface round the pile. In clay, the pile was loaded with 10 tons, and after 5 or 10 minutes

umping the pile would sink 6 to 9 ins. At a depth of 11 ft. in the clay, progress was very slow nd practically ceased at 13 ft., with the 10-ton load. These piles had flanged joints.

Timber piles can be similarly sunk, the pipe being taken down the side of the pile. On the ork referred to above, timber piles, 14 ins. in diameter at one end and 9 ins. at the other, were unk 16 ft. on an average ; the average time taken being 4 minutes, and the water pressure 5 to lbs. per sq. in. in sand and 30 to 40 lbs. per sq. in. in clay. The pipe (2-in.) was taken to a $\frac{3}{4}$-in. augur hole in the point of the pile.

In driving steel sheet piling at Hodbarrow (*H.S. Bidwell*) a water jet was used in hard ground. Double ram pumps $5\frac{1}{2}$ ins. and 6 ins. in diameter were used, with 10 to 14 h.p. boiler capacity, the ater being delivered by a 5-in. pipe, diminishing to 3-in. and to $1\frac{1}{2}$-in. From this a $1\frac{1}{4}$-in. vertical ipe led to two $\frac{3}{4}$-in. jets. The jet pipes were kept working up and down, with a block and tackle, bout level with or slightly below the point of the pile. After three or four tides, the ground ad recovered its normal consistency.

Piling Hammers.

Single Semi-Automatic Direct-Acting Steam Piling-Hammers.

(The British Steel Piling Co.)

This type of hammer, which is suitable for every description of pile driving, consists of a ylinder of cast iron raised by steam pressure and allowed to fall through gravity on the pile. he steam is admitted to the cylinder through a hollow piston rod by means of a piston valve, orked by a lever, at the upper end of this rod ; steam being led to the valve by a flexible tube. he lower end of the piston rod, which is solid, passes through the bottom end of the cylinder, hilst the piston is between, the whole being made of one steel forging drawn down from an ngot and bored from the solid. The piston is fitted with rings, whilst the ports are placed on he upper face of the same and lead into the hollow piston rod. When the lever is pulled down, it llows the steam to pass down this hollow rod through the ports into the cylinder, when the ylinder immediately rises, the pressure being between the piston and the cover. As soon as he cylinder is raised to the required height, the lever is released and the piston in the valve orced back to the exhaust position, thus cutting off the incoming steam and allowing the steam n the cylinder to escape to the atmosphere. When the operation is repeated the pistons in the alve, having differential areas, the tendency is always to keep the valve at the exhaust position. he piston valve is of very heavy pattern and made of gun-metal throughout, and fitted with hosphor-bronze piston rings. These hammers are so simple in their construction, and so trongly built, that spare parts are rarely required. They do not wet the top of the pile and annot overrun their stroke owing to a safety hole, placed in the lower end of the cylinder; hilst the whole weight of the hammer is always on the pile. The exhaust is particularly free, o that there is practically no cushioning in the cylinder and consequent loss of blow. One an can easily operate the hammer and maintain a speed of 50 to 60 blows per minute con-inuously. These hammers are made in sizes from 10 cwts. to 5 tons.

The McKiernan-Terry Patent Double-Acting Automatic Pile-Hammers.

With these hammers 90 lbs. pressure gives a striking blow of 7,800 ft.-lbs. per min., at 140 trokes per min. A 40 h.p. boiler is required. The net weight of the hammer is 6,800 lbs., and he cylinder stroke 16 ins.

Safe Load on Piles.

Rankine gives safe load on piles as follows :—
For piles driven till they reach firm ground, 1,000 lbs. per sq. inch of area of head.
For piles standing in soft ground, by friction, 200 lbs. per square inch of area of head.

Formulæ for Safe Load on Piles.

(1.)

If P = safe load on a pile ; h = height of fall in feet ;
w = weight of ram ; s = penetration per blow in inches
(P and w must be in the same units—i.e. both in lbs. or both in tons, for example),

$$P = \frac{2wh}{s+0{\cdot}1}.$$

(2.)

If P = safe load on pile ; a = sectional area of pile ;
w = weight of ram ; E = modulus of elasticity
h = height of fall ; x = weight of pile ;
s = depth driven by last blow ; l = length of pile.

Rankine's formula, $$P = \sqrt{\left(\frac{4Eawh}{l} + \frac{4E^2a^2s^2}{l^2}\right)} - \frac{2Eas}{l}.$$

Sanders' formula, $$P = \frac{wh}{8s}.$$

Weisbach's formula, $$P = \frac{w^2 h}{s(w + x)}.$$

In Rankine's formula the safe load is taken to be about $\frac{1}{5}$ of the greatest load; if there is a great vibration, the factor of safety should be increased to 8 or 9; where there is no vibration, a factor of safety of 3 or even less may be adopted.

'Engineering News' (U.S.A.) formula, $$P = \frac{fwh}{p + 1}.$$

Where p is the average penetration in the last six blows; f a factor ranging from 1 to 12, and recommended to be taken as 2.

Screw Piles.

Screw Piles, figs. 140 and 141, are either of wood or of cast or wrought iron; they are seldom less than 6, or more than 18 inches, in diameter. They should be cylindrical in section to enable them to be more readily turned. They are fitted with a screw disc at the foot of the pile, similar to an auger, which usually does not make more than one and a half turns. This

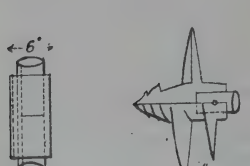


FIG. 140.—Wrought-iron pile with cast-iron disc.

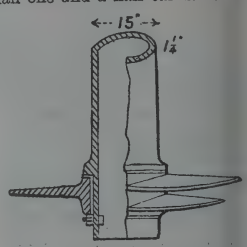


FIG. 141.—Cast-iron pile and disc.

disc is of cast-iron, which is made up to 6 feet in diameter. The piles are usually sunk by manual power acting on long levers fixed to a capstan head on the piles, so as to screw them down to a firm stratum. When screw piles have to be sunk through hard ground, a water jet may be used to facilitate sinking.

Cylinders.

Cylinders of cast-iron are sunk to a firm foundation by excavating inside and letting them sink by their own weight, or if that is not sufficient, adding additional weight. As the cylinder sinks, lengths are bolted on by means of flanges which are on the inside. When it is desirable to make the joints water-tight, a cloth strip saturated with thick paint is laid between the flanges.

Small cylinders from 4 to 10 feet in diameter are usually cast in lengths of from 5 to 10 feet, without any vertical joint, and from 1 to $1\frac{1}{4}$ inches in thickness with $1\frac{3}{4}$ or 2 inch internal flanges. The thickness in inches necessary to withstand the pressure of the water of small thin cylinders may be approximately found from the formula—

$$t = \cdot 001\, rh;$$

where r is the radius of cylinder, and h depth of water, both in feet, and assuming that the metal will stand with safety a compression of 5,000 lbs. per square inch. In no case should the thickness t be less than $\frac{1}{2}$ inch. The inside of the cylinder is excavated by hand, or if the water cannot be kept out, by means of a grab, and is afterwards filled up with concrete or masonry.

At the St. Louis Bridge, U.S.A., the cylinders were 4, 6, and 8 feet in diameter, cast in 10-feet lengths, the metal being $1\frac{1}{4}$ inch. thick with $2\frac{1}{2}$-inch flanges.

The bottom cylinder of the Albert Bridge over the Thames was 21 feet in diameter and 4 feet 6 inches high, cast in one piece; on this was a reducing ring tapering to 15 feet in diameter; all the other rings were 15 feet in diameter and 6 feet high, also cast in one piece.

Brick or masonry cylinders built on an iron or wooden curb are frequently used instead of iron cylinders.

Pneumatic Process of Sinking Cylinders.

Cylinders and large caissons are often sunk by the pneumatic process. The cylinder is made as nearly as possible air-tight, and an air-lock or chamber, with two doors, one opening from the outer air and the other into the cylinder, is bolted on to it; both of these doors open downward into the cylinder or against the pressure of the air. Air is pumped into the cylinder so as to drive the water out. The workmen then enter the air lock, the door communicating with the outer air is closed, and the compressed air allowed to enter from the cylinder; when the pressure has become equal the door into the cylinder is opened and the workmen descend. The excavated material is carried up through the air-lock, or blown up through a tube by air pressure. The

ylinder is buoyed up by the pressure of the air inside it, and when this is released it tends to ink. It has generally been considered that men cannot work in safety under a greater depth of vater than 100 ft.; in the St. Louis Bridge 108 ft. was reached, and 147 ft. under mean low water s said to have been attained in the East River Gas Company's tunnel at New York.

Steel Sheet Piling.

BRITISH PRACTICE.

FIG. 141A.—Universal Joist Section.

British standard joists are employed, having flanges 5 ins. wide and used in conjunction with standard clutch or locking bar. The ranges of joists are 15 ins. by 5 ins., 12 ins. by 5 ins., 10 ins. y 5 ins., 8 ins. by 5 ins. and 6 ins. by 5 ins. The clutch is put on the flange of joist at works and the wo driven as one. The section has great strength, and is very easily straightened for re-use and ossesses high salvage value, as the joists can be used for constructional purposes. Supplied up t 65 ft. lengths.

Simplex Section, 12 ft.; 26·5 lbs. per sup. ft.

Simplex Section, 8 ft.; 22 lbs. per sup. ft.

FIG. 141B.

These sections consist of one member only and are used for lighter forms of construction. hey can be obtained in lengths up to 40 ft.

With double-acting hammers, the cost of driving steel sheet piling, as against timber, is usually bout one-fourth, and frequently as low as one-twentieth. In a recent example, a No 6 double cting hammer (McKiernan-Terry), at Larne, drove 845 12-in. 'Simplex' piles, in lengths arying from 33 ft to 15 ft., in seventeen working days.

RANSOME TYPE 'D' STEEL SHEET PILING.
STANDARD SECTION.

Section.	Weight per ft. run.	Weight per sq. ft. Interlocked.	Sectional Area.	Moment of Inertia.	Radius of Gyration.	Section Modulus.	Dimension 'B.'
Standard	33 lbs.	28 lbs.	9·6 sq. in.	12·25 in.^{4}	1·12 in.	7·66 in.^{3}	$3\frac{3}{16}$ in.
	49 kgs. per metre	136·71 kgs. per sq. metre	6,200 sq. mm.	5,100,000 mm.^{4}	28·5 mm.	126,000 mm.^{3}	80·96 mm.
Uniform	31 lbs.	26·25 lbs.	9·12 sq. in.	11·9 in.^{4}	1·14 in.	7·32 in.^{3}	$3\frac{1}{8}$ in.
	46 kgs. per metre	128 kgs. per sq. metre	5,876 sq. mm.	4,953,000 mm.^{4}	28·9 mm.	119,000 mm.^{3}	79·37 mm.
Uniform light	26·88 lbs.	22·6 lbs.	7·76 sq. in.	7·152 in.^{4}	0·945 in.	5·031 in.^{3}	$2\frac{11}{16}$ in.
	40 kgs. per metre	110·4 kgs. per sq. metre	5010 sq. mm.	2,860,000 mm.^{4}	24 mm.	80,000 mm.^{3}	68·26 mm.

This section (fig. 141C) is claimed to be the strongest British piling in proportion to its weight per sq. ft., the strength being due to the trough-shape, with a neutral axis running through the centre of the pile, as shown in the figure.

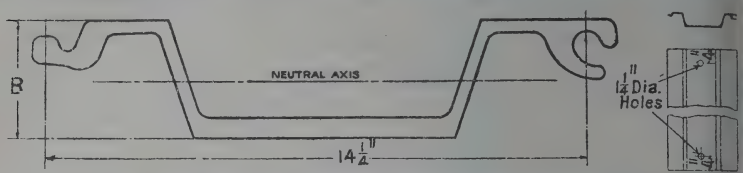


FIG. 141C.—Ransome Interlocking Type 'D' Steel Sheet Piling.

All the above sections are 14½ ins. wide between centres of interlock.

The interlock is water-tight, without clay puddling, and it is sufficiently flexible to enable circular cofferdams to be built as small as 5 ft. 3 ins. in diameter, without using special piles. The safe working stress is 16,000 lbs. per sq. in.

The advantage claimed for this piling is that, in view of its large covering capacity in proportion to its weight, one-third less tons of the piling are required to cover a given area, so that about one-third less has, consequently, to be paid for freightage.

The piling is made of special toughened steel that penetrates the hardest ground without damage to the piling. It is specially easy to drive and extract with Ransome plant, and can be used repeatedly.

Some of the classes of work for which Ransome type 'D' Piling is used are cofferdams, caissons, dams, retaining walls, lock, dock, harbour, breakwater, canal and reservoir work, bridge and other foundations, shaft-sinking, etc.

'SIDE-GROOVE' STEEL PILING.

These sections (figs. 141D and 141E), known as 'Side-Groove' Steel Piling (Annison's Patents), have an independent locking bar of heavy design and consequent great tensional strength in the joints of the assembled piles. The bars can be slid on to the sheet members at the mills before dispatch, one bar and sheet being driven together as one pile. Thus assembled they form the widest steel piling manufactured: time and cost in driving them is therefore comparatively low. These sections are very adaptable, and special piles, such as corner pieces, etc., can be readily manufactured for any class of work. The heavier types can be rolled in lengths up to 61 ft., and the lighter type up to 40 ft.

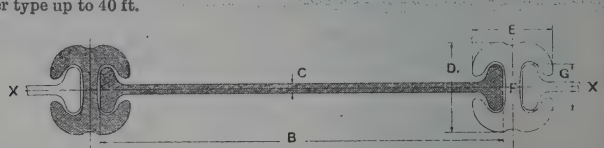


FIG. 141D.

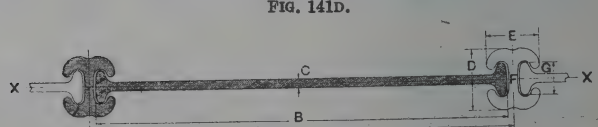


FIG. 141E.

The driving of 'Side-Groove' steel piles can be effected by any of the usual methods practised for driving timber piles, although they are easier to drive owing to their small sectional area. Short lengths can be driven by a hand maul, ringing engine, or drop hammer; while semi-automatic hammers of the 'Southgate Pile Driver' type, as well as double-acting automatic hammers, are generally used for driving the longer piles. It is advisable to use some form of cap on the heads of the piles, so as to protect them while being driven: they remain more serviceable in consequence, and can be pulled and re-driven many times.

DIMENSIONS AND WEIGHTS OF 'SIDE-GROOVE' STEEL PILING.

Side-Groove' Steel Piling.	Dimensions.							Weight per super ft. assembled.
	A	B	C	D	E	F	G	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Lbs.
Heavy section . .	$21\frac{3}{8}$	$20\frac{3}{8}$	$\frac{13}{32}$	$4\frac{5}{8}$	$4\frac{1}{8}$	$\frac{7}{8}$	$2\frac{5}{8}$	41·65
" " . .	$21\frac{3}{8}$	$20\frac{3}{8}$	$\frac{1}{2}$	$4\frac{5}{8}$	$4\frac{1}{8}$	$\frac{7}{8}$	$2\frac{15}{16}$	45·28
Light section . . .	$21\frac{3}{4}$	21	$\frac{13}{32}$	$2\frac{7}{8}$	$2\frac{15}{32}$	$\frac{13}{32}$	$1\frac{3}{4}$	25 approx.

AMERICAN PRACTICE.

The following are three principal varieties. In the first form, (*a*), (*b*), and (*c*), fig. 141F, the ction is symmetrical with respect to a longitudinal axis, but unsymmetrical with respect to a nsverse axis. In the second form, (*a*) and (*b*), fig. 141G, the reverse is the case. In the third

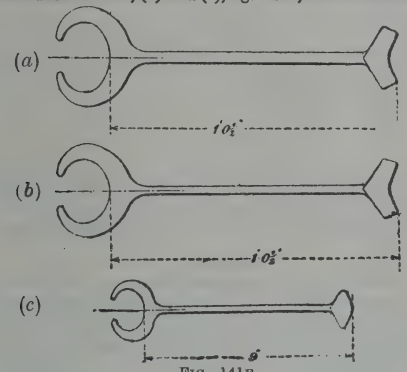


FIG 141F.

m, either of the two pieces together form a unit symmetrical to both axes. All the forms may used over and over again as steel sheet piles.

Sheet piles of the rolled forms may be secured from the mills in lengths up to 45 ft. for one or o light sections and up to 70 ft., or perhaps more, for other weights.

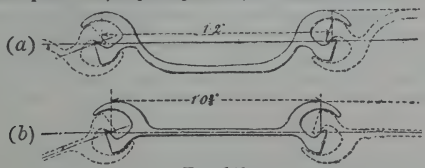


FIG. 141G.

In fig. 141H is shown a simple steel plate bent round a vertical axle of curvature and given table interlocking hooks at the sides. The curvature adds to the rigidity. This piling is embled with concavities and convexities alternating.

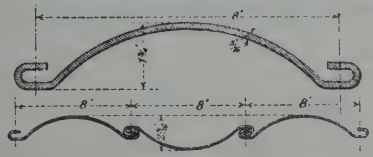


FIG 141H.

Another type of steel-plate sheet piling has vertical corrugations, such as shown in fig. 141 I. These corrugations are made on radii of curvature of but an inch or so. The interlock is made by overlapping edges and securing one or both by vertical straps riveted on to the piling. Sometimes the straps are not continuous, but are broken up into short and separated lengths. In driving piling of these classes it is usual to hammer shut the interlock opening on the

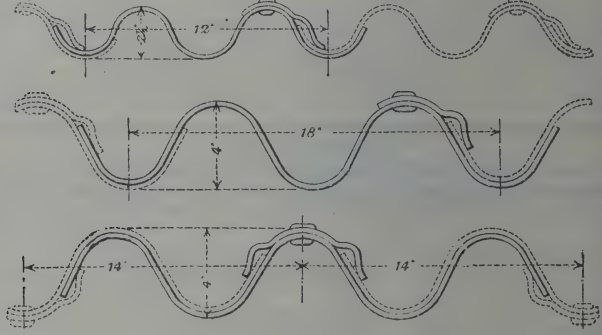


FIG. 141 I.

forward side at the bottom of the pile about to be driven. This tends to prevent rupture or distortion and to keep the interlock clear. When the next pile goes down it opens out the inter-locking space. The first two rolled forms are obtainable with $\frac{1}{4}$-in. webs. The second form is now obtainable with a web thickness of $\frac{7}{32}$ in. Plate steel sheet piling is obtainable in still thinner metal.

Driving.

The driving of the steel sheeting is generally effected by means of double-acting pile hammers the McKiernan-Terry being a usual type. The blows are given in rapid succession.

Light-weight sheeting, and also heavy piling, may at times be very advantageously driven with a water jet. Such material as mud, soft clay, and clear sand will ordinarily respond to the jet. If, however, the material is hard clay or a sand containing a heavy percentage of gravel the water jet is an inadvisable adjunct. A supply pipe of 1 in. diameter and a $\frac{3}{4}$-in. nozzle will be suitable for moderate weights of piling having a width of, say, 13 ins. or less.

Pulling.

It is quite customary to pull piles that have been used in temporary service. The cost of pulling is considerable. While, in general, it is not as great as the cost of driving, still it is to be rated as equal to a large percentage of the expense of driving the very same piles which it is proposed to pull out again. This percentage may rise as high as 75, or even higher. Where the piling has been driven with a wooden maul, or could have been so driven, a simple lever may suffice. This lever may have attached to it metal straps or other devices to facilitate connecting the pile head with the lever. Simple perforations in the top of the pile serve for the introduction of bolts or pins. Ordinary hoisting arrangements may suffice for these piles and for still heavier sheeting. Hydraulic jacks have been used for rather difficult pulling. The jacks may be used mainly for starting the units. By setting up jacks on the heads of the adjacent piles they may be brought to bear beneath a head block provided with a slot through which the intermediate pile may pass on its way up. Another method that has been used simply sets up a framework provided with a strong cross-piece, to which blocks and tackle may be rigged. The line may be operated by hand or by power, as circumstances may require. For pulling piles which had been put down to a considerable depth, a percussion-piston pile-driving hammer was hung upside down from a derrick boom and used thus to pull the piles. In pulling, the inverted hammer takes hold of the pile by means of the shackle, and steady tension is then exerted on the pile line, which pulls the shackle strap down upon the anvil block, and the hammer is placed in operation. Piles of 26 ft. penetration in clay, sand, and gravel were withdrawn in from 2 minutes to 10 minutes each, without distortion. The McKiernan-Terry pile hammers can also be used for pulling purposes.

Cost Data.

The following are the cost data relating to the driving of 19,654 lineal feet of 12-in. rolled piling of the first type.

The piling weighed 40 lbs. per lineal foot. The material penetrated was sand and clay, and the piles varied in length from 40 ft. to 60 ft. Twenty-one working days of 10 hours each were

nsumed on the work. Maintenance and operation are put at $7 per day. Nine men, including foreman, an engineer, and a fireman, constituted the crew. Their combined daily wage nounted to $28·50. The expense for 21 days, including a $60 item for handling and incidentals, talled $805·50. The total cost per foot of penetration is given as $0·041. Estimated on ie basis of the weight driven, the cost was $2·05 per ton of 2,000 lbs.

Caissons.

Very deep and large piers and abutments of bridges have recently been constructed with eel caissons braced internally so as to prevent them collapsing while sinking. These caissons e excavated and filled with concrete or masonry.

The foundations of the Hawksbury Bridge in Australia were sunk to a depth of 162 feet below gh-water level by dredging.

FRICTIONAL RESISTANCE OF PNEUMATIC FOUNDATIONS (SCHMOTT).

Tables of Coefficients of Friction.		Dry Material.		Wet Material.	
Material.	Soil.	First Movement.	During Motion.	First Movement.	During Motion.
Sheet-iron, without rivets	Gravel and sand	·4015	·4583	·3348	·4409
Sheet-iron, with rivets	" "	·3965	·4911	·4677	·5481
Cast-iron, unplaned	" "	·3677	·4668	·3646	·4963
Granite, roughly worked	" "	·4266	·5368	·4104	·4800
Pine, sawn	" "	·4088	·5109	·4106	·4985
Sheet-iron, without rivets	Sand	·5361	·6313	·3655	·3247
Sheet-iron, with rivets	"	·7269	·8391	·5156	·4977
Cast-iron, unplaned	"	·5636	·6063	·4744	·3796
Granite, roughly worked	"	·6473	·7000	·4728	·5291
Pine, sawn	"	·6633	·7340	·5787	·4793

The foundation must be vertical, being kept in equilibrium by the friction of its surface.

According to Mr. F. W. Sweeney in the *Journal of the Western Society of Engineers*, experience sinking concrete caissons for bridge foundations has shown that building the walls with a batter not only of no particular advantage in reducing the sinking friction, but it is positively detri-ental to the proper guiding of the caisson. It is considered the best practice to have a perfectly umb wall. When the depth of water will permit, it is generally cheaper to build up a river isson on shore in the form of a wooden shell, launch it, tow it into position between guide piles d sink it by filling with concrete.

Freezing Process of Sinking Foundations.

The Freezing Process has been used to sink large foundations in treacherous material, pecially quicksand. Pipes 10-inch in diameter, open at the bottom, are sunk vertically about eet apart round the ground to be excavated ; inside of these 8-inch pipes, closed at the bottom, e lowered, and again within the latter small pipes. The freezing material is pumped into the aller pipes, and returns to the cooling tank through the large ones. A solid cylinder of frozen ound is gradually formed round the pipes ; these frozen cylinders unite, forming a solid ring nd the place to be excavated. The material to be removed will, of course, be frozen solid, d therefore much more difficult to excavate.

Dams

If the depth of the water does not exceed 4 feet, the bottom moderately firm, and there is no rrent, a dam of clay puddle about 3 feet wide on top may be formed round the space to be closed ; before the dam is commenced care should be taken to remove all loose porous material d roots from the site, and, if possible, excavate a trench for its foundation. Long lengths of terproof canvas, sewn together and weighted with a chain stitched to the ends so as to keep it place, have also been used. The canvas should be supported by a framework of timber (see . 142). These frameworks are spaced about 8 feet apart and sheeted with boarding between. e ground should be dredged level to receive them.

PUDDLE DAMS.

Coffer dams of puddle usually consist of two parallel rows of sheet piling, the intervening ace between them being filled in with puddle ; sometimes three or even four rows, with a ddle wall between each, have been adopted in order to give greater stability and make the m more watertight.

It is always desirable to make the puddle wall as thin as possible; it is seldom more than

4½ or 5 feet in thickness. Bolts through coffer dams should be avoided as far as possible, as the puddle in settling leaves vacant spaces along them, causing leaks; to remedy this, iron discs through which they pass have been used; these discs are embedded midway in the puddle wall.

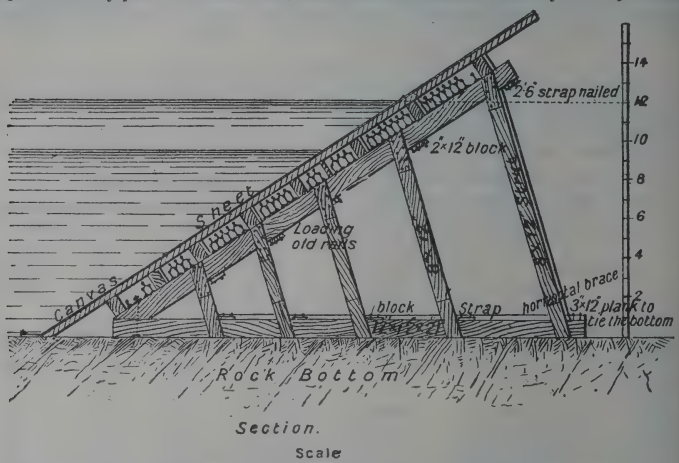


FIG. 142.

In coffer dams made for the construction of the East London Railway through the docks through bolts were entirely dispensed with, their place being taken by buttress piles driven a intervals on the outside which withstood the pressure of the puddle.

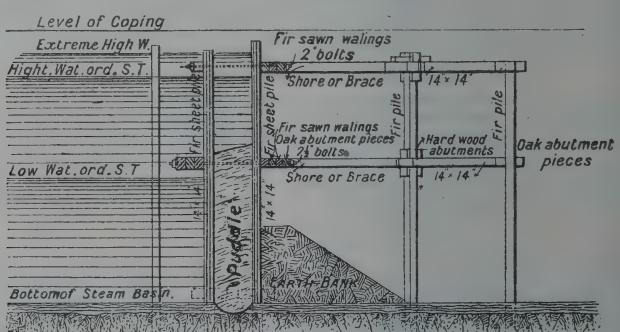


FIG. 143.

Fig. 143. shows a coffer dam used at Portsmouth Dockyard extensisn. The shoring piles we driven 9 feet centre to centre, and 12-inch by 12-inch struts, one horizontal and one incline were fixed to each.

Puddle should be free from large stones, roots and vegetable matter liable to decay. Son engineers consider a certain amount of sand or gravel renders it less liable to crack.

Single Balk Dams.

Dams have also been most successfully constructed of single rows of sheet piling grooved and iven between waling pieces. Fig. 143A is the more usual arrangement; the piles are from to 12 inches in thickness; a groove about 2 inches wide and 2 inches deep is cut out of each

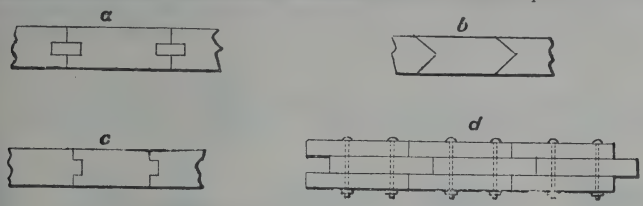


Fig. 143A.

ile; into this is fitted a tongue, which is cut to the exact size to fit it. Sheet piles should be awn die-square with the grooves perfectly straight and true. They should be of sufficient ickness to withstand the water pressure without bulging between the waling pieces. Small aks at the joints may be stopped by caulking with oakum.

Cribs.

Timber cribs or boxes, which are usually made watertight and floated into position and then nk, have been largely used in America for foundations of bridges on rock, or in places where ere is no fear of undermining by the currents. They are filled with concrete.

Scaffolding.

Standards are upright poles, generally of spruce, 20′ to 50′ long, 5″ to 8″ diam. at butt; those der 2½″ at tips are termed *rickers*, and run about 22′ long. They are firmly fixed in the ground r in tubs filled with earth, if excavation is inconvenient), 4′ 6″ from wall, 10′ to 12′ apart. When reater lengths are required, two are lashed together, tip to butt, and tightened with wedges o these, on the side next the wall, are lashed horizontal *ledgers*, or *runners*, parallel to the wall vertical intervals of 3′ 6″ to 5′. They support the *putlogs*, of squared timber (usually birch), ′ × 3″, 6′ long, one end of which rests on the ledgers, the other in a hole in the wall left by nitting a brick header; they are about 3½′ or 4′ apart, and support the *scaffold boards*, usually × 1½″, sometimes 3″. Poles called 'braces,' lashed diagonally across every three or four andards, stiffen the scaffold. Masons often use a second row of standards and runners, close the wall, to prevent the masonry being disfigured by putlog holes.

Fig. 144 (from Spon's 'Dict. of Eng.') shows the arrangement of a bricklayer's scaffold. When ie scaffold has to be carried to a considerable height, other poles are lashed to the standards with ropes tightened by wedges. Poles are also lashed diagonally across every three or four standards in the shape of a St. Andrew's cross; these are called braces, and they serve to stiffen or brace the scaffold longitudinally.

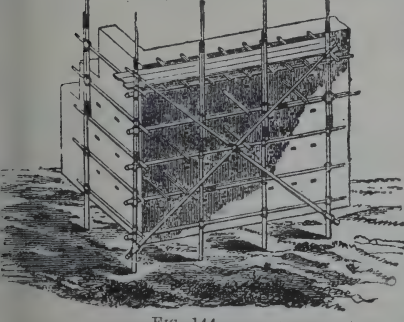


Fig. 144.

In buildings which do not admit of putlog holes in the walls, as where rubble stone or ashlar facing is used, and which do not require heavy machinery for hoisting, or strong timbers in the scaffold, two rows of standards with ledgers are used, one row being close to the wall, and the other at the usual distance, so that both ends of the putlogs may rest on the ledgers. Scaffolds such as we have just described are sometimes used for heights of 90′ or 100′ from the ground, as in building church steeples and similar work. In the erection of houses it is usual to construct a staging about 10′ square on the outside of the scaffolding, for the purpose of hoisting materials, and from which they are distributed for use.

This staging is usually formed with standards and ledgers in the same manner as the scaffold to which it is connected.

Scaffolding Knots.

The principles of a good knot are its facility in tying, its freedom from slipping, and its being easily untied. All knots will jam more or less when subject to a strain. The knots in fig. 144A are shown open before being drawn taut, in order to show the position of the parts. The names usually given, and their uses, are as follows :—

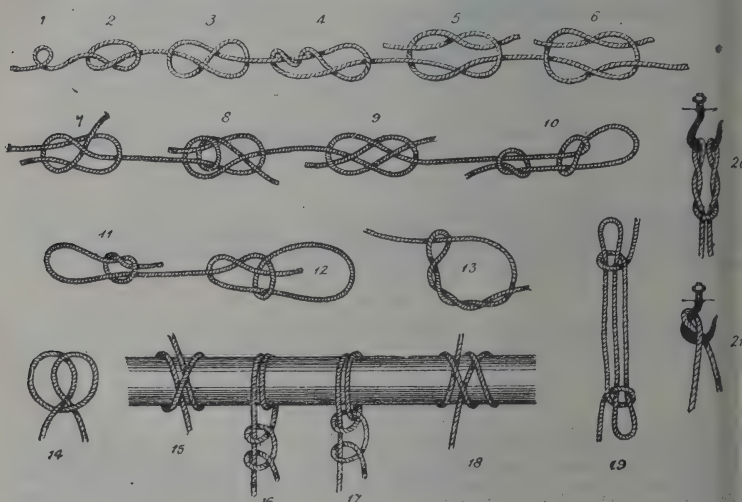


FIG. 144A.

1. Bight of a rope.
2. Overhand, or thumb, knot, to prevent a rope running through the sheave of a block.
3. Figure of eight knot, used as No. 2.
4. Stevedore knot : is useful when the rope passes through an eye. It is easily untied after being strained.
5. Square, or reef, knot. This is a most useful knot for joining two ropes of same size. However tight it jams, it is easily 'upset' and undone.
6. Granny, or thief, knot. This should not be used, as it will jam tight but not slip (as erroneously supposed), will not 'upset,' and consequently is difficult to undo.
7. Single sheet bend, or weavers' knot, used principally for joining two ropes of unequal size more securely than a reef knot.
8. Double sheet bend, more secure than No. 7.
9. Carrick bend, for fastening the four guys to a derrick.
10. Flemish loop.
11. Slip knot.
12. Bowline, for making a loop that will not slip. After being strained, this knot is easily untied. Commence by making a bight in the rope, then put the end through the bight and under the standing part, pass the end again through the bight, and pull taut. This knot should be tied with facility by everyone who handles ropes.
13. Timber hitch ; the greater the strain the tighter it will hold.
14. Clove hitch, consisting of two half-hitches ; used chiefly to tie ledgers to standards. This is the most useful of all the knots used in scaffolding, on account of its simplicity and security.
15. Clove hitch, as No. 14, showing its application around a pole.
16. Round turn and two half-hitches, for securing a rope to a ledger or for fastening the guy of derricks, shear legs, &c.
17. Fisherman's bend, used when a thick rope, such as a fall, is made fast to a ring.
18. Rolling hitch, used in a variety of ways, chiefly in making fast one rope to another that is held taut.
19. Sheepshank, for shortening a rope when the ends are inaccessible.
20. Catspaw. An endless loop, and used where great power is required.
21. Blackwaller. Easily applied, but requires watching ; has a tendency to slip.

Shoring Buildings.

A plank (fig. 151), C, 9 ins. wide, 3 ins. thick, the length varying with height of building, is ced against upper part of wall to be supported. In this rectangular holes are cut to admit timber 'needles,' D, from 4 ins. × 6 ins. × 6 ins., and about 12 ins. long. These are let into

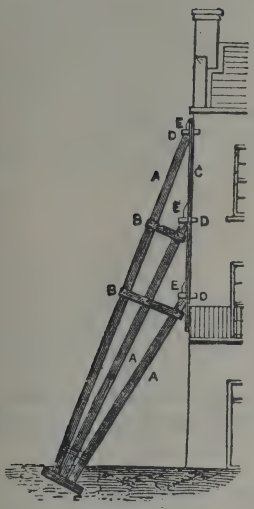
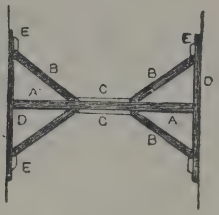


FIG. 151.

FIG. 152.



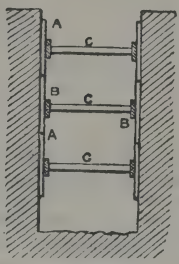


FIG. 153.

wall about 4½ ins., and project beyond the plank about 4½ ins. to receive the ends of the ores,' A.

A cleat, E, is usually nailed to the plank on the upper side of each needle.

The struts, A, are from 6 ins. × 4 ins. in very small buildings to 12 ins. × 9 ins. or 12 ins. in y large; usually half timbers 12 ins. × 6 ins. They are fixed to a footing block, F. The outer strut is called a 'top raker,' the inner the 'bottom shore,' the centre the 'middle er.'

Short pieces, B, about 1 in. thick and from 6 ins. to 9 ins. wide are nailed on each side the shores.

Struts between Houses.

A (fig. 152), horizontal strut, 6 ins. × 4 ins. to 9 ins. × 4 ins.
B, raking strut, 6 ins. × 4 ins.
C, straining-piece, 6 ins. × 3 ins.
D, plank, 9 ins. × 3 ins.
E, cleats.

The horizontal strut, A, is at height above ground equal to about two-thirds height from ound to eaves.

Timbering Trenches.

A (fig. 153), poling boards, about 3 ft. long, 1 in. to 1½ in. thick, 7 ins. to 9 ins. wide, placed ainst the side as each successive depth of 3 ft. is excavated.

B, waling planks, 9 ins. × 3 ins., placed longitudinally against the centre of each row of poling ards.

C, struts from 4 ins. square to 6 ins. or 8 ins. square, according to their length and the pressures. king pieces are added in bad ground.

RETAINING-WALLS

Pressure of Earth.

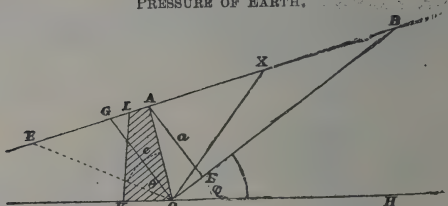


Fig. 153A.

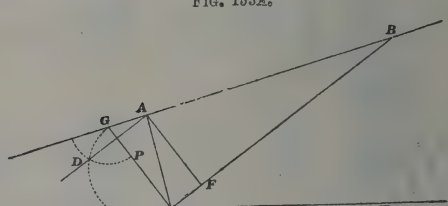


Fig. 153B.

Let AB, fig. 153A, be the surface of the ground, and OB the natural slope at an angle ϕ.

Draw OE, making an angle θ, this angle being equal to ϕ plus the angle of friction of earth against the back, AO, of the wall AOKL.

Take X so that $EA \times EB = (EX)^2$.

Then AOX is the triangle of maximum pressure against the wall.

Draw AF (a) and GO (c) perpendicular to OB, then.

$$\text{Maximum thrust} = \tfrac{1}{2}w\,(c - \sqrt{c(c-a)})^2,$$

where w = weight of a cubic foot of earth.

Describe a semicircle on GO (figs. 153A and 153B). Draw AD parallel to OB, cutting the semicircle at D. With G as centre and GD as radius describe a circle cutting GO at P, and join DP, then,

$$\text{Maximum thrust} = \frac{w}{2}\,(\text{OP})^2, \text{ acting at } \tfrac{1}{3}\text{ AO, and making an angle } \theta \text{ with the normal to AO.}$$

Walls for Railway Cuttings.

For walls over 18 ft. in height—

Thickness at bottom = $\frac{2}{3}$ height − 3 ft.

For walls less than 18 ft. high—

Thickness at bottom = $\frac{1}{3}$ height + 3 ft.

The two equations give the same result for a height of 18 ft. No allowance is necessary for surcharge of less than 6 ft. (*Pennsylvania Railroad Co.*)

Pressure of Water.

The moment of pressure of water on a retaining wall per each foot of length of wall is $d^3 \times 10$ where d is the depth of water in feet. This is the moment at 1 foot. The total pressure is $31{\cdot}2\,d$ assumed to be concentrated at one-third the depth from the bottom of the water. Hence the moment $10{\cdot}4\,d^2$. The weight of the wall may be assumed concentrated at its centre of gravity and the effect of the pressure of the water is to turn the wall upon the point O (fig. 153). Calling H the height of the wall in feet, and t its thickness in inches, and assuming one cubic foot to weigh 120 pounds, the moment of stability is $\frac{H\,t^2}{2{\cdot}4}$ for rectangular walls, per foot of length; or $d^3 \times 10{\cdot}4$ must not exceed $\frac{H\,t^2}{2{\cdot}4}$; or $t^2 = \frac{25\,d^3}{H}$. This enables the thickness of a wall to be determined, that will exactly balance the pressure. Safety would be just secured by adding 50 per cent. to the thickness at the base, and subtracting the same amount from the top thickness, the

iving the wall a sloping back as per dotted line, increasing the acting leverage of the C.G. centre of gravity) of the section, so that the resultant pressure will now fall within the middle hird of the wall thickness. This method is approximate and useful for small construction. arge masonry dams require more special consideration, and may be designed by calculations at ach few feet of depth, designing the wall in a series of steps and drawing a final shape to enclose he whole in one harmonious section, which must also fulfil the conditions of strength proper to he material and crushing stress. Special care is necessary that water does not get in between ed joints, as it would greatly assist to turn a wall over.

It is usually considered desirable that the resultant of pressure on a wall should fall within the nfddle third of its thickness. Thus in fig. 153D, if $a\,b$ to any scale represents the total pressure $1{\cdot}2\,d^2$ concentrated at the centre of pressure upon the face of a wall, and $b\,c$ to the same scale s the weight of the wall, the line $b\,c$ being drawn through the C.G. of the cross section, then if the iagonal of the rectangle $a\,b\,c\,d$ cuts the base of the wall within its middle third of thickness, he wall may be assumed fully safe. If the diagonal fall outside the middle third, the thickness of he wall must be increased. It may be made safe by building the wall higher, and thus loading it ; ut the danger of this method is that a greater area is exposed to wind pressure, and if margins f safety are narrow the addition may be worse than useless in small work. Where a tank wall orms a continuation of an earth retaining wall, for example, special care is necessary.

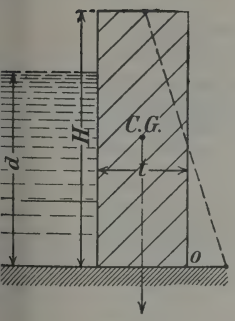


FIG. 153C.

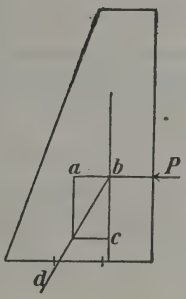


FIG. 153D.

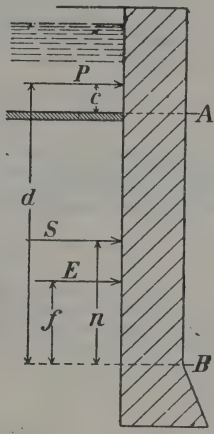


FIG. 153E.

The upper part of the wall must be safe at the bed joint level with the bottom of the tank nd the wall, taken as a vertical cantilever subject to a lateral thrust at a distance two-thirds of ne water depth from the water surface; it must be safe against overturning at any joint lower own. It must also be safe against the added thrust of the earth behind the lower portion plus ne further pressure due to the tank full of water above, which must be treated as per the rule n page 618 fig. 155. Thus in fig. 153E the wall must be safe on the line A against the moment of ne water pressure P c. It must be safe at the line B against the moment $(P \times d) +$ the moment $E \times f) +$ the moment $(S \times n)$. Here E is the horizontal component of the earth pressure, and is one-third A B ; S is the horizontal component of the surcharged load, and n is one-half of A B. he safety must be proved at sufficient other depths between B and A and below B. Economy is romoted by sloping the wall against the earth between the points A and B. The wall in the gure is palpably erroneous, being far too thin for its height; it might be made safe by a fficiency of cross-ties buried in the concrete bottom of the tank, in which case the wall from A B must be made safe by treating it as a beam exposed to a virtual load at S and E.

Equilibrium of Retaining-Walls.

By Rankine's theory the pressure of earth on a vertical plane, AB (fig. 154), may be considered s acting at a point, P, one-third AB from base A, and in a direction parallel to the surface. et w = weight of earth in pounds per cubic ft., ϕ = angle of repose of earth, P = total pressure, = height of wall in feet.

For a bank with horizontal top

$$P = \frac{wh^2}{2} \cdot \frac{1 - \sin \phi}{1 + \sin \phi}.$$

For bank with any surface slope, θ, of indefinite length

$$P = \frac{wh^2}{2} \cos\theta \frac{\cos\theta - \sqrt{\cos^2\theta - \cos^2\phi}}{\cos\theta + \sqrt{\cos^2\theta - \cos^2\phi}}.$$

For bank with maximum surface slope, ϕ, of indefinite length

$$P = \frac{wh^2}{2} \cos\phi.$$

For bank with surface slope of definite length an intermediate value is taken.

To resist the pressure there is weight of wall and of earth, ABD, resting on its back, which call W; this acts vertically from centre of gravity, G. The revetment may fail by overturning round f, by crushing at f, by sliding on Af.

Overturning round f.—On any scale make $oa = W$, $ob = P$; then oc is resultant (R), acting in direction oe at e. If e falls within base, the revetment will not overturn without crushing the toe at f; but e should fall within the centre third of Af.

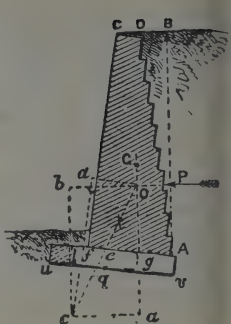


FIG. 154.

Crushing at f.—The resultant, R, must be resolved into two forces, cd (N), perpendicular to, and do parallel to, Af, acting at point e; the former is the crushing force.

Pressure per square inch at f on 1′ length of wall $= \frac{2N}{fg \times 12''}$, where $fg = 3fe$.

The pressure at f should not exceed power of material to resist crushing, divided by factor of safety, 4 to 8 (in practice seldom as high as 8).

Sliding on Af.—Force tending to produce sliding is od; force tending to resist it is N × coefficient of friction at the joint Af. od should not exceed N × $\frac{3}{5}$ coefficient of friction.

Surcharged Wall.

If n = height of wall in feet, c = height of surcharge in feet, t = mean thickness of wall, in feet, to sustain horizontal bank; t' = mean thickness of wall, in feet, to sustain bank with indefinitely long natural slope, the factor of safety being about the same as for t; t'' = mean thickness in feet of surcharged wall; then

$$t'' = \frac{nt + 2ct'}{n + 2c}.$$

Effect of Weight of Buildings on Retaining-Walls.

Let w_1 = weight of building per unit of surface; the rest of the notation as at commencement. The total horizontal pressure, P, on revetment, due to the weight of building

$$= w_1 (h - x) \frac{1 - \sin\phi}{1 + \sin\phi},$$

acting at $\frac{1}{2}$OB from O; and the total horizontal pressure, P_1, on revetment, caused by the earth

$$= \frac{w (h - x)^2}{2} \frac{1 - \sin\phi}{1 + \sin\phi}.$$

acting at $\frac{1}{3}$OB from O.

If the front of the building were farther back from AO the effect would be less, but cannot be determined.

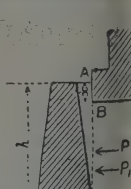


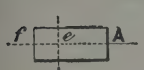
FIG. 155.

Foundations of Retaining-Walls.

Find the pressure perpendicular to uv (fig. 155), the weights and pressures being taken from point v instead of from A. If q is centre of pressure, qu should nearly equal qv, in order that the pressure may be uniformly distributed (this is unnecessary if the pressure at u is within what the earth can bear without yielding), and greatest pressure at u should not be greater than earth will bear, usually 1 to 1½ ton, or say 2,500 to 3,500 lbs. per square foot. Foundations to be carried deep enough to avoid effects of heat and frost.

Prof. Rankine advises that the distance, fe, of centre of pressure from outside edge in buttresses, himneys, walls, &c., should be as follows :—In a

Rectangle (solid).

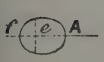


$fe = \text{or} > \frac{1}{3} fA.$

Square (solid).

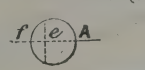
$fe = \text{or} > \frac{1}{3} fA.$

Ellipse (solid).



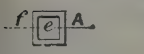
$fe = \text{or} > \frac{3}{8} fA.$

Circle (solid).



$fe = \text{or} > \frac{3}{8} fA.$

Hollow square (factory chimneys).



$fe = \text{or} > \frac{1}{6} fA.$

Circular ring (factory chimney).

$fe = \text{or} > \frac{1}{4} fA.$

Example of Brick Retaining-Wall.

Brickwork in mortar 100 lbs. per cubic ft., with a resistance to crushing of 500 lbs. per sq. in. d factor of safety of 8. Coefficient of friction for damp mortar, ·7. Weight of earth (w), 110 lbs. r cubic ft. ; angle of repose (ϕ), 37°. Pressure on foundation of sandy gravel not to exceed ton per sq. ft. Height of wall (h) above footings, 18 ft. Wall sustains horizontal bank level th top. Top of wall two bricks thick, to allow of solid coping. Batter, $\frac{1}{12}$.

Assume for trial fA (fig. 154) $= \frac{1}{3}h = 6$ ft. The back of wall being built with offsets of $4\frac{1}{2}''$ at ery 18″ in height, DB will = 3′. Foundations to be 3 ft. below ground.

Weight of wall above bed joint, fA = 6,750 lbs. per foot run of wall.
„ earth in front of AB = 3,025 „ „ „
Total weight on fA = 9,775 lbs. = W „ „

The wall is more likely to overturn at f than at any other point ; it will be sufficient, therefore, inquire into the stability of that joint.

$$P = \frac{wh^2}{2} \frac{1 - \sin\phi}{1 + \sin\phi} = 4{,}594 \text{ lbs., which acts at P ; AP being one-third AB.}$$

Drawing the parallelogram of forces, oc cuts Af at e, making $fe = 9\frac{1}{2}''$.

Resolving oc perpendicular and parallel to Af gives cd = 10,100 lbs.

$$\text{Pressure per sq. in. at } f = \frac{2 \times 10100}{3 \times 9\frac{1}{2}'' \times 12''} = 59 \text{ lbs.}$$

This gives a factor of safety of 10, which is more than sufficient.

Angle ocd will be found to be 20°, tan 20° = ·36, which gives a factor of safety of 2, the efficient of friction being ·7. The wall is therefore stable.

The pressure on foundations perpendicular to uv will be found to be 14,000 lbs., or $6\frac{1}{4}$ tons, acting q. To equalise the pressure on the earth, let $qu = qv$, which will make $uv = 12\frac{1}{2}$ ft., giving a essure of about $\frac{1}{2}$ ton per sq. foot ; but as the earth will bear $1\frac{1}{4}$ ton without yielding, a much s width will suffice.

Practical Rules for Retaining-Walls.

A mean thickness of one-fourth height with counterslope of one-fifth, built in steps, will not far wrong for light soils. This gives a bottom thickness of about one-third height, a centre ickness of one-fourth height, and a top thickness of one-seventh height. A mean thickness e-third height will generally do for stiff clay.

The following rule has been extensively used for brick retaining-walls :—

Top thickness, 1 ft. $10\frac{1}{2}$ in. ; face batter of 1 in 6, and after every five courses from top increase ickness by half a brick ; front batter should not be more than one-sixth, or it will let in moisture

and encourage vegetable growth in the joints. Long walls should have counterforts at back. Walls retaining soils through which water freely passes, such as clean gravel and sand, should have a French drain of loosely packed rubble, &c., running along the back footings, from which good-sized weepholes, from 6 to 10 ft. apart, should lead through the base. With more retentive soils a French drain at least 9 or 12 inches wide should run nearly the whole way up the back of the wall. In some cases extra weepholes at higher levels may be advisable. The mouths of the weepholes should always be carefully protected by loose packing.

Trautwine's Rule for Retaining-Walls.

The horizontal thickness (*ab*, fig. 156) at the base of a vertical or nearly vertical retaining-wall, *cdba*, which sustains a backing of either sand, gravel, or earth, level with its top, *cd*, as in the figure should not be less than the following in railroad practice, when the foundations are not more than about 3 feet deep.

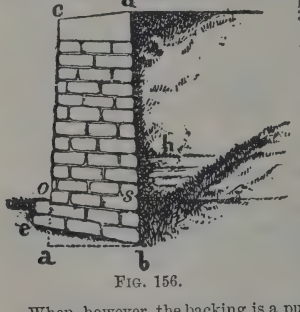


FIG. 156.

When the backing is deposited loosely, as usual, as when dumped from carts, cars, &c.—

Wall of cut stone or of first-class large-ranged rubble in mortar, *ab*.	·35 of its entire vertical height, *db*
Wall of good common scabbled mortar-rubble or brick	·4 of its entire vertical height, *db*.
Wall of well-scabbled dry rubble	·5 of its entire vertical height, *db*.

With good masonry, however, we may take the height *ds* instead of *db*, and then the above proportions of *ds* will give a sufficient thickness at the ground-line, *os*.

When the backing is somewhat consolidated in horizontal layers, each of these thicknesses may be reduced, but no rule can be given for this.

The offset, *oe*, in front of the wall is not included in these thicknesses.

When, however, the backing is a pure clean sand or gravel, we should use only the full dimensions, inasmuch as the tremor caused by passing trains would neutralise any supposed advantage from ramming materials so devoid of cohesion. Such sand may be rammed with much advantage for the purpose of compacting it in foundations; but a different principle is involved in that case. When it is done, even with cohesive earths, with a view of saving masonry in retaining-walls, it is probable that the expense will generally be found quite equal to that of the masonry saved.

The base, *ab*, in fig. 156, is four-tenths of the height, *bd*. In the foregoing thicknesses at base, the back, *db*, of the wall is supposed to be vertical; and the face, *ca*, either vertical or battered (sloped or inclined backward) to an extent not exceeding about 1½ inch to a foot; which limit it is rarely advisable to exceed in practice, owing to the bad effect of rain, &c., upon the mortar when the batter is great. The base of a vertical wall need not, in fact, be as thick as one with a battered face, but when the batter does not exceed 1·5 inch to a foot the difference is very small.

A mixture of sand or earth with a large proportion of round boulders, paving pebbles, &c., will weigh considerably more than the materials ordinarily used for backing, and will exert greater pressure against the wall, the thickness of which should be increased, say, about one eighth to one-sixth part, when such backing has to be used.

The wall will be stronger if all the courses of masonry be laid with an inclination inwards, as *oeb*; especially if of dry masonry, or if time cannot be allowed (as it always should be when practicable) for the mortar to set properly before the backing is deposited behind it. In retaining walls, as in the abutments of important arches, the engineer should place as little dependence possible upon mortar, but should rely more upon the position of the joints for stability.

An objection to inclining the joints in dry (without mortar) walls is that rain-water, falling on the battered face is thereby carried inward to the earth backing, which thus becomes soft, and settles. This may be in a great measure obviated by laying the outer or face courses horizontal, or by using mortar for a depth of only about a foot from the face. The top of the wall should be protected by a coping, *cd*, which had better project a few inches in front. After the masonry has been built up to the surface of the ground, the foundation pit should be filled up; and it is well to consolidated the filling by ramming, especially in front of the wall.

The back, *db*, of the wall should be left rough. In brickwork it would be well to let every third or fourth course project an inch or two. This increases the friction of the earth against the back, and thus causes the resultant of the forces acting behind the wall to become more nearly vertical, and to fall farther within the base, giving increased stability. It also conduces to strength not to make each course of uniform height throughout the thickness of the wall, but to have some of the stones (especially near the back) sufficiently high to reach up through two or three courses. By this means the whole masonry becomes more effectually interlocked, bonded together as one mass, and therefore less liable to bulge. Very thick walls may consist of a facing of masonry and a backing of concrete.

Where deep freezing occurs the back of the wall should be sloped forwards for 3 or 4 feet below its top, as at *co*, fig. 157, which should be quite smooth, so as to lessen the hold of the frost and prevent displacement.

FIG. 157.

A slight bulging in a new wall does not necessarily prove it to be actually unsafe. It is generally due to the newness of the mortar and to the greater pressure exerted by the fresh backing, and will often cease to increase after a few months. It need not excite apprehension if it does not exceed $\frac{1}{4}$ inch for each foot in thickness at *a*.

After a wall, *abco*, fig. 158, with a vertical back has been proportioned by Trautwine's rule, it may be converted into one with an offsetted back, as *aino*. This will present greater resistance to overturning, and yet contain no more material. Thus, through the centre, *t*, of the back, draw any line, *in*; from *n* draw *ns* vertical; divide *is* into any even number of equal parts (in the figure

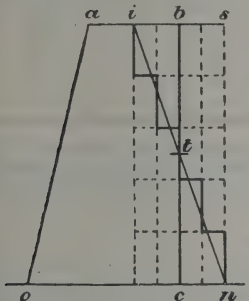


FIG. 158.

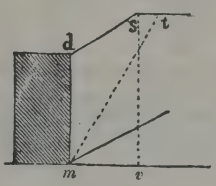


FIG. 159.

here are 4), and divide *sn* into one more equal part (in the figure there are 5). From the points of division draw horizontal and vertical lines for forming the offsets, as in the figure.

When, as in fig. 159, the backing is higher than the wall, and slopes away from its inner edge, *d*, at the natural slope, *ds*, of $1\frac{1}{2}$ to 1, the following thicknesses at base will at least be found sufficient for vertical walls with sand. They are deduced from experiments.

In Table I., the first column contains the vertical height, *sv*, of the earth, as compared with the vertical height of the wall, which latter is assumed to be 1; so that the table begins with backing of the same height as the wall, as in fig. 156. Without increasing the base these vertical walls may be changed to others with battered faces to any extent not exceeding $1\frac{1}{2}$ inch to a foot, or 1 in 8, without sensibly affecting their stability.

TABLE I.

Total Height of the Earth, compared with the Height of the Wall above Ground.	Wall of Cut Stone in Mortar.	Good Mortar Rubble or Brick.	Wall of Good Dry Rubble.	Total Height of the Earth, compared with the Height of the Wall above Ground.	Wall of Cut Stone in Mortar.	Good Mortar Rubble or Brick.	Wall of Good Dry Rubble.
	Thickness at Base, in Parts of the Height.				Thickness at Base, in Parts of the Height.		
1	·35	·40	·50	2	·58	·63	·73
1·1	·42	·47	·57	2·5	·60	·65	·75
1·2	·46	·51	·61	3	·62	·67	·77
1·3	·49	·54	·64	4	·63	·68	·78
1·4	·51	·56	·66	6	·64	·69	·79
1·5	·52	·57	·67	9	·65	·70	·80
1·6	·54	·59	·69	14	·66	·71	·81
1·7	·55	·60	·70	25			
1·8	·56	·61	·71	or more	·68	·73	·83

When the slope *nr*, fig. 160, of $1\frac{1}{2}$ to 1 starts from the outer edge, *n*, of the wall, greater thickness is required. Poncelet gives the following for this case, for dry sand (Table II.).

TABLE II.

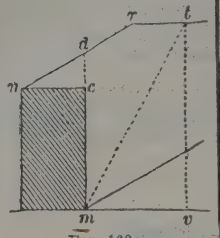


FIG. 160.

Total Depth of Earth, compared with Height of Wall.	Wall of Cut Stone in Mortar.	Wall of Brick-work.	Total Depth of Earth, compared with Height of Wall.	Wall of Cut Stone in Mortar.	Wall of Brick-work.
1	·35	·452	2·4	·762	1·02
1·1	·393	·498	3	·811	1·11
1·2	·439	·548	4	·852	1·18
1·3	·485	·604	6	·883	1·25
1·4	·532	·665	11	·909	1·28
1·5	·579	·726	21	·922	1·31
1·6	·617	·778	31	·926	1·32
1·7	·645	·824	Infinite	·934	1·34
1·8	·668	·847			
1·9	·690	·903			
2	·707	·930			

When the earth reaches above the top of the wall, as in figs. 159 and 160, the wall is surcharged and the earth that is above the top is called the surcharge. When the surcharge is carefully deposited above the wall, so as to slope back at a steeper angle than 1½ to 1, as, say, at 1 to 1, theory does not require the wall to be as thick.

WHARF WALLS

are an instance where the thickness should be increased, notwithstanding that the pressure o the water in front helps to sustain them. The earth behind such walls is not only liable to b very heavily loaded when vessels are discharging, but is apt to become saturated with wate especially below low-water level, and thus to exert a very great pressure against the wall Moreover, the water gets under the wall, and by its upward pressure virtually reduces its weigh and consequently its stability. The same cause, of course, diminishes the friction of the wa upon its base. Such walls are, therefore, very liable to slide if the foundation is smooth an horizontal, and have done so even when the foundation had a considerable inclination back ward.

TABLE III

CONTENTS IN CUBIC YARDS FOR EACH FOOT IN LENGTH OF RETAINING-WALLS WITH A THICK NESS AT BASE EQUAL TO ·4 OF THE VERTICAL HEIGHT, IF THE BACK IS VERTICAL.

Ht. Ft.	Cub. Yds.	Ht. Ft.	Cub. Yds.	Ht. Ft.	Cub. Yds.	Ht. Ft.	Cub. Yds.	Ht. Ft.	Cub. Yds.	Ht. Ft.	Cub. Yds.
1	·013	10½	1·38	20	5·00	29½	10·9	48	28·8	74	68·5
1½	·028	11	1·51	20½	5·25	30	11·3	49	30·0	76	72·2
2	·050	11½	1·65	21	5·51	31	12·0	50	31·3	78	76·1
2½	·078	12	1·80	21½	5·78	32	12·8	51	32·5	80	80·0
3	·113	12½	1·95	22	6·05	33	13·6	52	33·8	82	84·1
3½	·153	13	2·11	22½	6·33	34	14·5	53	35·1	84	88·4
4	·200	13½	2·28	23	6·61	35	15·3	54	36·5	86	92·5
4½	·253	14	2·45	23½	6·90	36	16·2	55	37·8	88	96·8
5	·313	14½	2·63	24	7·20	37	17·1	56	39·2	90	101·3
5½	·378	15	2·81	24½	7·50	38	18·1	57	40·6	92	105·8
6	·450	15½	3·00	25	7·81	39	19·0	58	42·1	94	110·5
6½	·528	16	3·20	25½	8·13	40	20·0	59	43·5	96	115·2
7	·613	16½	3·40	26	8·45	41	21·0	60	45·0	98	120·1
7½	·703	17	3·61	26½	8·78	42	22·1	62	48·1	100	125·0
8	·800	17½	3·83	27	9·12	43	23·1	64	51·2	102	130·1
8½	·903	18	4·05	27½	9·45	44	24·2	66	54·5	104	135·2
9	1·01	18½	4·28	28	9·80	45	25·3	68	57·8	106	140·5
9½	1·13	19	4·51	28½	10·2	46	26·5	70	61·3		
10	1·25	19½	4·75	29	10·5	47	27·6	72	64·8		

If the back is stepped according to the rule on p. 621 the proportionate thickness at base wi of course, be increased. Face batter, 1½ inches to a foot, or one-eighth of the height. Ba either vertical, or stepped according to Fig. 158. The strength is very nearly equal to that of vertical wall with a base of ·4 its height. Experience has proved that such walls, when co

osed of well-scabbled mortar rubble, are safe under all ordinary circumstances for earth level ith the top.

A retaining-wall is usually in greater danger for a few months after its completion than after ime has been allowed for the mortar to harden perfectly and for the backing to settle. When here are suspicions of the safety of a new wall, it would be well to place strong temporary hores against it, at about one-third to one-half of its height above ground. In some cases ermanent buttresses of masonry may be built for the purpose. They should be well bonded nto the wall.

The pressure of the earth backing will be much reduced if the first few feet of its height be nade up in thin horizontal layers, to be consolidated by being used by the masons instead of caffolding, as shown at *h*, fig. 156, p. 620. Frequently this can be done without inconvenience, nd at very trifling cost.

CHIMNEYS.

Stability of Chimney Shafts.

The limit of stability to be observed for chimney shafts is that the wind must never bring nsion on any joint. For this to be the case the 'weight moment,' that is, the weight of the ngth of shaft above any joint, multiplied by the diameter (or 'width' in the case of a square shaft) t the shaft at that joint, must not be less than the 'pressure moment,' *i.e.* the total wind pressure gainst the length of shaft above the joint, multiplied by the height of the shaft above the joint.

Assuming the shaft to be of uniform section from top to base, then

if

d = average breadth of shaft ; *h* = height, W = weight of the height *h*, in lbs. ; *c* = co-efficient wind pressure per sq. ft. (this co-efficient varies with the cross-section of the shaft, and for quare shafts = 56, for octagon shafts = 35, for round shafts = 28, though in the case of xceptionally heavy gales it may exceed these figures),

$$W = ch^2.$$

If the shaft is wider at the base than at other points of its length, then if d = average breadth, nd b = breadth of base,

$$W = c\frac{d\,h^2}{b}.$$

Example.—A square chimney shaft had an average breadth, d, of 8 ft., its base, b, being 10 ft. ne height, h, of the shaft was 100 ft. What should the weight of the shaft be in order that the himney may be stable ?

$$W = \frac{56 \times 8 \times 100 \times 100}{10} = 448{,}000 \text{ lbs.}$$

As brickwork weighs from 100 to 130 lbs. per cub. ft., such a chimney must average 13 inches ick to be safe. A round stack would weigh half as much, or have less base.

Dimensions of Chimneys, General Rules, and Formulæ.

Outside diameter at ground should not be less than $\frac{1}{10}$th the height, unless it is supported by me other structure.

Batter varies from 1 in 60 to 1 in 10 ; 1 in 24 is very common. Or the batter should be from th to $\frac{1}{2}$ inch to foot on each side.

Thickness of brickwork : One brick (8 or 9 in.) for 25 ft. from the top, increasing $\frac{1}{2}$ brick to 4$\frac{1}{2}$ in.) for each 25 ft. from the top downwards. If the inside diameter exceeds 5 ft., the o length should be 1$\frac{1}{2}$ brick, and if under 3 ft. it may be $\frac{1}{2}$ brick for 10 ft.

Generally a much less height than 100 ft. cannot be recommended for boiler chimneys, as the ver grades of fuel cannot be burned as they should be with a shorter chimney.

Tall Chimneys should always stand alone ; if connected with the rest of the buildings, the ncreased settlement due to their weight on so small a foundation area causes rupture in the asonry. The distance from furnace to shaft should not exceed $\frac{2}{3}$ height of shaft. They should built and allowed to settle before the connecting flue is made.

Circular form is best; with the same quantity of material it covers a great area, is therefore more stable, and the effect of wind upon it is much less.

In any case the flue should be circular; it can hardly be too large, as it can always be reduced by dampers. It should be lined with a detached skin of firebrick for a certain distance up, increasing in proportion to the heat of the vapours carried off, and separated from the main shaft by an air-space.

Chimneys to receive Vapours of a very high temperature are built altogether of fire-bricks.

Caps tie head of chimney together, but projecting caps catch the wind, and cause oscillation. A dangerous chimney has been saved by removing the cap.

The *Scaffolding* used for building a chimney should be so arranged that it does not prevent the chimney from settling.

The *Intensity of Draught* required varies with the kind and condition of the fuel and the thickness of the fires. Wood requires the least, and fine coal or slack the most. To burn anthracite slack to advantage a draught of 1½ inch of water is necessary, which can be obtained by a well-proportioned chimney 175 feet high.

Design of Tall Chimneys.

45 feet is an ordinary height to serve two steam boilers, but in some towns, as Manchester and Leeds, 90 ft. is the minimum allowed. They are sometimes proportioned for height according to the coal burnt per week of 56 hours, thus :—

4 tons per week =	75 ft. high.	50 tons per week =	150 ft. high.
13 " " =	100 "	100 " " =	180 "
26 " " =	120 "	150 " " =	200 "

Another rule is to make the height of the chimney three times length of boiler plus twice distance of furthest boiler to chimney; this allows 1 ft. of height for every foot the gases travel round the boiler, and 2 ft. of height for every foot of external flue.

A round chimney should not exceed twenty-five times its internal diameter in height.

Prussian Government Rules.—In April 1902 the Prussian Government issued regulations for the construction of chimney-stacks. Square stacks to be designed for a wind pressure of 25½ lbs. per sq. ft., with the centre of pressure at the centre of gravity of diametral vertical plane. Octagonal stacks, 71 per cent. of the above pressure, and circular stacks, 67 per cent. (*Engineering Record.*)

Thickness of Brickwork.—Up to 150 ft. high or 5 ft. inside diameter the top length is generally one brick (9 ins.) thick; above that height or diameter the top length should be one brick and a half thick, and the thickness should be increased by a 4½-in. set-off at every 20 ft. below the top. The outlet at top and the throat or internal diameter at each set-off should be of the calculated size to give the necessary area plus allowance for friction.

Batter.—If the diameter of the throat is kept uniform and a 4½-in. set-off occurs at every 20 ft., the intermediate portions being of uniform thickness, a batter of 1 in 53·33 will be given but the London County Council require a minimum batter of 1 in 48 = 2½ ins. in 10 ft., and besides that it will be requisite in most cases to provide a firebrick lining for at least the bottom 15 ft. or 20 ft., having a thickness of 4½ ins. and a clear space from the outer brickwork of 1½ in. to 2 ins., necessitating a still greater batter.

Chimney-Cap.—The chimney-cap or cornice, by the London County Council rules, must not project more than the thickness of the brickwork upon which it rests. It may be of cast-iron casings bolted together and filled with brickwork; or of granite or other good weathering stone, the separate blocks being cramped together with galvanised-iron cramps, or with an iron hoop sunk into the top and protected with cement; or of brickwork in cement.

Diameter at Base—The London County Council require that the width of a shaft at the base if square on plan must be at least one-tenth, and if circular on plan, at least one-twelfth of the total height.

Firebrick Lining.—The firebrick lining must be entirely self-supporting and have a clear space behind, to allow for expansion and contraction independently of the main structure. It is therefore necessary to cover the top of the space by an over-sailing course of bricks built out from the inside of the main shaft, protecting the space, but allowing a clearance above the lining of ½ in. for every 5 ft. of its height, to permit of its expansion when heated. The average height of this lining is one-fifth height of shaft + 10 ft. A common height is 20 ft. and thickness 4½ ins. when of greater height it is necessary to make the lower part 9 ins. thick. No air bricks should be inserted in the outer wall, as is sometimes done with the idea of cooling the air space, any such

openings being very detrimental to the draught. The only possible inlet for air to the chimney shaft should be through the fire-bars or over the surface of the incandescent fuel.

The smoke inspectors of the London County Council have lately recommended openings into the chimney-shafts near the bottom to reduce the smoke nuisance. The real effect is to dilute the smoke with air before it reaches the chimney-top so that it is not so black when expelled, but it does not reduce the actual amount of carbon emitted except so far as it tends to spoil the draught and so to reduce the fuel consumption and boiler efficiency.

Foundation.—It is important to note that a tall chimney should stand on an independent foundation in order that the settlement, or compression of the soil, may be uniform. When a chimney is built close alongside a boiler-house, or within the four walls of a warehouse, it is sometimes placed on an extension of the other foundations and bonded in with other work, but this invariably leads to unequal settlement and subsequent cracks in the brickwork.

(*Professor Henry Adams, M.Inst.C.E.*)

ARCHES.

Setting-out Arches.

Semi-elliptical Arch (fig. 164).—To set out a *semi-elliptical arch*, draw a line, AB, equal to the span or transverse axis of the ellipse. At the centre of AB draw the semi-conjugate, CD, at right angles, equal to the rise. Then, from the vertex, C, with radius AD or DB equal to half the span, describe an arc intersecting AB in E and F.

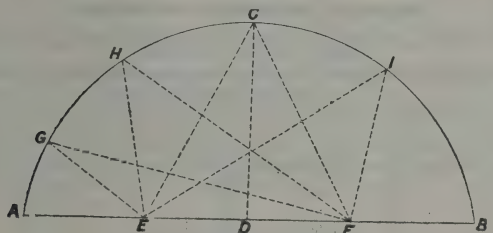


FIG. 164.

The points E, F, will be the foci of the ellipse. If two nails or pegs be fixed in the foci, and a line attached to them equal in length to AB, then the curve traced by a nail, keeping this line stretched, will be the ellipse required; the lines EGF, EHF, ECF, EIF, &c., being all equal to span AB, and to each other.

Many-centred Circular Arch.—Curves formed of arcs of circles of unequal radii, and similar in appearance to the ellipse, are sometimes adopted for the arches of bridges; with the same rise and span, they may be constructed to give a greater waterway, and in stone bridges they have been preferred by practical stonecutters, but in brick bridges they have no advantage in simplicity over elliptical arches. They may be described with three or a greater odd number of centres. The number of centres will depend on the relation between the span and rise; when the latter is one-third, or a greater fractional part of the former, three centres may be used, but if the rise is less than one-third of the span, then five, or a greater odd number, must be taken. In practice it will be found troublesome to describe arcs from a large number of centres, nor, indeed, will occasion be found for using curves of this description. The following is a method of describing a curve composed of three arcs each of 60°.

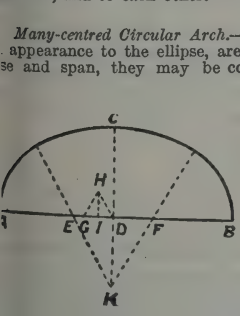


FIG. 165.

Let AB (fig. 165) represent the span, and CD the rise. Take DG = AD − DC, and on it describe an equilateral triangle, DGH; let fall the perpendicular HI, and take

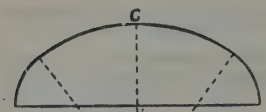


FIG. 166.

IE = HI. Lay off DF = DE. On EF describe the equilateral triangle EFK; then E, F, and K will be the centres required.

For an oval arch, rise one-third, bisect the half-spans AD and DB (fig. 166) in the points E and F, and produce versed sine CD to G, making DG = DC; then E, F, and G will be the three centres with which the curve may be described. In setting out arches, the practical difficulty arises from the elasticity of string. Instead of a string, soft wire about a tenth of an inch in diameter should be used. When the radius does not exceed 12 or 15 feet, a slip of wood may be used, with a nail at each end.

To find the Depth of Keystone for first-class Cut-stone Arches, whether Circular or Elliptic.

$$\text{Depth of key in feet} = \frac{\sqrt{\text{Rad.} + \text{half span}}}{4} + \cdot 2 \text{ foot.}$$

For second-class work this depth may be increased about one-eighth part; or for brick or fair rubble, about one-third.

TABLE.

Depths of Keystones for Arches

Of first-class cut stone. For second-class add about one-eighth part. For brick or fair rubble add about one-third part.

Span.	Rise, in Parts of the Span.						
	½	⅓	¼	⅕	⅙	⅛	1/10
Feet.	Key. Feet.	Key. Feet.	Key. Feet.	Key. Feet.	Key. Feet.	Key. Feet.	Key. Feet.
2	55	·56	·58	·60	·61	·64	·68
4	·70	·72	·74	·76	·79	·83	·88
6	·81	·83	·86	·89	·92	·97	1·03
8	·91	·93	·96	1·00	1·03	1·09	1·16
10	·99	1·01	1·04	1·07	1·11	1·18	1·26
15	1·17	1·19	1·22	1·26	1·30	1·40	1·50
20	1·32	1·35	1·38	1·43	1·48	1·59	1·70
25	1·45	1·48	1·53	1·58	1·64	1·76	1·88
30	1·57	1·60	1·65	1·71	1·78	1·91	2·04
35	1·68	1·70	1·76	1·83	1·90	2·04	2·19
40	1·78	1·81	1·88	1·95	2·03	2·18	2·33
50	1·97	2·00	2·08	2·16	2·25	2·41	2·58
60	2·14	2·18	2·26	2·35	2·44	2·62	2·80
80	2·44	2·49	2·58	2·68	2·78	2·98	3·18
100	2·70	2·75	2·86	2·97	3·09	3·32	3·55
120	2·94	2·99	3·10	3·22	3·35	3·61	3·88
140	3·16	3·21	3·33	3·46	3·60	3·87	4·15
160	3·36	3·44	3·58	3·72	3·87	4·17	
180	3·56	3·63	3·75	3·90	4·06	4·38	
200	3·74	3·81	3·95	4·12	4·29		
220	3·91	4·00	4·13	4·30	4·48		
240	4·07	4·15	4·30	4·48			
260	4·23	4 31	4·47	4·66			
280	4·38	4·46	4·63				
300	4·53	4·62	4·80				

In large arches it is advisable to increase the depth of the archstones toward the springs; but when the span is as small as about 60 to 80 or 100 feet, this is not at all necessary if the stone is good, although the arch will be stronger if it is done. In practice this increase, even in the largest spans, does not exceed from ½ to ⅓ the depth of the key, although theory would require much more in arches of great rise.

Amount of Pressure sustained by Archstones.

In bridges of the same width of roadway, if all the other parts bore to each other the same proportion as the spans, the total pressure would increase as the squares of the spans, while the pressure per square foot would increase as the spans. But in practice the depth of the archstones increases much less rapidly than the span; while the thickness of the roadway material, and the extraneous load per square foot, remain the same for all spans. Hence the total pressures, at key and at spring, increase less rapidly than the squares of the spans, but more rapidly than the simple spans; as do also the pressures per square foot. Thus, in two bridges of the same width, but with spans of 100 and 200 feet, with depths of archstones taken from the table on page 609, and uniform from key to spring, supposed to be filled up solid with masonry of 160 lbs. per cubic foot to a level of about 15 inches above the crown (including the stone paving of the roadway), with an extraneous load of 100 lbs. per square foot, the pressures will be approximately as follows:

Rise.	Span 100 Feet.				Span 200 Feet.			
	At Key.		At Spring.		At Key.		At Spring.	
	For 1 foot in width of its entire depth.	Per square foot.	For 1 foot in width of its entire depth.	Per square foot.	For 1 foot in width of its entire depth.	Per square foot.	For 1 foot in width of its entire depth.	Per square foot.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1/6	42¼	13⅜	58	18⅜	126	29¼	179	42
1/4	36⅜	12¼	57	19	112	27¼	181	44
1/3	31¼	11	57½	20	97	24½	188	47½
1/4	25	9	61½	22½	80½	21	207	54¼
1/2	18	6¾	67½	25	57½	15½	230	61½

It will be seen that with the same span the pressure at the key becomes less, while that at the spring becomes greater, as the rise increases. Also, that when the archstones are of uniform depth, the pressure at either spring of a semicircular arch is about 4 times as great as at the key; whereas when the rise is but one-sixth of the span the pressure at spring averages but about one-third greater than at the key. These proportions vary somewhat in different spans.

The greater pressure per square foot at the springs may be reduced by increasing the depth of the archstones towards the springs. This, however, is not necessary in moderate spans, inasmuch as good stone will be safe even under this greater pressure.

Thickness of Arches.

Centre of pressure at every joint of arch and abutment should fall within centre third.

Thickness of arch at crown $= \sqrt{r} \times B$, where r is the longest radius of curvature at intrados; B, as deduced from practice, is as follows:—

	Feet.
Arch above ground standing solitary between abutments . . .	B = 0·12
Arch forming one of series of arches with piers between . . .	= 0·17
Underground archway in hard materials, such as rock or conglomerate	= 0·12
Underground archway in gravel or firm earth	= 0·27
Underground archway in wet clay or quicksand	= 0·48

Centering for Arches.

Centering is made of such stuff as is available. Fig. 170 shows what would be suitable for a 0 ft. arch of brick 2 ft. 3 ins. thick. The king post and struts might be of 2-in. stuff. The lagging of 1½-in. plank, with centres 3 ft. apart; if 4 ft. to 5 ft. apart it should be of 2-in. plank. The struts are often placed at right angles to the arch, as shown in dotted lines.

In centering for *concrete arches* the lagging should be of narrow battens 3 ins. to 4½ ins., laid close, the joints being run in with whiting and plaster of Paris. The following dimensions have been followed:—25 ft. 6 ins. span: centres were 2 ft. apart, of 9-in. × 1½-in. stuff: lagging ⅞ ins. × 1½ in., a 9-in. × 3-in. plank cutting into four for lagging, into two for ribs. There were two lines of intermediate supports. For flat or prismoidal roof of concrete 2-in. or 3-in. sheeting was used, on centres of 3-in. stuff, 4 ft. to 6 ft. apart.

The centres rest by the ends of their chords upon wooden *striking* or *lowering wedges*, for striking or lowering the centre after the completion of the arch. These consist of pairs of wedge-shaped blocks, as W, W, fig. 171, of hard wood from 1 ft. to 2 ft. long, about half as wide, and a quarter or more as thick (sufficient to lower the centre from, say, 2 ins. to 6 ins. or more, according to span and other circumstances).

It is of the utmost importance, especially in large arches, that the *centres should be lowered very slowly*, otherwise the momentum acquired by so heavy a body as an arch descending suddenly, even but 2 ins. or 3 ins., might possibly affect its shape, or even its safety. For this reason the wedges should not have a taper steeper than about 1 in 6 or 8 for arches of less than about 50 ft. span, or than 1 in 8 or 10 for larger spans. Vertical lines at equal distances apart should be drawn on the long sides of the wedges, as a guide for lowering them all to the same extent at a time; and this should not exceed in all about half an inch a day in intervals of about an eighth of an inch for 50 ft. spans, or about ·1 to ·25 of an inch per day in all for spans over 100 ft. Slowness is especially to be recommended in *brick arches*, not only because their greater number of

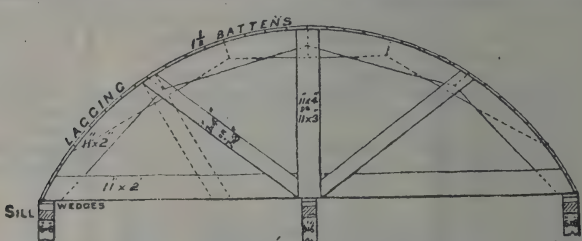


FIG. 170.

joints exposes them to greater derangement of shape, but because even good brick has much less than the average crushing-strength of good granite, limestone, or sandstone, and therefore is far more liable than they to crack, or even to crush, when the strains are thrown almost entirely upon their edges.

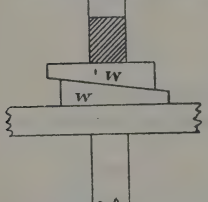


FIG. 171.

Easing and Striking Centres.—Much depends on temperature mass of masonry or brickwork, composition of mortar, etc. With ordinary lime, centres should be eased while mortar is quite green, as soon as the arch is loaded to stability, and struck on an average after five to eight days. With small arches, one or two and a half bricks thick, 6 ft. to 8 ft. span, built in dry weather, the centres may be struck in three or four days. With slow-setting cement, if the arch be small and slight, so that it can be loaded to stability before the mortar of portion first commenced has set, the centres may be eased, as with lime, but they may be struck sooner, and the limit may be taken as the time at which the joints would become too hard set to admit of being raked out for pointing without seriously injuring the brickwork. If, in consequence of the cement being strong and quick-setting or of the span or thickness of the arch being considerable, the arch cannot be completed before the portion first commenced has set, it is doubtful whether the centering should be eased at all, for fear of disturbing the setting of the cement. Centering for concrete should not be disturbed for at least fourteen days from the time of laying the concrete.

The main points to attend to are—to complete the arch to stability rapidly, and to prevent disturbance of the work while setting, by traffic over it, or vibrations from adjoining work, otherwise the setting power, of cement specially, is destroyed.

Piers.

Thickness of piers, generally from $\frac{1}{5}$ to $\frac{1}{3}$ span. Short piers have vertical sides; high piers may have side batter of $\frac{1}{12}$.

In viaducts and long bridges, 1 pier in every 5 or 6 may be thickened as an abutment pier, so that an accident to a part may not cause the destruction of the whole.

SECTION XIII

RAILWAYS

PART I

PERMANENT WAY

RAILS — BOLTS AND SPIKES — CHAIRS — SLEEPERS — ARRANGEMENT OF PERMANENT WAY — GAUGES — NARROW-GAUGE RAILWAYS—TUNNELS—RESISTANCES—CROSSINGS—CURVES . . . . . (pp. 631-666)

PART II

LOCOMOTIVES AND ROLLING STOCK

(Revised by H. Holcroft, M.I.Loco.E.)

LOCOMOTIVES—STEAM MOTOR CARS—CARRIAGES AND WAGGONS—LIGHTING AND HEATING RAILWAY CARRIAGES—BRAKES . . . . . (pp. 667-733)

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PART IV

RAILWAY EXPENDITURE AND RECEIPTS—STANDING ORDERS WITH REFERENCE TO RAILWAY BILLS (pp. 749-753)

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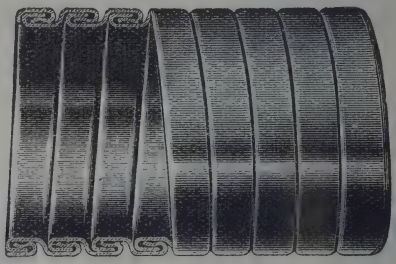

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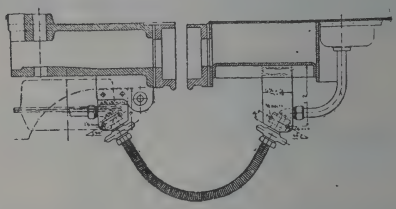

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SECTION XIII

PART I

PERMANENT WAY.

RAILS — BOLTS AND SPIKES — CHAIRS — SLEEPERS — ARRANGEMENT OF PERMANENT WAY — GAUGES — NARROW-GAUGE RAILWAYS—TUNNELS—RESISTANCES —CROSSINGS—CURVES.

RAILWAYS.

RAILS.

There are two descriptions of rails in general use—viz. the 'Bull-headed Rail,' and the 'Flat bottomed' or 'Flanged Rail.'

Steel rails have superseded those of iron.

Dimensions of Rails Used on British Railways.

The standard rails of leading English railways are as follows: (1) Midland Railway, 100 lbs. yard, 45 ft. long; (2) Great Western Railway, 97½ lbs., 30 ft.; (3) Great Northern Railway, lbs.; (4) Great Central Railway, 96 lbs., 36 ft., and 86 lbs., 30 ft. long; (5) London and North astern Railway, 95 lbs., 60 ft.; (6) North Eastern Railway, 90 lbs., 30 ft.; (7) London and uth Western Railway, 90 lbs.; (8) Lancashire and Yorkshire Railway, 86 lbs.; (9) Great Eastern ilway, 85 lbs. All of these are of the bull-head section, supported in heavy cast-iron chairs, which they are secured by wooden wedges (or sometimes wedges of coiled steel). The chairs fastened to the ties by round spikes and wooden spikes or trenails, through bolts being asionally used.

More recently the London Midland and Scottish Railway has adopted a standard rail length 60 ft., and the remaining British railways a standard length of 45 ft.

BRITISH STANDARD SPECIFICATION AND SECTIONS OF BULL-HEAD RAILWAY RAILS.*

(No. 9—July 1927.) (*Abstract.*)

2. The steel for the rails shall be of the best quality made by the Open Hearth, Acid ssemer, or other process, as may be specified or required by the engineer (or by the pur-

* By permission of the British Engineering Standards Association.

chaser), and shall show on analysis that in chemical composition it conforms to the limits given for such processes respectively in Tables 1 and 2.

The steel shall conform to the limits of chemical composition appearing in Tables 1 and 2 under the headings of 'Ordinary Carbon' and 'Higher Carbon' respectively, as may be specified or required by the engineer (or the purchaser).

TABLE 1.—STEEL MADE BY THE OPEN-HEARTH PROCESS.

Element.	Acid.		Basic.	
	Ordinary Carbon.	Higher Carbon.	Ordinary Carbon.	Higher Carbon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Carbon . .	0·45 to 0·55	0·50 to 0·60	0·45 to 0·60	0·55 to 0·65
Manganese . .	0·90 (max.)	0·80 (max.)	0·90 (max.)	0·80 (max.)
Silicon . .	0·15 (max.)	0·10 to 0·30	0·15 (max.)	0·10 to 0·30
Phosphorus .	0·07 (max.)	0·06 (max.)	0·05 (max.)	0·04 (max.)
Sulphur . .	0·07 (max.)	0·06 (max.)	0·06 (max.)	0·05 (max.)

TABLE 2.—STEEL MADE BY THE BESSEMER PROCESS.

Element.	Acid.	
	Ordinary Carbon.	Higher Carbon.
	Per Cent.	Per Cent.
Carbon . .	0·40 to 0·50	0·45 to 0·55
Manganese . .	0·70 to 1·00	0·90 (max.)
Silicon . .	0·15 (max.)	0·10 to 0·30
Phosphorus .	0·075 (max.)	0·07 (max.)
Sulphur . .	0·07 (max.)	0·06 (max.)

6. A falling weight test shall be made in the following manner:—A piece of rail 5 feet (1·52 m.) long, taken from one of the rails selected by the engineer or the inspector (or the purchaser), shall be placed in a horizontal position with the head uppermost upon the two steel bearers of the British Standard Falling Weight Testing Machine, the bearers being 3 feet 6 inches (1·07 m.) apart at their centres, and having their upper surfaces curved to a radius of 3 inches (76·20 mm.).

The test shall comprise two blows delivered midway between the bearers from a falling iron weight. The height of the drop for the various sections of rails shall be as tabulated below. The blows shall be sustained without fracture, and the permanent set measured on the specified distance between the centres of the bearers resulting from the two blows must not exceed the limits given in the table, p. 634.

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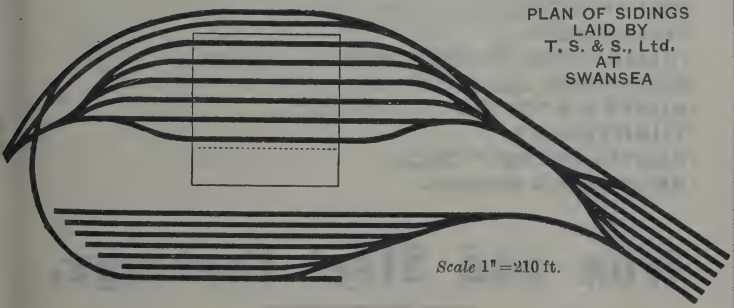

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F. 632

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SEE PREVIOUS PAGE

B.S. Section No. 60.
60 lbs. per yard
(29·76 kgs. per metre).

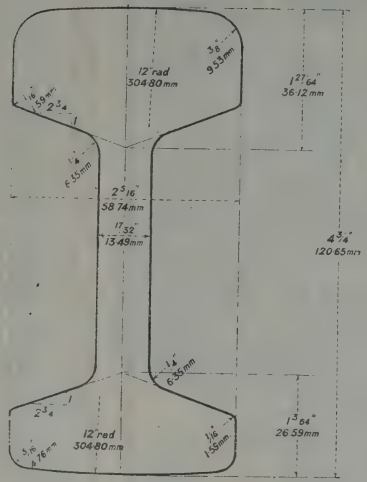

FIG. 1.

B.S. Section No. 80.
80 lbs. per yard
(39·68 kgs. per metre).

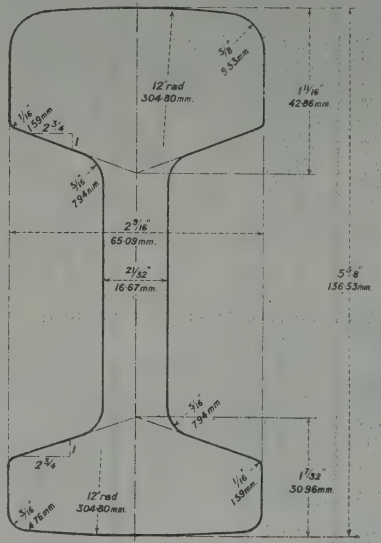

FIG. 2.

B.S. Section No. 100.
100 lbs. per yard (49·61 kgs. per metre).

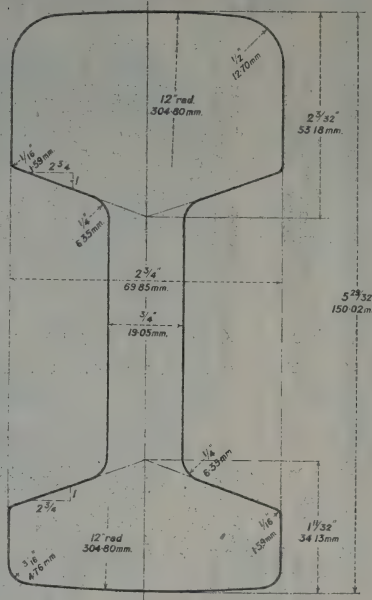

FIG. 3.

Falling Weight of 20 cwts. (1,016·05 kgs.)
Centres of bearers, 3 feet 6 inches (1·07 m.) apart.

No. of B.S. Section and Nominal Weight in lbs. per yard (kgs. per metre).	Height of Drop.		Maximum Permanent Set resulting from the two blows.		No. of B.S. Section and Nominal Weight in lbs. per yard (kgs. per metre).
	1st Blow.	2nd Blow.	Ordinary Carbon Rail.	Higher Carbon Rail.	
	ft. (m.)	ft. (m.)	in. (mm.)	in. (mm.)	
60 (29·76)	5 (1·52)	10 (3·05)	3·9 (99·06)	3·7 (93·98)	60 (29·76)
65 (32·24)	5 (1·52)	12 (3·66)	3·9 (99·06)	3·7 (93·98)	65 (32·24)
70 (34·72)	6 (1·83)	12 (3·66)	3·9 (99·06)	3·7 (93·98)	70 (34·72)
75 (37·20)	6 (1·83)	12 (3·66)	3·9 (99·06)	3·7 (93·98)	75 (37·20)
80 (39·68)	6 (1·83)	15 (4·57)	4·2 (106·68)	4·0 (101·60)	80 (39·68)
85R(42·16)	6 (1·83)	15 (4·57)	4·2 (106·68)	4·0 (101·60)	85R(42·16)
90R(44·64)	7 (2·13)	18 (5·49)	4·3 (109·22)	4·1 (104·14)	90R(44·64)
95R(47·13)	7 (2·13)	20 (6·10)	4·3 (109·22)	4·1 (104·14)	95R(47·13)
100 (49·61)	7 (2·13)	20 (6·10)	4·1 (104·14)	3·9 (99·06)	100 (49·61)

14. All ingots used in the manufacture of the rails shall be not less than 200 square inche (1,290·32 cm.²) in area at the larger end. The ingot shall be so fed into the cogging rolls tha the bottom end arrives at the shears or hot saws first. From each end of the bloom and/o rail bar sufficient crop shall be cut to ensure that all unsound portions have been removed.

24. Dimensions and Weights of 'B.S.' Bull-Head Railway Rails.

No. of B.S. Section and Nominal Weight in lbs. per yard (kgs. per metre).	Height of Rail.	Width of Head.	Calculated Weight of Rail before Drilling. Lbs. per yard (kgs. per metre).	No. of B.S. Section and Nominal Weight in lbs. per yard (kgs. per metre).
	ins. (mm.)	ins. (mm.)		
60 (29·76)	$4\frac{3}{4}$ (120·65)	$2\frac{5}{16}$ (58·74)	59·79 (29·66)	60 (29·76)
65 (32·24)	$4\frac{7}{8}$ (123·83)	$2\frac{3}{8}$ (60·33)	64·58 (32·04)	65 (32·24)
70 (34·72)	5 (127·00)	$2\frac{7}{16}$ (61·91)	70·13 (34·79)	70 (34·72)
75 (37·20)	$5\frac{1}{8}$ (130·18)	$2\frac{1}{2}$ (63·50)	74·56 (36·99)	75 (37·20)
80 (39·68)	$5\frac{3}{8}$ (136·53)	$2\frac{9}{16}$ (65·09)	79·49 (39·43)	80 (39·68)
85R (42·16)	$5\frac{15}{32}$ (138·91)	$2\frac{11}{16}$ (68·26)	84·88 (42·11)	85R (42·16)
90R (44·64)	$5\frac{35}{64}$ (140·89)	$2\frac{3}{4}$ (69·85)	89·77 (44·53)	90R (44·64)
95R (47·13)	$5\frac{23}{32}$ (145·26)	$2\frac{3}{4}$ (69·85)	94·59 (46·92)	95R (47·13)
100 (49·61)	$5\frac{29}{32}$ (150·02)	$2\frac{3}{4}$ (69·85)	99·84 (49·53)	100 (49·61)

27. The standard length of the rails for straight line shall be 30 feet (9·14 m.), 36 fee (10·97 m.), 40 feet (12·19 m.), 45 feet (13·72 m.) and 60 feet (18·29 m.).

29. The rails shall be the specified length at a temperature of 62° Fahr. (16·67° C.). An rail may be rejected which is more than three-sixteenths ($\frac{3}{16}$) of an inch (4·76 mm.) above below the length specified at that temperature, whether for straight or curved line.

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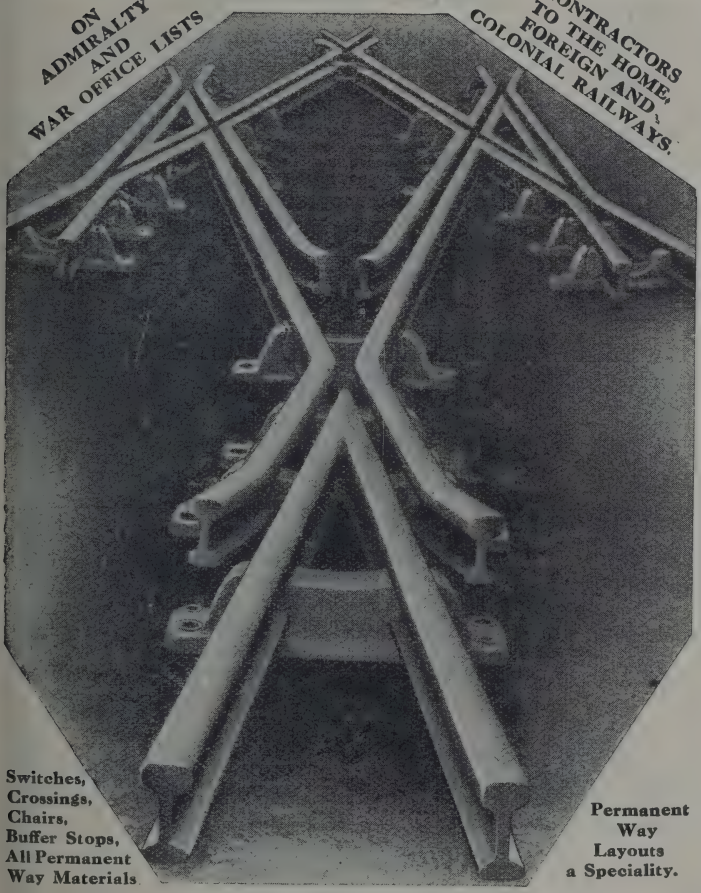

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F. 634

British Engineering Standards Association

LIST OF STANDARD SPECIFICATIONS AND REPORTS RELATING TO RAILWAYS.

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- 24 Part V.—1925. Copper Plates, Rods, Tubes and Pipes and Brass Tubes.
- 24 Part VI.—1921. Steel Plates, Angles, etc., and Rivets for Locomotives, Carriages and Wagons.

47A—1924. **STEEL FISHPLATES,** for Flat Bottom Railway Rails, Sections of. *Under Revision.*

50—1910. **LOCOMOTIVES FOR INDIAN RAILWAYS,** Third Report on. *Under Revision.*

51—1913. **WROUGHT IRON,** for use in Railway Rolling Stock ('Best-Yorkshire' and Grades A, B and C), Specification for. **2/-** net.

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103—1926. **FALLING WEIGHT TESTING MACHINES** for **Rails,** Specification for. *Gratis.*

104—1919. **LIGHT FLAT BOTTOM RAILWAY RAILS AND FISHPLATES,** Sections of. **2/-** net.

105—1919. **LIGHT AND HEAVY BRIDGE TYPE RAILWAY RAILS,** Sections of. **2/-** net.

A number of the Specifications and Reports of the Association have been issued in French, Italian, Portuguese, and Spanish. The English Editions and the Foreign Translations (which also include the English Text) are in octavo form at 5/- net per copy.

Complete list will be sent on application to the Publishers to the Association :—

CROSBY LOCKWOOD & SON,

7 STATIONERS' HALL COURT, LONDON, E.C. 4.

AREAS OF HEAD, WEB, AND FOOT OF 'B.S.' BULL-HEAD RAILWAY RAILS.

B.S. No. and Nominal Weight.		Head.			Web.			Foot.			Whole Section.			
		Area.			Area.			Area.			Area.		Calculated Weight.	
os. er d.	kgs. per metre.	sq. in.	mm.²	Per Cent.	sq. in.	mm.²	Per Cent.	sq. in.	mm.²	Per Cent.	sq. in.	mm.²	lbs. per yd.	kgs. per metre
0	29·76	2·71	1749	46·4	1·29	830	21·80	1·87	1208	31·80	5·87	3786	59·79	29·66
5	32·24	2·95	1906	46·6	1·36	880	21·50	2·02	1303	31·90	6·34	4089	64·58	32·04
0	34·72	3·21	2068	46·7	1·45	938	20·70	2·22	1435	32·60	6·88	4441	70·13	34·79
5	37·20	3·43	2212	46·8	1·53	989	20·80	2·36	1521	32·40	7·32	4722	74·56	36·99
0	39·68	3·62	2334	46·4	1·73	1119	22·10	2·45	1582	31·50	7·80	5034	79·49	39·43
5R	42·16	4·07	2623	48·79	1·81	1165	21·67	2·46	1588	29·54	8·33	5375	84·88	42·11
0R	44·64	4·27	2752	48·42	1·97	1268	22·30	2·53	1665	29·28	8·81	5685	89·77	44·53
5R	47·13	4·48	2892	48·27	1·97	1268	21·17	2·84	1830	30·56	9·28	5990	94·59	46·92
0	49·61	4·91	3169	50·12	1·97	1268	20·05	2·92	1886	29·83	9·80	6322	99·84	49·53

31. The holes for fishbolts shall be drilled through the web from the solid at each end of the ll of the sizes and in the position shown in the British Standard Specification for Steel Fish-ates for Bull-head Railway Rails (Report No. 47—1919) or on a drawing to be supplied by e engineer (or the purchaser).

These holes shall be at right angles to the web of the rail, and clean cut, all burrs being refully removed, and shall be checked by the manufacturer with suitable templates and gauges be furnished by him and at his expense, and approved by the engineer (or the purchaser).

32. Should any of the holes vary from the correct size or position more than one-thirty-second ₃₂) of an inch (0·79 mm.) the rail or rails in which such deviation occurs may be rejected.

FLAT-BOTTOMED OR FLANGED RAILS.

This form of rail is largely used in India, in the Colonies, and in America.

BRITISH STANDARD SPECIFICATION AND SECTIONS OF FLAT-BOTTOM RAILWAY RAILS.*

(No. 11—July 1927.) (*Abstract.*)

TABLE I (*Abbreviated*).—DIMENSIONS.

B.S. No. and Nominal Weight.	A	B	C	D	E	F	G	J	K
). per yd.	in.	in.	in.	in.	in.	in.	in.	in.	in.
25R	$2\frac{7}{8}$	$2\frac{3}{4}$	$1\frac{1}{2}$	$\frac{1}{4}$	$1\frac{29}{32}$	$\frac{7}{16}$	$1\frac{13}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
30R	$3\frac{1}{2}$	3	$1\frac{5}{8}$	$\frac{1}{4}$	1	$\frac{7}{16}$	$1\frac{19}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
35R	$3\frac{5}{8}$	$3\frac{1}{4}$	$1\frac{3}{4}$	$\frac{21}{64}$	$1\frac{3}{32}$	$\frac{1}{2}$	$1\frac{25}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
40R	$3\frac{3}{8}$	$3\frac{1}{2}$	$1\frac{7}{8}$	$\frac{1}{4}$	$1\frac{3}{32}$	$\frac{1}{2}$	$1\frac{31}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
45R	$3\frac{7}{8}$	$3\frac{3}{4}$	$1\frac{31}{32}$	$\frac{5}{16}$	$1\frac{7}{32}$	$\frac{9}{16}$	$1\frac{39}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
50R	$4\frac{1}{2}$	$3\frac{15}{16}$	$2\frac{1}{16}$	$\frac{5}{16}$	$1\frac{13}{32}$	$\frac{9}{16}$	$1\frac{45}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
55R	$4\frac{5}{16}$	$4\frac{1}{8}$	$2\frac{3}{16}$	$\frac{5}{16}$	$1\frac{11}{32}$	$\frac{9}{16}$	$1\frac{51}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
60R	$4\frac{1}{2}$	$4\frac{5}{16}$	$2\frac{1}{4}$	$\frac{5}{16}$	$1\frac{13}{32}$	$\frac{9}{16}$	$1\frac{57}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
65R	$4\frac{11}{16}$	$4\frac{7}{16}$	$2\frac{5}{16}$	$\frac{5}{16}$	$1\frac{29}{64}$	$\frac{11}{16}$	$1\frac{31}{32}$	$\frac{5}{16}$	$\frac{3}{16}$
70R	$4\frac{7}{8}$	$4\frac{5}{8}$	$2\frac{3}{8}$	$\frac{5}{16}$	$1\frac{15}{32}$	$\frac{11}{16}$	$2\frac{1}{32}$	$\frac{5}{16}$	$\frac{3}{16}$
75R	$5\frac{1}{16}$	$4\frac{13}{16}$	$2\frac{7}{16}$	$\frac{33}{64}$	$1\frac{9}{16}$	$\frac{11}{16}$	$2\frac{7}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
80R	$5\frac{1}{4}$	5	$2\frac{1}{2}$	$\frac{17}{32}$	$1\frac{19}{32}$	$\frac{11}{16}$	$2\frac{13}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
85R	$5\frac{7}{16}$	$5\frac{3}{16}$	$2\frac{9}{16}$	$\frac{35}{64}$	$1\frac{39}{64}$	$\frac{11}{16}$	$2\frac{19}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
90R	$5\frac{5}{8}$	$5\frac{3}{8}$	$2\frac{5}{8}$	$\frac{35}{64}$	$1\frac{23}{32}$	$\frac{11}{16}$	$2\frac{25}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
95R	$5\frac{13}{16}$	$5\frac{9}{16}$	$2\frac{11}{16}$	$\frac{37}{64}$	$1\frac{25}{32}$	$\frac{11}{16}$	$2\frac{31}{64}$	$\frac{5}{16}$	$\frac{3}{16}$
100R	6	$5\frac{3}{4}$	$2\frac{3}{4}$	$\frac{37}{64}$	$1\frac{27}{32}$	$\frac{11}{16}$	$2\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{16}$

* By permission of the British Engineering Standards Association.

BRITISH STANDARD FLAT-BOTTOM RAILWAY RAILS.

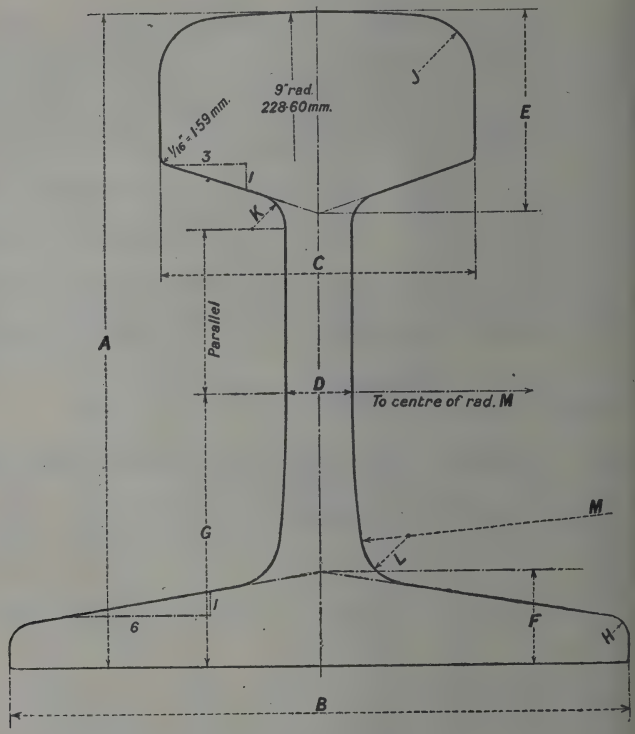


Fig. 4.—Key to Table of Dimensions.

British Standard Flat Bottom Railway Rails.

Table II (*Abbreviated*).—Areas of Head, Web, and Flange.

B.S. No. and Nominal Weight. lb. per yd.	Head.		Web.		Flange.		Whole Section.	B.S. No. and Nominal Weight. lb. per yd.
	Area. sq. in.	Per cent.	Area. sq. in.	Per cent.	Area. sq. in.	Per cent.	Area. sq. in.	
25R	1·129	46·04	0·438	17·82	0·886	36·14	2·453	25R
30R	1·355	45·96	0·563	19·10	1·030	34·94	2·948	30R
35R	1·598	46·49	0·656	19·09	1·183	34·42	3·437	35R
40R	1·771	45·14	0·805	20·52	1·347	34·34	3·923	40R
45R	1·996	45·21	0·898	20·33	1·522	34·46	4·416	45R
50R	2·242	45·66	0·978	19·92	1·690	34·42	4·910	50R
55R	2·420	44·76	1·120	20·71	1·867	34·53	5·407	55R
60R	2·644	44·90	1·193	20·25	2·053	34·85	5·890	60R
65R	2·804	44·00	1·342	21·05	2·227	34·95	6·373	65R
70R	2·978	43·30	1·470	21·37	2·430	35·33	6·878	70R
75R	3·193	43·45	1·588	21·61	2·568	34·94	7·349	75R
80R	3·375	42·95	1·698	21·62	2·783	35·43	7·856	80R
85R	3·598	43·09	1·825	21·85	2·928	35·06	8·351	85R
90R	3·781	42·83	1·886	21·37	3·161	35·80	8·828	90R
95R	4·026	43·15	1·992	21·35	3·313	35·50	9·331	95R
100R	4·274	43·56	2·066	21·07	3·471	35·37	9·811	100R

Weight of Rails per Mile.

Area.	Weight per Yard.	Weight per Mile.			Area.	Weight per Yard.	Weight per Mile.		
Sq. Ins.	Lbs.	Tons.	Cwts.	Lbs.	Sq. Ins.	Lbs.	Tons.	Cwts.	Lbs.
5	50	78	11	48	7	70	110	0	0
5¼	52	81	14	32	7½	75	117	17	16
5½	55	86	8	64	8	80	125	14	32
5¾	56	88	0	0	9	90	141	8	64
6	60	94	5	80	10	100	157	3	84
6½	64	100	11	48					

No. of 15-ft. rails per mile . . .	704	No. of 18-ft. rails per mile . . .	587
„ 16-ft. „ „ . . .	660	„ 20-ft. „ „ . . .	528

Weight of rail per yard in lbs. multiplied by $\frac{11}{7}$ equals tons per mile of single track.
Approximately, the weight of a rail in kilograms per metre × 2 = weight in lbs. per yard.

Allowable Rail Weight.

If

L = maximum load on one driving wheel in tons; v = maximum speed in miles per hour,

Minimum Allowable Rail Weight in lbs. per yd. $= 17\sqrt[3]{(L + 0{\cdot}0001\,Lv^2)^2}$.

(*Sir Benjamin Baker.*)

Loss of Strength in Steel Rails through Use on Railways.

(*Abstract from Board of Trade Report* 1900.)

The Report of the Board of Trade Committee appointed to inquire into the loss of strength in steel rails through use on railways, states that:

(*a*) The preponderance of fractures near the ends of rails seems to show that the greater straining action due to discontinuity at the joint is a contributing cause of fracture, and this can be remedied by adopting rails of sufficient strength with webs of ample thickness and secure types of fastening, and by care that no looseness arises in service.

(*b*) The fact that worn rails are improved in strength and ductility by annealing proves that part of the deterioration of rails in service is of the nature of what is sometimes termed 'fatigue.'

(*c*) It appears certain that in some cases fractures of rails have been due to fissures formed during service. How far the minute transverse fissures, very often noticed in the running surface of old rails, give rise to these larger induced flaws requires further investigation. It is not likely that they usually spread into the substance of the rail, because they are common in old rails, and fractures would be more frequent than they are if that were the case. Also, the evidence as to the existence of visible flaws or defects in the fractured surface of rails is very conflicting. In some cases, undoubtedly, the combined effects of the weakening of a rail by wear and corrosion, possibly also increased straining action from defective packing of sleepers, and the presence of a flaw or fissure of not inconsiderable size have led to fracture of the rail. That such defects appear most commonly in the head of the rail is evidence to a certain extent that they are induced by the hammer hardening of the top surface.

(*d*) It is very desirable that the mechanical tests to which rails are subjected should be as far as possible standardised in connection with (1) the weight ; (2) the section ; and (3) the chemical composition of the rail.

As regards chemical composition the Committee does not think it desirable to insist upon too high a proportion of carbon, manganese, or silicon in the steel, having regard to the ordinary contingencies of manufacture, and the greater susceptibility of high carbon steel to thermal influences.

Mr. E. Windsor Richards (in conjunction with Mr. E. P. Martin, of Dowlais) considers, after careful consideration from the points of view of a manufacturer and user, that, exclusive of the iron, a steel rail should have the following range of composition :

	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
Min.	·35	·05	·04	—	·75
Max.	·50	·10	·08	·08	1·00

The falling weight tests showed conclusively that double-headed rails worn in service on one head and afterwards turned down to rest on the chair so as to bring the unworn head into use, are dangerously brittle, owing to the worn head having developed numerous incipient small cracks, which really form 'nicks;' and such practice of using rails is recommended to be immediately discontinued.

THERMAL INFLUENCES.

Seasons at which Fractures most frequently occur.—Mr. Footner has given the following data from twelve years' experience on the London and North Western Railway : Fractures in spring, 29 per cent. ; in summer, 16 per cent. ; in autumn, 22 per cent. ; in winter, 33 per cent. There is other evidence as to the frequency of fractures in winter, and no doubt when the permanent way is hardened by frost the effect of concussions on the rails is much more serious. There is no satisfactory evidence that the steel itself is sensibly weakened by any ordinary cold temperature.

According to all statistics more than 50 per cent. of fractures occur before the rails have had a service of fifteen years.

Mr. Footner states that of fractured rails

3 per cent. } broke after { ½ to 5 } million
35 „ } carrying { 5 to 50 } tons.

45 per cent. } broke after { 50 to 100 } million
17 „ } carrying { 100 to 200 } tons.

So that 38 per cent. of the broken rails had carried less than 50 million tons.

According to Dormus, if f = breaking stress of rail steel in tons per square inch ; l = gauge length in inches ; Δ = ultimate elongation of length l in inches ; then $100f^2\Delta \div l$ should not be less than 22,000 ; only the worst qualities give a lower value than 16,120.

Sir I. Lowthian Bell does not think that the Committee (as the result of the investigation) should recommend any change in the mode of management of the permanent way of the railways of the United Kingdom.

BREAKING LOAD OF STEEL RAILS.

At five feet bearings the breaking load of steel rails in pounds may be taken at 1,000 × weight of rail per yard in pounds.

Chemical analyses of average Bessemer rail steel, as made at present for heavy rails, run about as follows :—

	Per cent.		Per cent		Per cent
Carbon . . .	·50	Sulphur	·08	Manganese . .	1·00
Phosphorus . .	·10	Silicon . . .	·12	Iron . . .	98·20

(*F. E. Abbott.*)

MAXIMUM ALLOWABLE AXLE LOAD.

If

W = weight of rail in lbs. per yd. V = maximum booked velocity of trains in miles per hour, then,

$$\text{Maximum allowable axle-load in tons} = \frac{W^2}{200} / \left(1 + \frac{V}{60}\right)$$

Rail-weight—lbs. per yd.	40	50	60	75	85	90	100
Maximum booked velocity—miles per hour	15	22½	30	40	45	50	60
Maximum axle-load—tons	6·4	9	12	16·7	18·3	22	25

(*Remfry, 'Proc. Inst. Civ. Engrs.,' vol. cxxv. p.* 338.)

Weight of rail in lbs. per yd.	30	35	40	45	50	55	60	65	70
Maximum axle loading in tons	4 to 5	5 to 7	6 to 8	7 to 9	8 to 10	9 to 11	11 to 13	13 to 15	15 to 17

(*Ministry of Transport.*)

Each 10 lbs. per linear yd. of rail on sleepers, not less than 14 per 30 ft. rail (2,464 per mile), should carry a safe load per wheel of 3,000 lbs. (1·34 tons).

(*Baldwin Locomotive Works.*)

The Government of India allows an axle-load of one-fifth of a ton for each pound per yard of rail-weight, but this rule is not now rigidly enforced.

Detection of Fatigue Cracks in Axles.

The following method of testing axles for fatigue cracks is employed in some American railway shops.

The wheels are removed from an axle which is to be tested, and the surface of the axle near the fillets, where almost all fatigue cracks occur, is rubbed with oil and then wiped clean.

If cracks are present the oil works down into them, and is not removed when the surface is wiped clean. The surface is then painted over with a wash consisting of whiting and alcohol.

When this coating is dry the axle is rotated and struck smartly with a hammer. This hammering squeezes the oil out of the minute cracks and discolours the whiting, thus locating the cracks.

(*University of Illinois Bulletin.*)

Wear Plate for Rail Joints.

A permanent way device which is being introduced on American railways to reduce the trouble with worn rail joints, is developed from a makeshift practice in vogue on both European and American railways. The arrangement, which has been introduced by the American Fork and Hoe Company, consists of a forged steel filler plate, fig. 5, which fits between the contact surfaces. This plate is 9 ins. to 12 ins. long, with a maximum thickness of about $\frac{1}{16}$ in. to $\frac{1}{8}$ in. for a length of 2 ins. or 3 ins. at the middle, and then tapering to the thickness of about No. 20 gauge sheet metal at the ends. It is $1\frac{5}{8}$ in. in width, and is bent to an angle shape, so that it is securely held in position. The length and thickness vary according to the design of rail joint and the amount of wear between rail and fish-plate. The device is applied easily by the track men, and is claimed to be an economical remedy for a rather frequent trouble.

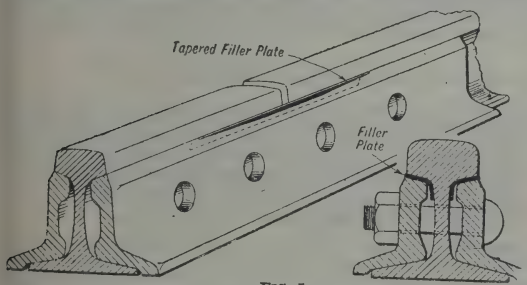


Fig. 5.

Cross-Overs.

Shortly after the Central London Railway was opened, practically all the cross-overs on it were changed to manganese steel. They have been in use for over ten years, and there has been no necessity for renewing them. With ordinary steel the life, with the traffic which the Central London carries, would be only from three to six months. Taking the relative prices of ordinary steel and manganese steel cross-overs, the life of the latter in order to produce the same economy would require to be from three to four years. It is thus seen that manganese steel, which has already had a life of ten years, is by far the cheapest in the end, and obviates the trouble of continual renewal work.

Check Rails.

Although practically all British railways state that they use a check rail on curves of 660 ft. or less radius in order to strengthen the track, the generally recognised purpose of the check rail is to safeguard rolling stock against derailment. The provision of a check rail on curves of 10 chains or less radius is compulsory under the regulations issued formerly by the Board of Trade and now administered by the Ministry of Transport. The Great Central section of the London and North Eastern Railway extends the use of a check rail to all curves under 20 chains radius, and, further, staggers the joints of the two running rails where the curve is of 30 chains radius or less.

The standard design of check chair now used for check rails allows a gap of 2 ins. only.

Ministry of Transport Regulations for Permanent Way.

British Standard Specifications and Sections for all details of permanent-way to be adopted, unless authority to the contrary is given. On lines on which the normal traffic is heavy and worked at high speed, the weight of new rails should not be less than 85 lbs. per yard, and, in the case of a chaired road, the common chairs should not weigh less than 45 lbs. each. On lines where traffic conditions are less severe, chairs weighing not less than 40 lbs. each may be used. The minimum length of rail, as a rule, to be 30 ft. On lines normally used for light traffic and moderate speeds, lower weights of rails and chairs may be used.

Chairs, if used, must be secured to the sleepers, at least partially, by metal bolts, screws, or spikes. With flat-bottom rails, or bridge rails, the fastenings at joints and at one or more intermediate places to consist of fang or other through bolts, and such rails, on curves with radii of 15 chains or less, to be tied to gauge by iron or steel ties at suitable intervals.

Fixed diamond crossings must not be flatter than 1 in 8 except in special circumstances. Movable diamond crossings may be at any angle and are to be treated as worked facing points.

Specification for Bolts, Nuts, Screws, and Spikes.

(London and North Western Railway.)

Specification for Steel Bolts and Nuts.

The steel from which the bolts and nuts are made is to have a tensile strength of not less than 36 tons per square inch, with an ultimate extension of not less than 20 per cent. upon 10-inch lengths. The heads are to be worked out of the solid, and not welded on, and are to be stamped with the letter 'S,' as approved by the engineer. The heads and nuts are to be at right angles with the centre line of the bolts, and central with the shank, which must be perfectly straight. They must be screwed to Whitworth's standard, and the threads must be clean and smooth.

Specification for Galvanised Steel Screws for Rail Chairs.

The steel from which the screws are made is to have a tensile strength of not less than 36 tons per square inch, with an ultimate extension of not less than 20 per cent. upon 10-inch lengths. The heads are to be worked out of the solid, and not welded on, and are to be at right angles with the centre line of the screws, and central with the shank, which must be perfectly straight. Each screw is to have a deposit of zinc of not less than 180 grs. smoothly and uniformly distributed all over.

Specification for Steel Spikes.

The steel from which the spikes are made is to have a tensile strength of not less than 36 tons per square inch, with an ultimate extension of not less than 20 per cent. upon 10-inch lengths. The heads are to be worked out of the solid, and not welded on, and are to be at right angles with the centre line of the spikes and central with the shank, which must be perfectly straight. The heads are to be stamped with the letter 'S,' as approved by the engineer.

Sleepers.

These are usually made of Baltic red timber, and measure 9 ft. long, 10 ins. wide, and 5 ins. deep; at the joints the width is 12 ins. Each load of 50 cubic feet should be impregnated with from 40 to 50 gallons of creosote, equal to from 2½ to 3 gallons per sleeper.

Plugging Worn Holes in Sleepers.

A plastic asphaltic composition is being used by the Western Australian Government Railways for filling worn spike holes in timber sleepers. The composition is poured in hot, the spike is re-driven and in about 15 minutes it is so secure that a pull of 4000 lbs. is required to draw a

⅝-in. spike. The composition is given as follows:—1 quart tar, 4 ozs. pitch, 1 lb. bitumen, ½ pt. kerosene, 2 lb. hardwood sawdust screened to remove material that will pass a 100-mesh screen.

Plugged sleepers have been used with marked success in large numbers by Chief Engineer Fredericia, of the Danish State Railway. A plain 1½-in. cylindrical creosoted plug of beech or birch is driven tight in a 1½-in. hole bored in the sleeper, and the spike is driven in a hole bored in this plug. Worn-out sleepers plugged in this way have been found to give good service, as the rail seems to be held down with exceptional firmness, and deterioration due to the pounding of loose rails is prevented.

Length of Wooden Sleepers.

If

L = length in ft.; G = gauge in ft.

$$L = 1{\cdot}45, G + 0{\cdot}5$$

with a minimum of the gauge + 2 ft.

	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Gauge	5 6	4 8½	3 6	*metre*	2 6	2 0
Sleeper length	8 6	7 3	5 7	5 3	4 6	4 0

(*Remfry*, '*Proc. Inst. Civ. Engrs.*,' *vol. ccxv. p.* 339.)

Creosote Treatment of Sleepers.*

A special creosote treatment process of sleepers has been adopted by the Canadian Pacific Railway Company as follows:—

Prior to creosoting, incisions are made in the surface of the sleepers lengthways with the grain of the wood. The number, depth, and arrangement of these incisions are varied according to the kind of wood to be treated. The sleepers are then creosoted in the ordinary way.

Distribution of the preservative, both lengthwise with and across the grain, proceeds from each incision. The rate of distribution varies with the species of wood, moisture content, character of creosote oil, and details of treatment. The number and arrangement of incisions used

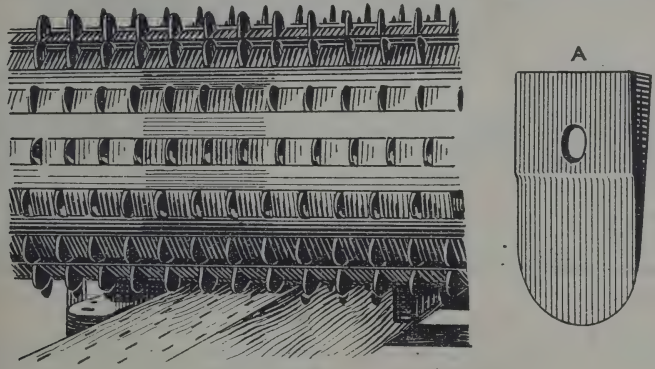


Fig. 6.

for any given kind of wood should be such that the penetration from each incision meets that from the adjoining ones in a reasonable time, thus forming a continuous treated zone of uniform thickness completely enclosing and protecting the inner and untreated portion of the wood. The thickness or depth of the treated zone is controlled by the depth of the incisions. The length of time of pressure necessary to secure a given depth of penetration in incised timber is much less than that required to obtain the same depth in the same timber not incised.

The sleepers are incised by passing them through a machine, fig. 6, provided with steel rollers equipped with removable incising cutters or members. The particular type of incising

* W. Kynock, B.Sc.F., F.E., and J. A. Coderre, B.A., F.E. Forest Products Laboratories of Canada, Montreal. *The Engineer*, Feb. 9, 1923.

member adopted is shown by A. The cutters do not crush or break the fibres of the wood, as some other forms tend to do, but merely press them apart slightly. This is so much the case that after treatment the incisions, narrow to begin with, close up and are hardly noticeable. Tests indicate that the reduction in strength due to incising is so small as to be quite negligible for practical purposes.

Incising presents the following advantages :—

(1) In the case of easily penetrable woods a very much better treatment than is usual without incisions, using less creosote oil per cub. ft. than is ordinarily specified.

(2) The successful creosote treatment of certain refractory woods.

(3) A shortening of the customary pressure period by at least one-half in the case of easily penetrable woods, and therefore—

(4) A considerably increased plant capacity with given equipment.

(5) Satisfactory penetration in every sleeper in a cylinder charge.

See also p. 463.

Metal Keys.

A patent metal key (Mills' patent) which is largely used on one of the Indian railways is shown by fig. 7. This key, which is of steel, in one piece, is stated to be 'fool proof,' and requires

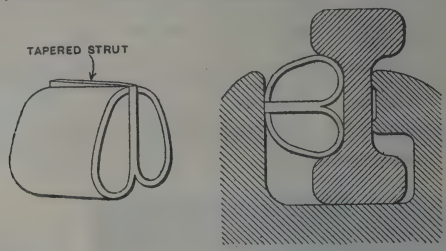


Fig. 7.

the same tools as are used for fitting wooden keys. The advantages claimed over the wooden key are : (1) the minimising of rail creep, (2) unaffected by climatic conditions, (3) longer life, (4) improved track alignment.

Ballast.

Cubic Yards per Mile of Ballast.

Depth of Ballast in Inches.	Side Slope of Ballast, 1 to 1. Width in Feet.					
	Single Track.			Double Track.		
	10	11	12	21	22	23
12	2,151	2,347	2,543	3,303	4,499	4,694
18	3,373	3,667	3,961	6,601	6,895	7,188
24	4,700	5,085	5,477	8,997	9,389	9,780
30	6,111	6,601	7,090	11,491	11,980	12,469

The depth of the ballast should be 2 feet below the top of the rails—that is, 1 foot 7 inches in thickness above the formation level. The ballast is usually laid in a double thickness, the upper layer consisting of stones not exceeding 3 cubic inches in bulk, and averaging about 2 cubic inches. The lower layer may be of stones varying in size from 3 to 30 cubic inches in bulk.

The width of the top ballast beyond the cross-sleepers should be about 18 inches, the total width in the case of a single line of rails being 12 feet ; in the case of a double line, 23 feet ; in the case of a triple line, 34 feet ; and for a quadruple line, 45 feet. Slope of ballast at sides, 1 to 1

Blast-furnace and steel slags are much used as ballast where supplies are readily available. Cinder ballast is now being superseded by stone or slag where a sufficient supply can be obtained at an economical cost; but where the railway is subjected to subsidences cinder ballast is used, otherwise successive liftings of the tracks would cause large quantities of the ballast gradually to disappear below the ordinary level of the ballasting. The use of slag ballast is generally avoided in tunnels, because in damp and confined situations it is considered to increase corrosion of the track; it is not used on the electrified lines of at least one administration, on account of certain chemical properties, and also because it is considered too retentive of moisture; this opinion is, however, not general, as it is ordinarily laid on other important electrified railways.

Details of Permanent Way.

Clear space outside rail, 4 ft. Middle space between two sets of rails, 6 ft. Clear space outside rail, 4 ft. Least head for the top of ballast, and least width for archways and tunnels, 13 ft. 1½ in. for single lines; 24 ft. 3 ins. for double lines. Spaces required for slopes of ballast and benches beyond them on top of embankments, from 3 ft. 10½ ins. to 8 ft. 10½ ins. for single lines; and from 3 ft. 9 ins. to 8 ft. 9 ins. for double lines. Total breadth on top of embankments, from 17 ft. to 22 ft. for single lines; and from 28 ft. to 33 ft. for double lines.

Lengthening Life of Track.

Perhaps the chief effort made towards lengthening the life of the track is annual lubrication of the fished rail joints, which, introduced some years ago, appears likely to become more generally adopted. The lubricants or preservatives—they serve as both—are tar or recovered machine oil. One railway is experimenting with the grease recovered from the gear-boxes of electric rolling stock; having more 'body,' it is anticipated that it will not dry up so soon as the 'thinner' substances. One Indian railway states that the fishplates are graphited and the nuts and bolts oiled once a year.

Rails laid in tunnels are in some cases painted with red lead, and in others are coated with tar. The painting or coating is usually done only when the rails are first laid; on one of the Irish railways, however, the tarring of rails and fishplates in tunnels and of fishplates exposed to the action of the sea is done periodically, and is said to have very materially prolonged their life. A similar practice is being tried on the Nigerian Railway in situations on the coast.

On the North Eastern section of the London and North Eastern Railway, when the bearing surfaces on the rails have become so worn as to cause ordinary fishplates to have little or no grip, it is found that the use of 'maintenance' fishplates, which are slightly greater in depth than the normal fishplates, materially reduces the wear and tear on the sleepers and fastenings at and close to the joint.

On the Great Northern section of the same railway sidecut rails are turned on all running lines. This practice is followed on several railways, and is being contemplated on others which previously discarded for main running lines rails the head of which is much worn on one side. The Canadian National Railways exchange the inner and outer rails on curves when wear has taken place; and another method, used in South Africa, is to exchange the rails in the curved and straight portion of the line.

On the District Railway, where the rails are particularly subject to uneven wear or 'battering,' used rails are taken up, machined to an even surface on the top, and replaced; this gives an increased life of about 100 per cent. while the cost of machining is only about 10s. a ton. The building up of used or damaged switches while in the track by oxy-acetylene flame is being tried in Canada.

Cost of Railway Construction.

In England, taking a fairly representative section of one of the main lines, outside the Metropolis, and constructed in recent years,* as an example, the percentages of the cost of about 40,000*l.* per mile, work out somewhat as follows:—

	Per Cent.		Per Cent.
Land and compensation	10	Sidings	3
Fencing	1½	Junctions and signals	1
Earthworks	24	Stations, including buildings (roadside only)	6½
Tunnels	12	Contingencies, including parliamentary, administration, legal and engineering expenses	6
Viaducts	8	Maintenance	½
Bridges for roads	9		100
Accommodation works	2		
Culverts and drainage	5		
Permanent way, ballast, including main line	11½		

* Pre-war period.

LONDON MIDLAND AND SCOTTISH RAILWAY (NORTH WESTERN SECTION).
DETAILS OF PERMANENT WAY.
General Arrangement.

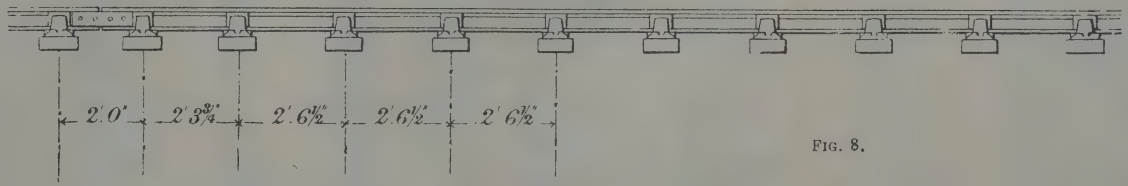
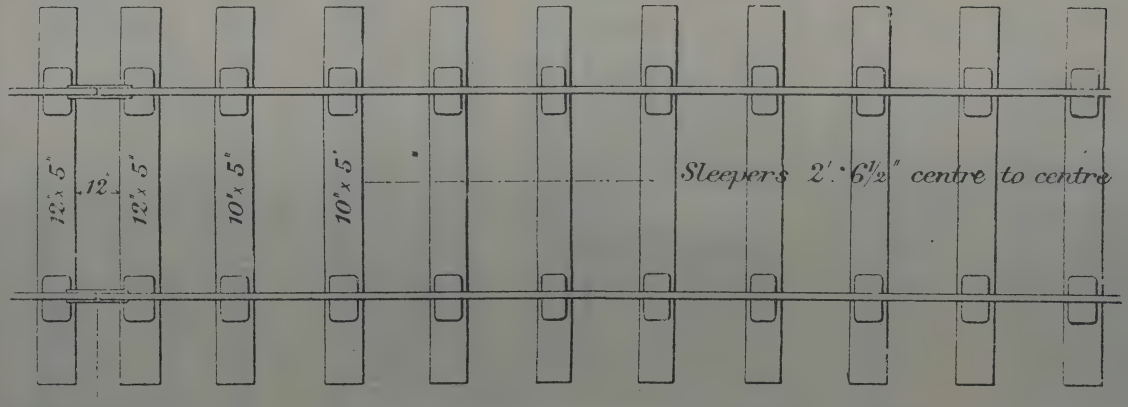


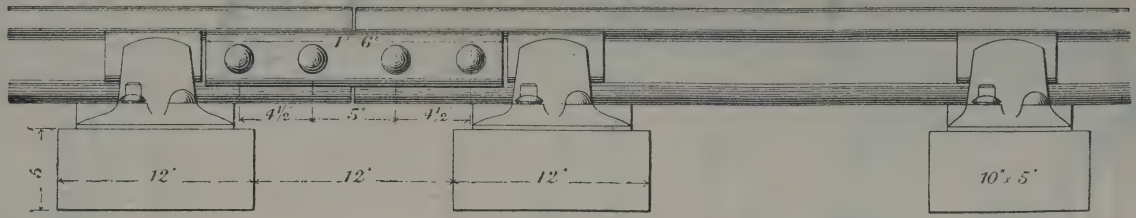
FIG. 8.



LONDON MIDLAND AND SCOTTISH RAILWAY (NORTH WESTERN SECTION).

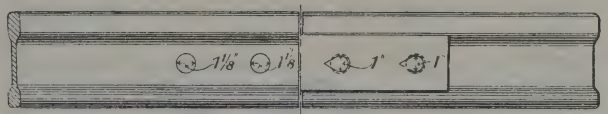
DETAILS OF PERMANENT WAY.

Rail Joints.



GENERAL ELEVATION OF JOINT

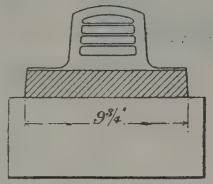
FIG. 9.



ELEVATION SHOWING HOLES IN RAIL

ELEVATION SHOWING HOLES IN FISHPLATE

FIG. 10.



SECTION OF JOINT CHAIR

WEIGHT 54 LBS.

FIG. 11.

L. M. & S. Railway (North Western Section).

DETAILS OF PERMANENT WAY.

Rail Setting.

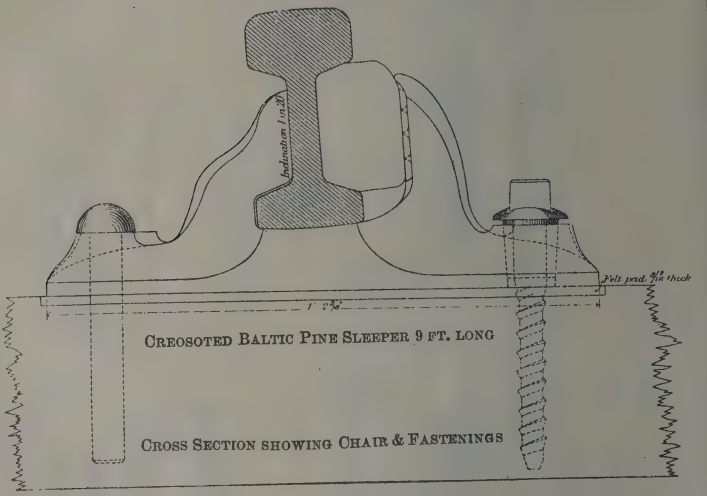
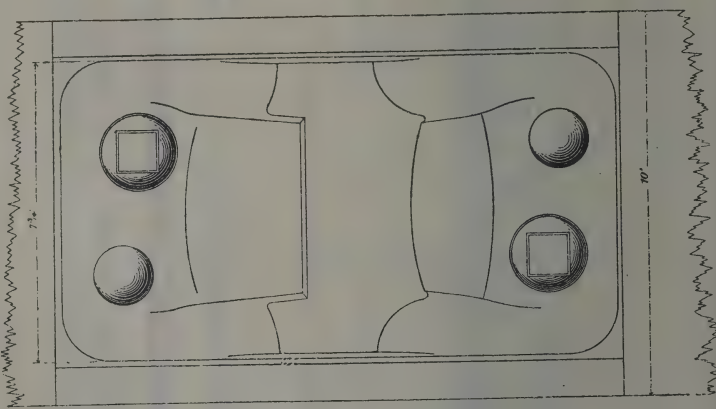


Fig. 12.



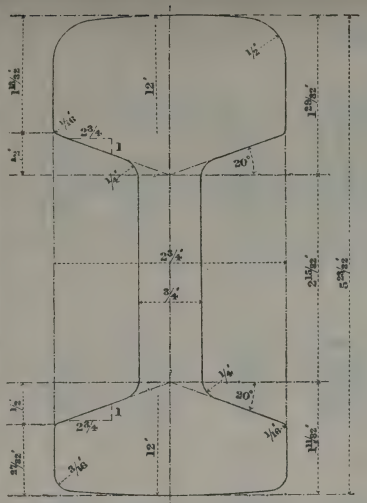
Plan of Intermediate Chair

(Rail and Key removed).

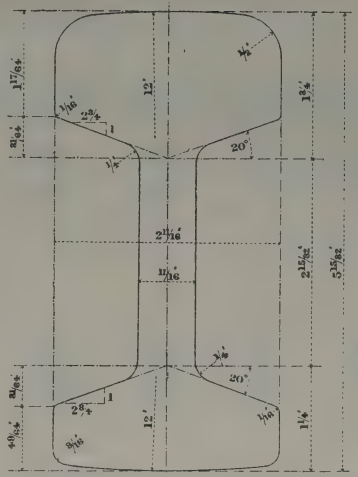
Weight 45 lbs.

Fig. 13.

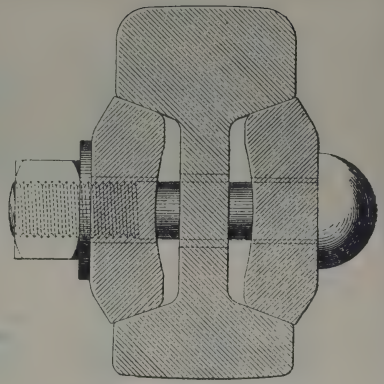
B.S. Rail Sections.



95 lbs. per yard. For Main Lines.



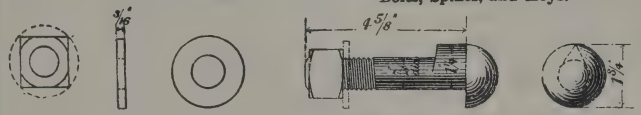
85 lbs. per yard. For Branch Lines.



Section of Rail and Fish Plates.

Ferrule.

Bolts, Spikes, and Keys.



Bolt. Weight, 1 lb. 12 ozs.

Galvanised Screw. Weight, 1 lb. 4 ozs.

Spike. Weight, 1 lb. 2½ ozs.

Oak Key. 6 ins. long.

FIG. 14.

LONDON MIDLAND AND SCOTTISH RAILWAY (MIDLAND SECTION).

DETAILS OF PERMANENT WAY.

General Arrangement.

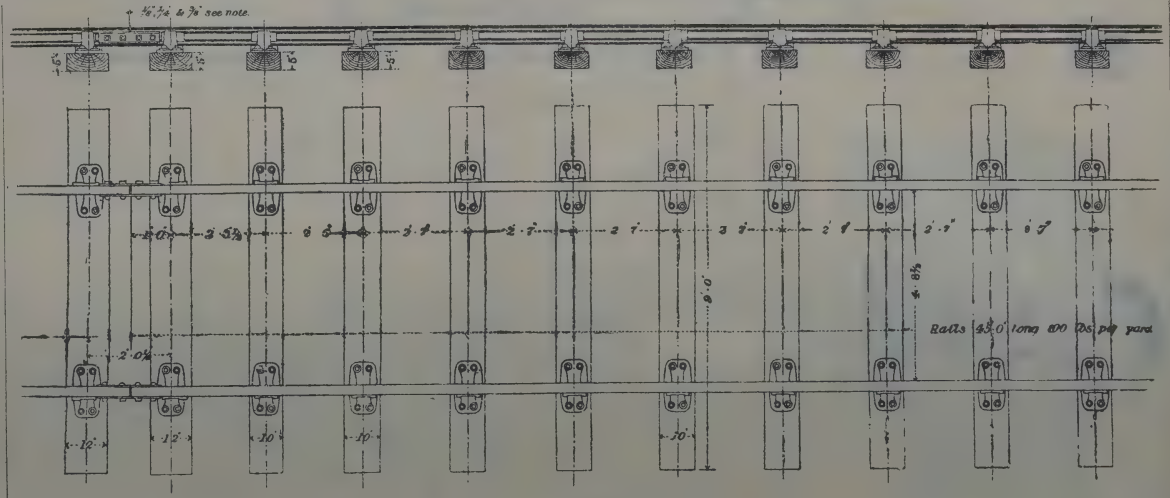


FIG. 15.

L. M. & S. Railway (Midland Section).

DETAILS OF PERMANENT WAY.

Rail Joints.

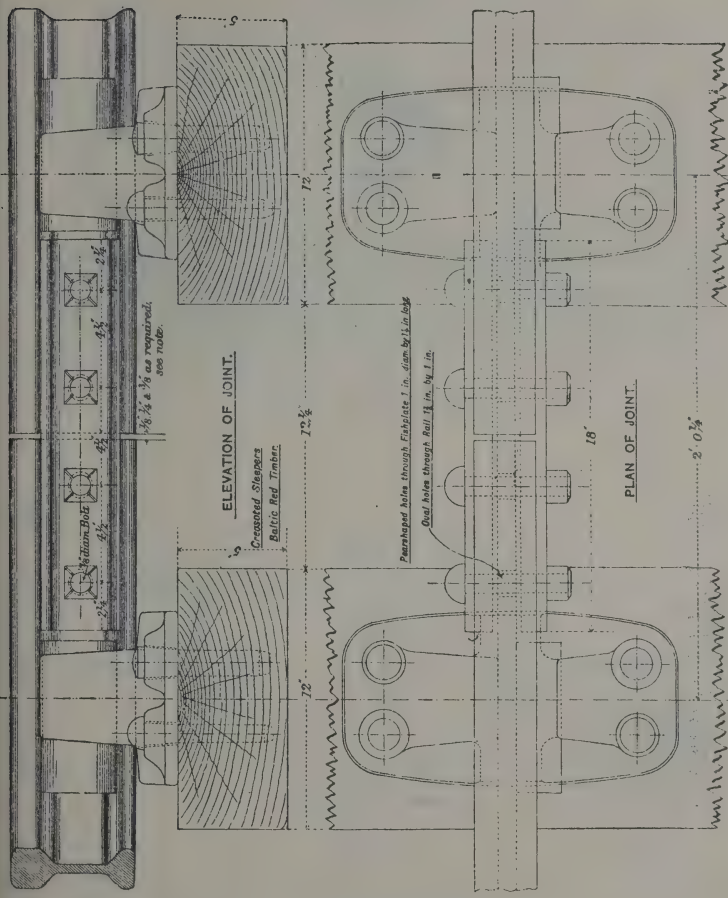
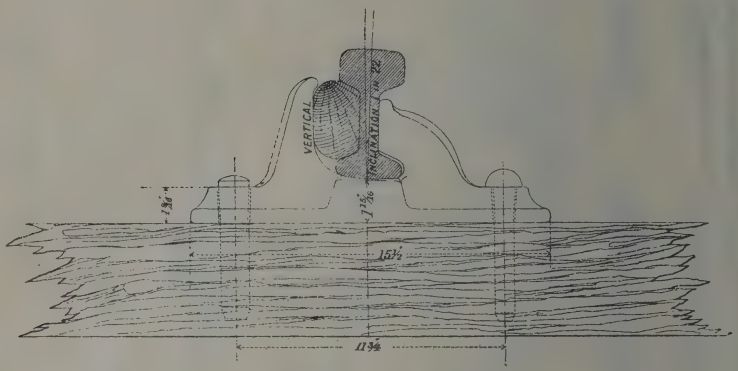


Fig. 16.

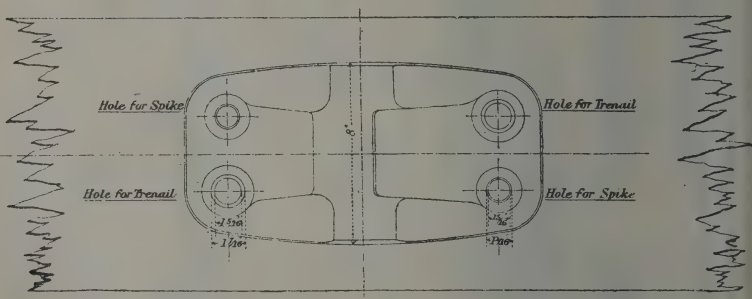
L. M. & S. Railway (Midland Section).

DETAILS OF PERMANENT WAY.

Rail Setting.



ELEVATION OF CHAIR.



PLAN OF CHAIR.

Fig. 17.

L. M. & S. Railway (Midland Section).

DETAILS OF PERMANENT WAY.

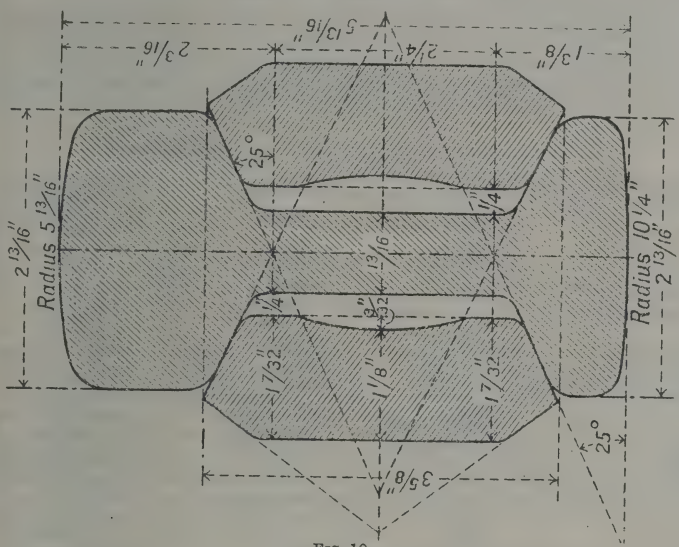
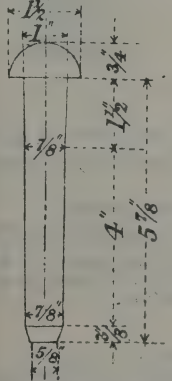
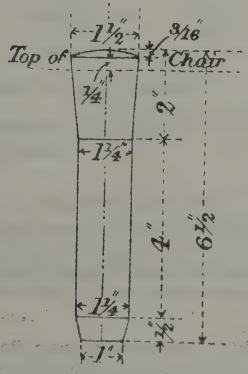


Fig. 18.

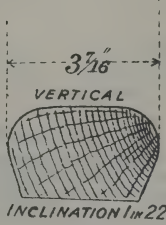
Spikes, Trenails, and Keys.



Wrought Iron Spike.



Solid Oak Trenail
(Before Driving).



Oak Key
7 ins. long.

Fig. 19.

From this it will be seen that, for country lines, the value of land does not form so important a factor in the total cost as is generally understood. The necessity for very easy gradients, and flat curves, in order to admit of high speeds, involves heavy earthworks, viaducts and tunnels, and expensive, well-ballasted permanent way, whilst stations and sidings have to be extensive to accommodate the traffic.

Experience has shown how to adapt the design of railways to their special surroundings. Their cost has varied from about 630,000*l.* per mile in London, and from an average of 52,378*l.* per mile in the United Kingdom, and of 8,127*l.* per mile in India, to a cost, in some parts of South Africa and South America, of 3,200*l.* to 3,500*l.* per mile, or, with equipment, of 4,000*l.* per mile—a rate at which, in new countries and under fairly normal conditions, railways can be provided, suitable for a speed of 30 miles per hour, and for heavy trains. (*Sir Douglas Fox.*)

Table showing Gauges of Various Railways

England, Scotland, and Wales	4 ft. 8½ ins. (1·435 metres)
Ireland	5 ft. 3 ins. (1·59 metres)
Canada	4 ft. 8½ ins.
New South Wales	4 ft. 8½ ins.
South Australia	5 ft. 3 ins.
Queensland	3 ft. 6 ins. (1·067 metres)
Victoria	5 ft. 3 ins.
Cape Colonies	3 ft. 6 ins.
New Zealand	3 ft. 6 ins.
British India	5 ft. 6 ins. (1·676 metres, & 3 ft 3⅜ ins. (1 metre)
Ceylon	5 ft. 6 ins.
Egypt	4 ft. 8½ ins. & 3 ft. 6 ins.
France	4 ft. 9 ins. (1·45 metres), 1·44 metres, & 3 ft. 3⅜ ins.
Belgium	4 ft. 9 ins.
Holland	4 ft. 9 ins.
Germany	4 ft. 8½ ins.
Austria	4 ft. 9 ins.
Switzerland	4 ft. 9 ins.
Italy	4 ft. 8⅞ ins. (1·445 metres)
Hungary	4 ft. 9 ins.
Spain	5 ft. 5⅝ ins. (1·67 metres)
Portugal	5 ft. 5½ ins. (1·67 metres)
Norway	4 ft. 8½ ins. & 3 ft. 6 ins.
Sweden	4 ft. 8½ ins.
Denmark	4 ft. 8½ ins.
Greece	1·44 metres
Poland	4 ft. 8½ ins.
Russia	5 ft. (1·524 metres)
Finland	5 ft.
Turkey	4 ft. 8½ ins.
Czechoslovakia	4 ft. 8½ ins.
Jugo-Slavia	4 ft. 8½ ins.
Lithuania	4 ft. 8½ ins.
Rumania	5 ft. & 4 ft. 8½ ins.
Sardinia	4 ft. 9 ins. & 3 ft. 1½ ins. (·95 metre)
United States	4 ft. 8½ ins.
Mexico	4 ft. 8½ ins. & 3 ft. (·91 metre)
Peru	4 ft. 8½ ins.
Brazil	3 ft. 3⅜ ins. & 5 ft. 3 ins.
Chili	5 ft. 6 ins. & 1 metre
Argentina	5 ft. 6 ins. & 1 metre
Uruguay	4 ft. 8½ ins.
Japan	5 ft. 6 ins.
China	4 ft. 8½ ins.

Widening of Gauge on Curves.

Under 8° . . standard gauge (4 ft. 8½ ins.).
Above 8° . . ½ in. for each 2° or fraction thereof, up to a maximum of 4 ft. 9½ ins.

(*American Railway Engineers Association.*)

Quantity of Land required for a Line of Railway.

This depends upon the width as determined by the depth of cuttings and height of embankments. Assuming average depth and height of 3 feet, and slopes of 1½ to 1, 5 to 6 acres will be required per mile of single line (4 ft. 8½ ins. gauge), made as in England, exclusive of sidings or stations. For each foot added to or deducted from the average of 3 feet given above (same slopes), 1 yard in width, or ⅛ acre per mile, must be added or deducted.

Light or Narrow-Gauge Railways.

Narrow-gauge railways will be found very suitable in districts where a standard-gauge line could not be made to pay, on account of the greater cost of construction and working of the latter. Narrow-gauge railways occupy less land, and the earthworks are of a less expensive kind than for standard-gauge lines, as heavy embankments and cuttings can be avoided by adopting sharper curves than are admissible with the standard gauge.

For the permanent way light material can be used, the rolling stock can be constructed to give a more favourable proportion between the dead and the paying loads than is possible on

standard-gauge lines, particularly if the traffic is made up of a great number of small consignments. On narrow-gauge lines the average proportion of dead load to paying load may be taken at about 1 to 2·33.

Whether steel or wood sleepers should be used is principally a question of cost, but it should be borne in mind that steel sleepers have a much greater life than wood sleepers.

The gauge and weight of rail should be determined in every case after a careful inquiry into the earning powers of the line. For the rails a weight of 25 lbs. per yard would be about the minimum. The 2-ft. gauge has the great advantage that it can be worked best in combination with portable railways which are joined on to branches of permanent line and continued to the farmyards, fields, or factories. The 2-ft. gauge is especially suitable for private lines and for lines of public utility with limited goods and little passenger traffic. It can be worked at a speed of fifteen miles per hour with curves 100 to 150 feet radius and gradients 1 in 80, for public lines; while on private lines, curves down to 60 feet radius and gradients up to 1 in 25 are admissible, according to the speed required and the amount of traffic. For lines with extensive goods traffic or principally for passenger traffic, 2 ft. 6 in. or 3 ft. gauge would be preferable.

If the goods are of a nature that they will not stand handling, the narrow-gauge waggon bodies could be made of such dimensions that three or four would fit into one main-line truck. A very simple device is also in practical use, of putting the main-line trucks on specially constructed bogies, and thus transporting them over the narrow-gauge railway.

(*A. Koppel.*)

The use of locomotives is not profitable on gauges of less than 18 inches.

The speed on narrow gauges may be as follows:—

2 ft. 0 in. gauge, 15 miles per hour.	3 ft. 0 in. gauge, 25 miles per hour.
2 ft. 6 in. gauge, 20 miles per hour.	3 ft. 6 in. gauge, 30 miles per hour.

Cost of Light Railways.

A fact which has militated against light railway construction is that the cost in Great Britain is very little less than that of building standard railways, ranging from £12,000 per mile in difficult country to £3,333 under easy conditions, while the average return on capital has been only a little over 2 per cent. On the other hand, the Decauville system of light railway adopted in the Argentine can be laid for £1,240 per mile, and the Road-Rail system, as tested in Uganda, South Africa, and Morocco, for £1,250 per mile. Another cheap form of rail transport is the Rutway, which it is said can on ordinary ground, such as the plains of India, be laid down, in lengths of 20 miles or more, at a cost of only about £1,000 per mile, including the provision of rolling stock. In this case the wheels run without any flanges on flat metal surfaces at the bottom of two deep ruts in the lowest part of the permanent way, and are confined to these ruts by the vertical sides of the rail angles and by the stone ballast heaped up along either side of each rail.

See also Section XLV., 'Cost of Engineering Works.'

Formulæ for Calculating the Power of Electric Locomotives for Light Railways.

W = weight of locomotive in tons loaded for service; g = percentage grade (rise per 100); L = weight of load in tons.

$$W = \frac{12+g}{120-g} \times L.$$

T = tractive force in lbs.

$$T = 2{\cdot}24\,(g+12)\,(W+L).$$

H = effective horsepower at driving wheels; S = speed in miles per hour.

$$H = \frac{T \times S}{375}.$$

C = current in ampères; E = electromotive force in volts at the motor terminals; m = mechanical efficiency of motor at 80 per cent. of H, allowing 20 per cent. for friction and electrical leakage.

$$C = \frac{H \times 746}{E \times m}.$$

For example: If $g = 18$ (*i.e.* 18 ft. per 100 ft.); L = 15 tons; S = 10 miles per hour; E = 500 volts then,

$$W = \frac{12+18}{120-18} \times 15 = \frac{30}{102} \times 15 = 4{\cdot}4 \text{ tons.} \quad T = 2{\cdot}24 \times 30 \times 19{\cdot}4 = 1{,}304 \text{ lbs.}$$

$$H = \frac{1304 \times 10}{375} = 35 \text{ H.P.} \quad C = \frac{35 \times 746}{500 \times 0{\cdot}8} = \text{about } 66 \text{ ampères.}$$

Hence the dynamo required would be of $66 \times 550^{*} = 36{,}000$ volt-ampères = 36 kilowatts.
Per kilowatt in the dynamo, there would be required, $1\frac{2}{3}$ H.P. in the steam engine,

or for 36 kilowatts, $36 \times 1\frac{2}{3} = 60$ H.P.

---

* This is the electromotive force at the dynamo terminals. Generators for tractive work are usually constructed for 550 volts, and allow of a loss of 50 volts between the dynamo and the motor terminals.

The strength of the dynamo must be calculated for the strongest current required.

For an installation intended to supply electricity both for lighting and power, a dynamo of 110 or 220 volts is the most suitable; if, however, the lamps are in circuit, a dynamo of 500 volts may be used. The advantage of the higher voltage is that the conductors may be made of a smaller section, while the loss of electromotive force remains the same.

The maximum loss of electromotive force can be taken at 20 to 25 per cent. of the voltage at the dynamo terminals.

By Ohm's Law,

where, $E_1 = C \times R$

E_1 = loss of electromotive force along conductor in volts; C = current in amperes; R = resistance of conductors in ohms.

If

d = diameter of copper wire in inches; W = weight of rails in lbs. per yard; l = length of track in yards, then,

$$R = l\left(\frac{1}{30000\,d^2} + \frac{1}{1100\,W}\right), \text{ and, } E_1 = C \times l\left(\frac{1}{30000\,d^2} + \frac{1}{1100\,W}\right).$$

(*A. Koppel.*)

Tunnels.

When deeply buried, a tunnel in soft earth is properly formed when its section is an ellipse whose major and minor axes have the ratio $c = \frac{\text{horizontal axis}}{\text{vertical axis}} = \sqrt{\frac{1 - \sin\phi}{1 + \sin\phi}}$, where ϕ is the angle of repose of the material. The horizontal axis must never be less than this ratio, but may be greater and will be still safe in firm earth. The whole ellipse is used in drains, but in tunnels the lower fourth or third is omitted, and a flat invert is put in.

Where tunnels are not deeply buried below the surface, the form of section is the 'Geostatic' arch, derived by transformation from the 'Hydrostatic' arch. To design a geostatic arch, given the depth of the crown below the surface $= x_o$, first design a hydrostatic arch and contract its horizontal ordinates in the ratio $c : 1$. This will give the figure required. As the greatest horizontal width will be a fixed quantity, the problem resolves itself into finding the depth below surface of the greatest hydrostatic breadth.

If x_o = depth of crown below surface; s = half span of geostatic arch; ϕ = angle of repose of earth; w = weight of a cubic foot of earth in lbs.; $c = \sqrt{\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)}$ = ratio of horizontal ordinates of two arches; y = half span of hydrostatic arch $= s \times \frac{1}{c}$; $s = cy$; $c = \frac{s}{y}$; x_1 = depth of greatest horizontal diameter $= x_o + a$; a = rise of arch above greatest diameter; b = a function depending on the relations of x_o, a, and x, then

$$b = a\sqrt[3]{\frac{x_o + a}{x_o}} \ (1); \quad y = b - \frac{b^2}{30a} \ (2); \quad b = y + \frac{y^2}{30a} \ (3); \quad x_o = a\frac{a^2}{b^3 - a^3} \ (4).$$

By assuming a value for a in (1) the value of b may be found and placed in (2); if a does not agree with its value assumed, further trials can be made until a sufficiently approximate result is obtained.

If r_o = radius of hydrostatic arch at crown; r_1 = radius of hydrostatic arch at greatest horizontal diameter or depth, x_1; k_o = geostatic crown radius $= r_o c^2$; k_1 = geostatic radius at depth $x_1 = \frac{r^1}{c}$; then

$$r_o = a + \frac{a^2}{2x_o}; \quad r_1 = a - \frac{a^2}{2(x_o + a)}; \quad r_c = \frac{a^2}{1}\left(1 + \frac{b^3}{a^3}\right); \quad r_1 = \frac{a}{2}\left(1 + \frac{a^3}{b^3}\right).$$

Thickness of Walls $= \sqrt{\cdot 12}R$ up to $\sqrt{\cdot 48}R$, where R = greatest radius $= \frac{a^2}{2}$.

Pressure on Brickwork $= \frac{w[x_1(s + t) - 0{\cdot}8\ a.s]}{t}$ lbs. per square foot, where w = weight per cubic foot of earth.

Breadth of Footings.—If t_1 = breadth of footings, then t_1 must not be less than

$$\frac{W}{2}\left\{\frac{(1 - \sin\phi)}{(1 + \sin\phi)}\right\}^2, \text{ where W = half width of bricked tunnel.}$$

To Draw the Hydrostatic Arch (figs. 20, 21).—Make $a\,b = r_o$ and $c\,d = r_1$; from d strike an arc with radius $d\,e = f\,b - c\,d$; from a with radius $a\,f$ draw arc cutting this at e. Then d, e, and a are centres to strike half arch.

The radius of the hydrostatic arch at any point is inversely as its depth at that point below surface hence $r_o x_o = r_1 x_1 = r_n x_n$. Through mud the section will be practically the hydrostatic

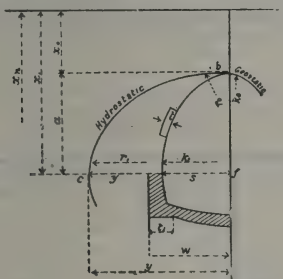


FIG. 20.

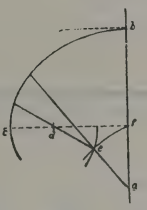


FIG. 21.

unless deeply buried, when the circular form would be correct; for in very soft material an invert resisting as an arch would be impracticable. An invert, however, could be used if strong enough to act as a beam against the upward pressure.

Superelevation of Outer Rail.

When a vehicle runs round a curve it tends either to overturn or to run off the line.

The tendency to run off is counteracted by a high centre of gravity for the vehicle, because this throws a heavier pressure on the outer rail and keeps down the wheel flanges from mounting. Low centre of gravity produces detrusive effects upon the rail, and tends to force the flange over the rail. Every speed has its proper degree of superelevation which brings in gravity to balance centrifugal force. The superelevation necessary for sharp curves and high velocities would cause slow trains to run off the rail at the *inside* of the curve. In practice the maximum superelevation is limited to 7 or 8 ins., and the speed round the curve is regulated to fit that superelevation.

To determine the Superelevation of the Outer Rail of a Railway Curve.

Let v = speed of train in miles per hour; r = radius of curve in feet; G = gauge in feet.

$$\text{Superelevation in inches} = G \times \frac{v^2}{1{\cdot}25r} = \frac{v^2}{r} \times 3{\cdot}77 \text{ for 4 ft. } 8\tfrac{1}{2} \text{ ins. gauge.}$$

TABLE SHOWING SUPERELEVATION OF OUTER RAIL FOR A GAUGE OF 4 FT. 8½ INS.

Radius of Curve in Feet.	Velocity in Miles per Hour.				Radius of Curve in Feet.	Velocity in Miles per Hour.			
	10	20	30	40		10	20	30	40
	Superelevation of Outer Rail in Inches.					Superelevation of Outer Rail in Inches.			
500	·75	3·01	6·78	12·05	3,000	·13	·50	1·13	2·01
1,000	·38	1·51	3·39	6·03	4,000	·09	·38	·85	1·51
2,000	·19	·75	1·70	3·01	5,000	·07	·30	·68	1·21

PRACTICAL RULE FOR DETERMINING THE SUPERELEVATION OF THE OUTER RAIL OF ANY CURVE. (*Price.*)

Let v = speed of train in feet per second; c = length of chord, in feet, whose versed sine equals the superelevation required; G = gauge of railway in feet; then

$$c = \tfrac{1}{4} v \sqrt{G}.$$

For 5 ft. 3 in. or 4 ft. 8½ in. gauge, and a speed of 40 miles per hour, c is approximately equal to 66 feet, or a Gunter's chain.

Stretch a 66-foot tape as a chord on the rail of the curve the superelevation of which it is required to find. Measure the distance of the rail from it at its centre point. This distance will equal the superelevation.

RADII OF CURVATURE AND VERSED SINES FOR RAILS.

Radius of Curvature in Feet.	Versed Sines for Rails, the Length in Feet being				Radius of Curvature in Feet.	Versed Sines for Rails, the Length in Feet being			
	15	16	18	20		15	16	18	20
	In.	In.	In.	Ins.		In.	In.	In.	In.
286	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{11}{16}$	$2\frac{1}{16}$	573	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$1\frac{1}{16}$
301	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{5}{8}$	2	636	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{5}{16}$
318	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{1}{2}$	$1\frac{7}{8}$	716	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$1\frac{3}{16}$
337	1	$1\frac{1}{8}$	$1\frac{7}{16}$	$1\frac{3}{4}$	818	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$
358	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{3}{8}$	$1\frac{11}{16}$	955	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
382	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{9}{16}$	1,146	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{1}{2}$
409	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{3}{16}$	$1\frac{7}{16}$	1,432	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
441	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	1,910	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$
477	$\frac{11}{16}$	$\frac{13}{16}$	1	$1\frac{1}{4}$	2,865	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$
521	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{15}{16}$	$1\frac{1}{8}$	5,739	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$

The above radii are those corresponding (commencing at the top) to angles of deflection from 20 to 1 deg.

Upon sharp curves it is customary to widen the gauge ½ in. for curves of a radius of 750 to 1,000 feet, ¾ in. for a radius of 500 feet, and 1 in. for curves of a less radius.

Angles and Leads of Crossings.

Let R and r = radii of curves in feet; G = gauge of railway in feet; L = lead of crossing in feet (*i.e.* the distance from the nose of the crossing to the nose of the switch); θ = angle of crossing.

Curve Curving off a Straight.

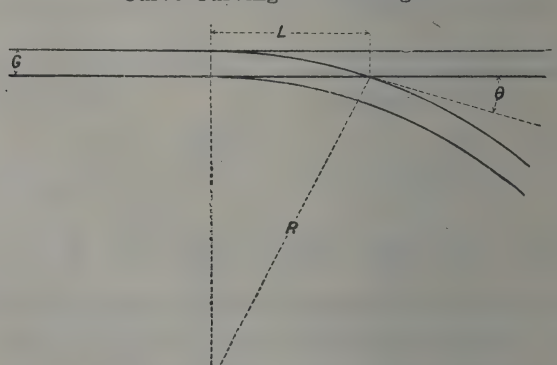


FIG. 22.

$$L = \sqrt{G(2R - G)} = \sqrt{2RG} \text{ (approximately)}; \quad \sin\theta = \frac{L}{R}.$$

It is in some instances, where trains have to run fast over a crossing, thought necessary to adopt a curve with a larger radius than usual. In this case it may be considered advisable, in order to prevent an elbow occurring at the heel of the switch, to adopt a longer switch than usual. The length of the switch can be calculated from the following formula when the curve is off a straight.

$$\text{Length of switch} = \sqrt{2R(c + t - e)},$$

where c = the clearance between the rails and the heel of the switch (in feet), this is usually about 2 inches; t = thickness of head of rail; e = the projection of the nose of the switch, if any.

Two Curves Curving in Opposite Directions.

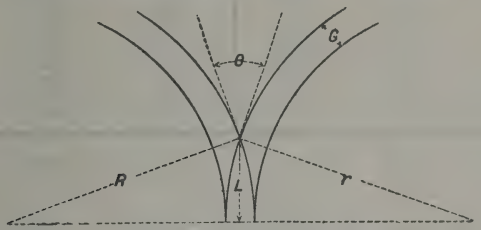


FIG. 23.

$$L = \sqrt{\frac{2RrG}{R + r}} \text{ (approximately)}; \quad \sin\theta = \frac{2\sqrt{2Rr(R + r)G}}{2Rr + (R + r)G}.$$

Two Curves Curving in the Same Direction.

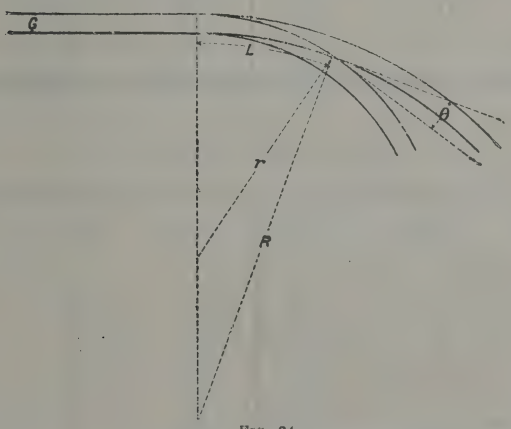


FIG. 24.

$$L = \sqrt{\frac{2RrG}{R - r}}, \quad \sin\theta = \frac{2\sqrt{2Rr(R - r)G}}{2Rr + (R - r)G}.$$

TABLES OF LEADS AND ANGLES OF CROSSINGS CURVING OFF A STRAIGHT LINE.

I. GAUGE, 5 FEET 6 INCHES.

Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.	Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.
400	66	1 in 6·0	1000	105	1 in 9·5
450	70	„ 6·4	1050	107	„ 9·8
500	74	„ 6·7	1100	110	„ 10·0
550	78	„ 7·0	1150	112	„ 10·2
600	81	„ 7·4	1200	115	„ 10·4
650	84	„ 7·7	1250	117	„ 10·6
700	88	„ 7·9	1300	120	„ 10·8
750	91	„ 8·2	1350	122	„ 11·0
800	94	„ 8·5	1400	124	„ 11·2
850	97	„ 8·7	1450	126	„ 11·5
900	99	„ 9·0	1500	128	„ 11·7
950	102	„ 9·3	1550	131	„ 11·8

II. GAUGE, 3 FEET

Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.	Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.
400	49	1 in 8·1	1000	78	1 in 12·8
450	52	„ 8·6	1050	79	„ 13·2
500	55	„ 9·0	1100	81	„ 13·5
550	58	„ 9·4	1150	83	„ 13·8
600	60	„ 10·0	1200	85	„ 14·1
650	63	„ 10·3	1250	87	„ 14·3
700	65	„ 10·7	1300	88	„ 14·7
750	67	„ 11·1	1350	90	„ 15·0
800	69	„ 11·5	1400	92	„ 15·2
850	71	„ 11·9	1450	93	„ 15·5
900	74	„ 12·1	1500	95	„ 15·7
950	76	„ 12·5	1550	96	„ 16·1

III. GAUGE, 3 FEET 3⅜ INCHES (1 METRE).

Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.	Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.
400	51	1 in 7·8	1000	81	1 in 12·3
450	54	„ 8·3	1050	83	„ 12·6
500	57	„ 8·7	1100	85	„ 12·9
550	60	„ 9·1	1150	87	„ 13·2
600	63	„ 9·5	1200	89	„ 13·4
650	65	„ 10·0	1250	91	„ 13·7
700	68	„ 10·3	1300	92	„ 14·1
750	70	„ 10·7	1350	94	„ 14·2
800	73	„ 10·9	1400	96	„ 14·5
850	75	„ 11·3	1450	98	„ 14·8
900	77	„ 11·6	1500	99	„ 15·1
950	79	„ 12·0	1550	101	„ 15·3

IV. Gauge, 4 Feet 8½ Inches.

Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.	Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.
400	61	1 in 6·5	1000	97	1 in 10·3
450	65	„ 6·9	1050	99	„ 10·6
500	69	„ 7·2	1100	102	„ 10·7
550	72	„ 7·6	1150	104	„ 11·0
600	75	„ 8·0	1200	106	„ 11·3
650	78	„ 8·3	1250	108	„ 11·5
700	81	„ 8·6	1300	111	„ 11·7
750	84	„ 8·9	1350	113	„ 11·9
800	87	„ 9·1	1400	115	„ 12·1
850	89	„ 9·5	1450	117	„ 12·3
900	92	„ 9·7	1500	119	„ 12·6
950	95	„ 10·0	1550	121	„ 12·8

V. Gauge, 5 Feet 3 Inches.

Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.	Radius of Curve (R) in Feet.	Lead (L) in Feet.	Inclination of Crossing, $\frac{1}{\theta}$.
400	65	1 in 6·1	1000	102	1 in 9·8
450	69	„ 6·5	1050	105	„ 10·0
500	72	„ 6·9	1100	107	„ 10·2
550	76	„ 7·2	1150	110	„ 10·4
600	79	„ 7·5	1200	112	„ 10·7
650	83	„ 7·8	1250	115	„ 10·8
700	86	„ 8·1	1300	117	„ 11·1
750	89	„ 8·4	1350	119	„ 11·3
800	92	„ 8·6	1400	121	„ 11·5
850	94	„ 9·0	1450	123	„ 11·7
900	97	„ 9·2	1500	125	„ 12·0
950	100	„ 9·5	1550	128	„ 12·1

Approximate Rule for Leads of Crossings.

The lead of any crossing is equal to twice the gauge multiplied by the angle of the crossing.

If curves are carefully plotted to an enlarged scale of, say, 10 or 20, or often even 33 feet to an inch, the leads and angles of the crossings can be scaled off with sufficient accuracy for all practical purposes.

The gauge should be generally about 1 inch tighter at the nose of the crossing and points than anywhere else on the lead, in order to prevent the wheels having any lateral play.

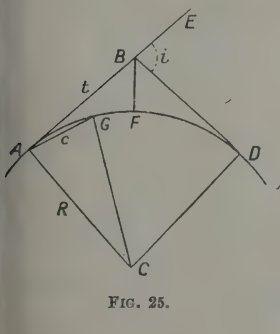


Fig. 25.

Ranging out Curves with a Theodolite.

R = radius of curve = AC. i = angle of inclination of intersection = EBD. t = tangent AB or BD = R tan $\frac{i}{2}$.

Length of curve = AFD = ·0002909Ri.

Tangential (or 'setting off') angle (angle between c and t) in minutes for any chord c

$$= 1718{\cdot}873 \ \frac{c}{R}.$$

R and c being expressed in feet and i in minutes.

The angle ACG is called the 'deflection' angle, and is twice the tangential angle, *i.e.* the tangential angle is one-half the deflection angle.

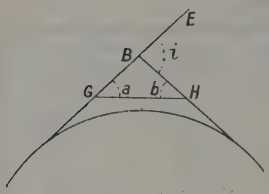


FIG. 26.

To find the Angle of Intersection and Point of Intersection where the latter is inaccessible.

If B is the inaccessible point, then—

Range the line GH.

$$i = a + b,$$

$$GB = \frac{GH \sin b}{\sin i}, \quad HB = \frac{GH \sin a}{\sin i}.$$

TABLE OF TANGENTIAL ANGLES FOR CHORDS OF 1 FOOT AND 100 FEET.

Radius of Curve.	Tangential Angle. Chord 1 ft.	Tangential Angle. Chord 100 ft.	Radius of Curve.	Tangential Angle. Chord 1 ft.	Tangential Angle. Chord 100 ft.	Radius of Curve.	Tangential Angle. Chord 1 ft.	Tangential Angle. Chord 100 ft.
Ft.	Min.	Deg. Min.	Ft.	Min.	Deg. Min.	Miles.	Min.	Deg. Min.
500	3·438	5 43·77	3,000	0·573	0 57·30	$\frac{1}{8}$	2·604	4 20·44
600	2·865	4 46·48	3,500	0·491	0 49·11	$\frac{1}{4}$	1·302	2 10·22
700	2·456	4 5·55	4,000	0·430	0 42·97	$\frac{1}{2}$	0·651	1 5·11
800	2·149	3 34·86	4,500	0·381	0 38·20	$\frac{3}{4}$	0·434	0 43·41
900	1·910	3 10·99	5,000	0·344	0 34·38	1	0·326	0 32·55
1,000	1·719	2 51·89	5,500	0·313	0 31·25	$1\frac{1}{4}$	0·260	0 26·04
1,100	1·563	2 36·26	6,000	0·286	0 28·65	$1\frac{1}{2}$	0·217	0 21·70
1,200	1·432	2 23·24	7,000	0·246	0 24·56	$1\frac{3}{4}$	0·187	0 18·70
1,500	1·146	1 54·59	8,000	0·215	0 21·49	2	0·163	0 16·28
2,000	0·859	1 25·94	9,000	0·191	0 19·10	$2\frac{1}{2}$	0·130	0 13·02
2,500	0·688	1 8·76	10,000	0·172	0 17·19	3	0·109	0 10·85

A curve in America is expressed as an $n°$ curve (deflection angle), and is one of such a radius that a chord of 100 ft. subtends an angle of $n°$ at the centre.

Setting out Curves by Offsets

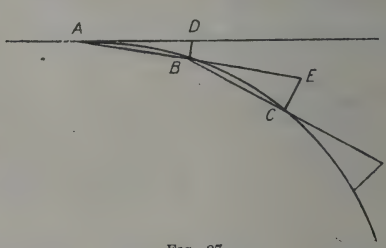


FIG. 27.

First offset BD from the tangent line.

$$DB = \frac{AD^2}{2 \text{ radius}}.$$

Offset from any chord AB produced

$$E = EC = \frac{AE \times EB}{2 \text{ radius}}.$$

Or where AB = BE, then

$$EC = \frac{AB^2}{\text{radius}}$$

TABLE OF RADII OF CURVES.

(Chords = 66 feet.)

V	R	V	R	V	R	V	R	V	R	V	R	V	R
0	Straight	1	99	2	49½ 49·500	3	33	4	24¾ 24·750	5	19⅘ 19·800	6	16½ 16·500
1/16	1,584 1584·01	1/16	93 3/17 93·176	1/16	48	1/16	32 16/49 32·326	1/16	24 24/49 24·369	1/16	19⅝ 19·5	1/16	16 32/97 16·330
1/8	792 792·005	1/8	88	1/8	46 10/17 46·588	1/8	31 17/26 31·680	1/8	24	1/8	19 13/41 19·317	1/8	16 8/49 16·163
3/16	528	3/16	83 7/19 83·368	3/16	45 9/35 45·257	3/16	31 1/17 31·059	3/16	23 43/97 23·641	3/16	19 7/33 19·084	3/16	16
1/4	396	1/4	79⅕ 79·200	1/4	44	1/4	30 6/13 30·461	1/4	23 7/17 23·294	1/4	18 9/11 18·857	1/4	15 21/23 15·840
5/16	316⅘ 316·800	5/16	75 3/7 75·428	5/16	42 30/37 42·811	5/16	29 47/48 29·886	5/16	22 22/23 22·956	5/16	18 14/35 18·635	5/16	15 69/101 15·683
3/8	264	3/8	72	3/8	41 13/16 41·684	3/8	29⅓ 29·333	3/8	22 22/45 22·628	3/8	18 18/49 18·418	3/8	15 9/17 15·529
7/16	226 7/7 226 285	7/16	68 20/23 68·869	7/16	40 8/13 40·615	7/16	28⅘ 28·800	7/16	22 22/41 22·310	7/16	18 8/39 18·207	7/16	15 39/103 15·378
1/2	198	1/2	66	1/2	39⅗ 39·600	1/2	28 2/7 28·286	1/2	22	1/2	18	1/2	15 3/13 15·230
9/16	176	9/16	63 9/25 63·360	9/16	38 26/41 38·634	9/16	27 15/19 27·789	9/16	21 21/43 21·700	9/16	17 11/49 17·798	9/16	15 3/5 15·086
5/8	158⅘ 158·400	5/8	60 12/13 60·923	5/8	37⅖ 37·714	5/8	27 9/29 27·310	5/8	21 15/37 21·405	5/8	17⅗ 17·600	5/8	14 50/53 14·943
11/16	144	11/16	58 2/3 58·666	11/16	36 28/53 36·837	11/16	26 5/53 26·847	11/16	21 3/25 21·120	11/16	17 37/41 17·407	11/16	14 86/107 14·804
3/4	132	3/4	56 4/7 56·571	3/4	36	3/4	26 2/5 26·400	3/4	20 16/19 20·842	3/4	17 5/23 17·217	3/4	14 2/3 14·666
13/16	121 11/15 121·846	13/16	54 18/29 54·621	13/16	35⅕ 35·200	13/16	25 59/61 25·967	13/16	20 4/7 20·571	13/16	17 1/31 17·032	13/16	14 58/109 14·532
7/8	113 3/7 113·143	7/8	52 4/5 52·800	7/8	34 10/23 34·434	7/8	25 1/7 25·548	7/8	20 4/13 20·307	7/8	17 4/7 17·851	7/8	14 2/5 14·400
15/16	105 3/8 105·600	15/16	51 3/31 51·097	15/16	33 33/47 33·702	15/16	25⅐ 25·143	15/16	20 4/7 20·051	15/16	16 24/25 16·674	15/16	14 19/35 14·270

V = versed sine in inches. R = radius of curve in chains.

NOTE.—If 33-foot chords are used for finding curves, the versed sine measured must be multiplied by 4 and then looked up in this table.

TABLE OF RADII OF CURVES (*continued*).

(Chords = 66 feet.)

V	R	V	R	V	R	V	R	V	R	V	R	V	R
7	14 1/7 14·143	8	12 3/8 12·375	9	11	10	9 9/16 9·900	11	9	12	8 1/4 8·250	13	7 8/13 7·615
1/16	14 9/113 14·017	1/16	12 12/43 12·280	1/16	10 134/145 10·924	1/16	9 135/161 9·838	1/16	8 80/89 8·949	1/16	8 40/193 8·207	1/16	7 1/10 7·579
1/8	13 17/19 13·894	1/8	12 12/85 12·184	1/8	10 23/73 10·850	1/8	9 7/9 9·7	1/8	8 80/89 8·899	1/8	8 16/97 8·165	1/8	7 1/38 7·543
3/16	13 89/115 13·774	3/16	12 1/181 12·091	3/16	10 35/49 10·775	3/16	9 117/163 9·718	3/16	8 153/179 8·849	3/16	8 8/65 8·123	3/16	7 107/211 7·507
1/4	13 13/29 13·655	1/4	12	1/4	10 25/37 10·702	1/4	9 27/41 9·658	1/4	8 4/5 8·800	1/4	8 4/49 8·081	1/4	7 25/53 7·471
5/16	13 7/13 13·538	5/16	11 121/133 11·910	5/16	10 94/149 10·630	5/16	9 3/5 9·600	5/16	8 136/181 8·751	5/16	8 8/197 8·041	5/16	7 31/71 7·436
3/8	13 25/59 13·423	3/8	11 55/87 11·820	3/8	10 11/23 10·560	3/8	9 45/83 9·542	3/8	8 84/91 8·703	3/8	8 8	3/8	7 49/107 7·402
7/16	13 37/119 13·311	7/16	11 11/15 11·73	7/16	10 74/151 10·490	7/16	9 81/167 9·485	7/16	8 40/81 8·655	7/16	7 191/199 7·960	7/16	7 79/215 7·367
1/2	13 1/5 13·200	1/2	11 11/17 11·647	1/2	10 8/19 10·421	1/2	9 3/7 9·428	1/2	8 14/33 8·608	1/2	7 23/26 7·920	1/2	7 1/3 7·333
9/16	13 1/11 13·09	9/16	11 77/137 11·562	9/16	10 6/17 10·353	9/16	9 63/169 9·372	9/16	8 104/185 8·562	9/16	7 59/67 7·880	9/16	7 65/217 7·300
5/8	12 80/81 12·983	5/8	11 11/25 11·478	5/8	10 3/7 10·285	5/8	9 27/85 9·317	5/8	8 18/31 8·516	5/8	7 85/101 7·841	5/8	7 29/109 7·266
11/16	12 80/41 12·878	11/16	11 56/139 11·395	11/16	10 34/145 10·219	11/16	9 5/19 9·263	11/16	8 8/17 8·470	11/16	7 168/217 7·803	11/16	7 17/73 7·233
3/4	12 24/31 12·774	3/4	11 11/35 11·314	3/4	10 2/13 10·153	3/4	9 9/43 9·209	3/4	8 20/47 8·425	3/4	7 13/17 7·764	3/4	7 1/5 7·200
13/16	12 84/135 12·672	13/16	11 1/7 11·234	13/16	10 14/137 10·089	13/16	9 27/173 9·156	13/16	8 8/21 8·381	13/16	7 142/205 7·727	13/16	7 37/221 7·167
7/8	12 1/7 12·571	7/8	11 11/71 11·155	7/8	10 2/79 10·025	7/8	9 3/29 9·103	7/8	8 32/65 8·337	7/8	7 73/103 7·689	7/8	7 5/37 7·135
15/16	12 80/121 12·472	15/16	11 1/13 11·077	15/16	9 51/53 9·962	15/16	9 9/175 9·051	15/16	8 56/191 8·293	15/16	7 15/23 7·652	15/16	7 23/213 7·103

V = versed sine in inches. R = radius of curve in chains.

NOTE—If 33-foot chords are used for finding curves, the versed sine measured must be multiplied by 4 and then looked up in this table.

TABLE OF RADII OF CURVES (*continued*).

(Chords=66 feet.)

V	R	V	R	V	R	V	R	V	R	V	R	V	R
14	$7\frac{1}{14}$ 7·071	15	$6\frac{3}{5}$ 6·600	16	$6\frac{3}{16}$ 6·187	17	$5\frac{14}{17}$ 5·823	18	$5\frac{1}{2}$ 5·500	19	$5\frac{4}{19}$ 5·210	20	$4\frac{10}{20}$ 4·950
$\frac{1}{16}$	$7\frac{1}{25}$ 7·040	$\frac{1}{16}$	$6\frac{138}{241}$ 6·572	$\frac{1}{16}$	$6\frac{42}{257}$ 6·163	$\frac{1}{16}$	$5\frac{73}{91}$ 5·802	$\frac{1}{16}$	$5\frac{139}{256}$ 5·481	$\frac{1}{16}$	$5\frac{59}{305}$ 5·193		
$\frac{1}{8}$	$7\frac{1}{113}$ 7·008	$\frac{1}{8}$	$6\frac{6}{11}$ 6·54	$\frac{1}{8}$	$6\frac{6}{43}$ 6·140	$\frac{1}{8}$	$5\frac{107}{137}$ 5·781	$\frac{1}{8}$	$5\frac{67}{146}$ 5·462	$\frac{1}{8}$	$5\frac{3}{17}$ 5·176		
$\frac{3}{16}$	$6\frac{223}{227}$ 6·978	$\frac{3}{16}$	$6\frac{14}{27}$ 6·518	$\frac{3}{16}$	$6\frac{30}{269}$ 6·116	$\frac{3}{16}$	$5\frac{19}{25}$ 5·760	$\frac{3}{16}$	$5\frac{43}{97}$ 5·443	$\frac{3}{16}$	$5\frac{49}{307}$ 5·159		
$\frac{1}{4}$	$6\frac{18}{16}$ 6·947	$\frac{1}{4}$	$6\frac{30}{61}$ 6·491	$\frac{1}{4}$	$6\frac{6}{65}$ 6·092	$\frac{1}{4}$	$5\frac{13}{43}$ 5·739	$\frac{1}{4}$	$5\frac{31}{73}$ 5·425	$\frac{1}{4}$	$5\frac{1}{7}$ 5·143		
$\frac{5}{16}$	$6\frac{210}{229}$ 6·917	$\frac{5}{16}$	$6\frac{114}{245}$ 6·465	$\frac{5}{16}$	$6\frac{2}{29}$ 6·069	$\frac{5}{16}$	$5\frac{190}{277}$ 5·718	$\frac{5}{16}$	$5\frac{119}{203}$ 5·406	$\frac{5}{16}$	$5\frac{13}{103}$ 5·126		
$\frac{3}{8}$	$6\frac{102}{115}$ 6·887	$\frac{3}{8}$	$6\frac{18}{41}$ 6·439	$\frac{3}{8}$	$6\frac{6}{131}$ 6·045	$\frac{3}{8}$	$5\frac{97}{139}$ 5·697	$\frac{3}{8}$	$5\frac{19}{49}$ 5·387	$\frac{3}{8}$	$5\frac{17}{155}$ 5·109		
$\frac{7}{16}$	$6\frac{6}{7}$ 6·857	$\frac{7}{16}$	$6\frac{102}{247}$ 6·413	$\frac{7}{16}$	$6\frac{6}{263}$ 6·023	$\frac{7}{16}$	$5\frac{81}{91}$ 5·677	$\frac{7}{16}$	$5\frac{103}{205}$ 5·370	$\frac{7}{16}$	$5\frac{39}{311}$ 5·093		
$\frac{1}{2}$	$6\frac{24}{29}$ 6·827	$\frac{1}{2}$	$6\frac{12}{31}$ 6·387	$\frac{1}{2}$	6	$\frac{1}{2}$	$5\frac{23}{35}$ 5·657	$\frac{1}{2}$	$5\frac{13}{37}$ 5·351	$\frac{1}{2}$	$5\frac{1}{13}$ 5·077		
$\frac{9}{16}$	$6\frac{186}{233}$ 6·798	$\frac{9}{16}$	$6\frac{30}{83}$ 6·361	$\frac{9}{16}$	$5\frac{255}{265}$ 5·977	$\frac{9}{16}$	$5\frac{179}{251}$ 5·637	$\frac{9}{16}$	$5\frac{1}{3}$ 5·333	$\frac{9}{16}$	$5\frac{19}{313}$ 5·061		
$\frac{5}{8}$	$6\frac{10}{13}$ 6·769	$\frac{5}{8}$	$6\frac{42}{125}$ 6·336	$\frac{5}{8}$	$5\frac{127}{135}$ 5·955	$\frac{5}{8}$	$5\frac{29}{47}$ 5·617	$\frac{5}{8}$	$5\frac{47}{149}$ 5·315	$\frac{5}{8}$	$5\frac{7}{157}$ 5·044		
$\frac{11}{16}$	$6\frac{174}{255}$ 6·740	$\frac{11}{16}$	$6\frac{78}{251}$ 6·311	$\frac{11}{16}$	$5\frac{83}{89}$ 5·932	$\frac{11}{16}$	$5\frac{169}{283}$ 5·597	$\frac{11}{16}$	$5\frac{89}{299}$ 5·297	$\frac{11}{16}$	$5\frac{1}{35}$ 5·028		
$\frac{3}{4}$	$6\frac{42}{59}$ 6·711	$\frac{3}{4}$	$6\frac{3}{7}$ 6·285	$\frac{3}{4}$	$5\frac{61}{67}$ 5·910	$\frac{3}{4}$	$5\frac{41}{71}$ 5·577	$\frac{3}{4}$	$5\frac{7}{25}$ 5·280	$\frac{3}{4}$	$5\frac{1}{19}$ 5·012		
$\frac{13}{16}$	$6\frac{54}{79}$ 6·683	$\frac{13}{16}$	$6\frac{6}{23}$ 6·261	$\frac{13}{16}$	$5\frac{230}{206}$ 5·888	$\frac{13}{16}$	$5\frac{53}{65}$ 5·558	$\frac{13}{16}$	$5\frac{79}{301}$ 5·262	$\frac{13}{16}$	$4\frac{314}{317}$ 4·997		
$\frac{7}{8}$	$6\frac{78}{119}$ 6·655	$\frac{7}{8}$	$6\frac{30}{127}$ 6·236	$\frac{7}{8}$	$5\frac{13}{15}$ 5·86	$\frac{7}{8}$	$5\frac{7}{13}$ 5·538	$\frac{7}{8}$	$5\frac{37}{151}$ 5·245	$\frac{7}{8}$	$4\frac{82}{88}$ 4·981		
$\frac{15}{16}$	$6\frac{150}{236}$ 6·628	$\frac{15}{16}$	$6\frac{18}{85}$ 6·212	$\frac{15}{16}$	$5\frac{229}{271}$ 5·845	$\frac{15}{16}$	$5\frac{149}{287}$ 5·519	$\frac{15}{16}$	$5\frac{23}{161}$ 5·227	$\frac{15}{16}$	$4\frac{28}{29}$ 4·965		

(*C. E. Murray.*)

V = versed sine in inches. R = radius of curve in chains.

NOTE.—If 33-foot chords are used for finding curves, the versed sine measured must be multiplied by 4 and then looked up in this table.

Transition Curves.*

The superelevation of the outer rail on the curve which is needed at its full height for the whole length of the curve renders it necessary to begin canting the rails some distance back along the straight, called the 'run off,' in order that it may attain its full amount at the tangent point. To obviate the sudden centrifugal effect and also the difficulties due to the 'run off,' *transition curves*, or *spirals*, have been introduced. A true transition curve should determine, by slowly increasing its curvature, that the centrifugal force is applied gradually, and thus prevent any sudden oscillation, and also so that the full superelevation is gained gradually throughout its length.

The superelevation at any particular point in the transition curve should be the correct one for the curvature at that point, on the assumption that it has been designed to suit a certain maximum speed.

The formula $L = \sqrt{R}$, where L is the length and R the radius of the curve, gives very efficient transition curves for circular curves of less than 56·8 chains radius, which corresponds to about the maximum velocity used on any of our railways—84 miles per hour. But for curves of larger radius than 56·8 chains, the formula $L = 0{\cdot}00072428 \frac{V^3}{R}$ should be used, where V is the velocity in miles per hour, and L and R are in chains.

The formula $L = \sqrt{R}$ for determining the length of transition to be used has much to commend it, though it is used very little on British railways as yet, the custom at present being to take a length of 50, 60, or sometimes 66 ft. for every inch of superelevation on the circular curve. It might seem to a permanent-way engineer that the length provided by this formula for transitions to sharp curves was much too small, for instead of increasing in length as the curvature becomes sharper, it diminishes, consequently making the rate of gain of superelevation much quicker than 1 in. in 60 ft. But as the curves are sharper, the maximum speed permitted on them is also less, and thus in surmounting the superelevation at a lower velocity no uncomfortable motion is felt by passengers, as the discomfort of the motion varies as the cube of the velocity, a speed of 50 miles per hour causing nearly 5 times as much oscillation as that due to one of 30 miles per hour.

Again, for speeds of 70 and 80 miles per hour and a radius of between 40 and 60 chains, it may seem that the lengths of transitions are much too long, but here the excessive speeds demand a very gentle gradient on which to gain the full cant if the sensation of having the coach heaved up at one side is to be sufficiently gradual. Thus at speeds of 70 to 80 miles per hour the gain of superelevation should amount to 1 in. in 80 ft. or more if the best running is to be obtained. Therefore a general rule of, say, 1 in. in 60 ft. for the cant on all transition curves is unscientific and not productive of the best results. All the principal railways have now taken to the introduction of transition curves, where possible, at some parts of their systems.

The feeling that circular curves of large radius provide sufficiently good running to render them immune from the transition innovation is one which should be dissipated. As long as large easy curves are used for only *moderately high speeds* the need for a transition curve is not great. But the tendency on some of our principal railways to insert curves only of large radius and without transition curves on their main lines is a mistake, as the approach to any of these curves by trains at *high speed* is necessarily accompanied by irregularities of motion which would not occur had it been made on a transition curve.

Speaking broadly, it may be said that it is only on curves of large radius that there is any great need for a transition approach, as these curves are generally associated with high speeds, whereas the sharper curves are excluded from lines intended for fast traffic. Also, it must be remembered that on a high speed track an irregularity so slight as to escape the eye of the platelayer entirely may cause a very serious jar in the running at that point.

It is advisable that marks of a permanent nature be fixed along the 6-foot way, from which measurements may be taken to the curve in order to refix it in its true position and to the correct elevation during the operation of reballasting or other renewal work. The foreman platelayer should be provided with these and a plan giving the lengths of the offsets. A type of mark which has been adopted with some success is a centre peg made of a fish-plate set in a block of concrete, the fish-plate having a saw cut in it to indicate the centre line of the railway. It is not possible to fix these at the level of the rails, as their projection above the surface of the 6-foot way would be a danger to platelayers, also if a material train was unloaded at such a point a rail dropped on the marks would destroy their accuracy. However, if fixed well down in the pitching and formation so that the top surface of the plate is flush with the top surface of the sleeper or at a definite number of inches, say, 7 below the surface of the rail, they can be always used for re-establishing the rail in its correct position.

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* Abstract from paper by Prof. S. W. Perrott, B.A., M.Inst.C.E., read before the Liverpool Engineering Society, March 7, 1917.

Another method, which has been used on the former Great Southern and Western Railway in Ireland, is that of using short lengths of old flat-foot rails with the flange turned towards the line and placed so that the ordinary road gauge measured the distance from the outside of the running rail head to the flange of the rail used as a mark. These pegs were put in at intervals of 25 ft., either on the inside or outside of the curve (the line was single), as the ground was more suitable, and each was set so that its top was at the correct level of the corresponding rail at the point and the correct superelevation was marked on it with a punch.

The custom of making the length of the transition proportional to the number of inches of superelevation was adopted in America, probably for the purpose of obtaining easy hauling for freight trains travelling at a moderate speed. The Canadian Pacific Railway, as also some of the leading railways in this country, adopts 60 ft. for every inch of superelevation on the circular curve, but the former seldom uses more than 5 ins. of superelevation. Also, transition curves are only used for curves of superelevation of 3 ins. and upwards. The tendency in America is to keep down the superelevation as much as possible. This is for the benefit of freight trains, which are considered of primary importance but travel at lower speeds, as the higher superelevation means increased resistance to hauling, caused by the wheels binding against the lower rail. The American Railway Engineering Association has laid down the rule that, in all cases of 2 ins. of superelevation and upwards transition curves should be inserted.

The principal point of danger of a sharp curve is at its entry. If trains could be brought on to curves without any sudden irregularity of motion before settling down to the uniform motion on the curve, very much sharper curves could be adopted for high-speed trains than are used to-day. Indeed the results of experience and experiments seem to show that trains traverse curves of 5 chains radius at 35 miles per hour with perfect ease and without showing any tendency to leave the metals.

There is no hard and fast rule adopted in this country with regard to the number of points set out on the ground to fix each transition curve, the tendency being to fix 8 or even 10 points on a long transition curve and 6 on the shorter ones. A point at every half chain is generally sufficient, but some prefer to fix points about 1 chain apart at the tangent end and half that amount at the circular curve end. This gives good results, as the curvature is so much sharper at that end, and wants its position defining at nearer points.

On the Canadian Pacific Railway it is usual to set out the centre point and two-quarter points only in addition to the extremities, except in the case of very long transition curves. If these are set out by deflection angles from the beginning of the spiral they are in the ratio of 1 : 4 : 9 : 16 as they vary as the square of the length. Also if set out from the end of the spiral the ratio of the four angles is 11 : 20 : 27 : 32. So when any one of these angles is found (generally that to the end point) the others are easily calculated.

Setting out Spiral Points.

A convenient formula for setting out spiral points by deflection angles is the following :—

The deflection angle in minutes to any chord point is given by $\frac{N^2L}{10}$ where N is the number of chords between the point where the instrument is set and the required point, and L is the length of the chord in feet. This formula will not apply if the instrument is set up at the intermediate chord points.

The operation of calculating the deflection angle θ for any point in a transition curve can be easily and rapidly done in the field without the need of any offset tables, as $\theta_n = \frac{L}{6R}$, which can be determined immediately the length of the transition is decided upon. Consequently the operation of setting out the transition spiral by deflection angles from the spiral tangent point is as simple as setting out the ordinary circular curve by deflection angles.

Example of a Transition.

A transition spiral is required to connect a straight with a 25-chain curve.

Taking the length of the transition $= \sqrt{R}$, then L = 5 chains,

$$\therefore \theta_n \text{ for the end of spiral} = \frac{L}{6R} = \frac{5}{150} = \frac{1}{30} \text{ radians}$$

$$\therefore \theta_n = \frac{57^\circ 3}{30} = 1^\circ\ 54'\ 36''.$$

If the points on the spiral are put in every half-chain, there will be ten deflection angles as follows :—

			°	′	″	°	′	″
θ_1	=	$(\frac{1}{10})^2$	(1	54	36) =	0	1	8·76
θ_2	=	$(\frac{1}{5})^2$	(1	54	36) =	0	4	35·00
θ_3	=	$(\frac{3}{10})^2$	(1	54	36) =	0	10	18·84
θ_4	=	$(\frac{2}{5})^2$	(1	54	36) =	0	18	20·16
θ_5	=	$(\frac{1}{2})^2$	(1	54	36) =	0	28	39·00
θ_6	=	$(\frac{3}{5})^2$	(1	54	36) =	0	41	15·36
θ_7	=	$(\frac{7}{10})^2$	(1	54	36) =	0	56	9·24
θ_8	=	$(\frac{4}{5})^2$	(1	54	36) =	1	13	20·64
θ_9	=	$(\frac{9}{10})^2$	(1	54	36) =	1	32	49·56
θ_{10}	=	$(1)^2$	(1	54	36) =	1	54	36·00

In setting out the same transition curve by deflection angles from its end, it is usual to calculate the deflection angles for the circular curve for the corresponding points, and deduct from each its deflection angle as given in the previous table.

The circular deflection angles are simply found as follows :—

$$\frac{1718'\cdot87}{R} = \frac{1718'\cdot87}{25} = 68'\cdot75,$$

which is the deflection angle in minutes for a whole chain ;

$\therefore$ 34′ 22″·5 is the angle for a half-chain.

The following table gives the deflection angles to be used with theodolite at point 10, in fixing points 9, 8, 7, etc.

(1) Deflection angle to point.	(2) Circular deflection angle.			(3) Corresponding values of θ_1, etc.			Difference between (2) and (3) giving deflection angles to spiral.		
	°	′	″	°	′	″	°	′	″
9	0	34	22·5	0	1	8·76	0	33	13·74
8	1	8	45	0	4	35·00	1	4	10·00
7	1	43	7·5	0	10	18·84	1	32	48·86
6	2	17	30	0	18	20·16	1	59	9·84
5	2	51	52·5	0	28	39·00	2	23	13·50
4	3	26	15	0	41	15·36	2	44	59·64
3	4	00	37·5	0	56	9·24	3	4	28·26
2	4	35	00	1	13	20·64	3	21	39·36
1	5	9	22·5	1	32	49·56	3	36	32·94
0	5	43	45	1	54	36·00	3	49	9·00

Vertical Curves for Joining Gradients.

For important railways, rates of change of 0·1 per 100 ft. on summits, and 0·05 in sags, should not be exceeded. On minor railways 0·2 per 100 ft. on summits and 0·1 in sags might be used.

The length of curve should be about 600 ft. at summits, and 800–1,200 ft. in sags.

(*American Railway Engineering Association.*)

Platforms.

The minimum clear width of any platform throughout its length to be 6 ft. At important stations the width to be not less than 12 ft., except for short distances at either end in any case of difficulty. In the case of island platforms, the minimum width for an adequate distance on each side of the centre of its length to be 12 ft. The descent at the ends of platforms to be by ramps and not by steps.

Columns for the support of roofs, and other fixed works, not to be less than 6 ft. clear from the edge of platforms. A general clear headway of not less than 8 ft. to be provided over platforms. The height of platforms above rail level may vary according to traffic and other conditions ; as a rule, it should be 3 ft., but in no case less than 2 ft. 9 ins. or more than 3 ft. at permanent stations, without special approval.

The edges of the platforms to overhang not less than 12 ins., and the recess so formed to be kept clear as far as possible of permanent obstruction. (*Ministry of Transport.*)

Stations.

It is desirable to avoid constructing a station on, or providing a siding in connection with, a line which is laid upon a gradient steeper than 1 in 260. (*Ministry of Transport.*)

SECTION XIII

PART II

LOCOMOTIVES AND ROLLING STOCK.

LOCOMOTIVES — STEAM MOTOR CARS — CARRIAGES AND WAGGONS—BRAKES.

(Revised by H. Holcroft, M.I.Loco.E., Editor of Journal, Institution of Locomotive Engineers.)

LOCOMOTIVES.

Some Recent Additions to British Locomotives.

For their heaviest passenger traffic, three of the four large British railways use the 4–6–0 type of locomotive with wheels about 6 ft. 9 ins. diameter. In the case of the L.M. & S.R. it has three high-pressure cylinders, while those on the G.W.R. and S.R. have four high-pressure cylinders. In the G.W.R. engine, the inside and outside cranks are set at 180° to one another, but the Southern engine has these cranks arranged at 135° to one another. By this means eight separate impulses are given to the wheels per revolution in place of four, as with cranks at 180°.

The L. & N.E.R. adopts the 4–6–2 or 'Pacific' type for the heaviest work. This engine has three high-pressure cylinders.

For lighter work the L.M. & S.R. continues to build 4–4–0 type engines. These are compound engines with one high-pressure cylinder inside the frames and two low-pressure outside. The L. & N.E.R. is building this type, but it has three high-pressure cylinders. The S.R. has recently added to the number of 4–4–0 type locomotives having two inside cylinders.

The 2–6–0 type with two outside cylinders and wheels about 5 ft. 6 ins. is being built by the L.M. & S.R. for mixed traffic purposes, and the G.W.R. and S.R. have also extensively adopted the type. The L. & N.E.R. has been constructing this class with three high-pressure cylinders.

For the heaviest mixed traffic work the G.W.R. uses a 2–8–0 type with 5 ft. 8 in. wheels, while the S.R. prefers a 4–6–0 type having 5 ft. 7 ins. diameter wheels.

The heaviest mineral traffic on the L. & N.E.R. is run by three-cylinder engines of the 2–8–2 or 2–8–0 types.

The 0–6–0 type goods engine is still being built by the L.M. & S.R. and L. & N.E.R., and a large number of these engines remain at work on the other lines. Many of the older engines of the type have been modernised by rebuilding and superheating.

Large passenger tanks of the 4–6–4 type have been built by the L.M. & S.R.; others for the S.R. have been of the 2–6–4 type.

The 'Garratt' articulated type of locomotive, which is extensively used on colonial railways, has been adopted to a limited extent on the L.M. & S.R. for hauling heavy mineral traffic. An engine of this type, but having two sets of three cylinders, has been put into use on the L. & N.E.R. for banking heavy mineral trains up a steep gradient.

No radical departures from normal locomotive design have been made on British railways as yet, although several experimental locomotives driven by turbines and fitted with condensers have been tried. Steady progress in efficiency is nevertheless being made by a process of gradual evolution.

Section of Railway.	Type.	Class	Service.	Cylinders. No.	Cylinders. Position.	Cylinders. Size.	Wheels. Bogie.	Wheels. Coupled.	Wheels. Trailing.	Wheel Base. Coupled.	Wheel Base. Total.
LONDON MIDLAND & SCOTTISH RAILWAY.							ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
L.& N.W.	4-6-0	—	Hvy. pass.	2	In.	19 ×26	3 9	6 3	—		
,,	4-6-0	Claughton	,,	4	In. & out.	16 ×26	3 3	6 9	—	15 3	29 0
,,	4-4-0	—	Pass.	2	In.	20½×26	3 3	6 9	—	10 0	25 1½
,,	0-8-0	—	Mineral	2	In.	20½×24	—	4 5½	—	17 3	17 3
Midland	4-4-0	—	Pass.	1	In. H.P.	19×26	3 6½	6 9½	—	9 6	24 3
				2	Out. L.P.	21×26					
,,	0-6-0	—	Goods	2	In.	20 ×26	—	5 3	—	16 6	16 6
,,	0-10-0	—	Banking	4	In. & out.	16½×28	—	4 7½	—	20 11	20 11
L. & Y.	4-6-0	—	Hvy. pass.	4	In. & out.	16½×26	3 0½	6 3	—	13 7	25 7
Caledonian	4-6-0	956	Hvy. pass.	3	In. & out.	18½×26	3 6	6 1	—	15 0	28 8
,,	4-6-0	903	,,	2	In.	21 ×26	3 6	6 6	—		
,,	4-4-0	139	Pass.	2	In.	20½×26	3 6	6 6	—		
,,	2-6-0	34	Goods	2	In.	19½×26	3 6	5 0	—		
L.M.S.	2-6-0	13,000	Mxd. traf.	2	Out.	21 ×26	3 6½	5 6	—	16 6	25 6
,,	4-6-0	Royal Scot	Hvy. pass.	3	In. & out.	18 ×26	3 3½	6 9	—	15 4	27 6
LONDON & NORTH EASTERN RAILWAY.											
G.N.	2-6-0	1,000	Mxd. traf.	3	In. & out.	18½×26	3 2	5 8	—	16 3	25 2
,,	2-6-0	—	,,	2	Out.	20 ×26	3 8	5 8	—	16 3	25 2
,,	2-8-0	477	Mineral	3	In. & out.	18½×26	3 2	4 8	—	18 6	27 2
,,	2-8-2	2,393	,,	3	In. & out.	20 ×26	3 2	5 2	3 8	18 6	36 2
,,	4-6-2	4,480	Hvy. pass.	3	In. & out.	20 ×26	3 2	6 8	3 8	14 6	35 9
G.C.	2-8-0	—	Mineral	2	Out.	21 ×26	3 6	4 8	—	17 1	25 5
,,	4-6-0	—	Mxd. traf.	2	Out.	21 ×26	3 6	5 8	—	15 3	27 6
,,	4-4-0	11 E	Pass.	2	In.	20 ×26	3 6	6 9	—	10 0	25 3
,,	4-6-0	—	Hvy. pass.	4	In. & out.	16 ×26	3 6	6 9	—	15 6	28 1
,,	4-6-0	—	Mxd. traf.	4	In. & out.	16 ×26	3 6	5 8	—		
G.E.	4-6-0	1,500	Hvy. pass.	2	In.	20 ×28	3 3	6 6	—	14 0	28 6
,,	4-4-0	1,850	Pass.	2	In.	19 ×26	3 9	7 0	—	9 0	23 6
,,	0-6-0	1,240	Goods	2	In.	20 ×28	—	4 11	—	17 8	17 8
N.E.	4-4-2		Hvy. pass.	3	In. & out.	16½×26	3 7¼	6 10	4 0	15 7	29 6
,,	4-6-0	—	,,	2	Out.	20 ×26	3 7¼	6 1½	—	14 0	26 0
,,	4-6-0	S3	Mxd. traf.	3	In. & out.	18½×26		5 8	—		
,,	0-8-0	T3	Mineral	3	In. & out.	18½×26	—	4 7½	—	18 6	18 6
,,	4-6-2	—	Hvy. pass.	3	In. & out.	19 ×26	3 1½	6 8	3 9½	15 0	37 2
N.B.	4-4-2	—	Hvy. pass.	2	Out.	21 ×28	3 6	6 9	4 3	7 3	27 9
,,	0-6-0	—	Goods	2	In.	19½×26	—	5 0	—	16 11	16
,,	4-4-0	—	Pass.	2	In.	20 ×26	3 6	6 6	—		

Grate Area.	Heating Surface.			Weight of Engine.		Tender.		Engine and Tender.		Tractive Effort at 85 per cent. of Boiler Pressure.
	Tubes.	Firebox.	Superheater.	On Coupled Wheels.	Total.	Coal.	Water.	Total Weight.	Total Wheel Base.	
sq. ft.	sq. ft.	sq. ft.	sq. ft.	T. C.	T. C.	Tons.	Galls.	T. C.	′ ″	lbs.
25·0	1,908	133	—	46 15	65 15	6	3,000	102 15		19,680
30·5	1,161 486	171	413	59 0	77 15	7	3,000	117 0		24,440
22·4	1,005 380	162	302	38 5	59 17	6	3,000	99 2	47 2¾	20,070
23·6	1,161 465	147	378	60 5	60 5	6	3,000	99 10	41 1½	28,040
28·4	1,170	147	291	39 4	61 14	5½	3,500	104 8	47 1½	22,649 (Simple)
28·4				38 10	58 5	7	3,500	104 3		20,330
31·5	1,560	158	445	73 13	73 13	4	2,050	106 5	46 3¾	43,312
27·0	1,717	176	430	59 6	79 1	6	3,000	119 1	50 3½	29,470
28·0	1,700 500	170	270	60 0	81 0	5½	4,500	129 0	54 0½	28,000
26·0	1,666	148	516		73 0	5	5,000	130 0		21,240
21·0	1,220	145	330		59 0	5	4,600	115 0		19,760
20·6	1,071	119	267		54 0	4½	3,000	92 0		23,800
27·5	1,361	160	307	55 3	66 0	5	3,500	108 4	48 11½	25,800
31·2	1,892	189	445	61 12	84 18	5½	3,500	127 12	52 9¼	33,150
28·0	1,900	182	407	60 0	71 14	6½	3,500	114 16	48 0½	30,000
24·0	1,523	144	403	53 8	63 14	6½	3,500	106 16		22,100
27·5	1,340 528	163	430	67 7	75 16	6½	3,500	118 18	52 2¼	36,468
41·2	1,880 835	215	525	71 10	100 0	7	4,700	151 8	59 8	38,500 47,000 with Booster
41·2	1,399 1,123	215	706	66 0	96 5	8	5,000	152 11	60 10⅝	36,465
26·0	1,050 591	174	308	67 18	75 4	6	4,000	123 10	51 2½	30,813
26·0	1,050 591	174	308	53 18	72 18	6	4,000	121 4	50 8½	5,376
26·0	1,502	157		29 12	61 0		4,000	109 6	48 8½	19,385
26·0	1,881	163	343	57 3	77 18	7	4,000			25,140
26·0	1,881	163	343			7	4,000			29,950
26·5	1,123 366	143	286	43 8	62 19	4	3,700	102 4	48 3	21,970
21·6	1,561	118	—	34 9	51 14					17 100
21·6	874 283	118	226	47 7	47 7					25,820
27·0	1,798	180		39 17	77 2			122 8		17,852
23·0	1,173 504	144	545		68 17	5	3,940	109 19		19,310
27·0		166			77 14			123 16		30,032
27·0				71 12	71 12	5½	4,125	115 14	44 3¾	41,070
41·0	1,517 694	211	696	60 0	97 0	5½	4,125	143 2	61 11¾	29,918
28·5	1,136 483	185	385	40 0	76 14	7	4,240	122 2	53 2	23,320
19·8	927 339	142	324	54 14	54 14	7	3,500	93 13		23,100
21·3	871 295	140				7	4,235	103 6		18,700

Section of Railway.	Type.	Class.	Service.	Cylinders. No.	Cylinders. Position.	Cylinders. Size.	Wheels. Bogie.	Wheels. Coupled.	Wheels. Trailing.	Wheel Base. Coupled.	Wheel Base. Total.
GREAT WESTERN RAILWAY.											
G.W.	4-6-0	King George V	Hvy. pass.	4	In. & out.	16½ × 28	3 0	6 6	—	16 3	29 5
,,	4-6-0	Castle	,,	4	In. & out.	16 × 26	3 2	6 8½	—	14 9	27 3
,,	4-6-0	Star	,,	4	Do.	15 × 26	3 2	6 8½	—	14 9	27 3
,,	4-6-0	Saint	,,	2	Out.	18½ × 30	3 2	6 8½	—	14 9	27 1
,,	2-8-0	—	Hvy. goods	2	Out.	18 × 30	3 2	4 7½	—	16 10	25 7
,,	2-8-0	4,700	Mxd. traf.	2	Out.	19 × 30	3 2	5 8	—	20 0	29 3
,,	4-4-0	County	Pass.	2	Out.	18 × 30	3 2	6 8½	—	8 6	24 0
,,	2-6-0	4,331	Mxd. traf.	2	Out.	18½ × 30	3 2	5 8	—	14 9	23 6
SOUTHERN RAILWAY.											
Western	4-6-0	"Lord Nelson"	Hvy. pass.	4	In. & out.	16½ × 26	3 1	6 7	—	15 0	29 6
,,	4-6-0	"King Arthur"	,,	2	Out.	20½ × 26	3 7	6 7	—	14 6	27 6
,,	4-6-0	S^{15}	Mxd. traf.	2	Out.	20½ × 28	3 7	5 7	—	13 9	26 7
,,	4-6-0	T^{14}	Pass.	4	In. & out.	15 × 26	3 7	6 7	—	14 4	27 8
,,	0-6-0	700	Goods	2	In.	19 × 26	—	5 1	—	16 6	16 6
Eastern	2-6-0	N	Mxd. traf.	2	Out.	19 × 28	3 1	5 6	—	15 6	24 4
,,	4-4-0	E_1	Pass.	2	In.	19 × 26	3 6	6 6	—	9 6	23 6
,,	4-4-0	L	,,	2	In.	19½ × 26	3 7	6 8	—	10 0	24 3
Central	4-4-2	H_2	,,	2	Out.	21 × 26	3 6	6 7½	3 6	6 10	26 4
,,	2-6-0	K	Mxd. traf.	2	Out.	21 × 26	3 6	5 6	—	15 6	23 9
,,	4-4-0	B¹/x	Pass.	2	In.	20 × 26	—	6 9	—	10 0	24 6

Section of Railway.	Type.	Class.	Service.	Cylinders. No.	Cylinders. Position.	Cylinders. Size.	Wheels. Bogie.	Wheels. Coupled.	Wheels. Trailing.	Wheel Base. Coupled.	Wheel Base. Total.
LONDON MIDLAND & SCOTTISH RAILWAY.											
L.&N.W.	4-6-2	—	Pass.	2	In.	20 × 26	3 3	5 8½	3 3	14 0	33 9
N. Staff.	0-6-4	—	Pass.	2	In.	20 × 26	—	5 0	3 4	16 0	27 9
Furness	4-6-4	—	Pass.	2	In.	19½ × 26	3 2	5 8	3 2	13 3	40 9
L.M.S.	2-6-0	Garratt	Mineral	4	Out.	18½ × 26	3 3½	5 3	—	16 6	79 0
	0-6-2										
LONDON & NORTH EASTERN RAILWAY.											
G.N.	2-8-0	2,395 (Garratt)	Banking	6	In. & out	18½ × 26	2 8	4 8	2 8	17 10½	79 1
	0-8-2										
,,	0-6-2	N2	Suburban	2	In.	19 × 26	—	5 8	3 8	16 3	23 9
N.E.	4-6-2	—	Goods	3	In. & out.	16½ × 26	3 1½	4 7½	3 9½	14 6	34 3

OMOTIVES—(*continued*).

Grate Area.	Heating Surface.			Weight of Engine.		Tender.		Engine and Tender.		Tractive Effort at 85 per cent. of Boiler Pressure.
	Tubes.	Fire-box.	Super-heater.	On Coupled Wheels.	Total.	Coal.	Water.	Total Weight.	Total Wheel Base.	
n.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	T. C.	T. C.	Tons.	Galls.	T. C.	′ ″	lbs.
)	34·3	(Total) 2,514			67 10	89 0	6	4,000	135 14	57 5½	40,300
5	30·3	1,885	164	263	58 17	79 17	6	4,000	126 11	54 6½	31,625
5	27·0	1,686	155	286	55 8	75 12		3,500	115 12		27,800
5	27·0	1,686	155	286	54 16	72 0		3,500	112 0		24,395
5	27·0	1,686	155	286	61 18	68 6		3,500	108 6		33,490
5	30·3	2,062	169	323	73 8	82 0		3,500	122 0	56 9¾	28,764
)	20·5	1,350	129	216	37 12	58 16		3,500	98 16		20,527
)	20·5	1,350	129	216	52 12	62 0		3,500	102 0		25,670
)	33·0	1,282 513	194	376	61 19	83 10	5	5,000	140 4	60 9	33,490
)	30·0	1,252 464	162	337	60 0	80 19	5	5,000	138 10	58 0	25,320
)	28·0	1,252 464	162	337	60 0	80 14	5	5,000	137 2	57 1½	29,860
5	31·5	873 407	158	269	53 3	75 15	5	5,800	136 3	55 7	22,000
)	20·3	523 266	117	167	46 14	46 14	—	3,500	83 8	39 1	23,500
)	25·0	1,391	135	203	50 18	59 8	5	3,500	98 13	47 9½	25,942
)	24·0	827 322	127	228	33 10	52 10	4½	3,450	91 10	45 2⅜	18,411
)	22·5	914 338	155	235	38 0	58 10	5	3,500	99 0	46 2¾	18,907
)	30·9	1,348 547	136	460	37 10	68 10	4	3,500	107 10	50 3	20,931
)	24·8	1,155	139	279	55 4	63 10	4	3,940	105 10	47 11	25,075
)	24·8	1,155	139	279	37 18	58 1	4	3,600	97 6	46 11	19,695

OMOTIVES.

Pressure.	Grate Area.	Heating Surface.			Weight of Engine.		Tanks.		Engine and Tender. Total Weight.	Tractive Effort at 85 per cent. of Boiler Pressure.
		Tubes.	Fire-box.	Super-heater.	On Coupled Wheels.	Total.	Coal.	Water.		
s. in.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	T. C.	T. C.	Tons.	Galls.	T. C.	lbs.
'5	23·9	638 309	138	248	44 0	77 0	3	1,700		22,580
	21·0	887 258	129		52 0	72 0	3½	2,200		
'0	26·0	1,850	153	—	54 18	93 5	4	2,200		21,006
)0	44·5	1,954	183	500	116 10	148 15	7	4,500	116 10	45,620
)0	56·4	2,757	237		143 18	178 0	7	5,000		72,940
'0	19·0	880	118	207	52 15	70 6	4	2,000		19,950
)0	23·0	1,508	140	—		87 8	5	2,300		29,420

BRITISH TA

Section of Railway.	Type.	Class.	Service.	Cylinders. No.	Cylinders. Position.	Cylinders. Size.	Wheels. Bogie.	Wheels. Coupled.	Wheels. Trailing.	Wheel Base Coupled.	Wheel Base Total.
						" "	' "	' "	' "	' "	'
GREAT WESTERN RAILWAY.											
G.W.	2-8-0	—	Mineral	2	Out.	18½×30	3 2	4 7½	—		
,,	2-6-2	—	Goods	2	Out.	18½×30	3 2	5 8	3 8	14 9	31
,,	4-4-2	—	Pass.	2	Out.	18 ×30	3 2	6 8½	3 8	8 6	32
SOUTHERN RAILWAY.											
Western	4-6-2	H[16]	Goods	2	Out.	21 ×28	3 7	5 7	3 7	15 0	36
,,	4-8-0	G[16]	Shunting	2	Out.	22 ×28	3 7	4 7½	—	18 0	32
Eastern	2-6-4	K	Hvy. Pass.	2	Out.	19 ×28	3 1	6 0	3 1	15 0	34
,,	0-4-4	H	Suburban	2	In.	18 ×26	—	5 6	3 7	7 6	21
,,	0-6-0	S	Shunting	2	In.	18½×26	—	5 2	—	16 6	16
,,	0-6-4	J	Suburban	2	In.	19½×26	—	5 6	3 7	16 6	27
Central	4-6-2	J	Pass.	2	Out.	21 ×26	3 6	6 7½	4 0	14 6	35
,,	4-6-4	L	Hvy. Pass.	2	Out.	22 ×28	3 6	6 9	3 6	14 9	40

AMERICAN TEN

Railroad.	Type.	Class.	Service.	Cylinders. No.	Cylinders. Position.	Cylinders. Size.	Wheels. Bogie.	Wheels. Coupled.	Wheels. Trailing.	Wheel Bas Coupled.	Wheel Bas Total.
						" "	' "	' "	' "	' "	'
Pennsylvania	2-10-0	115	Freight	2	Out.	30½×32	2 9	5 2	—		
,,	2-8-2	—	,,	2	Out.	27 ×30	2 9	5 2	2 9		
,,	4-6-2	—	Pass.	2	Out.	27 ×28	3 0	6 8	3 0		
Lehigh Valley	4-8-2	5,000	Freight	3	In. & out.	25 ×28		5 9		18 0	41
New York Central	4-6-4	5,200	Pass.	2	Out.	25 ×28	3 0	6[*]7	3 0 & 4 3	14 0	40
Southn. Pacific	4-6-2	—	Pass.	2	Out.	25 ×30	3 0	6 1½	4 3½	13 0	35
,,	2-10-2	—	Freight	2	Out.	29½×32 Comp'd.	2 9	5 3½	4 3½	22 10	42
Virginia	2-10-0 / 0-10-2	800	Freight	4	Out.	30 ×32 / 48 ×32		4 8	—		
Northern Pacific	4-8-4	2,600	Pass.	2	Out.	28 ×30	3 0	6 3	3 0 & 3 9¾	20 3	47
Union Pacific	4-12-2	9,000	Freight	3	Out. / In.	27 × 32 / 27 × 31	2 6	5 7	3 9	30 8	52
Delaware & Hudson	2 8 0	John B. Jervis	Freight	2	Out.	Comp'd 22½×30 / 38½×30	3 0	4 9	—	18 0	29

[*] Maximum cut-off limited to 50 per cen

COMOTIVES—(*continued*).

Working Pressure.	Grate Area.	Heating Surface.			Weight of Engine.		Tanks.		Tractive Effort at 85 per cent. of Boiler Pressure.
		Tubes.	Fire-box.	Super-heater.	On Coupled Wheels.	Total.	Coal.	Water.	
In.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	T. C.	T. C.	Tons.	Galls.	lbs.
0	20·5	1,350	129	216	70 0	78 0		1,800	31,450
0	20·5	1,350	129	216	56 4	78 16		2,000	25,670
5	20·3	1,009	122		37 0	75 0		2,000	20,000
0	27·0	910 357	139	231	59 0	96 8	3½	2,000	28,200
0	27·0	910 357	139	231	72 18	95 2	3½	2,000	34,000
0	25·0	1,391	135	203	52 15	82 12	2½	2,000	23,842
0	16·6	1,002	102	—	33 12	54 8	2½	1,200	17,357
0	16·6	1,089	110	—	53 10	53 10	2	1,200	19,519
0	17·6	593 294	112	234	51 18	70 14	3½	2,000	20,373
0	25·0	997 464	125	357	54 10	89 0	3	2,000	20,931
0	26·6	1,535	152	383	56 10	98 5	3½	2,700	24,225

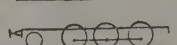
COMOTIVES.

Grate Area.	Heating Surface.			Weight of Engine.		Tender.		Engine and Tender.		Tractive Effort at 85 per cent. of Boiler Pressure.
	Tubes.	Fire-box.	Super-heater.	On Coupled Wheels.	Total.	Coal.	Water.	Total Weight.	Total Wheel Base.	
sq. ft.	sq. ft.	sq. ft.	sq. ft.	T. C.	T. C.	Tons.	U.S.A. Galls.	T. C.		lbs.
70·0	2,731 1,313	290	1,418	152 14	166 0	17½	9,000	247 4		90,000*
70·0				117 0	151 10					57,850
70·0				89 7	140 0					41,845
84·3	2,832 1,505	392	1,249	110 0	164 14			254 8		64,700
81·5	4,203	288	1,965	81 5	153 2	18	10,000	246 9	76 1½	42,400
						Oil. Galls.				
70·4	3,069	282	836	80 8	133 0	4,000	12,000	230 6	75 9½	43,660
82·5	4,722	399	1,208	132 14	172 6	4,000	12,000	271 8	82 7½	75,150
108·2	5,592 2,511	532	2,120	275 10	305 8	Tons 12	13,000	401 2		176,600 147,200
115	4,115	485	1,992	116 1	190 4	24	15,000	333 2	90 0	75,500
108·2	4,459 803	529	2,560	158 10	221 0	21	15,000	350 0		96,650
82	788 1,116	1217	700	131 14	150 5	20	16,000	285 5	74 11½	85,000 (Simple)

E. taken at 75 per cent. of boiler pressure.

Locomotive Types.

The classification of locomotives is by wheel arrangement. Abbreviations are used, the Anglo-American system denoting in their order leading carrying wheels, coupled wheels, and trailing carrying wheels by number of wheels to each group. Where there are no carrying wheels at either end a cipher is added. The letter T denotes a tank engine. Articulated engines are denoted by the wheel arrangement of their separate parts. The Continental system merely states number of axles coupled and total axles of engine, and gives the proportion of adhesive weight without specifying the actual arrangement of wheels. In addition to identity by wheel grouping, the various types receive code names in America. Example:

Diagram.	Code Name.	Anglo-American Notation.	Continental Notation.
	Atlantic	4–4–2	2–5
	Mogul	2–6–0	3–4

In France it is usual to classify a locomotive by groups of axles in their order, instead of by wheels: thus a 4–4–2 engine is known there as type 2–2–1; and a 2–6–0 engine is expressed as type 1–3–0.

Another system, coming into use in Germany and Switzerland, is similar to the French, but groups of coupled axles are represented by letters—A for one driving axle, B for two, C for three, etc.: so that a 4–4–2 engine becomes type 2–B–1. A 2–6–0 engine is denoted by 1–C only, a cipher not being necessary to indicate absence of carrying wheels with this system.

Types of Locomotives most generally used on British Railways.

Tender Engines.

Type.	Principal Use.	Type.	Principal Use.
0–6–0	Ordinary goods traffic	0–4–2	Branch passenger traffic
0–8–0	Mineral traffic	4–4–0	Fast passenger trains
2–8–0	Heavy goods traffic	4–4–2	Main line express
2–6–0	Mixed traffic	4–6–0	Heavy express
2–4–0	Branch passenger traffic	4–6–2	Exceptionally heavy express

Tank Engines.

Type.	Principal Use.	Type.	Principal Use.
0–4–0	Private yard shunting	0–4–2	Light passenger trains
0–6–0	Ordinary shunting	2–4–0	
		4–4–0	
0–8–0	Heavy shunting, banking and mineral trains	0–4–4	Suburban passenger trains
0–8–2		0–6–4	
0–8–4		2–4–2	
2–8–4			
4–8–0			
2–8–0			
2–6–2	Main line goods trains	2–6–4	Main line passenger trains
4–6–0		4–4–2	
0–6–2		4–4–4	
		4–6–2	
		4–6–4	

The particular uses of the various types of tank engines are not so well defined as with tender engines. Several of the engines specified for goods traffic are often used on passenger trains, and *vice-versa*. Generally speaking, the total adhesion type (i.e. engines without carrying wheels) are mostly used for shunting and local work. Carrying wheels are added as the water and coal capacity are enlarged to permit of greater radius of action. The tank engines with two or more pairs of carrying wheels are capable of travelling considerable distances without replenishing fuel and water.

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AXLES
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No firm except Beardmore have manufactured a cast steel chain to pass Admiralty tests. This chain was a twelve-fathom 5" stud link joint, with shackle. 304 ton test load stretched it ½", 400 tons stretched it 6¾" but without breaking. There was no testing machine available which could break it.

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General Design of Locomotives.

The principal limitations governing locomotive design are:—

(1) *Loading gauge*, giving extreme dimensions as to heights and widths.
(2) *Rail gauge*, affecting stability, etc.
(3) *The track*, which limits the maximum axle load.
(4) *Bridges*, the strength of which restricts the weight per ft. run over total wheel base.
(5) *Curves*, which limit the length of engine and determine rigid wheel base.

Other factors to be taken into consideration are:—

(1) *Loads*, as to weight and type of rolling stock.
(2) *Gradients*, both ruling and maximum.
(3) *Resistance of curves.*
(4) *Speed.*
(5) *Prevailing atmospheric conditions.*

These are inter-related, load becoming a maximum for both directions of travel when there are no gradients or curves and the speed is low. An increase in speed or the presence of gradients, curves, and side winds reduces loads.

Some further points to be looked into when designing new engines are:—

(1) *Length and strength of turn-tables* and clearances round them.
(2) *Engine sheds*, as to clearances, length of pits, etc.
(3) *Coal stages*, height of platform, method of coaling, etc.
(4) *Position of water columns* at stations and in yards in relation to signals and points.
(5) *Distance between available coal and water supplies.*
(6) *Capacity of workshops*, in regard to load on cranes, length of pits and traversers, necessity for special tools, etc.

The bulk of the work on British railways is done by tender engines of the 0–6–0 type for goods and 4–4–0 type for passenger trains. Many of these engines are of fairly recent construction. Some of the older engines have been brought up to date by being rebuilt with larger boilers fitted with superheaters and with new cylinders provided with piston valves. The goods engines usually have cylinders 19 ins. × 26 ins. and wheels 5 ft. 0 ins. diameter; the passenger engines 20 ins. × 26 ins. cylinders and 6 ft. 6 ins. wheels. Boiler pressure is about 180 lbs. per sq. in.,

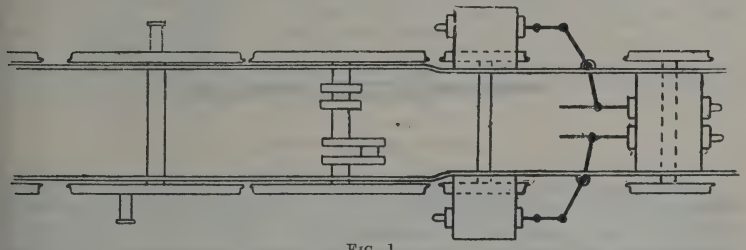


FIG. 1.

but with high degree of superheat it is usually some 10 lbs. less, while the diameter of cylinders is increased a little to compensate. The single-wheel engines once so numerous are now almost extinct on British railways, as are also compound engines, except on the Midland section of the L.M. & S.R.

For heavy passenger work the 4–4–2 and 4–6–0 types are resorted to. The former has no more adhesion than the 4–4–0 type, but increased boiler power permits heavy trains to be hauled at high speeds. The 4–6–0 type can also take heavy trains at high speed or, alternatively, exceptionally heavy trains at moderate speed on account of its greater adhesive weight. The 4–6–2 type hauls exceptionally heavy trains at high speeds. For mineral traffic and long goods trains an eight-wheel coupled engine is used. The present tendency is to prefer the 2–8–0 to the 0–8–0 type, many of the latter having been converted to the former. The 2–6–0 type with wheels about 5 ft. 6 ins. is being used to an increased extent as a mixed traffic engine, and a similar engine of the 2–8–0 type has been introduced for heavier trains of this description. They are especially suitable for fast goods, excursion trains, etc. In the large passenger and goods engines outside cylinders predominate. The advantages claimed for the outside position are shorter wheel base, long connecting rods, no crank axle, direct drive through rods on all wheels, horizontal cylinders. The distance between centres of cylinders is about 6 ft. 8 ins. and cannot be reduced very appreciably on account of the necessity for finding sufficient bearing surface for coupling and connecting rods. Thus, the diameter of cylinders is limited by the remaining space

within the load gauge, which varies on the different railways. Since the load gauge is at its narrowest near rail level, advantage can sometimes be gained by inclining outside cylinders so that they are brought up into a wider part of the gauge.

The demand for larger cylinder capacity can be met by increased diameter or stroke of cylinders, or both. Another way is to multiply the number of cylinders, hence three- and four-cylinder high-pressure engines. Multi-cylinders are also being adopted for mechanical reasons, as they give better balancing and turning movement, less disturbance in running, subdivision of driving forces, increased bearing areas and other advantages. Multi-cylinder engines are necessarily more costly and complicated than two-cylinder. It is therefore desirable to reduce their working parts to a minimum. This can be done by providing two sets of valve gear only and operating the additional valve or valves through rocking levers attached to the valve gears. The arrangement adopted on the Great Western Railway four-cylinder engines is shown in fig. 1. Two sets of Walschaert gear drive the inside valves directly and the outside valves by means of rocking levers. The levers are not straight, the outer arms being set backwards, resulting in an improvement of the valve events. The London Midland and Scottish engines have Walschaert valve gear outside the frames and work the inside valves through straight rocking levers. All cylinders drive on one axle.

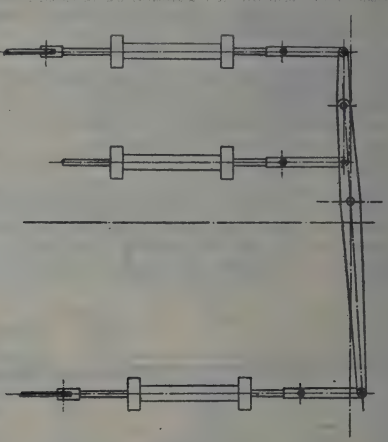


FIG. 2.

Three-cylinder engines can be arranged in a similar manner. Fig. 2 shows in plan the arrangement as used on the Great Northern section of the L. & N.E.R. for three-cylinder engines of the 2–6–0, 4–6–2, and 2–8–0 types. A long lever at the front of the engine is pivoted to a cross stretcher on the frame, the ratio of the arms being as 2 : 1. The longer end is attached to the tail spindle of the right-hand valve. To the shorter end another lever with equal arms is pivoted at its centre. The outer end of this is attached to the spindle of the left-hand valve, and the inner end to the spindle of the inside valve, all valves being in line and set at the same inclination; but in order that the crosshead may clear the leading coupled axle, the inside cylinder is inclined 1 in 8. The valves of the outside cylinders are, of course, directly operated by two sets of Walschaert valve gear. A variation of the same principle is in use in Germany and Spain, in which one rocking shaft having equal arms is mounted on the shorter arm of another rocking shaft having arms in ratio 2 : 1. Modifications of the arrangement are in use on the L.M. & S.R. (Caledonian section) and Southern Railway (S.E. & C. section).

Four-cylinder high-pressure locomotives are in use on the Continent. In some of these there is a single piston valve for each pair of cylinders, one of which has crossed ports. In others a double-headed piston valve is used. British practice favours separate valves for each cylinder.

Four cylinders are more used in fast passenger engines. Since the forces and masses in each pair of motions are opposed, the balancing is good and the disturbances to smooth running reduced. The mechanical efficiency is high, but otherwise there is little advantage over two cylinders. Owing to the more regular turning movement, three cylinders are applied to engines in which the most is to be made of the available adhesion, such as the 'Atlantic' and 'Pacific' types and heavy shunting tanks. In the latter instance there is the further advantage of six exhaust beats per revolution in place of four, with less disturbance to the fire when working slowly.

Tank engines are used for fast passenger trains on the Tilbury section of the L.M. & S.R., Metropolitan Railway (Aylesbury extension), and to some extent on the Southern Railway.

Boiler pressures tend to increase; 200 lbs. per sq. in. is now common, and recent engines carry 250 lbs. pressure.

'Poppet' or double-beat lift valves, which have been used to a limited extent on the Continent for some years, are undergoing trials under British railway conditions. On the L. & N.E.R. several passenger and goods engines have had the cylinders with slide valves removed and new cylinders with 'Lentz' valves substituted, the existing link motion valve gear being retained to operate the rocking cam shafts. Six of a new batch of engines are being fitted with Walschaert valve gear, and two with the valves operated by rotary sliding cams driven by gearing connected to the driving axle. A somewhat similar arrangement to the latter, the 'Beardmore-Caprotti' valve gear, is in use on the L.M. & S.R., one engine being fitted for trial. (For description see *Engineering*, September 2, 1927, p. 292.)

Some recent American locomotives are of enormous size. For the heaviest freight traffic Mallet articulated compounds are in use on the Virginian R.R. weighing, with tender, nearly 400 tons, a pair of cylinders being added to the tender to make use of its adhesive weight, the total tractive effort being about 80 tons. The latest engines on the New York Central and Northern Pacific have a trailing bogie below the firebox, being of the 4–6–4 and 4–8–4 types. On the Southern R.R. engines of the 'Mikado' or 2–8–2 type are provided with steam tenders made from obsolete engines of the 2–8–0 type, in which the boiler is removed and a water tank substituted. For passenger traffic in mountain sections the Canadian Pacific Railway has engines of the 4–8–2 type with 5 ft. 3 in. wheels, cylinders 23½ ins. diameter by 32 ins. stroke, heating surface 5,123 sq. ft. and grate area 60 sq. ft. The axle loads on the Pennsylvania R.R. reach 30 tons. In order to reduce dynamic loading of wheels the reciprocating parts are of alloy steel. With small wheels the revolving masses must likewise be reduced, since it is not always possible to make the balance weights in the wheel large enough. Outside valve gears such as the Walschaert, Baker-Pilliod, or Southern are general, and piston valves are of large diameter with inside admission. The two-cylinder engine with superheater has superseded all compounds except the Mallet type. Three-cylinder engines are now being extensively used. The valve gear for the middle cylinder is similar to that shown by fig. 2. Tank engines are not common, even switching engines having tenders.

A recent development is the 'booster.' This is a small steam engine geared to the carrying wheels, and which can be thrown in or out of action as required. It is used to assist the main engine when starting a heavy train from rest or in climbing grades. The device has also been applied to the tender wheels.

New locomotives for passenger service are mainly of the 4–6–2 and 4–8–2 types. For freight traffic the 2–8–2 type is mostly favoured, but the 2–10–2, 2–10–0 and 2–8–0 types are also being built to some extent. Three cylinder engines of the 4–10–2 and 4–12–2 types have been introduced for mixed traffic purposes on heavily graded roads.

An experimental engine, the 'Horatio Allen,' has been put into service on the Delaware & Hudson R.R. This is a cross compound of the 2–8–0 type, and is notable for having a water-tube firebox. The boiler pressure is no less than 350 lbs. per sq. in. It has been followed by another engine, the 'John B. Jervis,' having a pressure of 400 lbs.

TRAIN RESISTANCE.

Resistance of Air to Train.

(1) The area of resistance presented by the first carriage is its front superficies; that of the following carriages, about 10 square feet, but depending upon the distance between them.

Q = resistance of ar, in lbs. A = surface of resistance, in sq. ft. = about 70 ft. + $10(n - 1)$ for railway waggons, where n = number of waggons in train. (54 ft. according to M. Vuillemin, &c., 50 ft. Unwin.) v = velocity, in feet per second. $e = 1{\cdot}43$ for a thin surface = $1{\cdot}17$ for a cube, = $1{\cdot}07$ for a train of 5 waggons, = $1{\cdot}04$ for a train of 25 waggons.

$$Q = {\cdot}0011896 e A v^2 \text{ (\textit{Pambour}).}$$

(2) If P = pressure on the front ends in pounds per square foot; V = velocity in miles per hour:—

$$P = {\cdot}00265\ V^2.$$

Assuming the superficial area of the front end to be about 75 sq. ft., the following table shows the total pressure and the power required to overcome that pressure at various speeds:—

Speed in miles per hour.	Total pressure, lbs.	H.P.
20	79·5	4·24
40	318·0	33·92
60	715·5	115·28
80	1272·0	271·36
100	1987·5	530·0

It will be seen that at speeds below 40 miles an hour the effect of head end resistance is practically negligible; but at speeds of 60 miles an hour or more the power required to overcome head end resistance is by far the most important element in train resistance. As the number of cars in a train is increased, the relative effect of head end resistance is decreased.

An engineer of the firm which furnishes electric locomotives for the Simplon Tunnel says that at a speed of 50 miles an hour in the tunnel the air-resistance absorbs 400 horse-power, or 40 per cent. of the capacity of the locomotive, against 95 horse-power in the open air.

Resistance to Traction on a Level Railroad.

The most complete record of experiments on Train Resistance is probably that of Mr. J. A. F. Aspinall, given in a paper by him read before the Institution of Civil Engineers, November 26, 1901, and published in vol. 147, May 1902, of the Proceedings of the Institution. The conditions vary so much with the character of the train and other factors that no definite formulæ covering all cases and separating the various resistances making up the total can be given. The following are the principal formulæ given in the Proceedings referred to, abstracted from a list of 55, dating from that of Clark in 1855.

FORMULÆ FOR TRAIN RESISTANCE.

R = tractive resistance in lbs. per ton (2,240 lbs.).

V = velocity in miles per hour.

W = weight of engine and tender in tons (2,240 lbs.).

w = ,, carriages ,, ,,

A = area of front of train in square feet.

L = length of train in feet.

No.	Authority.	Value of R.	Conditions.	Reference.
1	Clark	$8+\frac{V^2}{171}$	Whole train	D. K. Clark, 'Railway Machinery,' 1855, p. 297.
2	,,	$6+\frac{V^2}{240}$	Carriages only	
3	,,	$12+\frac{V^2}{114}$	Whole train Narrow gauge	Z. Colburn, 'Locomotive Engineering,' 1871, p. 291.
4	,,	$\left\{6+\frac{V^2}{240}+\left\{\left(\frac{2+V^2}{600}\right)\times\left(\frac{W+w}{W}\right)\right\}\right\}$	Engine and train	
9	Wellington	$4{\cdot}48+\frac{V^2}{116}$	20 loaded box cars	Trans. Am. Soc. C.E., vol. viii. p. 52.
10	,,	$6{\cdot}72+\frac{V^2}{94{\cdot}7}$	40 empty box cars	
11	,,	$\frac{V^2}{100{\cdot}8}$	20 loaded flat cars	
12	,,	$\frac{V^2}{72{\cdot}3}$	40 empty flat cars	
13	,,	$4{\cdot}48+\frac{V^2}{162}$	Engine and train	A. M. Wellington, 'Economic Theory of the Location of Railways,' 1887, p. 497.
14	,,	$4{\cdot}48+0{\cdot}0056\,V^2+0{\cdot}46\frac{V^2}{w}$	Carriages only	*Street Railway Journal*, 1899, p. 144.
22	Baldwin Co.	$3{\cdot}36+\frac{0{\cdot}56\,V}{3}$	—	*Engineering*, vol. lxviii. p. 1850.
23	,,	$1{\cdot}68+0{\cdot}224V$	47 to 77 miles per hour	*Railway Gazette*, 1897, p. 198.

Up to 30 miles per hour

FORMULÆ FOR TRAIN RESISTANCE—*continued*.

No.	Authority.	Value of R.	Conditions.	Reference.
24	Blood	$4{\cdot}48+0{\cdot}168V+0{\cdot}336\frac{V^{1{\cdot}8}}{W+w}$	—	*Street Railway Journal*, 1899, p. 145.
32	Clayton	$6{\cdot}5+0{\cdot}16\ V$	Oil-lubrication	—
33	,,	$6{\cdot}5+0{\cdot}005V^2$	Grease-lubrication	
35	Deeley	$3+\frac{V^2}{290}$	—	*The Engineer*, vol. lxxxv. p. 276.
36	Wolff	$3+\frac{V^2}{250}$	—	Students' Paper, Inst. C.E., 1898.
37	,,	$3\left(\frac{V+12}{V+3}\right)+\frac{V^2}{300}$	—	*Mechanical Engineer*, 1899, p. 256.
38	Eastern Railway of France	$0{\cdot}305V+5{\cdot}24-\frac{w}{89{\cdot}2}$	—	*Railway Engineer*, vol. ii. p. 344.
39	,,	$0{\cdot}305V+4{\cdot}1$	Train only $w=102{\cdot}6$ tons	
40	,,	$3{\cdot}96+0{\cdot}18V$	$w=185$ tons 7·5 to 20 miles per hour	*Street Railway Journal*, 1899, p. 143.
41	,,	$4{\cdot}032+0{\cdot}289V+0{\cdot}28\frac{V^2}{w}$	20 to 31 miles per hour	
42	,,	$4{\cdot}032+0{\cdot}289V+0{\cdot}194\frac{V^2}{w}$	31 to 40 miles per hour	
43	,,	$4{\cdot}032+0{\cdot}505V+0{\cdot}129\frac{V^2}{w}$	43 to 50 miles per hour	
48	Barbier	$3{\cdot}58+1{\cdot}658V\times\left(\frac{1{\cdot}609V+50}{1000}\right)$	Four-wheeled coaches	*Le Génie Civil*, April, 1898, and Bulletin of the International Railway Congress, vol. xii. p. 1275.
49	,,	$3{\cdot}58+1{\cdot}644V\times\left(\frac{1{\cdot}609V+10}{1000}\right)$	Bogie coaches	
50	,,	$8{\cdot}51+3{\cdot}24V\times\left(\frac{1{\cdot}609V+30}{1000}\right)$	Locomotive and tender	
51	Aspinall	$2{\cdot}5+\frac{V^{\frac{5}{3}}}{58{\cdot}7}$	Oil axleboxes: 5 bogie-coaches and dynamometer-car	
52	,,	$2{\cdot}5+\frac{V^{\frac{5}{3}}}{65{\cdot}82}$	Oil axleboxes: 10 bogie-coaches and dynamometer-car	
53	,,	$2{\cdot}5+\frac{V^{\frac{5}{3}}}{73{\cdot}05}$	Oil axleboxes: 15 bogie-coaches and dynamometer-car	
54	,,	$2{\cdot}5+\frac{V^{\frac{5}{3}}}{80}$	Oil axleboxes: 20 bogie-coaches and dynamometer-car	
55	,,	$2{\cdot}5+\frac{V^{\frac{5}{3}}}{50{\cdot}8+0{\cdot}0278L}$	Oil axleboxes: General formula, bogie-coaches, oil axleboxes	

From tests carried out on the L. & N.E.R. with four-wheeled goods waggons of 6 tons tare and 10 tons capacity, and with bogie waggons of 17 tons tare and 50 tons capacity, the following results were obtained :—

Speed—m.p.h.	10	20	30	40	50
Resistance in lbs. per ton—10-ton waggons	$4\frac{1}{4}$	$4\frac{1}{4}$	$5\frac{1}{2}$	8	$12\frac{1}{2}$
Resistance in lbs. per ton—50-ton waggons	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{3}{4}$	$4\frac{3}{4}$	$6\frac{3}{4}$

All waggons were fitted with oil axleboxes, and were fully loaded.

Resistance of Curves.

Resistance due to curvature of track varies inversely as the radius, and directly as the rail-gauge and length of rigid wheel base. It also depends to some extent on the state of the surfaces of wheels and rails. The practice of watering the rails or lubricating the flanges of the wheels lessens the resistance, whilst the occasional necessity of sanding the rails for the locomotive greatly increases it. On main lines the curve resistance is usually very small, and no allowance is made for it. In special cases, where the curves are sharper, such as in sidings, station yards, or at junctions, it is sometimes necessary to form some estimate of the resistance. The American Master Mechanics' Association gives the resistance per ton (of 2,240 lbs.) as 0·77 lbs. for each degree of curvature of track in the case of cars (with bogies), and double this amount—1·54 lbs. —for locomotives.

In British practice, curvature is expressed by the radius in feet or chains. As 1° of curvature corresponds to a radius of 5,730 feet, the radius of any curve in degrees is given in feet by $\frac{5730}{x^\circ}$ or in chains by $\frac{87}{x^\circ}$.

Resistance in lbs. per ton $= \frac{4412}{\text{radius in ft.}}$; or $\frac{67}{\text{radius in chains}}$ for cars.

" " $= \frac{8824}{\text{radius in ft.}}$; or $\frac{134}{\text{radius in chains}}$ for locomotives.

To find the equivalent up-gradient, 1 in n, that offers same resistance as curve :—

$$n = \text{radius in ft.} \times 0{\cdot}5.$$
$$= \text{radius in chains} \times 33.$$
$$= \frac{2871}{\text{curvature in degrees.}}$$

Resistance due to Gradients on Railways.

The force, F, required to move 1 ton up a slope of 1 in n, neglecting friction and resistance of air $= \frac{1 \text{ ton}}{n} = \frac{2{,}240 \text{ lbs.}}{n}$, or resistance in lbs. due to gravity on any incline $= \frac{2{,}240}{\text{rate of gradient}}$ per ton of train.

On a gradient of 1 in 300 the total resistance becomes about twice that on a level at a speed of 30 m.p.h., and therefore only half the utmost load can be carried, or the speed must be diminished. Gradients above 1 in 330 are considered first class ; 1 in 330 to 1 in 150, fair working gradients.

In American and Continental practice, gradient is given as rise per cent. or per thousand, so that grade of 1 in $n = \frac{100}{n}$ per cent., or $\frac{1000}{n}$ per thousand. Thus 1 in 300 = 0·33 per cent. or 3·3 per mille.

Rise in feet per mile $= \frac{5280}{n}$, or 17·6 ft. for 1 in 300.

Effect of Gradients on Speed of Passenger Trains.

The work done by the locomotive in a given time is proportional to total resistance × speed. For speeds over 25 m.p.h. on the level, the resistance of an average engine and train may be fairly represented in lbs. per ton by the simple formula $R = 5 + {\cdot}003v^2$. The work done on the level is therefore proportional to $v(5 + {\cdot}003v^2)$. On a gradient of 1 in n this becomes $v\left\{(5 + {\cdot}003\,v^2) + \frac{2240}{n}\right\}$. If the engine is capable of maintaining a speed of 60 m.p.h. on the level, and the horse-power output is constant, the effect of the gradients on the speed is as follows :—

Inclination		Level	1 in 2,500	1 in 1,000	1 in 750	1 in 500	1 in 250	1 in 150	1 in 120	1 in 100	1 in 90	1 in 80	1 in 70
Speed	Miles per hour	60	59	57	55	53	47	40	36	33	31	28	26

TABLE SHOWING THE SPEED OF AN ENGINE WHEN THE TIME OF PERFORMING A QUARTER, HALF, OR ONE MILE IS GIVEN.

Speed per Hour.	Time of Performing			Speed per Hour.	Time of Performing			Speed per Hour.	Time of Performing		
	¼ Mile.	½ Mile.	1 Mile.		¼ Mile.	½ Mile.	1 Mile.		¼ Mile.	½ Mile.	1 Mile.
Miles.	M. S.	M. S.	M. S.	Miles.	M. S.	M. S.	M. S.	Miles.	M. S.	M. S.	M. S.
5	3 0	6 0	12 0	34	26	53	1 46	63	14	28	57
6	2 30	5 0	10 0	35	25	51	1 43	64	14	28	56
7	2 8	4 17	8 34	36	25	50	1 40	65	13	27	55
8	1 52	3 45	7 30	37	24	48	1 37	66	13	27	54
9	1 40	3 20	6 40	38	23	47	1 34	67	13	27	54
10	1 30	3 0	6 0	39	23	46	1 32	68	13	26	53
11	1 21	2 43	5 27	40	22	45	1 30	69	13	26	52
12	1 15	2 30	5 0	41	21	43	1 27	70	12	25	51
13	1 9	2 18	4 37	42	21	42	1 25	71	12	25	51
14	1 4	2 8	4 17	43	20	41	1 23	72	12	25	50
15	1 0	2 0	4 0	44	20	40	1 21	73	12	25	49
16	56	1 52	3 45	45	20	40	1 20	74	12	24	49
17	53	1 46	3 31	46	19	39	1 18	75	12	24	48
18	50	1 40	3 20	47	19	38	1 16	76	12	24	47
19	47	1 34	3 9	48	18	37	1 15	77	11	23	47
20	45	1 30	3 0	49	18	36	1 13	78	11	23	46
21	42	1 25	2 51	50	18	36	1 12	79	11	23	46
22	40	1 21	2 43	51	17	35	1 10	80	11	22	45
23	39	1 18	2 36	52	17	34	1 9	81	11	22	44
24	37	1 15	2 30	53	17	34	1 7	82	11	22	44
25	36	1 12	2 24	54	16	33	1 6	83	11	21	43
26	34	1 9	2 18	55	16	32	1 5	84	10	21	43
27	33	1 6	2 13	56	16	32	1 4	85	10	21	42
28	32	1 4	2 8	57	15	31	1 3	86	10	21	42
29	31	1 2	2 4	58	15	31	1 2	87	10	20	41
30	30	1 0	2 0	59	15	30	1 1	88	10	20	41
31	29	58	1 56	60	15	30	1 0	89	10	20	40
32	28	56	1 52	61	14	29	59	90	10	20	40
33	27	54	1 49	62	14	29	58				

Resistance of Locomotives.

The resistance of a locomotive is a very uncertain quantity, and there is no formula which can take account of all the variables. There are, however, several formulæ which give results approximating to the average resistances in ordinary working.

The resistance may be divided into three components:—

(1) Internal resistance of engine machinery, including driving wheels.
(2) Resistance of locomotive as a vehicle, including head-on air resistance.
(3) Resistance of tender as a vehicle.

According to Prof. W. F. Goss, the internal resistance is fairly constant for any given cut-off for a wide range of speed, but that the later the cut-off, and consequently more even the turning moment, the less the friction.

As a vehicle the locomotive not only has the usual rolling resistance, journal friction, etc., but it has to encounter the atmospheric pressure on the surfaces perpendicular to the direction of travel, and it shelters to some extent the train behind.

The reaction of the steam pressure on the cylinder covers, applied alternatively to either side of the engine, causes it to move in a sinuous path and sets up further flange friction.

The tender has a resistance very similar to any other vehicle of the train, but it is modified a little by the movement of the engine to which it is closely coupled.

Prof. Goss gives as total resistance of engine and tender,

$$\mathrm{WR} = 3{\cdot}8\ \frac{d^2 l}{\mathrm{D}} - w(2 + \tfrac{1}{4}\mathrm{V}) - 0{\cdot}11\mathrm{V}^2,$$

where

d = diameter of piston in inches; l = stroke in inches; D = diameter of drivers in inches; V = speed in m.p.h.; w = total weight of engine and tender (W) less weight on drivers, in tons (of 2,000 lbs.).

This formula does not take into account the increase in friction with the number of pairs of coupled wheels.

Mr. Lawford H. Fry gives separate formulæ for engines with 4, 6, and 8 coupled wheels, which in lbs. per ton (2,240 lbs.) of engine and tender can be expressed as:—

$$R = 8{\cdot}5 + 0{\cdot}09V + 0{\cdot}004V^2 \text{ for 4 wheels coupled.}$$
$$= 10{\cdot}0 + 0{\cdot}12V + 0{\cdot}004V^2 \text{ for 6 wheels coupled.}$$
$$= 13{\cdot}4 + 0{\cdot}48V + 0{\cdot}004V^2 \text{ for 8 wheels coupled.}$$

The equations are derived from the mean of the results obtained by numerous European experimenters. (*The Engineer.*)

About 22 lbs. per ton at 50 m.p.h. is the usual resistance of a British 4-4-0 type engine; and at 60 m.p.h. some 4 h.p. per ton is expended in moving the engine and tender.

In order to see how much power the locomotive absorbed as compared with the train, a certain number of experiments were tried on the former Lancashire and Yorkshire Railway, and it was found that the ten-wheeled engine No. 1392 absorbed 34 per cent. of the total horse-power. Mr. W. M. Smith (the Institution of Mechanical Engineers) gave the result of his experiments as about 36 per cent. of the total horse-power. Probably 34 per cent. or 36 per cent. was about the right percentage, other figures being much too high; but the actual figure depends on the load behind the engine.

Train Acceleration.

The resistances to be overcome in moving a train are frictional and gravitational. Any draw-bar pull in excess of them is available for accelerating the train; or

$$F = T - W(R_1 + R_2 \pm R_3),$$

where

F = accelerating force in lbs.; T = tractive effort in lbs.; W = weight of train in tons; R_1 R_2 and R_3 = opposition to traction in lbs. per ton due to train resistance, curves, and gradients respectively. A negative result indicates retardation.

For the actual acceleration or retardation produced, allowing 10 per cent. for rotary acceleration of wheels and axles,

$$a = \frac{F \times 32}{1{\cdot}10W \times 2240} = \frac{F}{77W} \text{ ft./sec.}^2$$

In American practice about 5 per cent. is allowed for rotary acceleration, as the car wheels are smaller in diameter and also bear a lesser ratio to the weight of car.

To produce a speed of V miles per hour in distance S feet,

$$F = \frac{82V^2W}{S} \text{ lbs.; or } F = \frac{82(V^2 - v^2)W}{S} \text{ lbs., } v \text{ being initial speed.}$$

To produce a speed of V miles per hour in t seconds,

$$F = \frac{112VW}{t} \text{ lbs.; or } F = \frac{112(V - v)W}{t} \text{ lbs.}$$

Power, Tractive Force, and Adhesion of Locomotives.

The pressure exerted on the piston is to the force exerted in the traction of the train inversely as the velocities of the piston and train, i.e., as twice the stroke of the piston to the circumference of the wheel.

Piston Speed.—Ordinary piston speed is about 900 feet per minute.

If

d = diameter of piston, in inches; a = area of piston, in sq. inches; l = length of stroke, in inches; p = indicated pressure per square inch, in lbs.; D = diameter of driving-wheel, in inches; V = velocity, in miles per hour; n = number of revolutions per minute = $336\frac{V}{D}$; then

$$\text{Tractive force at rails} = \frac{d^2 lp}{D} \text{ lbs.}$$

$$\text{Indicated horse-power} = \frac{d^2 plV}{375D} = \frac{4anpl}{33{,}000} \times \tfrac{1}{12}.$$

The calculated tractive (or starting) effort

$$T = \frac{cd^2Pl}{D} \text{ lbs.}$$

where

P = boiler pressure, and c is a coefficient varying from 0·8 to 0·9, but usually taken at 0·85 both in British and American practice.

The above relates to the ordinary two-cylinder high-pressure engines. Multiply results by 1·5 for three-cylinder, and by 2 for four-cylinder locomotives. (For compound locomotives see p. 687.)

The horse-power given out at the draw-bar is less than the indicated horse-power by the amount expended in moving the engine and tender. This is approximately 400 h.p. in modern locomotives running at 60 m.p.h., representing about 35 per cent. of the maximum indicated horse-power. (See Resistance of Locomotives, p. 681.)

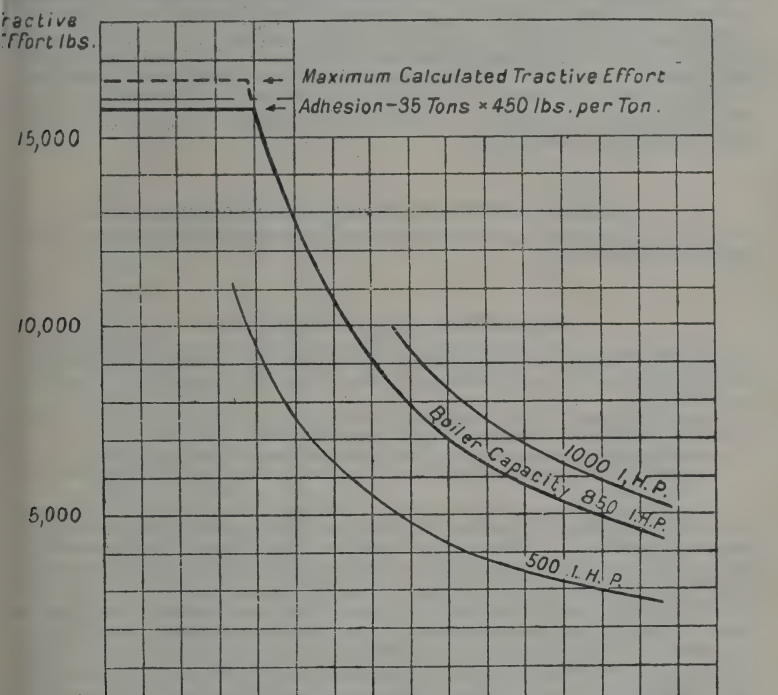


FIG. 3.

Draw-bar horse-power = 5·97 × pull (in tons) × speed (m.p.h.) = 0·0267 × pull (lbs.) × speed (m.p.h.).

If

T = tractive force at drivers; t = draw-bar pull; H = square feet of heating surface; V = speed in m.p.h.; d = diameter of piston in inches; L = stroke in inches; D = diameter of drivers in inches; W = weight of engine and tender, less weight on drivers (in tons of 2,000 lbs.),

$$T = 161\frac{H}{V}; \quad t = 161\frac{H}{V} - 3{\cdot}8\frac{d^2\,L}{D} - W(2 + \tfrac{1}{6}V) - 0{\cdot}11V^2.$$

Professor Goss, (*'Railroad Gazette,' Jan.* 17, 1902).

ADHESION.

The proportion of the weight on the driving wheels giving *adhesion* and available as tractive force varies considerably, from about 200 lbs. per ton in frosty and greasy weather to 600 lbs. in dry weather. It must, of course, exceed the tractive power, and is generally taken at about 350 lbs. per ton, this being quite feasible, as all locomotives are fitted with a sanding arrangement.

In average British practice, the factor of adhesion, that is, the ratio between adhesive weight and calculated tractive effort, is between 4 and 5 for four and eight-wheel coupled engines, and between 5 and 6 for six wheels coupled. In tank engines the factor varies with the amount of water and coal present. Multi-cylinder engines may have a lower factor on account of their more even turning moment.

The relation between horse-power, tractive effort, and adhesion, is shown by the characteristic curve of a locomotive in fig. 3, where tractive effort is plotted against speed. Horse-power appears on the diagram as a hyperbolic curve, since for any given horse-power pull × speed = a constant. In the example given the maximum calculated tractive effort is 16,500 lbs. The actual pull is limited by adhesion to 15,750 lbs., adhesive weight being 35 tons and the adhesion 450 lbs. per ton. The boiler capacity is taken as 850 i.h.p. and is plotted as a hyperbolic curve. The intersection of the curve with the maximum available tractive effort gives the lowest speed at which the boiler is fully used. Until this point is reached horse-power is limited by cylinder capacity or adhesion, as the case may be. Beyond it, the horse-power is approximately constant and the pull falls off as the speed rises. A deduction must be made for engine and tender resistance to obtain actual draw-bar pull.

Relation of Power to Weight of Locomotives.

Ordinary locomotives are capable of developing from 9 to 12 horse-power for each ton of their weight (inclusive of tender).

Weight Restriction in Locomotives.

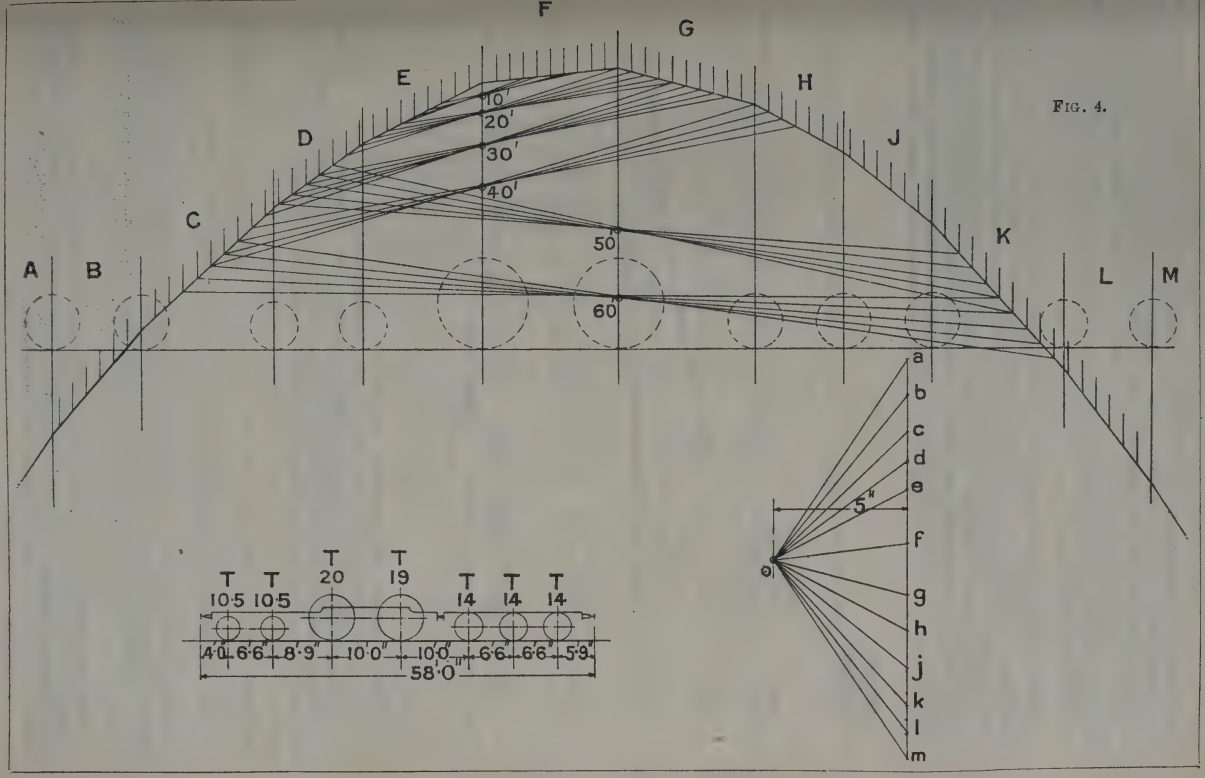
On English railways the heaviest load is usually 20 tons, but there are practically no lines in this country on which the permissible axle load exceeds 20 tons. The Southern Railway makes an exception in the case of 4-cylinder engines, where a load of nearly 21 tons has been permitted.

The axle loads carried with the goods engines are about 15 tons in Germany and Italy, 17 tons in England, Belgium, and France, and 23 to 27 tons in the United States.

The following is a formula given by F. J. E. Spring for locomotive driving-wheels :—

Safe load = 200 × diameter of wheel in inches × width of rail head on which wheel bears in inches.

In addition to restriction of individual loads on wheels, the total weight of a locomotive is limited by the strength of permanent-way structures. In designing a new locomotive, or rebuilding an existing one, it is essential to study the resulting bending moment imposed on bridges. This varies with the total length of engine, wheel base and spacing of wheels, and the weights on individual pairs of wheels. A short engine with the wheels close together may stress a bridge more than a heavier engine in which the weight is spaced over a longer base. The locomotive engineer, however, is not concerned in the actual stresses produced, but his problem is to keep within the boundaries of a limiting bending moment curve. The permanent-way engineer sets out the strength of the weakest bridges of various spans, and from them deduces a curve showing the maximum equivalent uniformly distributed load that the different spans can sustain. The curve is either set out giving the total load on the spans, or the tons per foot run of span. In fig. 5 the upper curve shows a limit determined by the permanent-way engineer in lbs. per ft. run. No locomotive may run that sets up on any bridge a greater bending moment than this. If the excess is small, a slight modification of the wheel spacing or distribution of loads may rectify matters. As the locomotive constitutes a rolling load, any direct calculation is very tedious. The loads must be advanced across the span a foot or so at a time, and the bending moment ascertained for each step. It is obvious that maximum bending will occur under one of the loads, but it is not always certain which load it is. The maximum also changes from under one wheel to another at a certain point. The most satisfactory way is to first of all solve the problem graphically : if care is taken the results are very reliable. Once a solution is obtained the bending moment can be exactly calculated, and this acts as a check on the drawing and reading of scales. For the loading of the span it is assumed that there are several locomotives of the type under consideration, coupled together. As an example of the method, a 4–4–0 type engine is taken, the loads and spacing of wheels being shown on the line diagram at the foot of fig. 4. The first step is to set up a vertical line and mark it off to a convenient scale, say 1 in. = 10 ft., to represent the wheel loads to scale. Thus, *c–d* is the weight on the leading bogie wheels, *d–e* on the next pair, *e–f* that on the first pair of coupled wheels, and *f–g* for the trailing wheels. The loads on tender wheels are represented by *g–h*, *h–j*,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T 10·5
T 20
T 19
T 14
T 14
T 14
4'0" 6'6" 8'9" 10'0" 10'0" 6'6" 6'6" 5'9"
58'0"

FIG. 4.

j–k. The lengths *a–b*, *b–c*, are tender wheels of the preceding engine; while *k–l*, *l–m*, are for bogie wheels of the following engine. If the span is a long one more loads must be added in their proper order. Having done this a pole O is taken, approximately in line with the centre of gravity of the loads, and at a distance of, say, 5 ins. from the vertical line. The various points on the line are then joined to the pole. The next step is to draw a horizontal base line and mark on it the wheel base of the engine to a scale of, say, ½ in. = 1 ft. Verticals are projected through the points, and the spaces are lettered A, B, C, etc., to correspond with the letters *a*, *b*, *c*, etc., on the vertical load line.

Commencing at any convenient place, a line is drawn through space A parallel to the polar line *o–a*. This is followed by line through space B parallel to *o–b*, and so on until complete. For convenience a number of vertical lines are spaced at intervals representing each foot of the span. In order to ascertain the bending moment for a 10-ft. span, the intersection of a vertical with the curve is joined to another ten spaces away and scaling 10 ft. when measured horizontally. The next and succeeding points are treated in the same way, and it will soon be evident where the greatest bending moment is enclosed. This is equivalent to moving the bridge span along under the engine. Having ascertained the greatest bending for a 10-ft. span, that for a 20-ft.

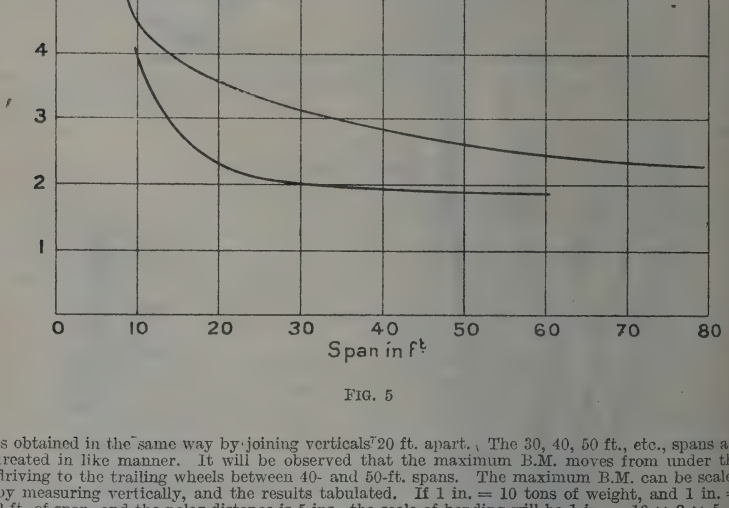


FIG. 5

is obtained in the same way by joining verticals 20 ft. apart. The 30, 40, 50 ft., etc., spans are treated in like manner. It will be observed that the maximum B.M. moves from under the driving to the trailing wheels between 40- and 50-ft. spans. The maximum B.M. can be scaled by measuring vertically, and the results tabulated. If 1 in. = 10 tons of weight, and 1 in. = 2 ft. of span, and the polar distance is 5 ins., the scale of bending will be 1 in. = 10 × 2 × 5 = 100 ton-ft. The final step is to obtain the equivalent uniformly distributed load by equating each result to it—i.e., B.M. $= \frac{WL}{8}$, so that $W = \frac{8 \times \text{B.M.}}{L}$, where W = total distributed load on span. For load per ft. run of span, B.M. $= \frac{wl^2}{8}$, and $w = \frac{8 \times \text{B.M.}}{l^2}$.

The results obtained can be plotted on the bridge curve supplied by the permanent-way engineer (as the lower curve in fig. 5), and unless all the plotted points fall below the upper curve, the design of the engine will have to be modified in some way, either by reduction of weight, or possibly by an alteration to the wheel base, or the addition of another pair of wheels.

When the position of maximum bending and the loads producing it are known, calculation is a simple matter, and it acts as a check on the graphical working. The position of load system giving maximum bending is such that the centre of span bisects the distance between point of maximum bending and centre of gravity of loads on span.

Compound Locomotives.

The general claim for compound locomotives, by most authorities, is a saving of about 20 per cent. in steam. Expansive working, and consequently exhausting at a low temperature, is the main object.

Many of the larger locomotives recently constructed on the Continent are four-cylinder compounds, while the two-cylinder cross-compounds are returning to favour in the Argentine. A number of three-cylinder compounds have been built in England for the L.M. & S.R., and several experimental engines have been put into service in the U.S.A.

Ratios of the Areas of the High-pressure Cylinders to the Low-pressure.

Wordsell, Von Borries, and others, 1 to 2–2½; Webb, 1 to 2·3; Vauclain and America, 1 to 3. In modern compounds ratio is 1 to 2·4 on L.M.S. Railway (Midland Section), 1 to 2·5 Mallet compounds in U.S.A., and about 1 to 2·2 on Continent.

Tractive Force.

Von Borries, who recommends a ratio of 1 : 2·2 or 2·3, gives tractive power of two-cylinder compounds as,

$$\text{T. F.} = \frac{psd^2}{4\,\text{D}},$$

where,

p = boiler pressure; s = stroke in inches; D = diameter of wheel in inches; d = diameter of low-pressure piston.

For four-cylinder compounds, Baldwin gives

$$\text{T.F.} = \frac{2\,psc^2}{3\text{D}} + \frac{psd^2}{4\text{D}},$$

c being diameter of high-pressure piston.

Another formula is given as

$$\text{T.F.} = \frac{0{\cdot}8\,psd^2}{(r+1)\text{D}} \text{ for two-cylinder compounds} = \frac{1{\cdot}6\,psd^2}{(r+1)\text{D}} \text{ for four-cylinder compounds,}$$

r being ratio of low to high-pressure piston area.

Cylinders of Simple and Compound Locomotives of Equivalent Power.

For proportioning the diameters of the cylinders of compound locomotives when designing them to generate a power equivalent to that of a given size of simple cylinder and of the same piston stroke, the average ratio of area of the simple cylinder and the high-pressure cylinder area of compound locomotives is 1 to 1·25 for the 2-cylinder and 1·10 for the 4-cylinder. In the case of the 4-cylinder engines the area is that of the sum of the two high-pressure cylinders.

(Railroad Gazette.)

Parts of Locomotives.

CYLINDERS.

The size of cylinders is governed by the maximum tractive effort required for starting the train, boiler pressure, diameter of driving wheels and adhesive weight available. $d^2l = \frac{\text{T.E.} \times \text{D}}{0{\cdot}85\text{P}}$, where d = diameter of piston in inches, l = length of stroke in inches, P = boiler pressure, D = diameter of driving wheels in inches, and T.E. = tractive effort in lbs.

Diameter of cylinder in inches = ·75 $\sqrt{\text{I.H.P.}}$, where I.H.P. = maximum H.P. that engine will be required to develop continuously for any length of time.

Stroke and diameter of driving wheels should be so proportioned that the piston speed is about 900 ft. per minute, as this is found to be the most economical speed.

Thickness of barrel in inches = ·02d + ·75, where d = diameter in inches.

Thickness of metal of steam passages may be ·7 t and of the flanges 1·25 t, where t = thickness of barrel in inches.

The studs for the cylinder cover should be calculated for a stress of 4,000 lbs. per square inch to allow a large margin of safety in case of priming.

For Flat Slide Valves.—Area of steam port $= d^2 + 15$, in the most modern practice. Length of ports should not be less than $\cdot 85\,d$. Area of exhaust port should be two and a half times that of the steam port.

Clearance between cylinder covers and piston is usually made from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. The *clearance volume*, including the passages, varies from 6 to 8 per cent. of the cylinder volume. If the clearance is too small the compression line at high speeds rises above the steam chest pressure, and the engine does not run well.

Cylinders for Highly-superheated Steam.—Owing to the very high temperatures, it is necessary that the steam chest walls should be separate from the walls of the cylinders. There is a very great variation in the temperatures of superheated steam, on the one side, and of the exhaust steam on the other. If a common wall is used between the two the result is that the cylinders are liable to fracture. (*H. N. Gresley*, '*Proceedings, Inst. Loco. Engineers.*')

Pistons.—One railway company makes all pistons 0·0625 in. smaller in diameter than the bore of the cylinder. Another railway allows 0·002 in. per inch of diameter for clearance.

VALVES.

For Flat Slide Valves.—Outside lap usually $= 0 \cdot 8a$, where a is the width of the steam port. As a rule there is no inside lap, but in some cases a small inside clearance not exceeding $\frac{1}{16}$ in. is allowed. The *lead* is about $\frac{1}{8}$ in., and the *maximum travel* is about $2 \cdot 7a$. Valves of tank engines and others that make frequent stops should be of soft grey cast iron. For long-run engines, 5 parts copper, 1 part tin. (*Wolff.*)

Cylindrical Valves.

Cylindrical or piston valves are extensively used in connection with superheated steam. A large proportion have internal admission of steam. Various packings are in use; some consist of segmental collapsible rings pressed against the liners by steam pressure; others have spring rings, of which there are several kinds. The advantages over flat slide valves are reduced friction, larger port opening, and wear is confined to the easily renewable packing rings.

The diameter of piston valves is about half that of the cylinders, so that circumferential length of ports is approximately $1 \cdot 5d$, where d equals diameter of cylinders.

The lap of the valves on the admission side is usually $\frac{7}{8}$ in. or 1 in., but this has been increased in recent years to $1\frac{1}{2}$ ins. or $1\frac{5}{8}$ ins., and the travel in full gear working has increased correspondingly from about $4\frac{1}{2}$ ins. to $6\frac{1}{2}$ ins. The advantages gained are sharper cut-off and freer exhaust, leading to greater mean effective pressure at high speed and greater economy in steam consumption.

Piston valves are of two kinds, inside admission and outside admission. In the former, steam is admitted between the heads, and exhaust takes place on the outside. The advantages are reduced area for radiation of heat and packing of spindle is only subjected to exhaust steam pressure. Outside admission valves are arranged like flat slide valves, with admission of steam on outside and exhaust inside.

The cast-iron valve liners are turned 0·003 in. to 0·001 in. larger than the steam chest, and are drawn into position by means of screw tackle.

MOTION WORK, ETC.

Allowances used in Fitting the Parts.

		In.			In.
Gland and neck rings	+ piston rod	0·03125	Slipper flanges	+ width of bar	0·03125
Eccentric straps	+ sheaves	0·015	Axle-box flanges	+ horn	0·03125
Side play of do.		0·03125	Brake gear holes	+ pin dia.	0·0156
Slide blocks	− bar opening	0·006	Valve gear pins	− holes	0·004

(*F. Thompson*, '*Journal of Inst. of Loco. Engineers.*')

Coupling and Connecting Rods.

In the case of outside cylinder engines the throw of coupling rods is usually the same as that of the connecting rods, namely, 12 ins. to 15 ins., but in a few cases the crank pins are turned eccentrically on their outer bearing, so that the throw of the coupling rod may be shortened a little. For inside cylinder engines the throws are from 9 ins. to 11 ins. Small throws require rods to be stiff laterally, in order to resist crippling loads, while large throws need a deep rod on account of the bending stresses set up by centrifugal force.

Where a fire-box comes between two coupled axles, some railways allow a little for expansion by heat of the frames by shortening the centres between axles by $\frac{1}{64}$ to $\frac{3}{64}$ in. When steam is raised the frames lengthen, so that the distance between centres of the axles is equal to the length of the coupling rods.

Most coupling rods have plain bushed ends, as have the solid-ended connecting rods of outside cylinder engines on the Great Western and other railways. The gun-metal bushes are turned

slightly larger than the hole by an allowance of 0·002 inch per inch of diameter. This requires a tonnage of 12 tons to press a 7-inch bush into place. A running clearance on the crank pin of 0·002 inch per inch of diameter is specified in one case, $\frac{1}{32}$ inch being a common figure. Another railway presses the bushes in with a load of 20 to 25 tons, and allows $\frac{1}{32}$ in. to $\frac{3}{64}$ in. clearance on the pin.

Valve Gear.

With inside cylinders Stephenson valve gear (see Section XXX, Part III) is general. In special cases, where eccentrics must be dispensed with, Joy's valve gear is used. Outside cylinder engines, with the valves inside the frames, also have the Stephenson gear; but when the valves are outside, the Walschaert valve gear is now preferred.

The outside cylinder engines on the Great Western Railway have 10-in. piston valves placed above the cylinders worked by Stephenson gear from the inside of the frames. The maximum valve travel is $6\frac{1}{4}$ ins., the lap being $1\frac{5}{8}$ ins., and the port opening $1\frac{1}{2}$ ins., although the steam ports are $1\frac{3}{4}$ ins. wide. The eccentrics are set to give $\frac{1}{8}$ in. lead at 25 per cent. cut off, resulting in the valves being about $\frac{1}{4}$ in. blind in full gear. This arrangement gives a sharp cut off, prolonged expansion and a free exhaust, resulting in large mean effective pressure at high speeds. See also p. 677.

Walschaert Valve Gear.

The Walschaert valve gear, figs. 6 and 7, is mainly used on outside cylinder engines. The travel of the valve is derived from two movements, the crosshead of the engine and a return

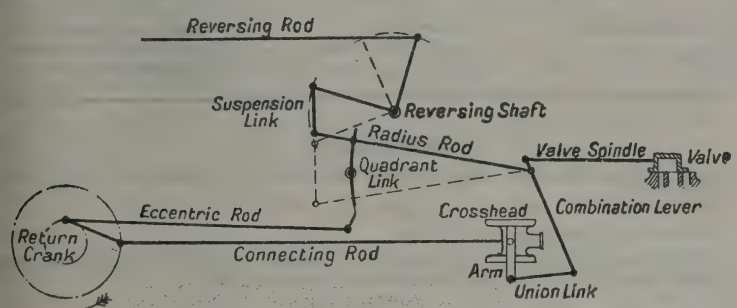


Fig. 6.

crank attached to the main crank pin, or, in the case of inside cylinder engines, from an eccentric on the crank shaft. The first movement is a reproduction of the travel of the crosshead to a reduced scale, the reduction being effected by a combination lever connected at its lower end to the crosshead through a link. In order that the angular movement of the lever shall not be too great by any restriction of length an arm is rigidly attached to the crosshead so that the lever may be suitably lengthened. The combination lever is also attached to the valve spindle and to the radius rod which forms its fulcrum. With an outside admission valve the valve spindle is attached above the radius rod and with inside admission of steam the positions are reversed (see figs. 6 and 7). The function of the combination lever is to give the mid-gear travel, equal to twice 'lap + lead,' and the lever is so proportioned that the stroke is reduced to this amount. The lead is constant for any length of travel.

The second movement, derived from the return crank, is transmitted to a quadrant link rocking on fixed bearings. The maximum angle through which this link swings should be kept within 45°. The radius rod is attached to the link through a die block and communicates its motion to the valve by way of the combination lever. This second movement is at a phase of 90° with the first, and its magnitude can be varied and its direction reversed by altering the position of the radius rod on the quadrant link. In mid-gear the second movement is nil, only the first movement being communicated to the valve. The position of the radius rod in the link is regulated by the reversing shaft, the attachment being either a vibrating suspension link (see fig. 6) or a slider consisting of a die block working in a long slot, as in fig. 7. In the latter case it is more convenient to use the bottom of the link for fore-gear running, while in the former either top or bottom can be used, since it is only necessary to alter the position of the return crank, which

is nominally 90° ahead or behind the main crank. For convenience of design the quadrant link is usually raised so that the eccentric rod is inclined, and this angle of inclination should be

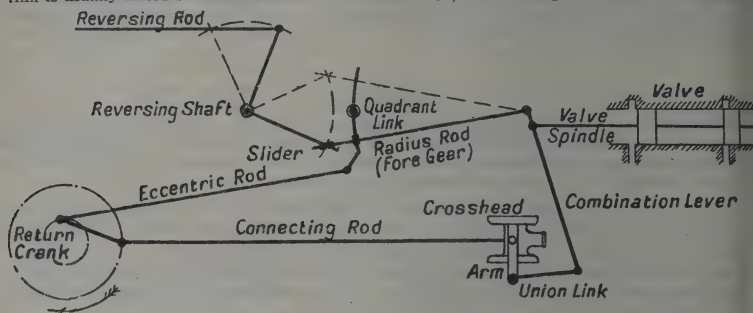


FIG. 7.

taken into account when setting the return crank, being added to or subtracted from the main angle of 90°. The setting of the return crank is as follows :—

Valve.	Fore Gear.	Return Crank.
Outside admission	At top of link	90° behind main crank
" "	At bottom of link	90° in advance of main crank
Inside "	At top "	90° in advance of "
" "	At bottom "	90° behind "

CRANK AXLES.

If W = weight of engine in tons, when in working order ; D = diameter of driving wheels in inches ; then

$$d = K\sqrt[3]{WD}.$$

For the best modern practice, K = ·522. (*Wolff.*)

Dimensions taken from the crank axles of a number of modern British locomotives, with cylinders ranging from 17 to 21 ins. diameter, give the following rule :—

$$d = 0{\cdot}375C + 1,$$

d being the diameter of main bearings and C the diameter of cylinders.

The crank-pin journals are usually the same diameter as the main bearings, the barrel of centre portion about ½ in. less and the wheel seat 1 in. more. Thickness of webs varies from 4 to 4½ ins.

Built-up crank axles are common. The advantages over a forged axle are cheapness, more effective bearing surfaces due to absence of radii, fractured parts may be replaced without scrapping the whole axle. By extending the webs a balanced axle is obtained. Special steels may be used.

The parts are assembled by shrinkage fits, the webs being heated in a gas furnace and shrunk on to the shaft and pins in special fixtures to set the throws in their correct positions. Holes are drilled between web and shaft, into which screwed dowel pins are fitted as keys.

The shrinkage allowance, or the amount by which the hole is smaller than the pin, depends on the tensile strength of the crank webs. For steel to B.S.S. 8c this is 0·025 in. in Horwich practice for axles about 8 ins. diameter.

BEARING SURFACES.

Angle included at centre of journal by arc of contact is usually for coupled wheels, 160° to 170°, for bogie, carrying, or trailing wheels, 60° to 80°. The maximum bearing pressures are approximately 250 lbs. per sq. in. of projected area for coupled wheels, 350 lbs. for bogie, and 450 lbs. for tenders. Bearing brasses are commonly of gun-metal to Admiralty specification and the white-metal lining of Babbitt. In some cases alloys having a lead base are used. Maximum crown wear of brasses or axle-boxes is ½ in.

Lubrication of bearings is by top feed from crown of box or from auxiliary oil boxes, and under pad of wool on spring frame. In case of bogie and tender wheels lubrication is often by underpad only.

The lubricating oil is a medium mineral oil mixed with about 10 per cent. of rape oil. An average oil consumption is 6 to 7 ozs. per bearing per 100 miles.

For crank-pin journals and coupling-rod pins, the pressure may be as much as 1,500 lbs. per sq. in., the load on connecting rod being taken as full boiler pressure on piston area.

For crosshead pins 4,000 lbs. per sq. in. is allowable on account of the small angular movement. Crosshead slippers should be about 60 lbs. per sq. in., a low pressure being advisable on account of the exposure of slide bars to sand and grit.

WHEELS AND TYRES.

Cast-steel wheels are general. The method of securing tyres by means of set screws through the rim of wheel is the most common. The alternative is to depend on the shrinkage of the tyre to grip the wheel, a retaining ring being inserted to lock the tyre in place laterally. This is a cheap and satisfactory fastening, but there is a tendency for tyres to become loose as they wear thin.

The shrinkage allowance for tyres is usually between 1/750th and 1/1000th of the diameter of wheel centre.

In G.W.R. practice the total shrinkage is given as $\frac{1{\cdot}0625\ D + 10}{1000}$, D being the diameter of wheel in inches.

Driving wheels have tyres with flanges about $\frac{1}{8}$ in. thinner than the other wheels. This eases the engine on curves and protects the crank axle to some extent. Blind or flangeless tyres are uncommon in England, although often resorted to in America.

Of modern types the 4–4–0 engine is the most economical in tyre wear. The flanges of the leading bogie wheels which guide the engine wear much faster than the second pair. Bogie wheels wear less than radial truck wheels, as a bogie sets itself tangentially to any curve. In engines of the 0–6–0 and 0–8–0 types mileage is determined by the flange wear of the leading coupled wheels.

Tyres with treads worn hollow are detrimental to points and crossings. A flange worn sharp is liable to cause derailment. Tyres are turned down to $1\frac{5}{8}$ ins. on tread and allowed to wear to $1\frac{1}{4}$ ins. before they are scrapped, except in case of large driving wheels, where $1\frac{3}{4}$ ins. or 2 ins. is the limit.

Wheels are forced on axles by hydraulic pressure. A minimum of 10 tons per inch diameter of wheel seat should be allowed when rape oil is used as a lubricant, 100 tons being a usual amount for large axles; or, if D is the diameter of wheel seat in inches, the load = 10D tons.

The wheel is bored slightly less in diameter than the axle, the difference expressed as a fraction of an inch being from $\frac{2D + 3{\cdot}5}{1{,}000}$ to $\frac{4D + 2}{1{,}000}$, depending on rigidity of the boss, quality of steel, etc.

In some cases the wheel and wheel seat are slightly tapered, the difference in diameter in the length of the wheel seat being $\frac{3}{64}$ in. The G.W.R. practice is to bore the hub parallel to and smaller than the axle by an allowance varying from 0·0015 to 0·002 per inch of diameter. Tonnage for pressing on the wheels by hydraulic press is from 8 to 12 tons per inch of diameter, the intensity of the grip depending to a large extent on the thickness of the hub. The best results are obtained when this is not less than half the diameter of the axle in thickness.

If the tyre is on the wheel, it takes 25 per cent. more pressure to force the wheel on the axle for the same allowance.

Keys should be tapered $\frac{3}{32}$ in. per foot and fitted to within $\frac{1}{64}$ in. before being driven home.

Crank pins should be forced in with a minimum pressure of 13 tons for each inch of diameter, and the ends of the pins riveted over inside the wheels.

BRITISH STANDARD CONTOURS FOR LOCOMOTIVE TYRES.*

(FOR BRITISH RAILWAYS 4 FT. 8½ IN. GAUGE.)

(No. 276—1927.) (*Abstract*.)

Contour A recommended for the leading and trailing wheels of bogies, the wheels of pony trucks and radial axles, or any pair of wheels which constitute the leading or trailing wheels of a locomotive, whether tender or tank engine.

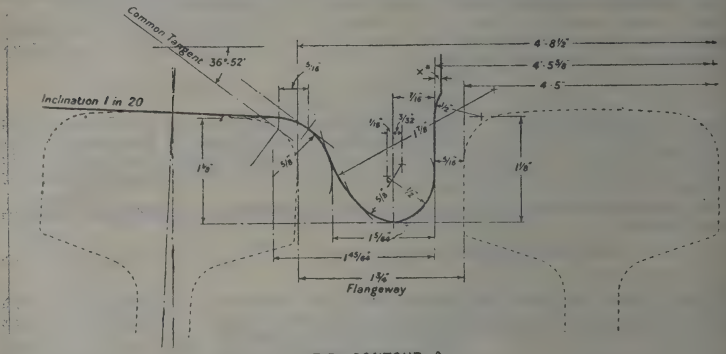
Contour A or G recommended for the leading wheels of a set of coupled wheels, when led by a bogie, pony truck, radial axle, or any pair of carrying wheels.

Contour A or G recommended for the trailing wheels of a set of coupled wheels, when followed by a bogie, pony truck, radial axle, or any pair of carrying wheels.

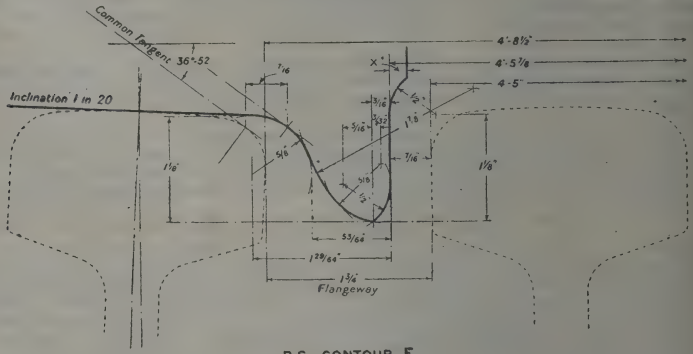
Contour G or E recommended for coupled wheels, other than the leading and trailing coupled wheels of groups 6, 8, and 10 coupled.

* By permission of the British Engineering Standards Association.

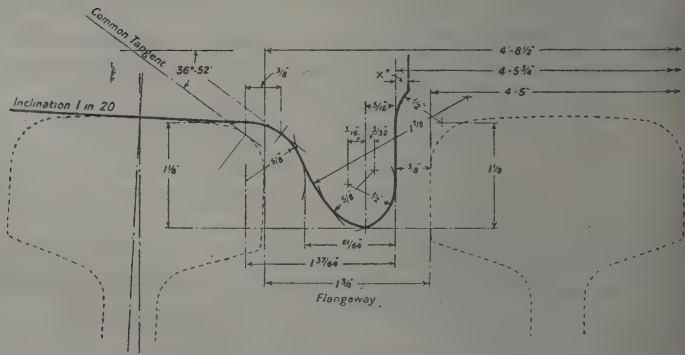
BRITISH STANDARD CONTOURS FOR LOCOMOTIVE TYRES FOR BRITISH RAILWAYS.



B.S. CONTOUR A.



B S CONTOUR E.



B.S. CONTOUR G.

Flexible Wheel Base.

Main-line engines should be capable of traversing a curve of 5 chains radius, and sufficient de-play is given to bogies and radial wheels for this. The theoretical amount required is not ttained in practice, as engine frames and track spring a little on sharp curves.

There is a small amount of side-play allowed between flanges of wheel and rail. With new yres on new rails, this is about $\frac{5}{8}$ in. each side, or a total of $\frac{1}{4}$ in. The flanges of driving wheels re thinned down to give about $\frac{3}{4}$ in. to $\frac{7}{8}$ in. total. Additional side-play is sometimes given by llowing a little clearance between axle-boxes and guides. It is very exceptional to give any ide-play between journal and bearings.

Baldry's rule for the radius of pony trucks is

$$R = \tfrac{1}{2}\left(B - \frac{A^2}{B}\right),$$

here B is horizontal distance from truck wheels to centre of rigid wheel base and A is half igid wheel base.

Bogies, in addition to turning on the pin, are allowed a certain amount of transverse move- ient. This is controlled by springs, suspension links, or inclined slides. Some bogies have urved slides giving radial instead of transverse movement. Fixed centre bogies are now but ttle used.

Counterbalancing Locomotive Driving Wheels.

The revolving and about 60 per cent. (this figure varies considerably) of the reciprocating parts hould be counterbalanced. The tendency at the present time is to reduce this figure, and in ecent three- and four-cylinder engines it has been as low as 40 per cent. The revolving parts evelop centrifugal force, the horizontal component of which disturbs the engine longitudinally, o which must be added that due to the momentum of the reciprocating parts: also, these two orces produce a sinuous motion by acting first upon one side of the engine and then on the other. he vertical component of the centrifugal force generates a rolling motion by acting alternately pon each side of the engine. A peculiar effect is also produced by the obliquity of the connecting- od to the slide bars, a turning upon a horizontal axis, together with an up-and-down movement t the crank axle. The horizontal forces are the most injurious, although some American engineers onsider the vertical to be so; but English practice is to take a medium course between excessive orizontal and vertical disturbing influences. It has been clearly demonstrated that high centres f gravity are advantageous.

When of outside type, balance the balance weight by means of the moving parts on one side nd a small weight, at the same angle from the balance weight, in the far wheel.

For inside cylinder engines place a balance weight in each wheel inversely proportional to he distance from the cylinder and diametrically opposite the crank. Thus there are two ounterweights in each wheel, but these are combined to form a single balance weight, usually f crescent shape.

American practice is to allow 1/400th part of the engine weight to remain unbalanced in the eciprocating parts on each side. The remainder is then divided amongst the coupled wheels; r,

$$r = \left(R - \frac{W}{400}\right)/N,$$

here,

r = reciprocating weight in each wheel at crank pin radius; R = total weight of reciprocating arts; W = weight of engine in working order; and N the number of coupled axles.

Cast steel wheels have the balance weights cast solid with them; occasionally the weights ave pockets cored out for the reception of lead. Another practice is to cast the wheels without eights and to rivet steel plates to the spokes. Molten lead is then run into the pockets formed etween the spokes.

In order to obtain uniformity of results, some railways make use of a wheel-balancing machine. he pair of wheels to be tested is mounted on bearings supported by springs set radially round hem. Weights are attached to the crank pins to represent the revolving and a proportion f the reciprocating parts. The wheels are then spun round at high speed and the counterbalance djusted until steady running is obtained.

Boilers.

Locomotive boilers should have a factor of safety of 5: considerations of weight make a arger factor undesirable. The copper fire-box stays should not be stressed greatly in excess of ,000 lbs. per square inch, as copper loses much of its tensile strength at the steam temperature, hile steel is not greatly affected (see pp. 281, 283).

Coned boiler barrels, although more costly, are adopted by some railways in order to obtain he most powerful boiler for a given weight, by the reduction in diameter at the front end, while llowing ample space by reason of the larger diameter in the region of the fire-box tube plate, here steam generation is at a maximum.

Some railways prefer the 'Belpaire' type of fire-box, while others adopt the round top with irect crown stays. In British practice the long narrow fire-box is almost universal. The naximum length practicable is about 10 ft. 6 ins., giving a grate area of some 30 sq. ft. For arger grate areas the wide fire-box is adopted in American practice, permitting of 70 sq. ft. or nore, but it necessitates the addition of a small pair of carrying wheels.

Grate Area and Heating Surface.

Grate area in square feet $= \frac{\text{average I.H.P.}}{30}$. Total heating surface should be not less than 60 × grate area, and at least 10 per cent. of this should be in fire-box.

The ratios giving the best results are as follows:—Grate to total heating surface, 1 : 55 to 65; grate to fire-box heating surface, 1 : 5 to 5·5; and fire-box heating surface to total heating surface, 1 : 11 to 12.

Bituminous coals require space in the fire-box for the proper combustion of their gases before entering tubes. The fire-box volume should be 6 or 7 cubic feet for every square foot of grate. Under these conditions 15 lbs. of air are needed for each pound of coal burnt. The air spaces through fire-bars should not be less than 33 per cent. of grate area, and the damper opening not less than 15 per cent. Air spaces of 50 per cent. and damper opening 20 per cent. are not too large. In coupled engines, where an axle comes close under the grate the slope of pan over it should be not less than 45°; and the restricted space for air between pan and fire-bars must have an area of at least 15 per cent. of the part of the grate which it supplies.

Fire-bars are of wrought iron or cast iron, and usually $\frac{3}{8}$ in. wide at top. Gaps of $\frac{3}{8}$ in. to $\frac{1}{2}$ in. between these give an air space of 30 per cent. to 40 per cent. of the grate area.

Boiler Tubes.

Diameter and Length of Tubes.—The diameter of tubes varies with the length of barrel. Short barrels require 1½ in. to 1⅝ in. outside diameter tubes; those over 10 ft. long, 1¾ in. to 1⅞ in. tubes. Long barrels, 13 ft. and upwards, require tubes 2 ins. to 2¼ ins. diameter.

Thickness of locomotive boiler tubes (Caledonian Railway), 5-in. superheater flue tubes, No. 8 W.G.: 1¾-in. tubes, No. 11 W.G.

British Standard.—For 1⅝ in. outside diameter, 13, 12 or 11 s.w.g.; for 1¾ in., 1⅞ in., and 2 ins., 12, 11 or 10 s.w.g.; for 2¼ ins., 11 or 10 s.w.g.

Water space between tubes should not be less than $\frac{5}{8}$ in. for 1½ in. diameter tubes, and ¾ in. for 2¼ in. tubes at the fire-box end, but may be pitched $\frac{1}{16}$ in. closer to the smoke-box.

Life of Boiler Tubes.

The life of copper and steel tubes in locomotive boilers, taken over a period of eight years is as follows:—

	Miles.
Copper 1st period (new)	110,000
„ 2nd period (drawn)	80,000
„ 3rd period (pieced)	50,000
Total	240,000

Subsequently 30 to 40 per cent. of those pieced are treated so again.

	Miles.
Steel 1st period (new)	70,000 to 80,000
„ 2nd period (pieced)	30,000 to 40,000

(*G. Hughes.*

Calculation of the Heating Surface of Boilers for Locomotives.

The Association of Railway Locomotive Engineers' method of calculating the heating surfaces of locomotives is as follows:—

Fire-box.—The outside (wetted surface) of inner fire-box plates to be taken to top of foundation ring. Areas of tube-holes and sectional area to wetted side of fire-hole ring, or flanged plate, as the case may be, to be deducted; section of fire-hole being taken close up to the inner fire-box plate.

No deductions to be made for copper stays or roof stays. If the boiler has fire-box water tubes the surface to be taken on the inside (wet side) of tube.

Tubes.—The outside surface of tubes (wet side) to be taken, calculated on uniform diameters for both ordinary and superheater tubes; the length of tube being taken between tube-plates.

Elements.—The inside surface (steam side) of elements to be taken, the effective length of tube being from and to smoke-box end of large flue tube.

Smoke-box tube-plate.—No allowance to be made.

Equivalent heating surface of superheaters—In order to compare the steaming capacities of superheater and non-superheater boilers, an equivalent heating surface is sometimes given for the superheater boiler, as owing to the lesser evaporative surface of the tubes, it appears less powerful. If 1·5 times the superheater surface is added to the evaporative heating surface, an equivalent heating surface is formed, which may be compared with that of a non-superheater boiler. Thus, a non-superheater boiler has 2,455 sq. ft. of heating surface, but when converted to superheater has 2,031 sq. ft. of evaporative heating surface and 460 sq. ft. of superheating surface. The addition of 1·5 times the superheating surface to the evaporative gives a total of 2,721 sq. ft., and indicates that the boiler is 11 per cent. more powerful when superheated.

Fire-Boxes.

Many attempts have been made to substitute steel for copper plates in fire-boxes of British locomotives, but the results have not been very successful. Steel fire-boxes are universal in

merica, where conditions favour their adoption. Greater success had attended the introduction of steel side stays for copper fire-boxes. Owing to the higher tensile strength the diameter over threads is about $\frac{5}{8}$ in. for a pitch of $3\frac{1}{2}$ ins. The stay projects through the fire-box casing plate about $\frac{1}{2}$ in., but the projection through the copper plate is furnished with a hexagon nut of reduced thickness. This forms a renewable head for the stay and protects it from injury by the fire.

With the very high pressures now being used in America, the flat plates have given place to fire-box walls formed of steel tubes set closely together and expanded into drums, top and bottom, connected to the boiler barrel. A casing round the outside completes the fire-box.

In locomotive practice a pitch of about 4 ins. is almost invariably adopted for the screwed stud stays in the fire-box. Theoretically this is much closer than is necessary, but the practice is good, as it provides a substantial margin of wear in the copper plates.

Life of Fire-boxes.

The life of fire-boxes depends more upon the tons hauled than the actual miles run. Copper fire-boxes on the Lancashire and Yorkshire section of the L.M. & S.R. have a life of from 10 to $6\frac{1}{2}$ years. The older engines with 140 lbs. pressure are found to run their fire-boxes up to as much as 500,000 miles: an average figure for 70 engines being 310,000 before replacement by new ones. In standard engines, such as the radial tank and 6-wheeled coupled goods classes, working at 160 lbs. pressure, the average life of a copper fire-box is eleven years, with average mileages of 272,000 and 235,000 respectively. These figures are based upon records of 120 locomotives. Individual copper tube-plates in the fire-boxes above named require renewing during the life of the box. In the radial tank class, records of 53 tube-plates show an average life of seven and three-quarter years with 205,000 miles before renewing, whilst the 6-wheeled goods average 135,000 miles for 144 tube-plates. The remaining plates, viz., door and wrapper plates, practically do not require replacing during the life of the fire-box, but certain repairs and patches are fitted if necessary.

Smoke-boxes.

In superheater engines the blast pipe is set some 30 ins. forward of the tube-plate, to allow ample room for the superheater header, and the orifice is about 7 ins. below the centre line of the boiler, but this figure varies considerably. The blast pipe should not be too low or there is risk of cinders being drawn into it. The diameter of the orifice should be as large as possible consistent with good steaming. For cylinders 16 ins. to 22 ins. diameter, the orifice varies from $\frac{1}{2}$ ins. to $5\frac{3}{8}$ ins., 5 ins. being usual with a 19-in. cylinder, but a good deal depends on class of coal, work performed, and other conditions.

Chimneys are made as high as load gauge permits, and are extended downwards into the smoke-box. The main consideration as to dimensions is that a cone of steam diverging from the blast pipe orifice with a total angle of 1 in 6, should just pass clear through the top of the chimney, leaving a small annulus for the gases. The chimney should be slightly tapered and terminate in a bell, so that gases may be gradually entrained and increased in velocity.

In American practice a diaphragm is fitted across the smoke-box above the top row of tubes and carried down just below the blast-pipe orifice, terminating a little in front of it. By this means the draught on the tubes is equalised and the emission of sparks prevented. Some British engines are also fitted with this device.

The smoke-box vacuum obtained in modern superheater engines varies with the horse-power, and is about 5 ins. of water, with a maximum of 7 ins., in heavy passenger work, and about half these amounts for superheater goods engines.

Regulators.

The Hulburd 'Servo' Type Locomotive Regulator.

(*Hulburd Patents, Ltd.*, 28 *Park Road North, Acton, London, W.*3.)

In this arrangement a small auxiliary valve only is operated by the operating lever. The main valve, which is without mechanical connection with the operating lever, is *moved exclusively by the action of the steam* and in strict conformity with the spindle motion.

As the small resistance of the throttle may be overcome without effort with a short operating lever, the regulator is made with a comparatively *long spindle stroke* contrary to all other types of regulators. This long stroke permits the slots in the lantern to be shaped so that the quantity of steam which is admitted to the steam chests *increases gradually* during the greater part of the spindle stroke. The pressure in the steam chests will therefore increase rapidly only towards the end of the stroke until perfect balance with the boiler pressure has been attained. This feature of the regulator, it is claimed, results in even the longest trains being started quietly and without loss of time, whilst jerks are absolutely eliminated; also it is claimed that 'Priming' is eliminated, even with a high water level.

Superheaters.

The superheater of a locomotive boiler performs two functions. In the first place, it acts as a steam drier by evaporating the moisture carried over with the steam to the cylinders. Secondly, the dried steam is heated some 200°–400° F. above its normal temperature at the working pressure, and a volumetric increase occurs. By superheating the steam, not only is the loss due to moisture avoided, but initial condensation in the cylinders is eliminated or greatly reduced. Losses due to leakage are also less. The expansion line of indicator diagrams taken from cylinders using

superheated steam show a more rapid fall of pressure than with saturated steam. On the other hand, the compression line is also lower, showing less back pressure, so that there is little difference in the mean effective pressure to that of cylinders using saturated steam at the same initial pressure and cut-off. The orifice of the blast pipe with a superheater engine needs to be about $\frac{1}{8}$ in. smaller as the weight of steam discharged in a given time is less than in saturated steam engines. The chief gain due to superheating the steam to a final temperature of about 650° F. results in a saving of from 15 to 25 per cent. in fuel and 20 to 30 per cent. in water. The steam consumption of saturated engines is approximately 27 lbs. and coal consumption 4 lbs. per i.h.p. The corresponding consumptions of engines superheated about 200° F. are reduced to 19 lbs. of steam and 3·0 lbs. of coal per i.h.p.

Boiler repairs are also less, due to smaller demand for steam and lower rate of combustion of fuel. In some cases the working pressure is reduced, larger cylinders being used on account of the increase in volume of steam due to superheating. Engines fitted with superheaters can run longer distances without replenishing water and fuel supply. This is particularly advantageous in the case of tank engines, where the supplies of both are limited. The superheater adds little or nothing to the starting power of an engine, but it enables a larger horse-power output to be maintained, and consequently the hauling power is increased when running. Engines which had become obsolete on account of the growth of train loads have been given a new lease of useful life by the addition of a superheater. In some cases it has been successfully applied to engines with flat unbalanced slide valves between the cylinders, the only alteration being the provision of new tube plates for the superheater flues. A moderate degree of superheat does not appear to affect bronze valves provided great care is taken with the lubrication. Either a mechanical force-feed or a sight-feed displacement lubricator can be used, but the lubricant must be of first-class quality. With piston valve engines, the chief trouble is the formation of carbon deposit. This clogs the packing rings, chokes the ports and coats pistons, covers valve heads and spindles, etc. When steam is shut off, the pumping action of the main pistons, when running, draws smoke-box gases, dust, and ashes down the blast pipe, and solids adhere to the oily surfaces. Some decomposition of the oil also occurs. This action can be considerably lessened by (1) putting the reversing lever into full gear when steam is shut off; (2) by the provision of air valves to automatically admit air to the steam chests and destroy any vacuum created; (3) by automatic by-pass valves which put the opposite ends of the cylinder in communication when steam is shut off. Another practice is to admit a very small quantity of steam, either through the regulator or by means of a special valve. By filling the spaces with steam instead of air, decomposition of the oil is prevented.

Fire-tube Superheaters are principally employed. Several rows of large fire tubes are fitted in the boiler, and into these superheating tubes extend from a header or headers in the smoke-box towards the fire-box and back again. The construction of the header varies, as well as the arrangement of tubes, but the object in all designs is to direct steam through small tubes exposed to hot gases direct from the furnace and supplying an extended steam path, so that while travelling at high velocity a considerable degree of heat is taken up by the steam.

The Swindon (used only on the Great Western Railway) and Vaughan-Horsey (previously fitted in Canada) designs are of this class, with their own constructional features, and both are designed for a moderate degree of superheat. The Schmidt design aims at a high superheat—from 250° to 530° F above the temperature of saturated steam. It consists of a suitable header or steam collector, to which are attached four-fold elements. This provides a long steam path, and in virtue of the high steam velocity it is able to take up the required heat.

To obtain superheated steam of from 625° to 675°, the net gas area through flue tubes should be approximately 51 per cent. of the whole.

In conjunction with some fire-tube superheaters a damper mechanism operated by an automatic steam cylinder was fitted so that the passage of furnace gases through the apparatus was prevented when steam was not being used. In some cases this was hand operated, so that the dampers could, if desired, be kept open during shunting, and like operations, to maintain the superheat. The provision of dampers or draught retarders is no longer considered essential.

Some railways fit snifting or anti-vacuum valves on the top of the smoke-box. When an engine is drifting with steam shut off, air is drawn from the valves through the superheater elements, and prevents overheating. At the same time the air is heated before coming in contact with the valves, and thus reduces the risk of the valve liners becoming loose by contraction from sudden cooling.

'M.L.S.' SUPERHEATERS.

(The Superheater Company, Limited, London and Manchester; 'Schmidt' and 'Robinson' Superheater Patents.)

The headers or collectors of this apparatus are all made of cast iron of a special semi-steel mixture, giving a tensile strength of not less than 28,000 lbs. per sq. in., and are situated in the smoke-box.

The elements, fig. 8, are of double loop type, giving a four-fold steam path; they are made from solid cold-drawn steel tubing, and the three return bends on each element are formed by the 'M.L.S.' Integral Machine Forged Return Bend Process, by which these bends are made integral with the tubing itself, and all electric and oxy-acetylene welding eliminated, thereby prolonging the life of the element and ensuring a clean smooth finish both internally and externally.

FIG. 8.—'M.L.S.' Ball Joint Element.

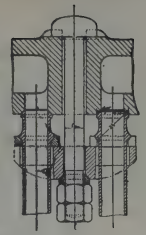


FIG. 9.—'M.L.S.' Ball Joint.

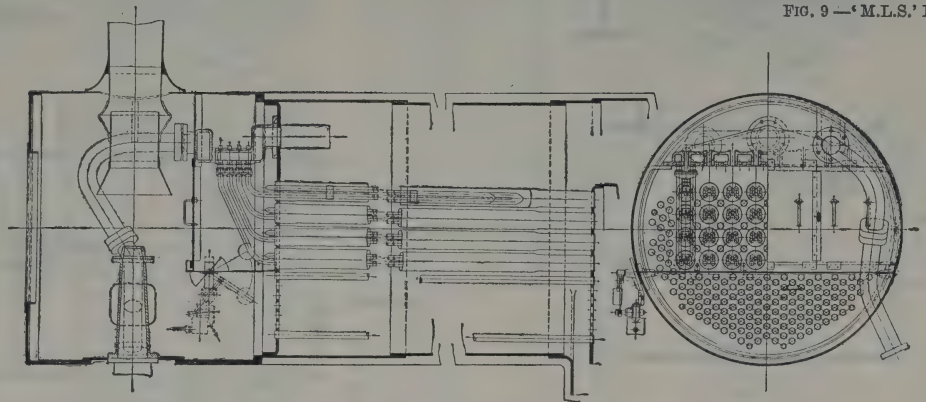


FIG. 10.—'M.L.S.' Through Bolt Header, Type 'A.M.,' with Ball Joint Attachment.

THE 'M.L.S.' SUPERHEATER.

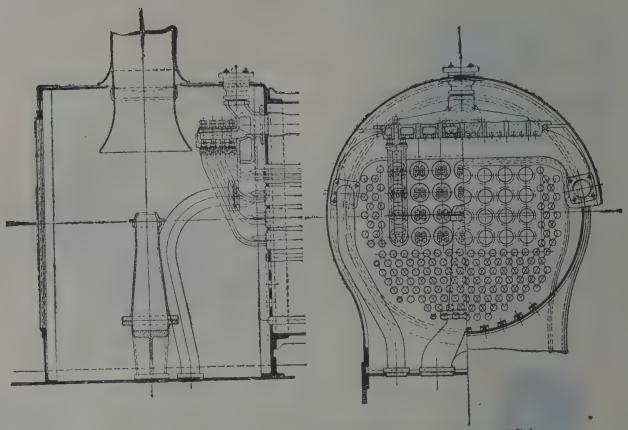


FIG. 11.—'Stirling' Through Bolt Header, Type 'AS.'

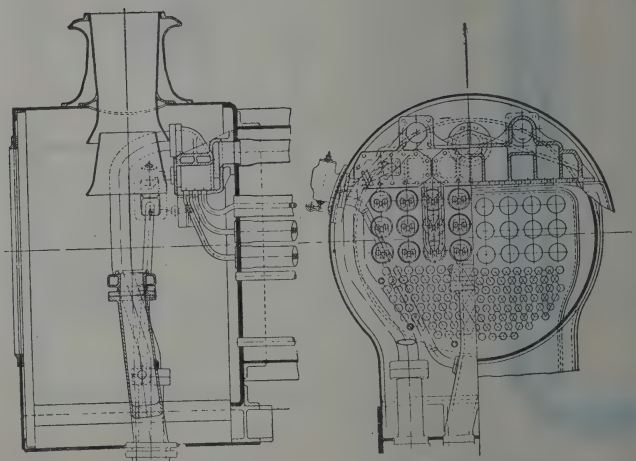


FIG. 12.—'Robinson' Expanded Joint Header, Type 'AR.'

Where elements are supplied having the ball joint attachment, fig. 9, the ball end is also de integral with the tube itself by upsetting the tube, thus avoiding any welding. It is afterrds turned and ground to gauge, having a diameter of 2⅛ ins.

Where bolts are required for the joint, these are supplied in high tensile steel having a tensile engtth of not less than 50 tons per sq. in. with a yield point of 35 tons per sq. in., so eventing the possibility of stretching when screwing up.

Other details, such as clamps and washers, are all made from drop forgings, which ensures nd material and maximum strength.

All elements are fitted with one or more steel bands and supports of robust construction, so anged on the elements that the latter are properly positioned in the flue tube and at the same ne reducing the obstruction to the flow of gases to a minimum.

Through Bolt Header, Type 'A.M.'

In this design of header, fig. 10, the casting is divided into transverse compartments or ckets communicating alternately with the saturated and superheated steam passages which e situated longitudinally at the back and front of the header respectively. Air passages which : as insulating spaces between these compartments are utilised for housing the element clamp lts, the 'T' heads of which lie in a horizontal plane above the header, the nuts being below, if desired the bolts may be used with their heads bearing upon the element clamp and the ts on the top of the header. The ball joint attachment is almost universally fitted with this pe of header, and is shown in fig. 10. As will be seen, any element can be easily withdrawn thout removing the bolt.

'Stirling' Through Bolt Header, Type 'AS.'

This header, fig. 11, has similar insulating passages between the compartments or pockets. this case, however, the saturated and superheated passages are arranged one above the other the back of the header with communicating compartments or pockets at right angles. The ts or insulating passages, in addition to allowing for independent expansion of the compartment lls, are utilised for housing the clamp bolts with nuts either on top of the pockets or below the mps as desired. It will be observed that to withdraw the element it is merely necessary slacken the nuts, after which the bolt will slide out of the insulating space as the element is thdrawn, without having to remove the bolt from the clamp.

This type is very extensively fitted in India and the Colonies in conjunction with the ball nt attachment.

'Robinson' Expanded Joint Header, Type 'AR.'

This type of header, fig. 12, is designed to allow the superheater element inlet and outlet ends ing expanded directly into the bottom wall, instead of being connected by bolts, nuts, flanges, . There are two longitudinal chambers, one for saturated steam at the back of the header, d one for superheated steam at the top, and these chambers open out alternatively into saturated d superheated steam compartments.

The latter are open at the front of the casting to permit of the introduction of tools for expand- and extracting the elements. Front cover plates, secured by studs and nuts, are provided r closing these openings.

The Weir System of Boiler Feeding and Feedwater Heating.

In this system, fig. 12A, the boiler feeding is carried out by means of a direct acting steam mp, B. The discharge side of the pump is connected through J to a surface heater, A, special design. The heater is arranged in any convenient position on the locomotive, and es part of the exhaust steam from the blast pipe, this steam passing to A through a pipe, D, hich is teed off from the blast pipe. The heating steam impinges on the outside of the heater bes. The orifice of the blast pipe is not altered in fitting the heater connection, so that the ective exhaust area is substantially increased with consequent reduction in back pressure on e engine.

The pump, B, has double acting steam and water cylinders. The suction and delivery valves r both ends of the water cylinder are arranged within the casing in front of the pump. Steam the cylinder passes through H, and is controlled by a Weir piston valve chest. No drain valves e provided on the steam cylinder, as the pump will start from cold, even with the cylinder ll of water of condensation. Plugs are fitted, however, on the steam cylinder, the steam valve est, the water valve chest, and the pump cylinder, and may be utilised when it is considered ecessary to empty the system.

While the vertical type of pump is usually adopted special circumstances may arise in which e use of a horizontal type is more convenient; and to meet these cases the larger sizes of mps are designed on the horizontal pattern.

In the design of the heater, strength and simplicity with ready facilities for inspection are ecial features. A rectangular shell of cast iron forms the steam space, with branches for the lmission of the exhaust steam, and a connection for draining the condensed water. The tube ates are fixed to the ends of the shell by collar bolts, which also carry the end covers. The tter are provided with ribs which divert the feed water through the various passes of the eater. The tubes are of heavy solid drawn copper, and are so expanded into the tube plates at they form strong and reliable joints under all conditions.

THE WEIR SYSTEM OF BOILER FEEDING AND FEEDWATER HEATING.

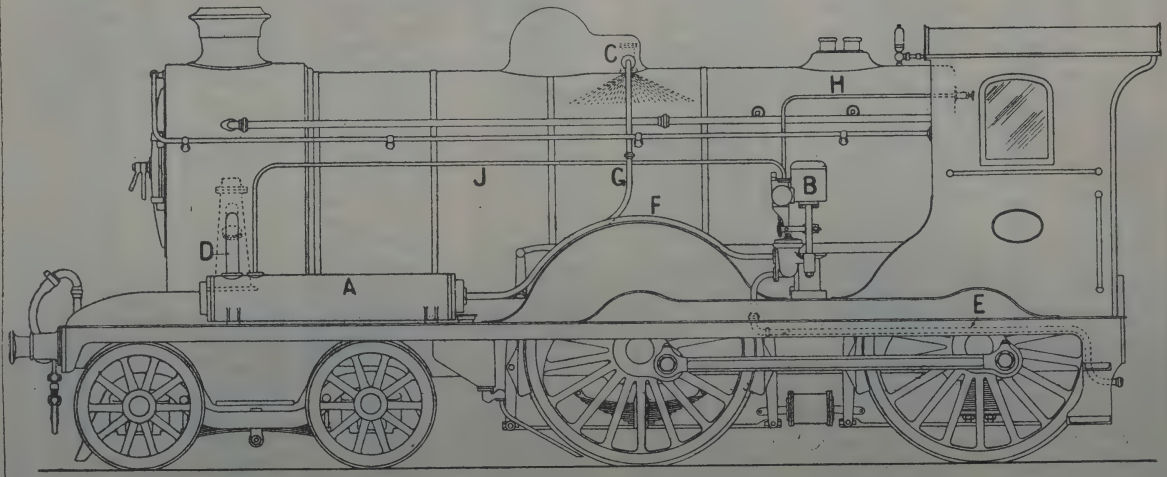


FIG. 12A.

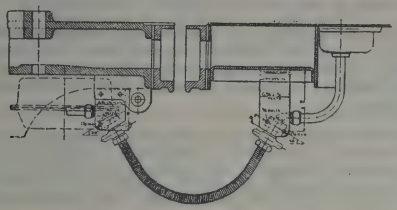


FIG. 13.—Feed Water Connection.

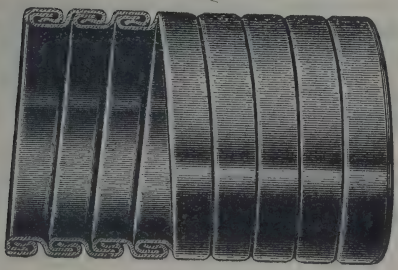


FIG. 14.—Section of Flexible Metallic Tubing.
(*United Flexible Metallic Tubing Co. Ltd.*)

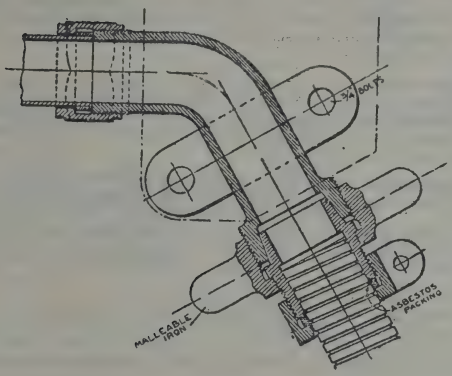


FIG. 15.—'Ball and Socket' Joint.

The feed water, after traversing the heater tubes, passes through G directly into the stea space, through a special spraying valve, C, situated on the top of the boiler. By this mea the feed water reaches the water surface in the boiler at practically the steam temperatu and secures increased efficiency and decreased upkeep of the boiler, due to the uniformity temperature maintained. Where chalky waters are in use, the heating of the feed water the steam temperature has also a pronounced effect on the character of the deposit; this tak the form of a fine sludge, which may be readily washed out. Both pump and heater are neat and compact design, the installation occupies very little space and is in no way obtrusi on the locomotive. The fitting of the gear is, moreover, simple, as it involves no serious alter tions in design or structure.

It is claimed that by the system, with feed-water temperatures below 60° F. in the tend and with any type of locomotive, saturated or superheated, a definite fuel economy of not le than 10 per cent. for the same locomotive duty is obtained, or for the same fuel consumpti an increase of 10 per cent. in the evaporative power of the boiler; the feed pump gives a degr of feed flexibility and reliability which is not obtainable with injector feeding.

Hulburd's Seamless Soft Copper Jointings.

(*Hulburd Patents, Ltd.*, 28, *Park North Road, Acton, London, W.* 3.)

These copper jointings are made from pure copper, and are absolutely seamless. Unl thin corrugated stamped metal jointings, they require no red lead or other filling, but placed between the flanges just as they are, and make an absolutely metal to metal joi under no conditions do they stick to the faces of the flanges; they are practically in structible, as they may be used over and over again, and the joints made with them can broken as often as desired; cases are known in which the same jointing has been used as ma as eighteen times.

The jointings, which are made to any size and shape, will stand any known pressure, a are standard equipment on all the largest railways in the world in connection with cylind valve chests, boiler domes, safety valve seatings, manhole covers, cleaning doors, and sup heater elements, etc., and all classes of pipe work.

There is no record of a single failure where the jointings have been used.

Flexible Metallic Tubing.

On the locomotive, an essential fitting is the feed-water connection between the engine the tender, fig. 13 (p. 701), this connection allowing any surplus steam from the boiler to used to heat the feed water in the tender. Fig. 14 shows Flexible Metallic Tubing (*The Un Flexible Metallic Tubing Co.*) which is specially suitable for the purpose, as rubber connecti will not withstand the heat.

Flexible Metallic Tubing is also used for carriage heating, and being much stronger lighter than rubber hose it will stand the full boiler pressure if the reducing valve fails, pressure at the carriages being only about 40 lbs., whereas the boiler pressure is probably 200 The tubing when exposed to cold is in no way affected, even should any accumulation of w in the pipes be frozen solid.

With this Flexible Metallic Tubing there is no possibility of the drain valves of the coupl being stopped up by anything wearing or blowing off the interior of the tubes.

The 'Ball and Socket' joint, fig. 15 (designed by the locomotive engineer of the former Lan shire and Yorkshire Railway), when fitted to the tubing, gives great flexibility. The asbe ring, upon which the 'ball' rests in a measure, allows the ball joint to be flexible when un steam pressure.

The tubing is manufactured in various lengths, and in sizes from ⅛ in. to 12 ins. inte diameter, and to resist pressures from 20 lbs. to 4,000 lbs. per sq. in.; it has been largely u in the place of rubber hose on account of its great strength, flexibility at all temperatures, liability to the attacks of vermin or insects, and that it remains indestructible by great h oils, or grease.

Flexible Metallic Tubing is specially suitable for tropical climates, as the sun's rays hav effect upon it, whether 'in stock' or in use.

Injectors.

Table showing Maximum Delivery of Combination Injectors.

allons per hour working on dry steam, with feed water at 60° F., lifting 3 ft. and delivering against pressure equal to steam at back of nozzle.)

ize.	Boiler Pressure in lbs. per Square Inch.							Size of Pipes.			
	60	90	120	150	180	210	225	Steam.	Water.	Out-flow.	Deliv-ery.
								Ins.	Ins.	Ins.	Ins.
6	550	670	780	870	840	800	790	1	1¼	1¼	1¼
7	750	920	1,070	1,190	1,140	1,090	1,080	1	1⅜	1⅜	1⅜
8	980	1,200	1,400	1,550	1,490	1,420	1,410	1½	1½	1½	1½
9	1,240	1,520	1,770	1,970	1,880	1,800	1,790	1¼	1¾	1¾	1¾
10	1,530	1,880	2,180	2,430	2.330	2,220	2,200	1½	1⅞	1⅞	1⅞
11	1,850	2,270	2,650	2,940	2,820	2,700	2,670	1½	1⅞	1⅞	1⅞
12	2,200	2,700	3,150	3,500	3,350	3,200	3,150	2	2	2¼	2¼

(*J. N. Gresham*, '*Jour. of Inst. of Loco-Engineers.*')

Metcalfe's Patent Exhaust Steam Injector.

The simplest method of using exhaust steam for feed-water heating is by an exhaust steam jector. A saving of 10 to 15 per cent. of coal, and 12 to 15 per cent. of water is claimed.

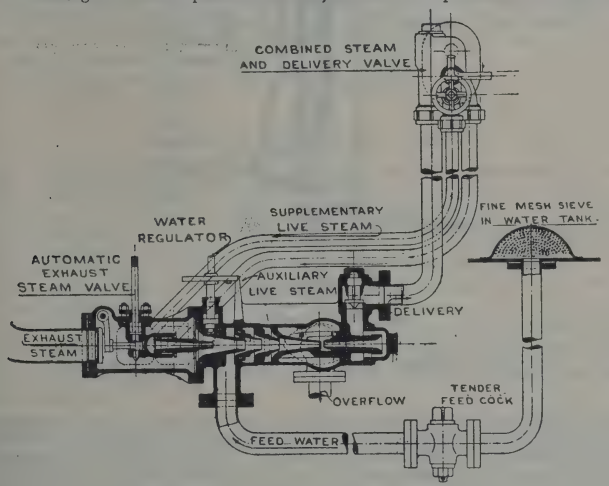


Fig. 16.—'Metcalfe' Patent Exhaust Injector (F. Type).

he 'F' type Metcalfe Patent Exhaust Injector is capable of working on exhaust steam lone against boiler pressures up to 150 lbs. per sq. in., and with the aid of a small jet of supple-ientary live steam it can feed against 300 lbs. pressure. The temperature of feed water delivered

to boiler varies from 200° to 220° F., depending on exhaust steam pressure. The amount of supplementary live steam is very small and does not exceed 2½ per cent. of evaporation of boiler. The water regulator, which slides the cone, can be adjusted so that the injector is kept continuously at work throughout the run, and will maintain a constant water level and steam pressure. By the introduction of very hot feed water the steaming power of the boiler is extended and the stresses in the plates, due to unequal contraction, are reduced. When the engine regulator is shut and the flow of exhaust steam ceases, the injector can be kept at work by the admission of a small quantity of live steam to take its place : this is termed auxiliary steam. The exhaust steam is conveyed from the cylinders to the injector by means of a large pipe. After leaving the cylinders the steam passes through a simple form of grease separator, consisting of a sleeve covered with Turkish towelling. Greasy water is discharged through an automatic drip valve.

In the latest ' H ' type, the operation of the injector is entirely automatic upon the opening of the steam valve. The admission of steam opens the water valve and exhaust steam inlet, and these automatically close when the steam valve is shut. If the regulator is closed so that there is no exhaust from the cylinders, an auxiliary supply of live steam is automatically given in place of the exhaust when the injector is at work.

A size 10 injector will deliver a maximum of 2,300 gallons of water per hour, and this can be reduced by the water regulator to a minimum of 1,380 gallons per hour (working continuously).

Gresham's Patent Hot Water Combination Injector.

These injectors, fig. 17, work with either hot or cold water in the usual way, *i.e.* by opening the steam valve and water cock, and then regulating the water cock if necessary.

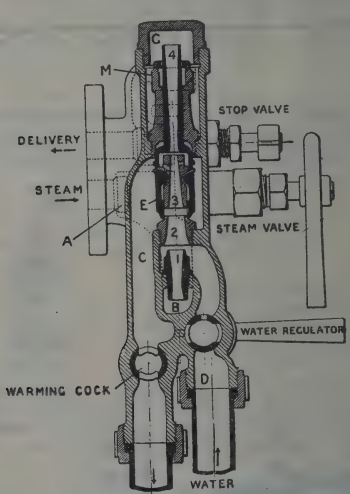


FIG. 17.—' Gresham ' Patent Hot Water Combination Injector.

An internal steam pipe from the dome of the locomotive conveys steam to the injector steam valve A, which, being opened, admits steam to the steam nozzle 1 by the passage B. The steam issuing from the steam nozzle opens the two side flaps E, it also lifts the sliding delivery cone 4 making an aperture at M and passes out freely down the overflow pipe. In doing so it creates a partial vacuum in the water pipe D, and the water rises to the injector. The water then coming in contact with the steam travels with it through the lifting cone 2, and, in condensing, it creates a vacuum which closes the two side flaps E, thus preventing any air entering the cones. The velocity of the steam being now largely transferred to the water, the latter passes from the lifting cone 2 through the combining cone 3. After passing through this combining cone, the jet flows out of the aperture M and down the overflow pipe O until such time as it attains sufficient velocity to carry itself past this space and enter the delivery cone 4. When it reaches this

oint the jet is at its maximum velocity, and is so great that it is sufficiently powerful to lift he back pressure valve (not shown) and so enter the boiler. At the same time the pressure hus created in the chamber G forces the sliding delivery cone down on to its seat and closes the perture M, shutting in the water which otherwise would be boiled off when the injector is working vith water at 130° F. When the water is below 100° F. the injector will work dry with the perture M open, like an ordinary injector.

In order to heat the feed water, exhaust steam is conducted from the cylinders to the tender y a large pipe. This connects to a multi-tubular heater through which the feed water flows. The condensation of the steam gives up heat which is absorbed by the feed water, thereby aising its temperature.

BRITISH STANDARD SPECIFICATIONS FOR MATERIAL USED IN THE CONSTRUCTION OF RAILWAY ROLLING STOCK.*

(Report No. 24—1921.) (*Abstract.*)

Locomotive Crank Axles—B.S.S. 1.

The crank axles shall be manufactured from the highest quality of steel made from the best elected material by the acid open-hearth process. On analysis, the steel must not show more han ·04 per cent. of sulphur or of phosphorus.

The metal must show a tensile breaking strength of not less than 32 tons per square inch, vith an elongation of not less than 22 per cent. on Standard Test Piece C or D. The yield point n either case must be not less than 50 per cent. of the ultimate tensile strength.

A test piece 9 ins. long and 1½ in. square, with $\frac{1}{16}$ in. radius at the edges, machined from each rank axle, must withstand being bent cold by direct pressure from a tool 2 ins. wide, the end having a radius of 1 in., until the sides of the test piece are parallel. The ends of the test-piece are then to be brought together without fracture, by direct pressure.

As an alternative to the cold bend test, the test piece may be placed upon bearings having a clear span of 6 ins., resting on a solid foundation, and must withstand, without fracture, 20 blows from a weight of 1,120 lbs., having a rounded end of 1½ in. radius, falling 6 ins. The test piece shall be reversed after the first and every alternate blow. The fall shall then be increased to 12 ins., and the test continued until fracture occurs. Crank axles having flat or oval webs, test pieces to be taken from between webs. Crank axles having round webs, test pieces to be taken from end of axle.

All crank axles shall be either normalised or oil-treated.

Locomotive Straight Axles—B.S.S. 2.

Quality of material same as for locomotive crank axles, except that steel must not show more than ·05 per cent. of sulphur or phosphorus.

The axle shall be placed upon bearings resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand, without fracture, 5 blows from a weight of 2,240 lbs., falling 16 to 35 feet, according as the diameter is under 4 or over 6 ins., the distance apart of the bearings being from 3 ft. to 5 ft.

The axle shall be turned after the first and third blow, and shall be broken after testing, both in the centre and at the journals.

The metal must show a tensile breaking strength of 35 to 40 tons per square inch, with an elongation on Standard Test Piece C or D of not less than 25 per cent. with 35 tons, and 20 per cent. with 40 tons; the sums of the intermediate tensile breaking strengths and corresponding elongations being not less than 60. The yield point must be not less than 50 per cent. of the ultimate tensile strength.

A test-piece 9 ins. long and 1½ in, square, with $\frac{1}{16}$ in. radius at the corners, must withstand being bent cold by direct pressure from a tool 2 ins. wide, the end having a radius of 1 in., until the sides of the test piece are parallel. The ends of the test-piece are then to be brought together without fracture, by direct pressure.

N.B.—This test taken only when less number than 15 axles are ordered and falling weight test has not been carried out.

All axles shall be either normalised or oil-treated.

* By permission of the British Engineering Standards Association.

Locomotive Straight Axles—B.S.S. 2A.

The axles shall be manufactured from the highest quality of steel made from the best selecte material by the acid or basic open-hearth or acid Bessemer process. In the event of the basi hearth process being employed, the maximum percentage of sulphur and phosphorus must no exceed ·05 per cent. The tests are the same as previous specification.

Carriage and Waggon Axles—B.S.S. 3, B.S.S. 3A.

Same as for locomotive straight axles (B.S.S. 2 and B.S.S. 2A), except that range of fallin weight test is from 15 to 30 ft. for axles under 3¾ ins. to over 6 ins.

Locomotive Tyres—B.S.S. 4.

Quality of material same as for locomotive straight axles—B.S.S. 2.

The tyre shall be placed in a running position with the tread resting on a block of metal o not less than 5 tons weight supported on a rigid concrete or other solid foundation, and mus withstand, without fracture, blows from a falling weight of 2,240 lbs. The weight shall be allowe to fall freely on to the tread from heights of 10 ft., 15 ft., 20 ft., and upwards, until the defle tion of the tyre corresponds to that given in the following formula, in which d is the interna diameter of the tyre as rolled, in inches, and t is the thickness of the centre of the tread, a rolled, in inches. For tyres having an inside snip exceeding 1¼ ins. in depth, the calculate deflection shall be reduced by 5 per cent., and for tyres having an inside snip exceeding 1½ ins in depth, by 10 per cent.

Class C.—Tensile Breaking Strength 50 to 55 tons per square inch, and minimum elongation 13 to 11 per cent. (Standard Test Piece O).

$$\frac{d^2}{50\,t^2}$$

Class D.—Tensile Breaking Strength 56 to 62 tons per square inch, and minimum elongation 10 to 8 per cent. (Standard Test Piece O).

$$\frac{d^2}{55\,t^2}$$

Class E.—Tensile Breakin Strength 63 to 69 tons pe square inch, and minimu elongation 10 to 8 pe cent. (Standard Test Piec O).

$$\frac{d^2}{60\,t^2}$$

When so specified in the inquiry each tyre shall be allowed to drop freely in a runnin position, from the height specified below, upon a rail fastened to an iron block of not les than 2 tons in weight. Each tyre shall then be turned round through an angle of 90 degree and dropped a second time.

Internal diameter of tyre.	Up to 3½ ft.	Over 3½ ft. and up to 4½ ft.	Over 4½ ft. and up to 5½ ft.	Over 5½ ft. and up to 6½ ft.	Over 6½ f
Height of fall	5 ft.	4 ft.	3 ft. 6 ins.	3 ft.	2 ft. 6 ins

Carriage and Waggon Tyres—B.S.S. 5.

The specification is the same as for locomotive tyres, with the addition of Class B tyre tensile breaking strength 42 to 48 tons per sq. in. and minimum elongation 18 to 15 per cen

Formula for deflection $\frac{d^2}{45\,t^2}$.

Carriage and Waggon Tyres—B.S.S. 5A.

Material same as locomotive straight axles—B.S.S. 2A. Otherwise same as carriage an waggon tyres—B.S.S. 5—except that Class E is omitted.

Laminated Springs—B.S.S. 6.

The spring plates shall be manufactured from the highest quality of steel made from th best selected material by the acid open-hearth process. The steel must not show more tha ·8 per cent. nor less than ·5 per cent. of carbon, nor more than ·05 per cent. of sulphur or phosphorus. The steel for the top plates, which have to be welded at the eye, must not contai more than ·7 per cent. nor less than ·45 per cent. of carbon.

All finished springs shall be tested by being deflected by a quick-acting scrag before the buckle is put on, to an amount equal to $\frac{L^2}{900\,t}$, where L is the length of the top plate in inches measured along the arc as shown in fig. 18, and t is the thickness of the thickest plate in inches. They must then stand being deflected again three times in quick succession without showing any permanent set. The required deflections are shown in the table and must not be exceeded at any time during manufacture by more tha 15 per cent.

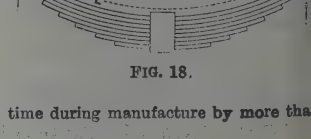


FIG. 18.

All plates shall be carefully hardened and tempered.

The buckles shall be made of good fibrous iron having a tensile breaking strength of from 20 to 24 tons per square inch, or of suitable steel having a tensile breaking strength of not more than 24 to 30 tons per square inch. The elongation in each case shall be not less than 20 per

L	Required Deflection under Scrag, in Inches.				
Ins.	$\frac{3}{8}$ in. plate.	$\frac{7}{16}$ in. plate	$\frac{1}{2}$ in. plate.	$\frac{9}{16}$ in. plate.	$\frac{5}{8}$ in. plate.
90	24	$20\frac{5}{8}$	18	16	$14\frac{3}{8}$
84	$20\frac{7}{8}$	$17\frac{7}{8}$	$15\frac{5}{8}$	14	$12\frac{1}{2}$
78	18	$15\frac{1}{2}$	$13\frac{1}{2}$	12	$10\frac{7}{8}$
72	$15\frac{3}{8}$	$13\frac{1}{4}$	$11\frac{1}{2}$	$10\frac{1}{4}$	$9\frac{1}{4}$
66	$12\frac{7}{8}$	11	$9\frac{5}{8}$	$8\frac{3}{8}$	$7\frac{1}{4}$
60	$10\frac{3}{8}$	$9\frac{1}{8}$	8	$7\frac{1}{8}$	$6\frac{3}{8}$
54	$8\frac{5}{8}$	$7\frac{3}{8}$	$6\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{1}{8}$
48	$6\frac{7}{8}$	$5\frac{7}{8}$	$5\frac{1}{8}$	$4\frac{1}{2}$	$4\frac{1}{8}$
42	$5\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{7}{8}$	$3\frac{1}{2}$	$3\frac{1}{8}$
36	$3\frac{5}{8}$	$3\frac{1}{2}$	$2\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$
30	$2\frac{3}{8}$	$2\frac{1}{4}$	2	$1\frac{7}{8}$	$1\frac{7}{8}$

cent. (Standard Test Piece A), and the material must admit of bending, when cold, without showing crack or flaw, as follows:—

For iron, $\frac{3}{4}$-inch thick through an angle of 120 degrees.
" $\frac{3}{4}$-inch " " 130 "
" $\frac{1}{2}$-inch " " 140 "
For steel, all thicknesses, through an angle of 180 degrees.

In all cases the inside radius of the bend shall be not greater than $1\frac{1}{2}$ times the thickness of the test piece.

Laminated Springs—B.S.S. 6A.

Same as specification B.S.S. 6, except that spring plates shall be manufactured from steel made from selected material by the acid or basic open-hearth or the acid Bessemer process. In the event of the basic open-hearth process being employed, the maximum percentage of sulphur and phosphorus must not exceed ·05 per cent.

Laminated Springs—B.S.S. 6B.

The spring plates and bars shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process, and must not show on analysis more than ·8 per cent. nor less than ·5 per cent of carbon, nor more than ·05 per cent. of sulphur or of phosphorus. The steel plates or bars to be used for top plates, which have to be welded at the eye, must not contain more than ·7 per cent. nor less than ·45 per cent. of carbon.

As a test pieces of steel 30 ins. long shall be cambered to a radius of eighty times their thickness, as shown below, hardened and tempered, and after being pressed straight once, and the camber carefully noted, must stand being pressed straight again six times in quick succession without any permanent set.

	Ins.	Ins.	Ins.	Ins.	Ins.
Thickness of plate . . .	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
Required camber . . .	$3\frac{1}{4}$	$3\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$
Minimum camber after first blow and the next six consecutive blows	$3\frac{1}{8}$	$2\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{1}{4}$	2

Laminated Springs—B.S.S. 6C.

Material for spring plates and bars same as B.S.S. 6A. Tests same as B.S.S. 6B.

Volute and Helical Springs—B.S.S. 7.

The springs shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process. The steel must not show more than 1·3 per cent. nor less than ·8 per cent. of carbon, and not more than ·05 per cent. of sulphur or of phosphorus.

Each spring shall be tested by being driven home once by a quick-acting scrag, the height being carefully noted after release. The spring must then stand being driven home again five times in quick succession without showing any permanent set. Up to 5 per cent. of the springs shall also be tested under varying loads to determine the range and deflection per ton.

All springs shall be hardened in oil and tempered in a bath of molten lead.

Volute and Helical Springs—B.S.S. 7A.

The springs shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth or the acid Bessemer process, and must not contain more than 1·3 per cent. nor less than ·8 per cent. of carbon.

Test same as B.S.S. 7.

Steel Forgings for Locomotives—B.S.S. 8.

The forgings shall be manufactured from steel made by the acid or basic open-hearth process.

The tensile breaking strength and minimum elongation on Standard Test Piece C or D to be as follows :—

Class.	Description of Forging.	Process of Manufacture.	Percentage of Sulphur or of Phosphorus.	Tensile Breaking Strength in tons per square inch.	Minimum Elongation per cent.
A	Special forgings which will be case-hardened	Acid or basic open-hearth	·05	Up to 27 tons	25
B	Ordinary forgings	Do.	·06	25 to 32 with	27
				32 with	20
C	Special forgings without wearing surfaces	Acid open-hearth	·05	32 to 38 with	25
				38 with	20
D	Special forgings with wearing surfaces	Do.	·05	40 to 45 with	20
				45 with	15
E	Boiler forgings	Do.	·05	26 to 32 with	28 to 22

The sums of the tensile breaking strengths and corresponding elongations must be not less than 52 for Classes A and B, 57 for Class C, 60 for Class D, and not less than 54 for Class E. In the case of Classes C and D the yield point must be not less than 50 per cent. of the ultimate tensile strength.

A test piece, 9 inches long and 1¼ inch square, or as near this size as the forging or forging selected will permit, with $\frac{1}{16}$ inch radius at the edges, machined cold, must without any reheating, withstand being bent cold by direct pressure from a tool 1½ ins. wide in the case of Classes A, B, and E, 1¾ ins. wide in the case of Class C, and 2½ ins. wide in the case of Class D, the ends having a radius respectively of ¾ in., ⅞ in., and 1½ ins., until the sides of the test piece are parallel. The ends of the test pieces of all classes of forgings, except Class D, shall then be brought together without fracture by direct pressure.

All forgings in Classes C and D shall be either normalised or oil-treated.

Steel Blooms for Locomotive Forgings—B.S.S. 9.

Specification and tests for Classes A, B C, D, and E same as for B.S.S. 8.

Test pieces cut from blooms may be normalised or oil-treated.

Steel Castings—B.S.S. 10.

The castings shall be manufactured from steel produced by an approved process, and must not show on analysis more than ·07 per cent. of sulphur or of phosphorus.

All castings shall be thoroughly annealed by heating to a temperature not less than the normalising temperature and allowing to cool slowly from the maximum temperature in a practically uniform manner.

The minimum tensile breaking strength and elongation on Standard Test Piece C or D to be as follows :—

Description of Casting.	Minimum Tensile Breaking Strength per square inch.	Minimum Elongation per cent.
Castings with wearing surfaces	35 tons	10
Other General Castings and Wheel Centres	26 tons	15

In the case of castings other than those with wearing surfaces, a test piece 9 ins. long, turned to 1 in. diameter, must withstand being bent cold through an angle of 90 degrees round a bar 2½ ins. diameter without fracture.

When wheel centres are tested to destruction, the test shall be made by dropping the wheel entre on to a block of metal of not less than 5 tons weight, supported upon a rigid concrete r other solid foundation. The wheel centre shall be raised and allowed to fall freely in a running osition through distances of 5 ft. and 10 ft. on the end of a spoke (where such exists), and then rned through 90 degrees and again raised and allowed to fall freely in a running position through istances of 5 ft. and 10 ft. on the end of a spoke (where such exists). Any sign of failure under is test will render the wheel centres liable to rejection. The test shall then be continued, he fall being increased 5 ft. each time until fracture results or the wheel centre is doubled up.

Copper Plates for Locomotive Fire-boxes.

(B.S.S. 11.—1924 of Report No. 24.)

The plates shall contain not less than 99·20 per cent. of copper, and shall contain not less han 0·30 per cent. nor more than 0·50 per cent. of arsenic.

Tensile breaking strength to be not less than 14 tons per square inch, with an elongation of ot less than 35 per cent. on Standard Test Piece A.

Pieces of the plate shall be tested both cold and at a red heat by the ends being bent through n angle of 180 degrees in opposite directions and doubled up close, without showing either rack or flaw on the outside of either bend.

Rolled Copper Rods for Locomotive Stay Bolts, Rivets, etc.

(B.S.S. 12.—1924 of Report No. 24.)

The rods shall contain not less than 99·20 per cent. of copper, and shall contain not less than ·30 per cent. nor more than 0·50 per cent. of arsenic.

Tensile strength to be not less than 14·50 tons per square inch, with an elongation of not less han 40 per cent. on Standard Test Piece B. For rods up to 1¼ inch diameter, the test shall be nade upon the unturned rod. For rods above 1¼ inch diameter, the rod may be turned down, when either Standard Test Pieces D or E shall be used, in which case the elongation shall be not ess than 45 per cent.

The rod shall, both when cold and at a red heat, withstand, without machining, being doubled p close without cracking.

A piece of rod 1 inch long shall be placed on end and hammered or crushed down when cold o a thickness of ⅜ inch without showing either crack or flaw on the circumference of the resulting lisc.

Extruded Copper Rods for Locomotive Stay Bolts, Rivets, etc.

(B.S.S. 12A.—1924 of Report No. 24.)

Tests the same as for B.S.S. 12.

Copper Tubes for Locomotive Boilers.

(B.S.S. 13.—1925 of Report No. 24.)

The tubes shall contain not less than 99·20 per cent. of copper, and shall contain not less than ·30 per cent. nor more than 0·50 per cent. of arsenic.

Tensile tests shall be made on pieces of tube or strips cut from the tube. If the test is made on a piece of tube, the tensile strength shall be not less than 14·50 tons per square inch, with an elongation of not less than 50 per cent. on 2 inches. If the test is made on a strip, the tensile strength shall be not less than 14 tons per square inch, with an elongation of not less than 40 per cent. on a test piece having a gauge length of four times the square root of the area.

The test piece shall stand bulging or drifting cold without showing either crack or flaw until diameter of bulged or drifted end measures not less than 25 per cent. more than the original diameter of the tube.

The test piece shall stand flanging cold without showing either crack or flaw until the diameter of the flange measures not less than 40 per cent. more than the original diameter of the tube.

The test piece shall stand the following test, both cold and at a red heat, without showing either crack or flaw. The test piece shall be flattened down until the interior surfaces meet, and be doubled on itself, that is, bent through an angle of 180 degrees, the bend being at right angles to the direction of the length of the tube.

Each tube shall be tested by an internal hydraulic pressure of 750 lbs. per square inch, or by such internal pressure as may have been specified.

Brass Tubes for Locomotive Boilers.

(B.S.S. 14.—1925 of Report No. 24.)

Brass for locomotive tubes may be of either 70/30 alloy or 2/1 alloy.

The tubes shall consist of an alloy of copper and zinc, and shall contain :—

70/30 Alloy.—Not less than 70 per cent. of metallic copper and not more than a total of 0·75 per cent. of materials other than copper and zinc.

2/1 Alloy.—Not less than 66·70 per cent. of metallic copper and not more than a total of 0·75 per cent. of materials other than copper and zinc.

The tubes shall be carefully annealed at both ends.

The test piece shall stand bulging or drifting cold without showing either crack or flaw until the diameter of the bulged or drifted end measures not less than 25 per cent. more than the original diameter of the tube.

The test piece shall stand flanging cold without showing crack or flaw until the diameter of the flange measures not less than 25 per cent. more than the original diameter of the tube.

The test piece when cold shall stand the flattening and doubling-over test applied to copper tubes, B.S.S. 13. Tubes to be tested by an internal hydraulic pressure of 750 lbs. per square inch or such internal pressure as may have been specified.

Weldless Steel Tubes for Locomotive Boilers.
(Report No. 53—1927).

The tubes shall be cold-drawn and weldless, and shall be manufactured from steel of the best quality made by the open-hearth process. They shall not show on analysis more than 0·035 per cent. of sulphur or more than 0·030 per cent. of phosphorus.

The tubes shall be sound, clean, smooth, and well finished, free from surface defects, rust, and longitudinal grooving, both internally and externally, and the ends shall be clean and square.

The tubes shall be carefully annealed throughout their length after the process of drawing and the ends shall be carefully annealed after the process of enlarging or decreasing the diameter.

The tubes shall be straight and cylindrical, of uniform thickness, concentric, and, unless otherwise specified, of uniform external diameter throughout. The tubes shall be of the dimensions specified subject to working margins, *on thickness*, plus one s.w.g. and minus half of one s.w.g. Where the tube is swelled or reduced an additional allowance for thinning or thickening the tube shall be allowed of 7½ per cent. under and over the specified thickness for swelled and reduced ends respectively. On *external diameter*, minus one per cent.; on *length*, plus one minus $\frac{1}{16}$ in. The actual weight of each tube shall not differ from the calculated weight by more than 5 per cent. above or 2½ per cent. below the weight calculated from the specified dimensions allowing 489·6 lbs. per cu. ft. of metal in the tubes.

The tubes or strips cut from the tubes shall, without further annealing, show a tensile strength of not less than 20 tons per sq. in., nor more than 26 tons per sq. in., with an elongation of not less than 28 per cent. in 8 ins. for tubes, and not less than 22 per cent. in 8 ins. for strips cut from the tubes. If strips are cut for testing from tubes over 2½ ins. diameter, they may be annealed before testing.

The tubes shall, when cold, stand bulging with a parallel drift (see fig. 19) without showing either crack or flaw, until the diameter of the bulged end exceeds the original diameter of the tube by not less than 15 per cent. for tubes under 11 s.w.g. in thickness and 12½ per cent. for tubes from 11 s.w.g. to 6 s.w.g. inclusive.

A piece of tube 2 ins. long shall be placed on end and shall, when cold, stand hammering down until it is reduced to 1¼ in. high without showing either crack or flaw.

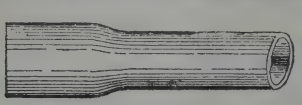


FIG. 19.

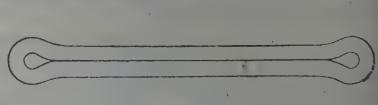


FIG. 20.

The tubes must, when cold, stand flattening without showing crack or flaw until the interior surfaces of the tubes meet, or, when the tubes are over 11 s.w.g. in thickness, until the interior surfaces are brought to a distance apart equal to the thickness of the wall of the tube (fig. 20).

Every tube shall be tested by an internal hydraulic pressure of at least 1,000 lbs. per sq. in.

Seamless Copper Pipes for Locomotives.
(B.S.S. 15—1925 of Report No. 24.)

The pipes shall contain not less than 99·20 per cent. of copper, and shall contain not less than 0·30 per cent. nor more than 0·50 per cent. of arsenic.

Tensile tests shall be made on pieces of pipe or strips cut from the pipe. If the tensile test is made on a piece of pipe, the tensile strength shall be not less than 14·50 tons per square inch with an elongation of not less than 50 per cent. on 2 inches.

If the tensile test is made on a strip cut from the pipe, the tensile strength shall be not less than 14 tons per square inch, with an elongation of not less than 40 per cent. on a test piece having a gauge length of four times the square root of the area.

The test piece shall stand drifting cold without showing either crack or flaw until the diameter of the drifted end measures not less than 25 per cent. more than the original diameter of the pipe.

Flattening and doubling-over test the same as for copper tubes, B.S.S. 13.

Tubes to be tested by such internal hydraulic pressure as may have been specified.

Steel Plates, Angles, etc., and Rivets for Locomotive Boilers.
(B.S.S. 16—1921 of Report No. 24.)

The plates, sections, and bars shall be manufactured from steel made from selected materials by the acid or basic open-hearth processes, as may be specified. The steel must not show on analysis more than ·05 per cent. of sulphur or of phosphorus.

When plates are required for flanging purposes it shall be so stated at the time of inquiry. Test pieces to be cut crosswise from rolled material in case of plates, and lengthwise in case of sectional material. When material is annealed or otherwise treated before dispatch, the test pieces shall be similarly and simultaneously treated with the material before testing. Any straightening of test pieces shall be done cold.

For plates, angles, etc., a Standard Test Piece A, and for round bars (other than rivet bars) a Standard Test Piece B, must show a tensile breaking strength of 26 to 30 tons per sq. in., with an elongation of not less than 22 per cent. When bars are above 1 in. in diameter and are tested full size as rolled, or have been turned down and the resulting test piece is above 1 in. in diameter, Standard Test Piece F may be used, in which case the elongation shall be not less than 27 per cent.

For rivet bars Standard Test Piece B must show a tensile breaking strength of 24 to 28 tons per sq. in., with an elongation of not less than 27 per cent. If tested on Standard Test Piece F the elongation shall be not less than 32 per cent. The bars may be tested the full size as rolled.

For both cold and temper bends the test piece must withstand, without fracture, being doubled over until the internal radius is not greater than the thickness of the test piece, and the sides are parallel.

Bend tests may be made either by pressure or by blows. For rivet bars temper bend tests only are required.

In all cold or temper bend tests the sheared edges may be removed by milling, planing, grinding, or other method. The cold bend test pieces shall not be annealed, unless the material from which they are cut is similarly annealed, in which case the test pieces shall be similarly and simultaneously treated with the material before testing.

For temper tests the test pieces shall be heated to blood red and quenched in water at a temperature not exceeding 80 deg. Fahr.

Tests for Manufactured Rivets.—The rivet shanks shall be bent cold, and hammered until the two parts of the shank touch, without fracture, on the outside of the bend. The rivet heads shall be flattened without cracking at the edges until the diameter of the head is 2½ times the diameter of the shank.

Steel Plates, Angles, etc., and Rivets for Locomotive Frames—B.S.S. 17.
(Report No. 24—1921.)

The plates, sections and bars shall be manufactured from steel made from selected material by the acid or basic open-hearth process. If the specification is *with analysis*, the steel must not show more than ·06 per cent. of sulphur or of phosphorus.

Plates must show a tensile breaking strength of 28 to 32 tons per square inch, with an elongation on Standard Test Piece A of not less than 20 per cent. for plates of ·375 in. in thickness and upwards, and 16 per cent. for plates below ·375 in. in thickness.

Sectional material must show a tensile breaking strength of 28 to 32 tons per square inch, with an elongation of not less than 20 per cent. on Standard Test Piece A or B, or 24 per cent. with Standard Test Piece F. For material under ·312 in. thick bend tests only are required.

Rivet bars must show a tensile breaking strength of 24 to 28 tons per square inch, with an elongation of not less than 27 per cent. on Standard Test Piece B, or 32 per cent. with Standard Test Piece F. Bars may be tested full size as rolled.

Cold and temper bend tests and tests for manufactured rivets same as B.S.S. 16.

Steel Plates, Angles, etc., and Rivets for Locomotive Frames—B.S.S. 17a.

Same as B.S.S. 17, but without analysis.

Steel Plates, Angles, etc., and Rivets for Carriage and Waggon Underframes—B.S.S. 18, B.S.S. 18a.

Specifications same as for locomotive frames, B.S.S. 17, B.S.S. 17a.

Wrought Iron.
(Report No. 51, 1913.)

Specifications are given for wrought iron, best Yorkshire and Grades A, B, and C. The tensile tests, etc., vary with the sizes of the different sections rolled.

Other Materials used in Locomotive Construction.

Iron Castings.—The tensile test is the most trustworthy; 7 tons per sq. in. is the usual specification; 8 and 9 tons may be demanded in reason and expected. General foundry iron up to 11½ and 12½ tons per sq. in. and cylinder iron up to 13½ and 14 tons per sq. in. are not unknown, each having good fractures, and being good workable foundry metal. The usual commercial test is generally made transversely upon bars 3 ft. long, 2 ins. deep, and 1 in. thick, without being machined, 25 to 32 cwts. being the specified central breaking load. The test bars should be cast by means of an attachment to the casting, and the specified ultimate loads should not vary more than 1 per cent.

(For further details see Section XL., 'Metallurgy.')

For *Bronze, Brass, White Metals, and other Alloys*, see Section XL.

Use of Materials made to British Standard Specifications.
(Report No. 24—1921 and 1925.)

No. 1.—Crank axles.

Nos. 2 *and* 2A.—Straight axles, locomotive and tender.

Nos. 3 *and* 3A.—Carriage and waggon axles.

No. 4.—Tyres for locomotive and tender. Class C is the most commonly specified.

Nos. 5 *and* 5A.—Carriage and waggon tyres. Class C for carriages and Class B for waggons are the most commonly specified.

Nos. 6 *and* 6A.—Laminated springs, purchased complete.

Nos. 6B *and* 6C.—Plates and bars for manufacturing laminated springs, spring wearing plates, flat springs.

Nos. 7 *and* 7A.—Manufactured volute and helical springs.

No. 8.—Steel forgings of Classes A to E (as below).

No. 9.—Steel blooms for making forgings. *Class A* is used for motion work and pins and other parts requiring to be case-hardened; spring hangers and links, brake work, draw bar, and safety links and pins, coupling screw and shackle, regulator rod, fire hole ring, foundation ring, and other parts requiring a weld. *Class B* for ordinary forgings, valve spindles, motion work not requiring case-hardening, reversing shaft and rod, reversing screw, buffer heads, regulator handle, roof slings, safety valve, and other seatings, wash-out doors and bridges, etc. *Class C*, connecting and coupling rods, crossheads, keys and cotters. *Class D*, piston rods, slide bar crosshead cotter. *Class E*, boiler forgings.

No. 10.—Steel castings. Wheel centres form one class; castings with wearing surfaces another, and this includes axle boxes and guides, bogie centres, bogie slide, brake shaft brackets, spring brackets, buffer plungers and guides. General castings without wearing surfaces include motion plate or slide bar brackets, smoke-box saddle, etc.

No. 11.—Copper fire-box plates.

Nos. 12 *and* 12A.—Copper stays and studs.

No. 13.—Copper boiler tubes.

No. 14.—Brass boiler tubes.

No. 15.—Copper pipes for feed water and steam.

No. 16.—Boiler barrel and fire-box shell plates, front tube plate, rivets, stays, nuts, angles, rods, etc., for boiler work. Expansion brackets, roof stays, palm stays.

Nos. 17 *and* 17A.—Locomotive and tender frame plates and cross stays, angles, bolts, rivets, plating, ash pan and doors, fire door, smoke-box and door, cab, tender tank plates, etc.

Nos. 18 *and* 18A.—Steel plates, angles, and other sectional material for carriage and waggon underframes.

Report No. 53 (1927).—Weldless steel tubes for boilers.

Contract Specification for Locomotive Construction.

The *Contract Specification* should provide for delivery and payment after running a guaranteed mileage (about 3,000 to 5,000). That all parts shall be constructed exactly to the drawings supplied, and no deviation made whatever without consulting those responsible for letting the contract, and that lack of information shall be no excuse for discrepancies in material or construction. The price quoted must be inclusive, and no responsibility shall devolve upon the purchaser for royalties and patent rights. The quotation should also include drawings (2 complete sets), photographs (12), lists of details, weights, etc., to be furnished with the (3rd or 5th) engine.

The specification should also stipulate that the workmanship should be accurate and well finished.

Liquid Fuel.

On the former Great Eastern Railway, express engines were fired with coal only on a consumption of about 50 lbs. per mile, or with coal and liquid fuel combined, on a consumption of 10 lbs. of coal and 30 lbs. oil fuel, including lighting up in each case.

The suitable oil fuels consist of petroleum residue, or Astatki, having a specific gravity of ·905, flash point 214° F.; distillates from coal gas tar with a specific gravity of 1·11, flash point 196° F.; coal gas tar with a specific gravity of 1·23, flash point 200° F.; or oil gas tar (refined) with a specific gravity of 1·05, flash point ·30° F.

The theoretical efficiency of oil fuel can be more nearly approached in practical working than that of coal, and with petroleum residue (the best oil fuel), 66·6 per cent. of its heat can be transferred into steam, whereas with steam coal 55·5 per cent. is about the average.

Engine No. 1862, a four-coupled bogie express, with a train weighing about 250 tons, exclusive of engine, ran from Liverpool Street to Cambridge on an expenditure of 120 gallons of oil fuel—oil gas tar—and a layer of coal and broken firebrick on the firebars. Steam was easily kept up during the trip, and no smoke was emitted from the chimney, thus showing that complete combustion of the fuel was effected (Holden's system).

On the former L. & N.W.R. an engine of the 'Precursor' 4–4–0 class (non-superheater) was itted for burning oil. In the arrangement shown in fig. 21, 1,000 gals. of fuel is carried in a pecial tank mounted on the tender and filled by means of a semi-rotary hand-pump fixed at the ear end of the tank. The burners, made by the Scarab Oil Burning Co., are of the gravity-feed ype, the atomising agent being steam, which is supplied at a pressure of from 10 to 15 lbs. per sq. n. through a reducing valve. A receiver is interposed between reducing valve and burners to teady the supply. The burners are below the front of the firebox and supported by a casing which lso supports the fire-brick floor of the firebox. Air-ducts are arranged underneath the floor so hat the air supply is preheated. Three arches are provided, one immediately above the burners pringing from near the foundation ring, another arranged as in a coal-burning engine but topping off about 16 ins. from the tube plate, and a third under the firehole door. Brickwork

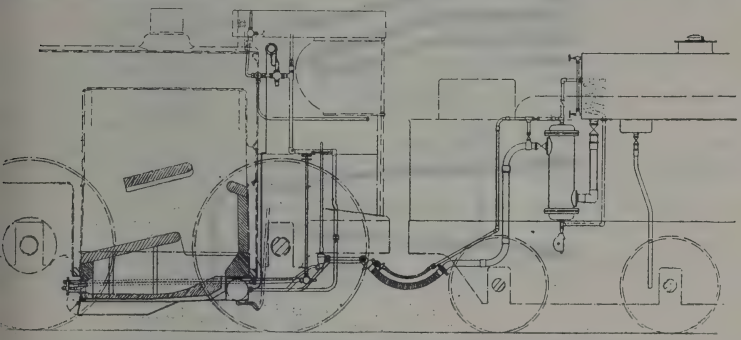


FIG. 21.—The Scarab System fitted to Main Line Express Locomotive.

carried up from the floor as far as the baffle arch. This construction, by lowering the floor ncreases the capacity of the box, which makes for improved combustion. The flooring just n front of the burners is perforated, allowing of a supply of air from the duct to be delivered nder the point where the oil breaks into flame. Three burners, one centre and two side, are tted, but it is found that the best results are obtained from the centre burner alone, and it is apable of generating enough steam to take trains up to the rated capacity of the locomotive. he raising of steam is accomplished by coupling up to another engine by means of a flexible

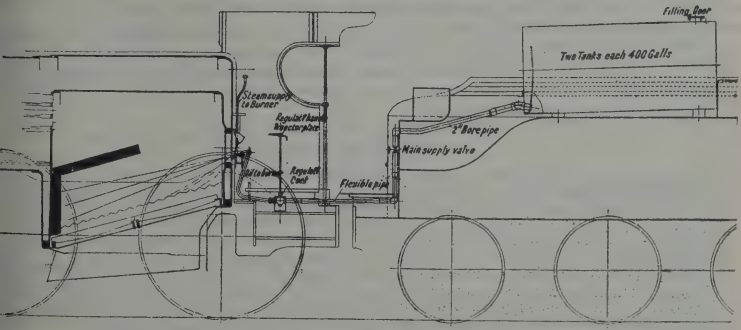


FIG. 22.—Oil-firing Arrangement, L.M. & S.R. (Midland Section).

pe. In this way steam is obtained for atomising the oil, and for the blower, which is kept action while steam is raised. A Royle heater is fitted for heating the oil supply in cold weather, that it flows readily. Arrangement is also made for blowing out the oil supply pipes with eam in order to keep them clean. On one trip the oil consumption recorded was 32 lbs. per ile, or 10·88 lbs. per 100 ton-miles with a train of 294 tons; and 24¼ lbs. per mile, or 9·25 lbs. r 100 ton-miles with a train of 264 tons. The average consumption of coal by the same engine about 70 lbs. per mile.

The Midland section of the L.M. and S.R. burns oil in conjunction with a certain amount of coal; the burner is inserted through the fire-hole door, no alteration being made to the fire-box except by bricking up the portion of the tube plate under the brick arch (fig. 22). The oil issues from the top portion of the burner in a thin stream or ribbon, and is atomised by coming in contact with a flat jet of steam which issues immediately under it from an orifice somewhat wider than that through which the oil flows. The details of the burner are shown in fig. 23.

The burner is inserted in the fire-hole, and is fed from two tanks placed on the tender, each of which holds from 400 to 500 gals. of oil. The flame is directed under the brick arch; the top portion of the fire-hole is closed by a special door which can be opened if it is necessary to use coal.

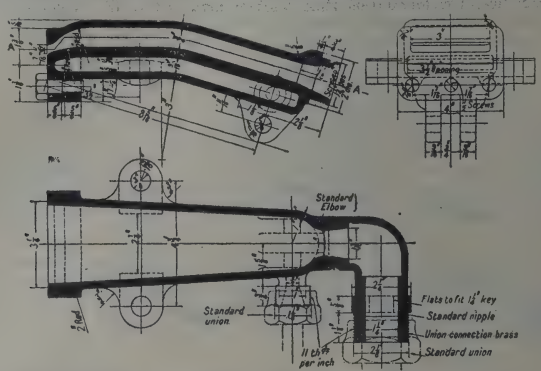


FIG. 23.—Oil Fuel Burner, L.M. & S.R. (Midland Section).

The fire-bars are covered with a layer of broken fire-brick, and if it is at any time necessary to use a little coal, it is put at the back of the fire-box. The fire can be started with wood, and as soon as the steam pressure reaches about 40 lbs. the burner can be used. In many cases no coal whatever is burnt for long periods, the engine steaming freely and the fire requiring very little attention. The best steaming results are, of course, obtained when there is a slight amount of smoke given off at the chimney. The locomotives fitted with this arrangement are able to deal easily with their accustomed loads. The advantage of the system is the ease with which it can be fitted up, and the simplicity in handling.

The company has one engine in which a similar burner is fitted in front of the ashpan, the fire-box being suitably bricked in on the sides and ends.

Liquid fuel burning is seldom resorted to on British railways except at times of coal shortage resulting from prolonged strikes at the collieries. The conversion to oil burning is readily made. Oil is extensively burned in the South-Western States of America, Mexico, and the Argentine Republic, as coal has to be imported and oil is nearer at hand or is more cheaply transported.

See also Section XXXIV., 'FUELS.'

Mechanical Stokers.

Mechanical stokers are used by the Canadian National and the South African Railways. The former adopted them not for reasons of economy but because the locomotives had become too large for their full capacity to be maintained by hand firing. The consumption per unit of power developed is approximately the same with either hand or stoker firing. The same grade of fuel is used with mechanical stokers as is fired by hand. The proper use of these stokers to obtain best results calls for as much skill on the part of the fireman as hand firing, but the labour is reduced.

Mechanical stokers can be justified only on locomotives too large to be fired to full capacity by hand. The minimum economical size of engine for them are those of a rated tractive effort of 50,000 lbs., and then only when operating on long heavy grades. Engines having a rated tractive effort of 55,000 lbs. or over justify the use of mechanical stokers on any territory in freight service, as also engines of 50,000 lbs. tractive effort in passenger service.

Mr. Emerson states that the mechanical stoker for locomotives is a development of the last twenty years, in response to the necessity of securing greater capacity from single power units. Mechanical stoking permits more tonnage to be handled at a higher sustained speed, and gives greater average dependability than would be practicable with hand stoking. Its development has rendered it possible to design locomotives capable of burning coal continuously at a rate much in excess of the capacity of any fireman to supply it by hand. It is generally considered that a tractive capacity of 50,000 lbs., or a coal consumption of 4,000 lbs. per hour, will justify the use of a mechanical stoker. The present commercial production of mechanical stokers in the United

States is confined to the overfeed or 'scatter' type, made by four companies. According to information supplied by those companies, 7,856 mechanical stokers were in service or on order on November 1, 1923.

Pulverised Fuel.

Finely powdered coal can be burned in locomotive fire-boxes in a similar manner to oil fuel, by injection with air. The powder must, however, be perfectly dry for successful burning, but as it is slightly hygroscopic it absorbs moisture from the air and must therefore either be freshly made or kept perfectly dry in air-tight containers. The difficulty rather lies in the storage and distribution of the fuel than in the combustion.

See also Section XXXIV.

Coal Consumption.

The average rate of combustion in British express engines on heavy service is about 100 lbs. per sq. ft. of grate area per hour, and about 50 lbs. of coal per mile; the maximum rate may reach 160 lbs. per sq. ft. of grate area per hour.

According to the Railway Returns for 1925, the lbs. of coal consumed per engine-mile for the four British railway groups were: for passenger service, 40·00 to 53·11 lbs., for freight service, 54·82 to 70·06 lbs.

The evaporative power of locomotive boilers amounts to from 7 to 10 lbs. of water per pound of coal consumed. Longridge states that no rule can be fixed as to the best relative proportions of heating surface between grate area, fire-box, and tubes. It is an axiom that the capacity of a locomotive depends entirely upon its fire-box.

The consumption of fuel in a locomotive engine at rest, as when standing in a station or at a signal, is about one-fifth of that consumed when the engine is in motion. When standing at a shed with fire banked, the consumption is very much less.

In a modern engine about 3½ cwt. of coal is actually consumed in raising steam in a boiler from cold water, and about 2½ cwt. from hot water. Some 10 cwt. is required for making up the fire before working a heavy train.

Water Consumption.

With a piston speed of 900 ft. per minute and a boiler pressure of 175 lbs. per sq. in., locomotives using saturated steam require about 24 lbs. per i.h.p. hour. The evaporation is approximately 8 lbs. of water per pound of coal, or 9½ lbs. from and at 212°F. The coal consumption is therefore 3 lbs. per i.h.p. hour. Locomotives using superheated steam require 25 per cent. less, or about 18 lbs. of steam per i.h.p. hour. The coal per i.h.p. is 12½ per cent. less, or roughly 2½ lbs. per i.h.p. hour, the evaporation being 7 lbs. of water per pound of coal.

Lubricating Oil Consumption.

The oil consumption of different railways varies considerably, but under favourable conditions 1 lb. of cylinder oil and 4 lbs. of engine oil are required per 100 miles. Superheater engines use rather more cylinder oil than non-superheater, and the quality of the oil is more expensive.

The oil consumption of the 4-6-0 Great Western engines averages 5 lbs. per 100 miles.

According to the Railway Returns for 1925, the consumption of lubricating oil per running-mile for the four British railway groups was: for passenger service, 6·18 to 7·91 pints; for freight service, 6·71 to 8·20 pints; for shunting service, 5·06 to 6·21 pints.

Sight feed lubricators on the hydrostatic principle, delivering oil to the steam pipes, are used on both superheater and non-superheater engines. It is more usual on superheater engines to employ a mechanical force feed lubricator driven by an attachment to some part of the engine motion. In this case oil is delivered direct to the piston valve heads and the middle of each cylinder bore.

The practice of feeding oil to the crowns of axle boxes by mechanical lubricators is also extending, more particularly in the case of heavy eight wheels coupled mineral engines.

For LUBRICATION AND LUBRICATORS, see Section XX., part II.

Tenders.

The water capacity of tenders on British railways varies considerably. On the L.M. & S. Railway many tenders are under 3,000 galls., and the Great Western Railway uses 3,500 galls. for the largest engines, but these railways possess numerous water troughs, so that light six-wheeled tenders suffice. Large bogie tenders of some 5,000 galls. capacity are in use on the Southern Railway (S.W. section) and on the Caledonian section of the L.M. & S. Railway.

The coal capacity does not vary so much, and lies between five and seven tons, depending on the size of the engine.

The connection between engine and tender consists of a simple eye-ended bar with one or both holes elongated to allow for the buffing which is taken up at the centre on a massive helical spring through which the bar passes. Safety links or loops are provided on either side, but only come into operation in the event of the bar breaking.

Several railways prefer side buffers as they help to damp out oscillations of the engine by the friction of the rubbing surface. The central arrangement is better for sharp curves.

Water Troughs.

Effective length is from 440 to 560 yards. Theoretically a quantity of about 1,000 gallons can be picked up, the mouth of the scoop being at rail level and 1½ ins. below water level. In practice considerably more is obtained owing to the heaping up of the water in front of scoop, the maximum being obtained at 45 miles per hour with some 1,700 galls. At higher speeds there is a considerable loss by spray. The lowest speed at which water can be picked up is 15 miles per hour.

When running at 60 miles an hour over a water trough ¼ mile long, a locomotive tender will pick up about 1,000 gallons or 10,000 lbs. of water.

Examination of Locomotives at Running Sheds.

A failure on the road is a serious matter, and the best way of reducing breakdowns to a minimum is by periodical examinations. The following is a list of the usual examinations of the L. & N.E.R. (G.N. Section):—

Slide valves:—		Small ends	6 months
Piston valves	2 months	Vacuum regulating valves	1 month
Richardson's	2 ,,	Water scoops	1 ,,
'D' valves, ⅞ in. thickness	4 ,,	Fire-boxes	1 week
'D' ,, ¾ and 1 1/16 in. ,,	3 ,,	Axle-box pads	3 months
'D' ,, ⅝ and 9/16 ins. ,,	2 ,,	Injectors	1 month
'D' ,, ½	1 month	Main steam pipes on superheated engines	1 ,,
Pistons	3 months	Tender wheels gauged	1 ,,
Tender tanks	1 month	Leading wheels of 2–4–0 type gauged	1 ,,
Drip valves	1 ,,	Engine and tender tyres gauged	1 ,,
Safety valves	6 weeks	Mechanical lubricators to slide valves and pistons	2 months
Ball valves in water gauge frames (dependent upon quality of water in district)	2 months	Mechanical lubricators to axle-boxes	1 month
Lead plugs	1 month		
Large ends	3 months		

Cracked frames, flaws in connecting and coupling rods, or any part of motion, loose tyres, etc., should also be watched for. (*G. A. Musgrave, 'Proceedings, Inst. Loco. Engrs.'*)

Engine and Tender Tools and Equipment.

Carried in Tool Boxes.

Flat chisel.
Pin punches (large and small).
Chipping hammer.
Wrench for union nuts.
Complete set of spanners.
Adjustable wrench.
Tommy bar.
Large can for engine oil (6 to 8 quarts).
Large can for cylinder oil (6 to 8 quarts).
Small can for paraffin (about 1 quart).
Spring valve oil feeder, long spout.
Spring valve oil feeder, short spout.
Flare lamp.
Case of fog signals.
Red flag.
Hand sweeping brush.
Packing drawer } (if required).
Tallow pot }
Spare glasses for water gauge.
Spare glasses for sight feed lubricator (if fitted).
Spare packing rings for glasses.
Copper wire for trimmings.
Worsted for trimmings.
Spare cotter pins.
Spare nuts.

Carried on Tender.

Fire rake
Pricker
Dart
Tube scraper } (length to suit firebox).
Clinker shovel
Slice (to suit depth of firebox at back).
Coal hammer.
Coal pick.
Pinch bar.
Bucket.
Fireman's shovel.
Screw-lifting and traversing jack (if specified)

Other Equipment.

Full set of head and tail lamps.
Full set of head boards or discs (when used).
Water gauge lamp.
Sight feed lubricator lamp (if required).

Special Equipment at Shed for Class of Engine.

Spanner for brake screw adjusting nuts.
Box spanner for fusible plugs.
Ashpan rake.

Brakes.

In addition to hand brakes the majority of engines and tenders are fitted with power brakes, usually the standard Westinghouse or Automatic Vacuum apparatus (page 728). Some of the large railways manufacture their own vacuum brake fittings. Goods engines not fitted with a continuous brake have a simple steam brake. Many engines are fitted with a steam brake working automatically with the vacuum by means of a valve of simple construction which can either be controlled by the vacuum in the train pipe or by hand. This is found to be a convenience, and the brake cylinders being of small diameter occupy but little space under the engine. The arrangement is extensively used and gives very satisfactory results.

Instead of a small ejector for maintaining the vacuum in the train pipe, several railways employ a vacuum pump about 5 ins. bore directly driven from one of the crossheads of the engine. As the pump is capable of creating a high vacuum, a relief valve is provided to limit the vacuity. On the Great Western Railway this is set for 25 ins., resulting in a running vacuum of 26 ins. of mercury. Other railways set the valve for the standard 20-inch vacuum, which results in 22 inches being maintained when running. Less trouble from pumps running hot is experienced with the higher vacuum, and the size of brake cylinders or leverage is reduced a little on account of the greater available atmospheric pressure, but no practical difficulties arise in the interchange of rolling stock with other railways.

Under average conditions as to load, leakage, and number of stops, the steam required by a vacuum ejector in maintaining a 20-in. vacuum results in the consumption of 42½ lbs. of coal per hour. The power absorbed by a vacuum pump coupled to the cross-head of the engine is equivalent to a consumption of 15 lbs. of coal per hour with a 20-in. vacuum, and 17½ lbs. per hour with a 25-in. vacuum.

(*J. N. Gresham, 'Journal of Inst. of Loco. Engineers.'*)

The percentage of brake power—that is, pressure on brake blocks in relation to load on wheels—should not exceed 75 per cent. for coupled wheels and 10 per cent. of weight when empty for tenders. If bogie wheels of engine are braked the percentage should not exceed 50 in order to minimise any chance of skidding.

To avoid frequent taking up of blocks brake leverage should not be too great. With steam the air brakes leverage is about 7 to 1; vacuum brakes are sometimes as much as 14 to 1 on account of difficulty of finding room for large cylinders. With this ratio a 7-inch piston travel allows ¼ inch clearance for blocks and ¼ inch wear.

Steam Rail Motor Cars.

A large number of rail motor cars were built between the years 1904 and 1909. There are two principal types, one having a steam bogie at one end on which a vertical boiler is mounted. The Great Western Railway still have many of these cars, some of which are 70 feet long over headstocks, the rest being 59 ft. 6 ins. in length. The cylinders are 12 ins. by 16 ins., the wheels 4 ft. diameter, water capacity of tanks 450 galls. The boiler is vertical, 4 ft. 6 ins. diameter with cone top, and has 458 tubes 1⅛ in. diameter, total heating surface 659 sq. ft. and grate area 11½ sq. ft. The pressure is 160 lbs. per sq. in. and the tractive effort 6,912 lbs. The 70 ft. cars seat 61 passengers and the weight on motor bogie is 26·9 tons, and on the trailing bogie 16·25 tons. Walschaert valve gear is fitted. The other type of rail motor car consists of a miniature tank locomotive on which one end of the car body rests, the trailing end being carried as usual on a standard carriage bogie. The dimensions and weights are very much the same as for the first type.

Very few cars have been built during the last ten years. The tendency is to use up obsolete locomotives and carriages by suitably converting them for motor services. A small tank engine is attached to one or more trailer cars to form a unit which can be driven from either end. When pushing the car, the locomotive is controlled by the driver from the opposite end of the train by means of levers and rods with universal joints connected to the regulator. A brake valve and whistle cord are provided and an electric bell signal enables the driver to communicate with the fireman on the footplate. In some cases control of the regulator is by means of compressed air or vacuum.

The latest development is the 'Sentinel-Cammel' design of car. This is of very light construction, without heavy buffing and draw gear, and approximates more to tramway practice. The 'Sentinel' type of steam road wagon boiler and engine supplies the motive power. On the Jersey Railway, the coal consumption (inclusive of lighting up) is given as 6·27 lbs. of Welsh coal per mile, the water consumption 3·89 gallons per mile, and the total cost (inclusive of fuel, wages, repairs, depreciation, etc.) as 6·16 pence per mile. A similar type of car is the 'Clayton.'

ROLLING STOCK.

(Revised by H. Holcroft, M.I.Loco.E.)

COMPOSITION OF TRAINS.

Some recent trains on the Great Western Railway consist of seven coaches, including a dining car. They are fitted with 'Buckeye' couplers and gangways, with the exception of two brake thirds and two third-class carriages. The latter have 'Buckeye' couplers and gangway at one end only and the ordinary screw coupling and collapsible gangway at the other end. The brake thirds have screw couplings and collapsible gangways only. This arrangement is to permit of the extension of the train by the addition of ordinary corridor stock when required. The dining car has the kitchen and pantry in the centre, and accommodation is provided for first-class passengers at one end and third-class at the other. Each vehicle is 9 ft. wide over body, underframe 69 ft. 10½ ins. long, wheel base 62 ft. 6 ins., bogie wheel base 9 ft., and axle journals 9 ins. by 4½ ins.

The principal main line trains on the Western section of the Southern Railway are formed of sets of lavatory coaches, each coach 56 ft. long, and each set of 4 coaches having 26 first and 160 third-class seats.

Suburban services are worked by sets of 8 coaches, divisible in the centre; 4 coaches only being used during that part of the day when the traffic is light. Each set of 4 coaches has 2 third brakes, 51 ft. long, 1 composite 51 ft. long, and 1 composite 49 ft. long, the total seating accommodation being 42 first and 218 third-class.

The branch line services are performed by two coach bogie sets, accommodating 10 first and 84 third-class passengers.

Trains for Bournemouth Service.—The coaches are of the corridor type. Each train has seating accommodation for 42 first and 154 third-class passengers, and consists of five coaches, as follows:—

Brake third	4 compartments,	one lavatory and one baggage compartment.
Third	8 compartments,	two lavatories.
Pantry third	7 ,,	one lavatory, one pantry.
First	7 ,,	two lavatories.
Brake third	4 ,,	one lavatory, one baggage compartment.

Continental Boat Trains.—New stock on the Eastern section of the Southern Railway consists of corridor carriages 64 ft. long over gangways. They are fitted with Pullman type gangways, automatic couplers and draught gear so as to work in conjunction with Pullman cars, and with adjustable buffers to work with ordinary stock when necessary. There are four types: first class (24 seats), second class (42 seats), brake first (20 seats), and brake second (36 seats), and the cars have end vestibule doors only.

Recent Developments in Carriage and Waggon Stock.

No very radical departures have been made in carriage and waggon stock on British railways, but in the United States steel is being used to some extent for passenger and freight car bodies. On British railways galvanised steel plates of about $\frac{1}{16}$ in. thickness are now being used for panels of carriages, but anything approaching an all-steel construction for bodies is very much heavier than with wood. On account of the doors with the compartment system, it is not possible to make use of the side of the body as a girder, as in the open American cars with end doors. The L.M.S. Railway have put into service a number of steel coaches of the open type with central gangway and end doors. The under-frame, roof, and sides form a box girder, and no truss rods are needed.

The L. & N.E.R., G.W.R., and Southern Railway use the American type of automatic coupling and vestibule for some of their main-line trains. In order that these vehicles can be attached to ordinary stock, the coupler is hinged and can be dropped down, exposing a hook for screw coupling. Side buffers are provided, and these have a loose sleeve which can be removed to allow the buffers to be pushed back when the automatic coupling and vestibule with central buffers are in use. The G.W.R. hinge the buffers so that they can be dropped out of action.

Pullman cars of the American type are extensively used on the Southern Railway, and to a lesser extent on the L. & N.E.R., L.M. & S., and Metropolitan Railways. Mr. Gresley's twin coaches, as used on the L. & N.E.R., consist of a pair of bodies hinged together. The outer ends rest on bogies in the usual way, but there is only one bogie for the inner ends, the bogie pin being at the hinge between the coaches. A flexible gangway connects the two bodies. This system has been extended to complete trains, so that a set train of five coaches has only six bogies.

The G.W.R. has also built some trains of articulated coaches.

The high-capacity bogie waggon makes but slow progress on British railways, owing to the lack of terminal facilities. The tendency is to build 4-wheel waggons of 12, 15, or 20 tons capacity. The fitting of a continuous brake to goods trains is limited to special trains for perishables, ballast, etc. Its more general application is retarded by the presence of a large number of private owners' waggons and the high capital costs involved.

A very simple form of self-contained buffer is now used by several railways. It consists of hollow cast-steel casing and plunger containing a helical spring; this butts directly against e headstock, and initial compression in the spring is obtained in bolting down the casing to adstock.

See also 'All-metal Cars for British Railways,' Vol. CCVIII. (April 1921), *Proceedings Inst. C.E.*

Axle Boxes.

These are usually of cast iron: for carriages oil boxes are universal, and a large number of w waggons are now being fitted with them instead of grease boxes. An oil reservoir in the ttom of the box conveys oil by capillary attraction, either by cotton-waste packing or by eans of a worsted pad with tail trimmings supported on springs. The bearing or 'brass' is gun-metal, or gun-metal lined with white metal. Some white metals have a tin base and ntain about 60 per cent. tin and 25 per cent. of lead, with 10 per cent. antimony and a little pper. The lead base alloys have about 76 per cent. of lead, 15 per cent. of antimony, 6 per nt. tin, and a small percentage of copper.

The oil used is a mineral oil, and sometimes contains a trace of fatty oil.

A leather-faced dust shield prevents dirt or water creeping in at the back of the box.

Wheels.

For carriages the wheel with wooden centre, once universal, has now been superseded to a rge extent by a steel disc centre of slightly dished form, on which is shrunk a steel tyre having lip on outside, and secured by retaining ring inside. Tyres are 5 ins. wide and are coned 1 20. In order to ensure smooth running, all carriage wheels are carefully balanced. Each ir of wheels is placed on a machine, the journals resting in bearings mounted on springs. When e wheels are revolved at high speed any irregularity in the running can be detected, and a rrection made by fastening small plates to the inside of the wheel, near circumference, so that ooth running results.

Wood centres must be bonded by a copper strip between tyre and hub, so as to conduct ectric current from rail to rail for operating signalling appliances. Tyre shrinkages are $\frac{3}{16}$ in. r wood centres, and about $\frac{7}{64}$ in. for steel centres.

Waggon wheels are made in a variety of ways. The bossed spoke wheel consists of spokes ade from flat bar bent into triangular shape. These are placed together in a mould and a st-iron boss is cast round them. The outer ends are then welded together to form a solid rim. stead of casting a boss, it may be forged by placing two discs brought to welding heat on either de of the spokes, and forcing them together in a powerful press. Spoked wheels have also en made by forging spoke bars and building up a wheel. But this has been largely superseded y a cast-steel spoke wheel. A few wheels are being made with steel disc centres, and there e a few solid cast-iron wheels with chilled treads running on British railways. These are on aggons originally built for war service in France.

Journals of axles are sometimes case-hardened, but very good results can be obtained by e simple process of burnishing in the lathe. After the journal is machined, a tool having a nall roller at the end is fixed in the slide rest and the journal is rolled all over with considerable essure; this closes all the pores and leaves a hard, bright surface.

The maximum bearing pressure for journals varies from 500 to 700 lbs. per sq. in. of projected ea.

A reduction in diameter by $\frac{1}{4}$ in. is allowed before axles are scrapped.

Springs.

Laminated bearing springs are usually $3\frac{1}{2}$ ins. wide for carriages, and 4 ins. for waggons, with lates $\frac{3}{8}$ to $\frac{1}{2}$ in. thick, approximately.

If L = distance in inches between centres of bearings measured along top plate; b = breadth f plates in inches; t = thickness of plates in sixteenths of an inch; n = number of plates; = safe load in tons; D = deflection in sixteenths of an inch per ton of load,

$$n = \frac{15LW}{bt^2}; \quad W = \frac{bt^2n}{15L}; \quad D = \frac{2L^3}{bt^3n}.$$

If there are different thicknesses of plates in one spring, it is necessary to find the equivalent umber of plates of uniform thickness from the square (or cubes in the case of deflection) of the ickness, thus:—

$$n = \frac{n_1 t_1^2 + n_2 t_2^2}{t_1^2}.$$

Buffer springs are largely made of rubber, and are formed of rubber discs $2\frac{1}{2}$ to 3 ins. thick laced between 6 or 8 metal discs.

For 'Helical Springs' see p. 707.

CARRI

Section of Railway.	Type of Vehicle.	Length of Body.	Width of Body.	Height from Rail to Top of Roof.	Corridor or Non-Corridor.
		′ ″	′ ″	′ ″	
LONDON, MIDLAND & SCOTTISH RAILWAY.					
L. & N.W.	Brake Third	65 6	9 0	12 5½	Corr.
,,	Compo.	65 6	9 0	12 5½	Corr.
,,	Brake Compo.	65 6	9 0	12 5½	Corr.
Caledonian	Third	68 0	9 0	—	Non-Corr.
,,	First	65 0	9 0	—	Non-Corr.
,,	Third	65 0	9 0	—	Corr.
L. & Y.	First	56 0	9 0	—	Centre Corr.
,,	Third.	56 0	9 0	—	Centre Corr.
,,	Third.	56 0	9 0	—	Side Corr.
L.M.S.	Third.	57 0	9 0	12 7½	Centre Corr.
LONDON & NORTH-EASTERN RAILWAY.					
G.N.	First Dining	65 6	9 0	—	Corr.
,,	Compo. Dining	65 6	9 0	—	Corr.
,,	Sleeping	58 6	9 0	—	Corr.
,,	Third	58 6	8 6	—	Corr.
,,	Brake Compo.	58 6	8 6	—	Corr.
N.E.	Third	52 0	8 6	—	Non-Corr.
G.C.	Brake Compo.	56 0	8 6	—	Corr.
,,	Compo.	56 0	8 6	—	Corr.
,,	Third	60 0	8 10½	—	Corr.
,,	First	60 0	8 10½	—	Corr.
G.E.	First	54 0	9 0	—	Non-Corr.
,,	Third	54 0	9 0	—	Non-Corr.
,,	Brake Van	50 0	8 9	—	—
GREAT WESTERN RAILWAY.					
G.W.	Brake Third	70 0	9 0	—	Corr.
,,	Third	70 8½	9 0	—	Corr.
,,	Compo.	71 4½	9 0	—	Corr.
,,	Dining	71 4½	9 0	—	Corr.
SOUTHERN RAILWAY.					
Western	Brake Third	57 0	9 0	12 5	Corr.
,,	Third	57 0	9 0	12 5	Corr.
,,	Pantry Third	57 0	9 0	12 5	Corr.
,,	First	57 0	9 0	12 5	Corr.
Central	First	57 0	9 0	—	Non-Corr.
,,	Third	54 0	8 6	—	Non-Corr.
,,	Compo.	56 0	8 6	—	Non-Corr.
Eastern	First	62 0	8 0¾	12 2	Corr.
,,	Brake First	62 0	8 0¾	12 2	Corr.
,,	Second	62 0	8 0¾	12 2	Corr.
,,	Brake Second	62 0	8 0¾	12 2	Corr.

AGES.

Weight Empty.	Compartments. 1st Class.	Compartments. 3rd Class.	Seats. 1st Class.	Seats. 3rd Class.	Bogie.	Bogie Wheel Base.	Centre of Bogies.	Remarks.
T. C.						′ ″	′ ″	
39 10	—	—	—	—	6 wheel	12 6	43 0	West
42 0	—	—	—	—	,,	12 6	43 0	Coast
41 4	—	—	—	—	,,	12 6	43 0	Stock
—	—	11	—	132	,,	—	—	—
—	9	—	72	—	,,	—	—	—
—	—	9	—	72	,,	—	—	—
26 0	—	—	40	—	4 wheel	—	—	—
25 19	—	—	—	66	,,	—	—	—
26 3	—	8	—	64	,,	—	—	—
30 0	—	—	—	56	,,	9 0	40 6	All-steel
40 0	2	—	20	—	—	—	—	—
41 8	1	1	8	18	—	—	—	—
35 0	11	—	11	—	—	—	—	—
29 7	—	8	—	48	—	—	—	—
29 19	3	3	12	18	—	—	—	—
24 0	—	8	—	80	—	—	—	—
34 6	2	3	8	24	4 wheel	—	—	—
38 9	2	4	12	32	,,	—	—	—
36 3	—	8	—	64	,,	—	—	—
36 16	7	—	38	—	,,	—	—	—
29 4	8	—	80	—	6 wheel	—	—	Suburban
27 9	—	10	—	120	,,	—	—	—
22 8	—	—	—	—	4 wheel	—	—	—
—	—	4	—	32	4 wheel	9 0	53 6	—
—	—	10	—	80	,,	9 0	53 6	—
—	4	5	24	40	,,	9 0	53 6	—
—	—	—	18	32	,,	9 0	53 6	—
—	—	4	—	32	4 wheel	9 0	41 0	5-coach Pantry Sets
—	—	8	—	64	,,	9 0	41 0	
—	—	7	—	56	,,	9 0	41 0	
—	7	—	42	—	,,	9 0	41 0	
28 10	6	—	42	—	,,	—	—	6 Lavatories
24 0	—	8	—	78	,,	—	—	2 ,,
26 10	4	4	24	40	,,	—	—	
31 14	6	—	24	—	,,	8 0	44 0	Continental Boat Train Stock
30 9	5	—	20	—	,,	8 0	44 0	
31 8	—	7 Second	—	42 Second	,,	8 0	44 0	
30 9	—	6 Second	—	36 Second	,,	8 0	44 0	

WAG-

Section of Railway.	Type of Waggon.	Carrying Capacity.	Length over Body.	Width over Body.
LONDON, MIDLAND & SCOTTISH RAILWAY.				
		Tons.	′ ″	′ ″
L. & N.W.	Open Goods	10	18 0	7 10
,,	,, ,,	20	21 0	7 9
,,	Covered ,,	10	18 0	8 0
Midland	Open ,,	10	16 0	7 10
,,	,, ,,	12	16 0	7 10
,,	,, ,,	20	21 6	7 11
,,	Covered ,,	10	17 6	7 8
L. & Y.	Open ,,	12	16 0	7 10
,,	,, ,,	20	21 6	8 0
,,	Covered ,,	10	20 0	8 0
,,	,, ,,	30	35 0	8 0
LONDON & NORTH EASTERN RAILWAY.				
G.N.	Open Goods	10	19 0	8 0½
,,	,, ,,	20	21 6	8 5
,,	Covered ,,	8	19 0	7 8
N.E.	Open ,,	10	15 0	8 0
,,	,, ,,	12	17 0	8 0
,,	,, ,,	20	20 0	8 0
,,	Covered ,,	10	17 0	8 0
,,	,, ,,	25	37 0	8 6
,,	Coal ,,	40	36 0	8 0
G.C.	Open ,,	10	19 0	8 0½
,,	,, ,,	20	21 6	7 9
,,	Covered ,,	10	19 0	7 8
G.E.	Open ,,	10	17 0	7 7
,,	,, ,,	20	21 6	8 2
,,	Covered ,,	10	19 0	7 9
,,	Guard's Brake	—	17 6	7 9½
,,	Cattle Waggon	10	19 3	7 11½
GREAT WESTERN RAILWAY.				
G.W.	Open Goods	10	16 0	8 0
,,	,, ,,	20	21 0	7 9
,,	Covered ,,	10	18 0	7 10
SOUTHERN RAILWAY.				
Western	Open Goods	10	16 0	7 11½
,,	,, ,,	12	18 0	7 11
,,	Covered ,,	10	18 0	8 0
Central	Open ,,	10	15 5	7 9
,,	,, ,,	12	16 6	7 11
,,	Covered ,,	8	18 4	7 8½
,,	Ballast	15	20 0	8 0
,,	Cattle Waggon	6	18 4	8 0
,,	Guard's Brake	—	16 0	7 9

GONS.

Depth inside.	Tare Weight.	Wheel Base.	Centres of Journals.	Size of Journals.	Remarks.
′ ″	T. C. Q.	′ ″	′ ″	″ ″	
3 0	6 13 0	9 9	6 6	9×4	
4 7	8 0 2	12 0	6 6	10×5	
7 8⅜	7 10 1	9 9	6 6	9×4	
3 2	5 17 3	9 6	6 6	9×3¾	
4 1⅜	6 10 1	9 6	6 6	9×4¼	
5 1⅛	8 7 0	12 0	6 6	10×5	
7 9	7 12 3	10 0	6 6	9×3¾	
4 1⅜	6 14 2	10 6	6 4	9×4¼	
5 11 5/16	9 16 0	12 0	6 6	10×5	
7 8	7 11 1	10 6	6 4	9×4½	
—	14 17 1	—	—	—	Bogie Waggon
3 5	6 9 0	10 0	6 4½	8×3¾	
5 2⅝	8 9 0	12 0	6 6	10×5	
7 1	6 18 0	10 0	6 4½	8×3¾	
2 2½	5 10 0	8 6	6 5	8×4	
3 1½	6 7 0	9 6	6 5	9½×4¼	
6 10½	9 1 0	10 6	6 6	10×5	
7 9	7 2 0	9 6	6 5	8×4	
7 10	15 0 0	—	—	—	Bogie Waggon
6 0	16 5 0	—	—	—	Bogie Hopper Waggon
3 5	6 10 0	10 0	6 6	8×4	
4 10	7 17 0	12 0	6 6	10×5	
7 1	7 10 0	10 6	6 6	8×4	
4 0½	6 7 2	9 6	6 6	8×3¾	
4 7	9 1 1	12 0	6 7½	10×5	
7 0⅞	6 9 2	10 6	6 6	8×3¾	
—	20 0 0	—	—	—	
—	7 6 2	—	—	—	
3 3	6 0 0	9 0	6 6	8×3¾	
4 9¾	8 12 0	12 0	6 6	10×5	
7 7⅛	6 10 0	9 0	6 6	8×4	
2 8⅞	5 19 0	9 0	6 8	9×4	
4 8⅜	6 18 2	10 6	6 8	9×4	
7 7½	6 17 0	10 6	6 8	9×4	
2 10¾	5 18 1	9 3	6 3	8×4	
4 2⅜	6 17 1	9 0	6 6	9×4½	
7 1	6 8 0	9 9	6 3	8×4	
—	7 0 0	—	—	—	
—	6 9 0	—	—	—	
—	10 0 0	—	—	—	

Couplings.

Draw bars should be 1¾ ins. diameter ; they should be made from the same quality of iron as the hooks, giving 23 per cent. elongation in 4 ins. and 23 tons per sq. in. ultimate stress. Area of end of eye = area of two sides × 1·2.

Couplings should be made of high-class chain-iron (giving about 35 per cent. elongation in 4 ins., and 45 per cent. reduction in area, with a tensile strength of 22 to 23 tons per sq. in.); when side-welded they should stand 35 to 40 tons total stress, equal to 11·7 to 13·4 tons per sq. in. Standard diameter = 1⅝ in.

Screw couplings are of wrought iron, or sometimes of steel (B.S.S. 9B).

Draw hooks should be of best selected wrought-iron scrap, giving about 23 per cent. elongation in 4 ins., and 23 tons per sq. in. ultimate stress. If stamped out, the grain of the iron should be kept running with the hook, an important point sometimes overlooked in second-rate work.

FOR BRITISH STANDARD SPECIFICATIONS FOR MATERIALS USED IN THE CONSTRUCTION OF RAILWAY ROLLING STOCK, see pp. 705 to 711.

LIGHTING AND HEATING RAILWAY CARRIAGES.

STONE'S SYSTEM OF ELECTRIC LIGHTING FOR RAILWAY CARRIAGES.

In this system, fig. 24, the dynamo for producing the electric current is suspended from the under-frame of the carriage so that its pulley is at approximately the same level as the pulley on the axle, from which it is driven direct by means of a belt.

Speed of Pulley on Axle of Motor (representing Axle of Railway Carriage).	Equivalent Speed of Train in Miles per Hour (approximate).	Speed of Dynamo, Revolutions per Minute.	Equivalent Speed of Dynamo if no Slip were to take place.	Output of Dynamo. Amperes.
Revs. per Minute 100	12	500	500	0
150	18	750	750	6
175	21	870	875	16
195	23	900	975	18½
225	27	915	1,125	20
275	33	915	1,375	20
325	39	915	1,625	20
375	45	915	1,875	20
450	54	915	2,250	20
600	72	915	3,000	20

However the speed of the train may vary, after a certain predetermined limit has been reached, *the dynamo always runs at a uniform speed and consequently always produces practically the same amount of electricity.* This result is obtained by suspending the dynamo by one corner of its frame by means of an adjustable link, so that the driving belt draws the dynamo out of the diagonal position in which it would naturally hang, thus putting a definite tension on the belt just sufficient to absorb power equivalent to the amount of electricity required. When the pull on the belt (owing to increase in speed of the train) exceeds the weight on the belt, due to the one-sided suspension of the dynamo, the latter is automatically drawn towards the driving pulley on the axle, thus allowing the belt to slip while the armature continues to revolve at its normal speed. That the arrangement is an effectual one is shown by the above table.

The latest developments in the system include the introduction of the firm's 'Liliput' dynamo compactly built on modern lines and provided with ball bearings throughout, a special feature being that all the parts are very easily accessible for inspection or removal. The armature is of the drum wound type with former wound coils, the machine itself being shunt wound.

The centrifugally operated switchgear embodied in the older dynamos is omitted from the 'Liliput' machine, the switching being now effected by a separate automatic cut-in and cut-out switch operating on voltage ; and in the case of a double battery system, a 'Pegoud' battery change-over switch is included, so as to change over the position of the charging and regulating batteries every time the dynamo switches into circuit.

The 'Liliput' dynamo (in which is embodied the pole-charging device) is made in two forms, either to run at a constant speed, as described above—the output being controlled by means of a slipping belt—or at a variable speed, that is, the speed of the dynamo following the speed of the train, the output remaining constant at all speeds, and as the lamps are switched 'on' or 'off' so the dynamo output increases or decreases according to the demand.

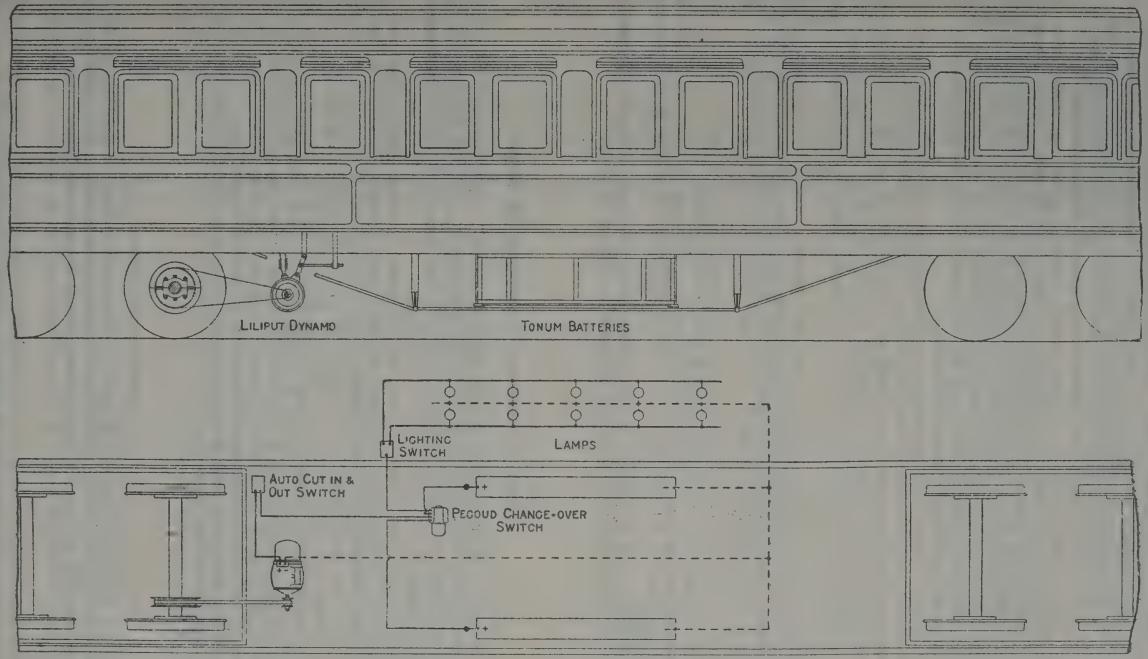

LILIPUT DYNAMO
TONUM BATTERIES
LIGHTING SWITCH
LAMPS
AUTO CUT IN & OUT SWITCH
PECOUD CHANGE-OVER SWITCH

FIG. 24.

The accumulator being always in connection with the lamps causes the light to be absolutely steady, acting as a regulator to absorb any excess of current generated by the dynamo.

The working parts of the dynamo are enclosed in a movable but dust-proof casing.

A switch is provided to each carriage, so that the lights can be either fully on or entirely off, or where there are tunnels, and the light is required in the daytime, half the lights may be used. When the lamps are not alight, the current is being stored in the accumulator.

'Tonum' batteries are used with either special formation pasted or Plante positive plates. When a single battery is installed, individual cells have twice as many positive plates and are twice as heavy as the cells in the equivalent double battery; and as the latter, *i.e.*, the double battery system, gives the best regulation and is more reliable in working it is always recommended. One battery being directly connected to the lamps keeps the light absolutely steady while the other battery is being charged by excess current generated by the dynamo over and above that required for the lamps, which are supplied by the dynamo through the lamp resistance. On the train stopping, both batteries supply the lamps.

The 'Tonum' type of cell is designed to withstand the rough handling to which cells are unavoidably subjected in railway work, and embodies several valuable features.

The grids of the plates are of such design as to combine efficiency with mechanical strength. The sections are contained in a lead-lined wood box fitted with a lid which does not require any metal holding down bolts or fasteners, and the top of the box is specially formed and the lining so fitted as to prevent any acid from running down between the lining and the wood and gradually attacking the box.

The positive and negative plates are separately supported on the bottom block, eliminating leakage from plate to plate through lodgment of sediment on the surface of the supporting strips. Ample space is provided beneath the plates for any possible accumulation of sediment, and above the plates to allow of a generous supply of acid, so that the cells do not require frequent 'topping' to make good evaporation.

A float is fitted which indicates the level of the electrolyte in the cell, showing at a glance—without opening the lid of the cell—whether the cell requires water.

The electrical qualities of the cell are (1) retention of capacity throughout its useful life and (2) the maintenance of a high initial voltage for a considerable time after the commencement of the discharge.

The whole of the apparatus is of British manufacture and made in London, the system being largely adopted by the leading railway companies throughout the world.

Heating Railway Carriages by Steam.

Heating of trains is by steam from the locomotive boiler. The train piping consists of 1½ in. bore iron piping, and flexible rubber hose connections with universal couplings are provided between carriages. Automatic ball valves and thermostats are fitted for drainage of water. A pressure of 60 lbs. per square inch is the maximum, but 30 lbs. is quite an average pressure for ordinary working.

Several systems are in use, but they may be classed under two headings, high-pressure and atmospheric. In the high-pressure systems, long cylindrical heaters, 4 ins. to 5 ins. diameter, are placed under one seat of a compartment. These are in direct communication with the train pipe, and steam under pressure fills them. As condensation takes place the water is drained away through a thermostatic valve. There are several modifications of this system.

In the atmospheric systems the heaters have an open outlet at one end, and a jet of steam entering at the opposite end expands to atmospheric pressure and condenses on the walls of the heater, the water draining away at the outlet. In some systems regulation of steam is by means of a thermostat, which automatically controls the steam. In others a choke plug in the branch pipe to the heater restricts the supply of steam to the necessary amount.

With coal of such a quality that it produces 7½ times its own weight of steam in the locomotive boiler, the average consumption of coal for the three coldest months should not exceed about 6½ lbs. per axle per hour.

Westinghouse System.

In the Westinghouse system of heating, steam at atmospheric pressure only is used in the heaters, and the temperature of the heaters is thus maintained equal throughout the train.

Fig. 25 shows a recently introduced form of the Westinghouse patent heater. It consists of a tube A, with external gills, which provide a large heating surface in comparatively small space.

This tube has caps B and C. Steam from the main pipe enters at D. E is a tube of an alloy with a high ratio of expansion. At one end is attached the screwed socket F. By means of

a pulley G fixed to the outer end of socket F, the latter can be turned through 90°, between the 'ON' stop H, and the 'OFF' stop J on the cap C. The pulley G is operated by means of Bowden wires, M and N, the opposite ends of which are attached to a pulley R on the spindle of the control handle P. This may be located in any suitable position in the compartment, and at any distance from the heater. The usual rods and bellcranks can, therefore, be dispensed with, thus greatly simplifying the mounting.

When the handle P is at the 'ON' position, and the heater cold, the valve K is away from the seat L. Steam enters and fills the heater, while the water of condensation escapes to atmosphere at S. As tube E becomes hot, it expands more than tube A, and valve K therefore approaches the seat L, and when the heater reaches a predetermined temperature, valve K closes the steam inlet. The heater then cools slightly, tube E contracts, and allows a further quantity of steam to enter. The temperature of the heater is thus maintained practically constant.

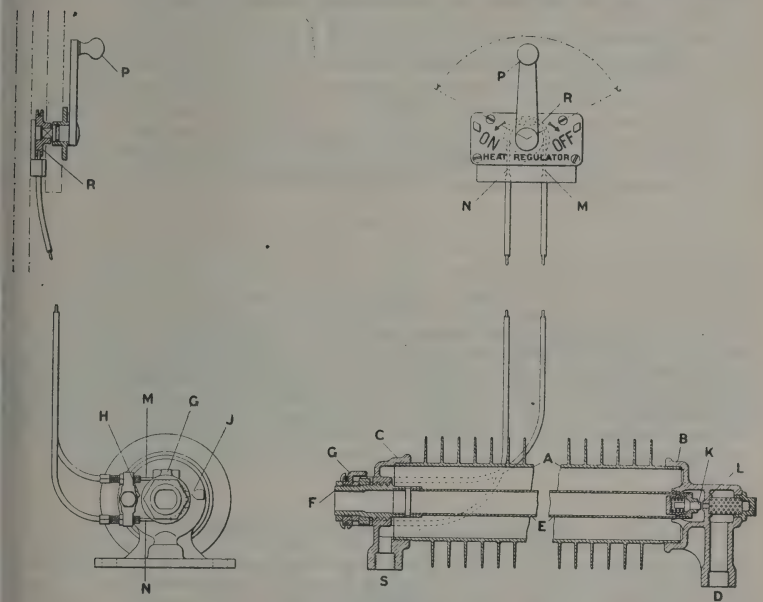


FIG. 25.—Westinghouse Patent Heater.

If it is desired to lower the temperature of the heater, handle P is moved towards the 'OFF' position, thus bringing valve K nearer the seat L. The tube E then does not require to expand so much to close the steam inlet, and steam is cut off when the heater reaches a lower temperature than before. The temperature of the heater can, therefore, be regulated to a nicety by means of the handle P.

If the handle is moved right over to the 'OFF' position, the valve K is brought to the seat L, thus completely shutting off steam. It will be seen that variation of pressure in the main pipe does not affect the temperature of the heater, which is determined by the position of the handle P, and automatically maintained constant. As the temperature in the heater cannot exceed 212°, steam is never at more than atmospheric pressure, and is completely condensed in the heater.

The Westinghouse system of heating is in use on the chief railways in the United Kingdom and on many railways in foreign countries, including some of the coldest in the world.

BRAKES.

Action of Brakes.

f = proportion which resistance produced by brakes bears to weight of train.

v = speed in feet per second.

V = speed in miles per hour.

Distance in feet in which the train is stopped on level $= \frac{v^2}{64{\cdot}4f} = \frac{V^2}{30f}$.

Brakes self-acting on all the wheels, $f = {\cdot}14$.

Ordinary brakes worked by hand in brake-vans, $f = {\cdot}031$ to ${\cdot}023$.

On gradient *ascending* 1 in n, resistance $= f + \frac{1}{n}$.

On gradient *descending* 1 in n, resistance $= f - \frac{1}{n}$.

Distance in feet for stopping $= \frac{f \times \text{distance on level}}{f \pm \frac{1}{n}}$.

Power required by Brakes.

The following results have been obtained as regards consumption of energy with different kinds of air brakes :—1. On city lines, the consumption of energy for excentric compressors was 41·5 watt-hours per car kilom. (66·4 watt-hours per car mile); with geared compressors, 31·2 watt-hours per car kilom. (49·9 watt-hours per car mile); and with motor compressors, 16·16 watt-hours per car kilom. (25·86 watt-hours per car mile). 2. On suburban lines, the consumption for excentric compressors was 22·8 watt-hours per car kilom. (36·5 watt-hours per car mile); with geared compressors, 14·6 watt-hours per car kilom. (23·4 watt-hours per car mile); and with motor compressors, 6·32 watt-hours per car kilom. (10·11 watt-hours per car mile).

The Westinghouse Automatic Brake.

The Westinghouse automatic brake is continuous throughout the train and is operated by compressed air furnished by the compressor and stored in the main reservoir on the engine. This compressed air is fed by the driver's brake valve into the train pipe and, past the triple valves, into the auxiliary reservoir on each vehicle.

The brake is applied by reducing the pressure in the brake pipe, which causes the pistons of the triple valve to move and permit some of the compressed air stored in the auxiliary reservoirs to pass to the brake cylinders, the pistons of which are forced outwards, applying the brake blocks to the wheels.

The brake is released by restoring the air pressure in the train pipe, which causes the triple valves to close the communication between auxiliary reservoirs and brake cylinders and open a port from the brake cylinder to the atmosphere, through which the compressed air escapes from the cylinder. The spring in the cylinder can then push back the piston and withdraw the blocks from the wheels.

The brakes are usually applied by the driver, or in cases of emergency by the guard, but a break-away, or rupture of a hose coupling, or other accident causing an escape of air from the brake pipe, also immediately applies the brakes.

It is recommended that a pressure of 90 lbs. per sq. in. be maintained in the main reservoir, and 70 lbs. per sq. in. in the brake pipe.

Improved Triple Valve.

This valve has been designed to give a closer approach to simultaneous action of all the triple valves in a train than heretofore. As shown in fig. 26, the valve is in the release position, and the bulb is open to the atmosphere. When the slide valve 6 is moved in applying the brakes, the bulb 3 is closed to the atmosphere and opened to the brake pipe by the cavity p and port s shown in dotted lines. The local reductions of brake pipe pressure thereby produced by the forward triples in a train cause an earlier action of the rearward triple valves, which results in a more nearly simultaneous braking effect being produced throughout the train in every case of first setting the brakes than heretofore, with a smoother and more efficient brake service generally.

A further improvement, also tending to smooth and even action of all the brakes, is shown in the passage leading from port a in the seat of the slide valve 6 to the brake cylinder at B. It consists of a removable plug 13, perforated with holes w and x, which are always open, and an additional hole y carrying an automatic check valve 14, supported by a spring 15. It is so arranged that, when the brakes are first set, the automatic valve is opened against the spring resistance by the excess of air pressure above it, so that the hole x controls the rate of flow of air to the brake cylinder: as the air pressure on the under side of the valve increases, the spring closes the valve, when the smaller holes w control the rate of flow to the brake cylinder. The diameters of the regulating holes w and x are made proportional to the diameter of the brake cylinder with which the triple valve is to be used. By changing these perforating plugs, the same pattern of valve is thereby suited to cylinders of various sizes.

The bulb at the bottom of the triple valve is made in different sizes, proportioned in content to the volume of the brake pipe of the vehicle on which the valve is to be used.

A separate passage a' is provided in the triple valve body from brake cylinder to slide valve 6, for the air to escape from the brake cylinder on releasing the brakes. The rate of release is controlled as hithertofore, by a nipple screwed into the outlet hole c in the triple valve body.

Driver's Equalising Brake Valve.

The principle of this brake valve, fig. 27, is not to allow the driver in ordinary applications of the brakes to discharge air directly from the brake pipe, but from a small reservoir connected with chamber T of the valve. The reduction of air pressure, thus effected in the reservoir, is then at once automatically and properly repeated in the brake pipe by means of a small equalising piston, 11, placed between the air in the chamber T, and that in the brake pipe E. The piston moves in accordance with the variations in pressure above and below it, and governs an exhaust valve U in such a manner that the air pressure in the brake pipe must always equalise with that in the small reservoir connected with the valve chamber T. Even if the exhaust of air from the brake valve reservoir is abruptly stopped by the driver, the discharge valve U is always gradually closed by the piston, when equilibrium of pressure is established throughout the train. The equalising device, therefore, will under all circumstances provide for a uniform reduction of the pressure in the main brake pipe, thus ensuring a uniform application of the brakes to all the vehicles in the train.

The compression of air is effected by a compressor (Westinghouse), a description of which is given in Section XXIII.

Pipe Couplings.

In the connecting-pipe *coupling*, which is shown by fig. 28, the two halves of couplings, 1, are exactly alike, and an air-tight joint is formed by means of the rubber packing-ring, 3, 1 in each, which rings face each other when the couplings are united. The air-pressure in the

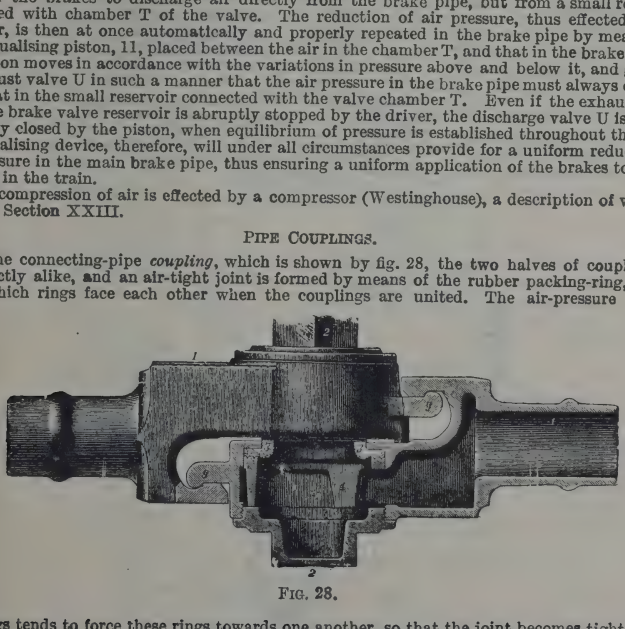


Fig. 28.

couplings tends to force these rings towards one another, so that the joint becomes tighter with increase of pressure. The tendency of the air-pressure in the couplings is also to force them apart in a direction at a right angle to the line of the india-rubber hose-pipes, and, consequently, the greater the pressure, the more firmly are the couplings held together by the projecting piece, g,

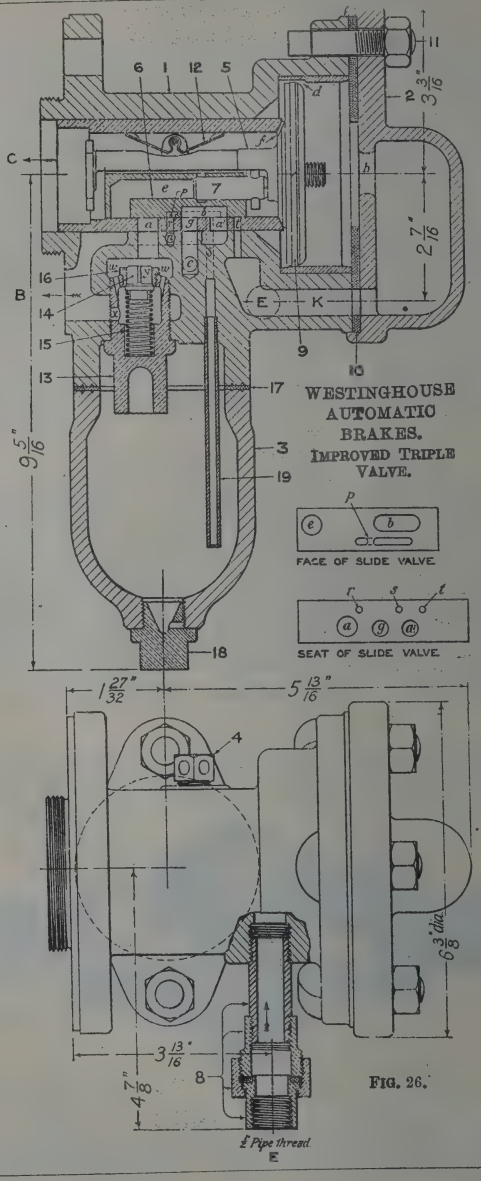

WESTINGHOUSE AUTOMATIC BRAKES. IMPROVED TRIPLE VALVE.
FACE OF SLIDE VALVE
SEAT OF SLIDE VALVE
1 27/32"
5 13/16"
3 13/16"
9 5/16"
2 7/16"
3 3/16"
6 3/8" dia.
4 7/8"
£ Pipe thread E

FIG. 26.

WESTINGHOUSE AUTOMATIC BRAKE.
DRIVER'S EQUALISING BRAKE VALVE.

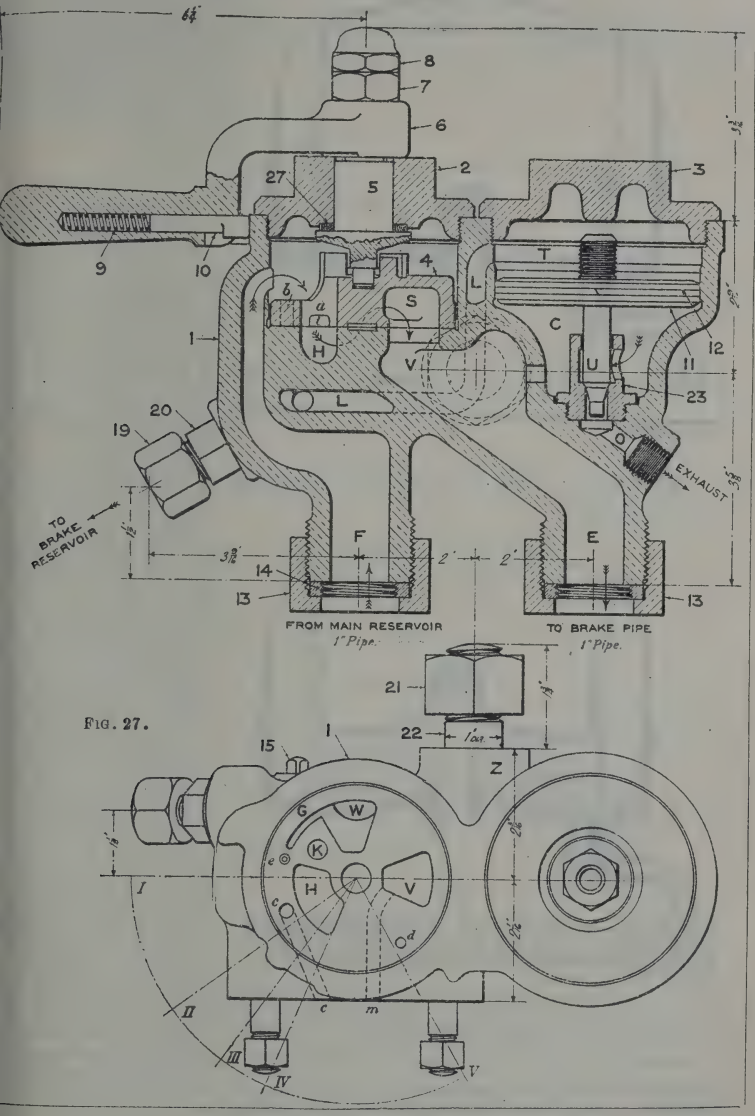


FIG. 27.

of each coupling, which fits in a corresponding groove of the other coupling. No damage is done if the couplings be drawn apart forcibly by the separation of the train, as the rubber rings, 3, 3, are forced into their respective couplings far enough to permit the projections to disengage from their grooves. These couplings are united by simply placing them face to face at right angles, the stop-pins being on the under side, and then turning the projection of the one into the groove of the other.

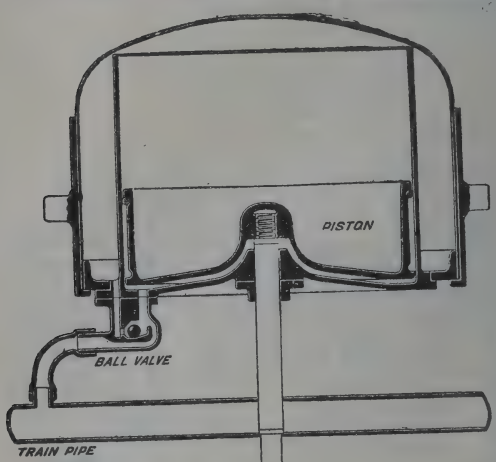


FIG. 29. Vacuum Automatic Brake. Brake off. Representing position of piston and valve when a vacuum is created and the brake is off.

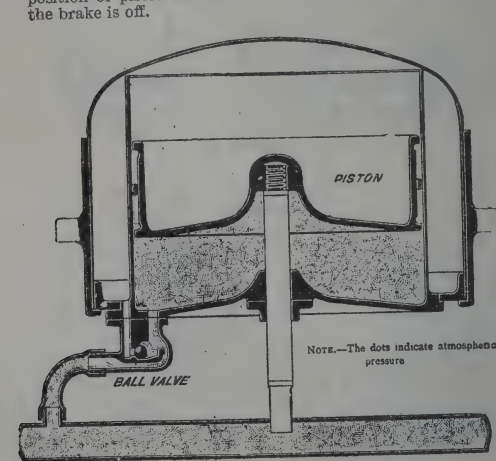


FIG. 30. Vacuum Automatic Brake. Brake on. Representing position of piston and valve when the brake is applied by the admission of air to the train pipe. The ball is held tightly to its seating, and preserves the vacuum on the top side of the piston, which is raised by the atmospheric pressure below it.

The Vacuum Automatic Brake.

In this brake an ejector placed upon the engine exhausts the air (to a vacuum of 20 to 24 inches) out of the continuous pipe and the cylinders. The brake is applied by the admission of air into the train pipe, and released by the withdrawal of the same through the ejector. The brake is self-acting in the case of an accidental parting of the train.

The brake-cylinder (figs. 29 and 30) is self-contained in the vacuum-chamber as applied to carriages, and is the only fitting required. The piston fits freely in the cylinder, and is packed by a rolling rubber ring, which, when the piston moves, rolls between it and the cylinder, making a perfect packing without friction. The piston-rod is coated with brass, and works through a brass bush, and a packing rubber prevents air passing the rod. At the bottom of the cylinder is attached the ball-valve, the branch of which is connected by a small hose-pipe to the train pipe. This valve is of the most simple construction, as there is only one moving piece, and that being a small brass ball, having a rolling action in a horizontal position, has consequently no friction. A spindle with release lever (not shown in the figures) is added for the purpose of withdrawing the ball from its seat when it is required to release the brake by hand. This spindle is made air-tight by a small diaphragm, the pressure on which when a vacuum is created pulls in the spindle and allows the ball to go freely to its seat.

The action of the cylinder is as follows: The air is drawn out through the train pipe from the bottom of the piston direct, and from the top by passing the ball which it forces up the

ncline of the spindle ; when all the air is withdrawn the ball rolls down the incline and on to its eating. To apply the brake, the air is let into the train pipe, and it then passes to the under ide of the piston, and, being prevented from entering to the top by the ball, lifts the piston, and o applies the brakes with any amount of force according to the quantity of air let in.

The couplings are extremely simple ; each consists of a pair of castings exactly alike, with horns op and bottom. It is impossible to couple them wrongly. To couple they are lifted up suffi- iently high to enable the bottom horns to be placed together, and then lowered, the top lug of ne being placed in the slot of the other. To uncouple it is simply necessary to raise the couplings, vhen they will separate.

SECTION XIII

PART III

RAILWAY SIGNALS.

MECHANICAL SIGNALS.

THE WESTINGHOUSE BRAKE AND SAXBY SIGNAL CO., LTD., SIGNALLING SYSTEMS.

Double Wire Working.

In this system two wires are utilised as the operating transmission for the working of point cks, locking bars, derailers, signals, etc. The system, which is employed practically universally n the continent of Europe, has been developed with a view to making it suitable for operation ith the British type of signal. A great advantage of the arrangement is the facility with which ie operating wires for points, etc., can be run, compared with the installation of the ordinary d. These operating wires can, if necessary, be placed at a sufficient height to avoid interference ith the ordinary use of pathways and sidings. There is a further advantage in definitely pulling ie signal to 'danger,' as compared with the gravity method, because it prevents any possibility f an arm remaining in the 'clear' position due to accidental causes, such as freezing of the signal rm or connections; also points and signals can be operated at a greater distance than is possible ith the ordinary mechanical system. Points 500 yards from the cabin are well within the limits working, and thus it is possible with the system to dispense with two interlocking frames here long passing loops or sidings are installed. Fig. 1 (p. 736) shows the type of lever generally ed for double wire working. Fig. 2 (p.736) shows a simple form of point mechanism, and indicates w, with a breakage of one wire, protection is given against accidental movement of the points; ie catches A and B prevent the driving pulley, to which the operating wires are connected, moving, d, consequently, shifting the points, unless an even tension is maintained in both operating ires; and, of course, functions in both positions of the points. Means are also provided, in se of a breakage of the return wire on signalling systems, for the immediate disconnection of e pulling wire, and the return to 'danger' of the semaphore arm, by gravity.

POWER SIGNALLING.

Electro-Pneumatic.

In the electro-pneumatic system the control and the indication of the operation of the points d signals is carried out by means of electric power, at, as a rule, a moderately low voltage, and the expense of quite small current consumption, this electric power being required only for the eration of small valve magnets, whereas the actual heavy work of shifting points, signals, etc., carried out by means of compressed air. This compressed air may be at any pressure, but, as rule, a pressure of 60 lbs. per sq. inch is chosen. Electric control may be by direct current, by alternating current.

Simple cylinders are used, to which air is admitted by the electro-magnetic valves before entioned. The motion of the cylinder being in a straight line, it is unnecessary to provide

special gear for changing the rotary into linear motion, as is necessary with apparatus operated by rotating electric motors.

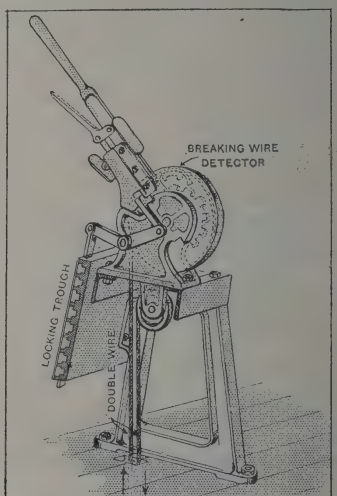


FIG. 1.
Signal or Point Lever (Double Wire).

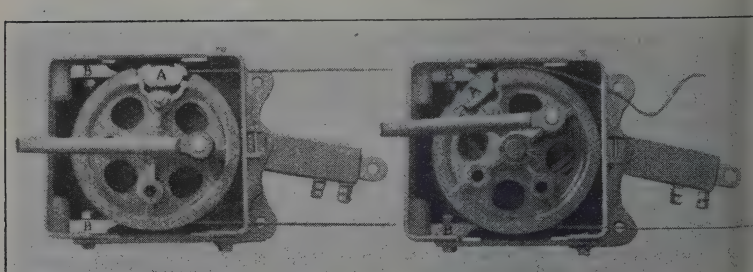


FIG. 2.

All-Electric System.

With the all-electric system, electric power is used both for operation and control. As a rule, for both direct-current and alternating-current systems, a pressure of 100 volts is used, this being applied directly to the motors for the signals or point machines. For operation on direct current, the motors are generally series wound, having two field windings, one of which is connected to the normal and the other to the reverse control wire; the remaining two wires of the field coil are connected to one armature brush, the other brush being connected to the return wire. Application of current to the normal control wire causes the motor to run in one direction, and in the opposite direction when current is applied to the reverse control wire.

Installations operating on this system have been in service at Baker Street (Metropolitan Railway), on the Berlin Underground Railways, and elsewhere, for many years.

With the alternating current system, split phase induction motors are used for the operation of the signals. The point motors are series repulsion type motors, and as the current taken by

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WITH D.C. OR A.C. TRACK CIRCUIT CONTROL.

Power Interlockings and Automatic Signalling.

Day Colour Light Signals : Long Distance Operation of Points & Signals by Battery or Hand Generator System.

POWER DECKING PLANT FOR COLLIERIES

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(See pages 735-740.)

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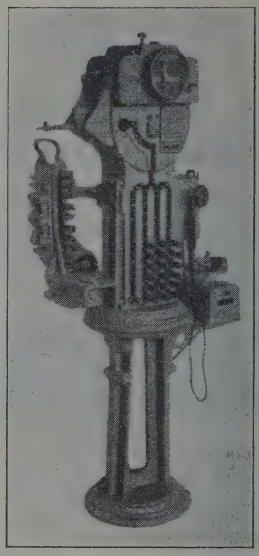

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S TYPE TRAIN STAFF INSTRUMENT WITH:—TOKEN BALANCING MECHANISM, PILOT LOCK, BELL & TELEPHONE

hese is considerably heavier than that required by direct-current motors exerting the same norse-power, it is generally found advisable to supply current to them from a local transformer, he control from the cabin comprising a polarised contactor and two wires which may be energised vith current in one direction, so connecting the field and armature together as to cause the motor o run in one direction, whereas when the current in the control wires and contactor is reversed he field and armature connections to the motor are also reversed, causing it to run in an opposite direction. The current for operating the polarised controller is very small, and comparatively hin conductors can be used between the lever and the controller. This patented system of upplying current locally enables alternating current to be applied in a very simple manner to he heavy work of shifting points.

Point Indication and Detection.

The system now almost universally adopted by the Westinghouse Co. employs a point detector at the points which, with one set of contacts, simultaneously detects both switch tongues and facing point bolt. This point detector can be wired up as a double pole change over switch, o which are connected two wires, which are taken to the signal cabin and operate a relay of the polarised type, so that the relay will be energised in one direction when the points are normal and in the other when the points are reversed. When there is no current on the wires the relay s de-energised. The system can be used either for direct current or alternating current, although he tendency is to use alternating current in all cases.

The arrangement enables all detection of signals over points to be carried out by taking the signal control circuits over the contacts of the relays located in the signal cabins.

Light Signals.

During the past few years there has been a very large development in the use of colour-light signals for daylight work. With these signals the same indication is secured both by night and by day, and signals can be easily distinguished in bright sunshine at 1,000 yards or more. Although he Westinghouse Co. have a number of designs of day colour-light signals, the type which has been most widely installed is that in which systems of lenses, one for each colour, are provided, behind which there are fixed special electric lamps accurately placed at the focal centre of the ens combination, the illumination of the various lamps being controlled by relay or lever contacts. The signal has therefore no moving parts and is very easy of maintenance. The first installation n the British Isles was made on the Liverpool Overhead Railway in 1921, and since that date further installations have been made on the L. & N.E.R. between Marylebone and Wembley, he L.E.R. from Golders Green to Edgware, on the Met. R. between Harrow, Rickmansworth, and Watford, and the Southern Railway. Also a very extensive installation for some 200 miles of ine in New Zealand. In service the indications given by these signals have proved very satisfactory. The latest type of signal developed by the Westinghouse Co. provides a short range ndication in addition to the main beam lights, so as to make the signal indication readily visible to he driver standing directly below and slightly at the side of the signal. With day colour-light signals the alternating current system of control is always used, as it is necessary with such signals o concentrate the source of light in as small a space as possible, and this can only conveniently be done with low-voltage metallic filament lamps. With alternating current, power can be transmitted from a cabin or other source to the signal at 100 volts and transformed down at the signal itself to a low voltage suitable for the lamps.

Track Circuits.

Track circuits may be of either direct-current or alternating-current type. In the first, primary batteries are often used with small direct-current relays, but all large modern installations or track circuiting are now carried out on the alternating-current system, in which transformers are used o step down the main supply of voltage to that suitable for use on the track rails, say one to two volts, and an alternating current relay is used. These alternating-current relays are so designed as to make them immune from operation by direct current, and they are therefore suitable for operation on lines where direct-current propulsion is used for electric trains. Where the propulsion current returns to the power station through the running rails, alternating-current track circuits are the only ones which it is possible to use. With these, impedance bonds are necessary at the ends of each track circuit, which impedance bonds are so designed as to allow the direct-current propulsion to pass without hindrance, whilst preventing the alternating-current from passing from one section to the other. Space does not permit of a full description of these.

Alternating-current track circuits were first installed in Great Britain on the C.L.R. and G.W.R. about 1910. Since then numerous alternating-current track circuits have been installed in all parts of the world.

WESTINGHOUSE ELECTRO-PNEUMATIC RAILWAY SIGNALLING SYSTEM.

This consists essentially of electrical circuits working in conjunction with a compressed air supply. The electrical system connects the signalman's levers at the cabin with the points and signals, whereby instantaneous response of the signals and points to the motions of the levers is secured, and also an instantaneous 'indication' of the movements of the points and signals is returned to the locking frame. The compressed air of about 60 lbs. per sq. in. pressure serves

as the actual power moving the signals and points. The levers in the signal cabin are merely small electrical switches, and they involve no heavy labour on the part of the signalman for their operation. The locking frame, the levers of which are closer together and far less in number than those in the hand system, is provided with two kinds of interlocking—a mechanical system and an electrical system. The mechanical interlocking is practically identical with that used in hand-power signalling systems, excepting, of course, that the parts are very much lighter. The electrical locking consists of a series of electro-magnets connected in the indication circuits from the signals and points; the armatures of these magnets engage with projecting lugs or sectors fitted to the shafts of the levers. By means of this combination of electrical and mechanical locking, the many complicated problems of special locking required by modern methods of signalling are successfully solved. The electrical contacts of the lever shafts, by which the circuits between the battery and the electro-magnetic valves of the point and signal motors are made or broken, consist simply of phosphor-bronze strips, working over contact pieces mounted on an ebonite bushing surrounding the lever shaft. The electric current is usually drawn from a small battery of storage cells, the pressure being about 14 volts. Primary cells are often used, the current required being only about 0·05 ampere per signal or point motor. Small wires made up into cables connect the locking frames with the various point and signal motors.

The actual work of pulling off a signal or throwing over a set of points is done by a small compressed air-motor fixed close by the signal or point to be operated. The definite, straight line motion of such motors is particularly suitable for the movement of signals and points. The valves controlling the air supply to these motors are opened by small electro-magnets. With this system selection of signals becomes simple, since it is easy to arrange the electrical contacts in such a way that the path of the electric current is made through the signal only which appertains to a route which is set by the movement of certain point levers, and when the signal lever is pulled over that signal only is operated by the electric current; whereas, if other point levers are operated or another route set, the path of the current being changed, another signal is operated when the same signal lever is pulled over.

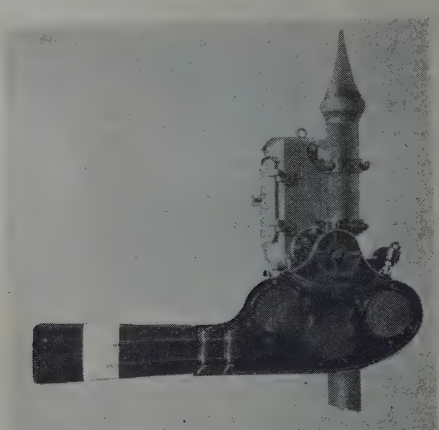


FIG. 3.

The pressure of the compressed air used is, as before stated, about 60 lbs. per sq. in. Experience has proved this pressure to be the most suitable for the purpose, having regard to the size of the motors, and the general convenience of installing, operating, and maintaining the system. The quantity of air used does not amount, even at the busiest centres, to more than half a cubic foot of free air per minute per lever.

The electro-pneumatic signal (fig. 3) is fitted direct to the post, and is designed for either two- or three-position working. The air cylinder C (see fig. 4) operates the arm to the 'caution' or 45° position, under the control of electro-pneumatic valve E, through crank A, which rotates the spindle on which is mounted the semaphore arm. This arm is operated to the 'clear' or 90° position by the air cylinder D, under control of electro-pneumatic valve F, through crank B. The apparatus is so designed that the 90° position cannot be reached by the semaphore arm unless the electro-pneumatic valve controlling the 45° position has first been energised. This arrangement greatly simplifies control wiring. Each signal has an internal circuit controller H, which provides contacts for controlling such external circuits as for indications, repeaters, etc. The return to the

'danger' position of the semaphore arm is by gravity, immediately the pressure is cut off, and the cylinders exhausted, by the electro-pneumatic valves. The exhaust of air is choked by an exhaust nipple which provides a cushioning effect, so that the arm will not drop too heavily.

The point motor, fig. 5, consists of a double-acting cylinder working horizontally, and is usually installed outside the track, alongside the points. Compressed air is admitted to this cylinder by

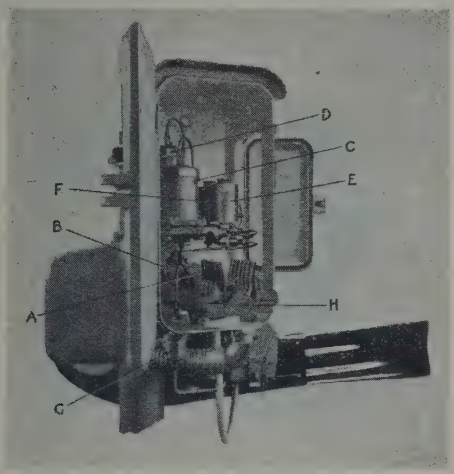


FIG. 4.

the point valve, which is usually mounted on a post near-by and connected to the cylinder by two pipes. The point valve consists of a slide valve C moved by pistons A and B, these pistons being in turn controlled by electro-pneumatic valves N and R respectively, which admit air (or exhaust it) behind pistons A and B, according to which valve is energised. The chamber in which the slide valve is located is under constant air pressure, and when the slide valve is moved to right or left it uncovers one or other of two ports which communicate direct with the back or front ends of

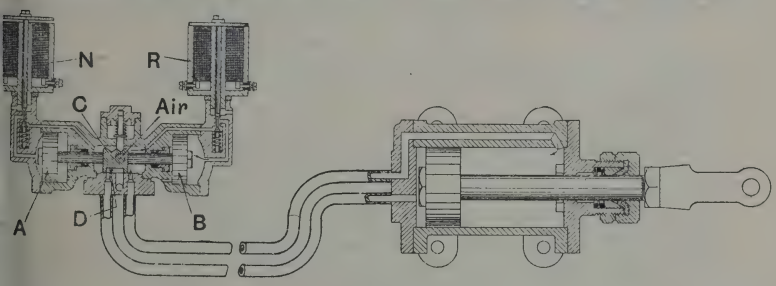


FIG. 5.

the cylinder. At the same time the covered port is bridged by a cavity on the face of the slide valve to a third port open to atmosphere.

The latest development is the point valve style C (fig. 6), which employs a third electro-pneumatic valve, the purpose of which is to lock the slide valve into position, and to cut off the air supply after each operation of the cylinder. This arrangement enables metal-packed pistons to be used in the point cylinder, and also economises in compressed air, as the cylinder is under air pressure only while the movement is taking place.

When the style 'C' point valve is used it can be arranged so that should the point tongues be accidentally or deliberately displaced, air is automatically applied to the point cylinder so that the tongues will be closed again.

Westinghouse electro-pneumatic signals are also largely used in connection with automatic signalling, both on steam and electric traction roads. For this purpose the running rails are divided into suitable sections or blocks which are electrically insulated from one another: the presence of a train or any vehicle in a block keeping the signals controlling the entrance to that block at danger. The signals are not cleared to admit a second train until the first train has cleared the block by a certain distance, depending upon the braking distance required by a train.

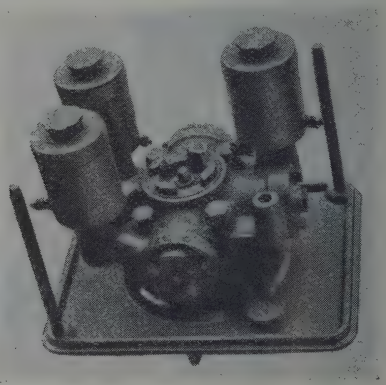


FIG. 6.

Such installations are largely used in America, there being nearly 10,000 signals of this type in operation. In Great Britain complete installations have been working for several years on the Metropolitan Railway, the Metropolitan District Railway, the London Electric Railways (consisting of the Baker Street and Waterloo; Great Northern, Piccadilly and Brompton; and Charing Cross, Euston and Hampstead Railways), the Central London and the East London Railways. These installations deal with a service of forty trains per hour, and have the additional protection of a train stop at every signal location which automatically applies the brakes on a train should it overrun a signal at danger.

The electro-pneumatic signalling apparatus, both for power-operation of points and signals and for automatic signalling, is manufactured and supplied by The Westinghouse Brake and Saxby Signal Co., Ltd.

'CREWE' ALL-ELECTRIC SYSTEM.

The Railway Signal Company, Ltd., are the manufacturers of a system, of which there are several installations on the London and North Western Railway—hence its name—of operating points and signals by electricity.

Fig. 7 shows the locking-frame, and it will be seen that the levers are in two tiers, those, *a*, in the upper tier taking odd numbers and, generally, working points, and those, *b*, in the lower the even numbers and, generally, working signals. To each lever is connected a down-rod *c* to which, immediately under the signal-box floor, are coupled cranks. These actuate the interlocking tappets in the usual interlocking-boxes. At the lower end of the down-rod is connected the switch *d*, the carbon contacts of which join, when the lever is moved, switches *e f* and *g h*, and so cause power to be sent to the points or signal as the case may be.

As in other power-signalling systems, the full stroke of a point lever from normal to reverse and from reverse to normal, and the complete stroke of a signal lever from the 'off' to the 'on' position, cannot be made until an indication is received that the operation set up by the initial movement of the lever has been completed. This, in the 'Crewe' system, is achieved by the check lock *j* attached below the switch. On the check lock *j* are two lugs k^1 k^2 which engage pawls l^1 l^2, the armatures of which can be attracted by the magnets m^1 m^2. When a point lever is moved, say, from normal to reverse, the down rod is raised and the lug k^2 on the check lock will then abut against and be stopped by the pawl l^2, but as soon as the current set up by the switches above has done its work, the return indication current energises the magnet m^2, so that the pawl p^2 is attracted and frees lug k^2, consequently the lever can then be pulled the remainder of the stroke. When the points are being restored to normal the down-rod descends and lug k^1 is then stopped by pawl p^1 until magnet m^1 is energised. When the points are reversed the switch *d* has its contacts on switches *e* and *g*, and when normal on switches *g* and *i*.

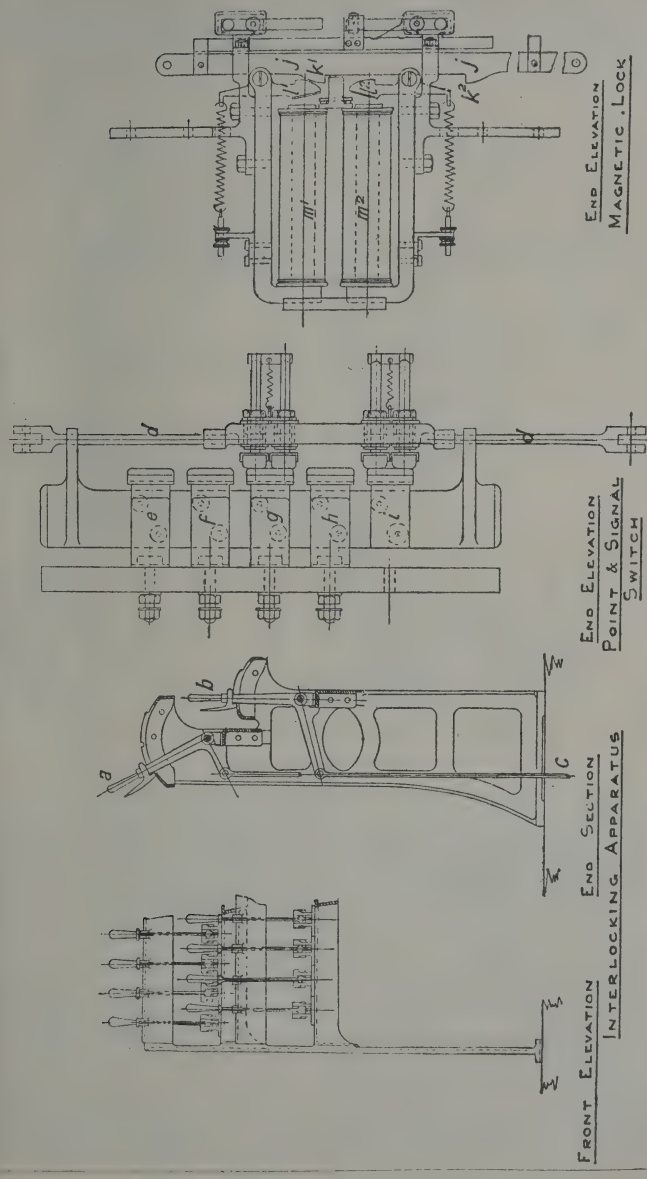

CREWE ALL-ELECTRIC SYSTEM.
FRONT ELEVATION
INTERLOCKING APPARATUS
END SECTION
END ELEVATION
POINT & SIGNAL
SWITCH
END ELEVATION
MAGNETIC LOCK
a
b
c
d
e
f
g
h
i
j
k
l
m1
m2

FIG. 7.

Fig. 8 is a plan and elevation of the lay-out of a pair of facing points. The motor (see also fig. 9), which requires a current of 20 amperes and 100 volts, is fixed in a cast-iron box below the rail level. The motor *a* (fig. 9), by means of a worm, drives the worm wheel *b*, fixed loose on the same shaft as the cam wheel *c*. Movement is transmitted to the cross shaft by means

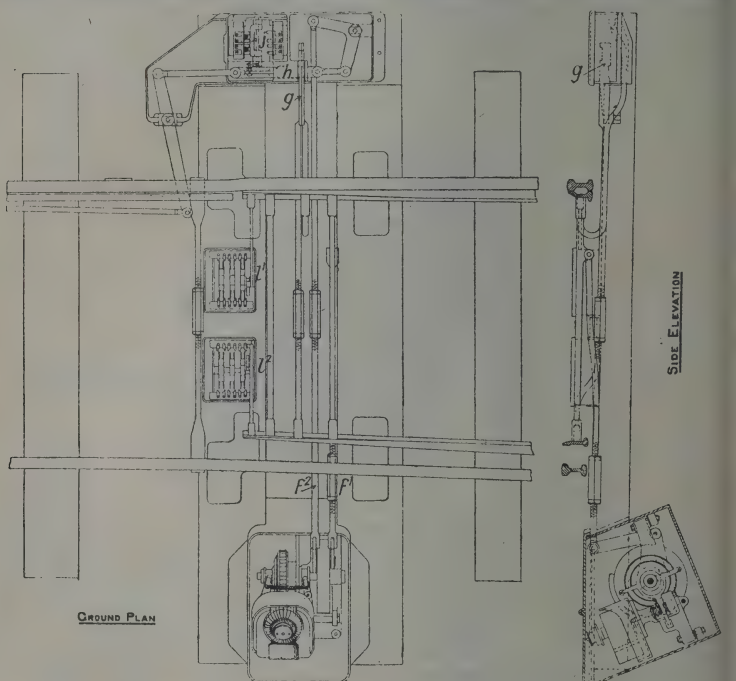


FIG. 8.

of one or other of the clutches d^1 d^2, which are right- and left-handed, so that if the worm wheel turns in one direction the right-handed clutch is engaged and if in the other direction the left-handed clutch. On either face of the cam wheel *c* is a cam-shaped slot of irregular contour in which works a roller attached to a crank, *e*. The crank on one side works the points by means of the rod f^1, and the other crank actuates the plunger and locking bar by means of rod f^2. Each point has an extension *g*, suitably slotted on the upper side for one position of the points and on the lower side for the other position of the points. Both extensions and, therefore, both switches of the points, must be accurate in their position or the plunger *h* will not pass through them. To the end of the plunger is connected a rod leading to the locking bar. On the upper side of the plunger are guides that move over a short lever and place the contact maker *j* in or out of contact with the springs k^1 k^2. The latter are connected to the magnets m^1 m^2 of the return indication in fig. 7 and cause pawls l^1 l^2 to be attracted and allow for the down rod *c* to complete its upward or downward movement and for the switch *d* to make contact with *eg*—if an upward movement—or with *g i* if a downward movement. This cuts off the current from the motor. But as will now be readily understood, this cannot occur until the plunger is shot and the switches held, nor can the plunger be shot unless and until the switches are in their correct position. Further detection is given by means of the contacts l^1 l^2, which are in the circuits to the signals concerned. The switches for these contacts are rotated by means of short rods connected as near as practicable to the 'nose' of both point switches.

Signals in the 'Crewe' system, whether semaphore signals or the dwarf signals used in shunting operations, are changed from the 'danger' to the 'clear' position by means of a long-pull magnet *m*, fig. 9. A current of about 15 amperes and 100 volts is required for a fraction of a second to clear a signal, which current is then passed, by means of the switch *n*, through a resistance,

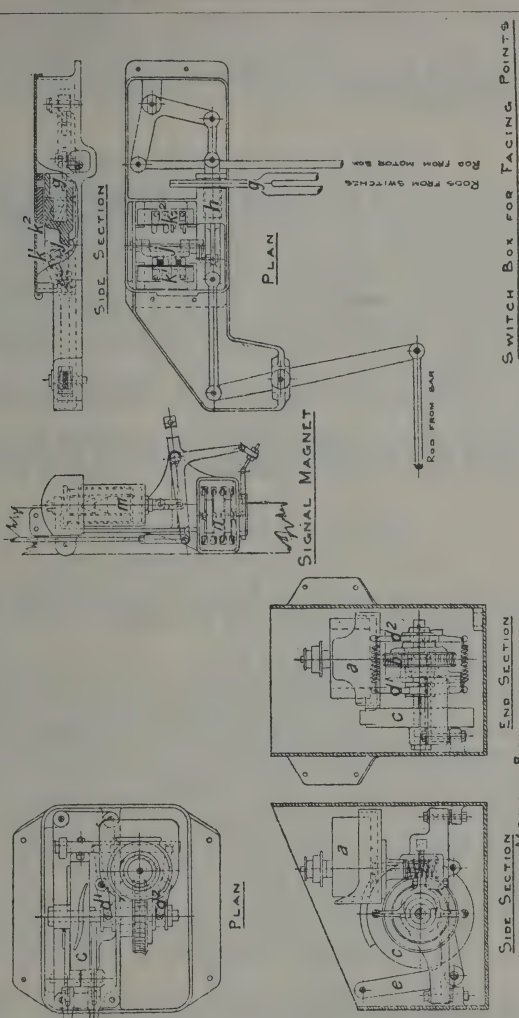

Crewe All-Electric System.
Side Section
Plan
Signal Magnet
Rod from bar
Rods from switches
Rod from motor box
Switch Box for Facing Points
Rod to switches
Rod to bar
Plan
Side Section
Motor Box
End Section

Fig. 9.

and about 2 amperes is enough to hold the signal at 'clear.' When the lever in the signal-box is replaced partly to normal the current supply to the signal is completely cut off and the arm goes to danger by its own gravity. When the signal is fully 'on' the switch n sends the return indication and allows for the lever to complete its stroke. No return indication is necessary to show that a signal has gone from 'danger' to 'clear.' What is of importance is that it has gone from 'clear' to 'danger.'

SYKES ELECTRO-MECHANICAL SYSTEM.

About 2,000 levers have been installed in the electro-mechanical system of the W.R. Sykes Interlocking Signal Co., Ltd., wherein all signals are actuated by electricity, the circuits for which are completed by a small slide being drawn forward or pushed back, and all points are moved by the usual mechanical lever, elevations of which are given in fig. 10

The slide a carries contact pieces b^1 b^2 which, when the slide is drawn out, put springs c^1 c^2 into contact with the plate d. This completes the circuit to the signal governed by the lever by means of wires passing through the box e. When it is necessary to control the movement of a slide, e.g., from another signal-box, or by a fouling bar or track-circuit, a pin rests normally in the slide which can only be lifted when the magnet f is energised. The slides are interlocked as in a mechanical frame, but on a miniature scale. The slide itself acts as its own tappet, and the locks are in the locking-boxes g g.

The tappet of the mechanical lever is h, and a stud h^1 turns the shaft h^2, and so, by a stud h^3, actuates a co-acting tappet in the electrical part. By this the mechanical levers and electrical slides are interlocked.

By an ingeniously arranged escapement wheel the movement of the mechanical tappet is only 2 ins., the same as the electrical slide. A lock j in the tappet k holds point levers when required until they are freed by the lock being lifted out of the tappet by the magnet l being energised.

LOW-VOLTAGE POINT MOVEMENT.

(The British Power Railway Signal Company, Ltd.)

The Low-Voltage Point Mechanism, which is used to a considerable extent on single lines, makes it possible to control both points and signals from a distance, and affords a convenient and economical means of operating many outlying points where the cost of a pointsman or interlocking frame would be prohibitive.

The main feature of the arrangement is that the actual operating battery consists of a small set of primary cells or accumulators situated somewhere near the points. Current is supplied to the point motor through control relays, which operate with a fractional amount of current, and can therefore be governed by small line wires over long distances.

Indicators provided in the operator's cabin show at all times the position of the points, and any irregularity of working is immediately detected. Each mechanism box is supplied with a special metal crank handle, which, when fixed on to the shaft of the motor, can be used to mechanically wind over the points for maintenance purposes or in case of battery failure. When not in use, and resting in its normal place in the mechanism case, this handle forms part of the electrical return circuit common to both the operating control relays, and also the signalman's indicators, so that the latter set themselves to show something amiss immediately the handle is removed from its proper place. The control relays are also rendered inoperable.

If track circuit is provided, as in a complete scheme, this can be utilised to prevent a movement of the switches while vehicles are fouling any part of the crossover.

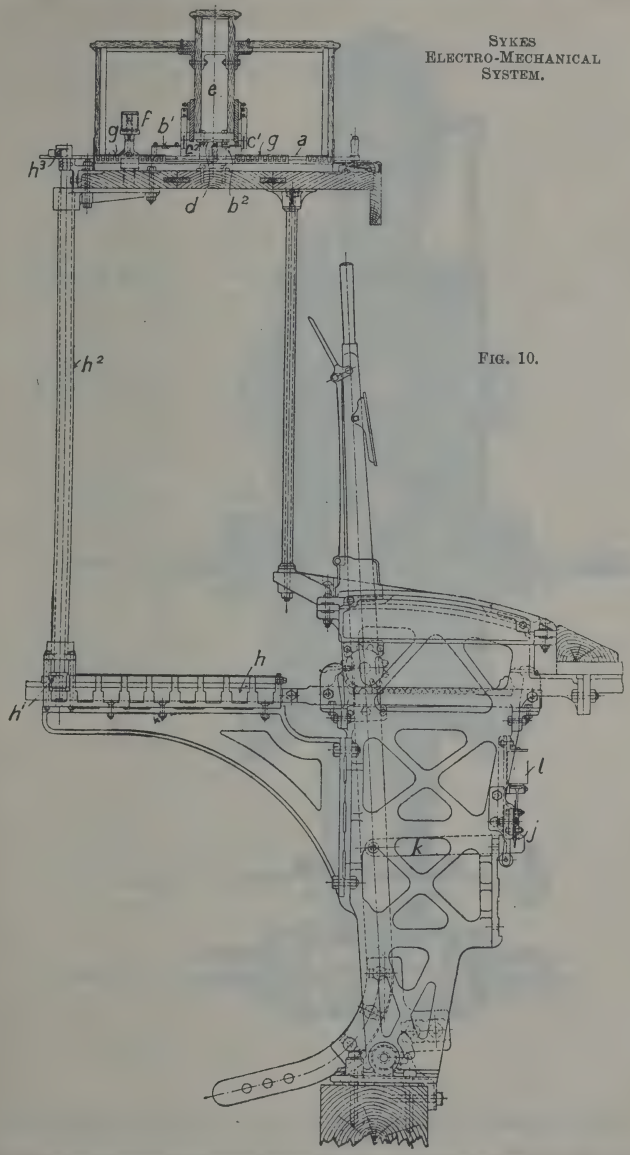
The controlling switch can be placed in any convenient position, and it is sometimes found useful to fix this in the telegraph or stationmaster's office, for instance, when there is only one pair of points for a siding, passing loop, or other purpose in the vicinity, but of course it can also be fixed to and operated by an ordinary lever interlocked with other signals and point levers if required.

Fig. 11 shows the British Power Railway Signal Co.'s patented point operating machine fitted with Point Lock and Point Detector outside attachment. This machine is standard for high (110 v.) or low voltage (20 to 30 v.) operation.

The main operating mechanism consists of a chain of gears comprising :—A bevel pinion fitted with safety clutch device and meshing with a bevel wheel keyed to a spur pinion, this in turn meshing with the main spur wheel. This spur wheel is fitted with roller devices for driving the power bars.

The motor is series wound, enclosed in a substantial weather-proof case. Provision is made for hand operation of the points by means of a crank handle, which requires an isolating switch contact arm to be swung out of the way before the handle can be placed in position.

Figs. 11 and 12 show one of a large number of variations or combinations of machine fixing and point connections.



SYKES
ELECTRO-MECHANICAL
SYSTEM.

FIG. 10.

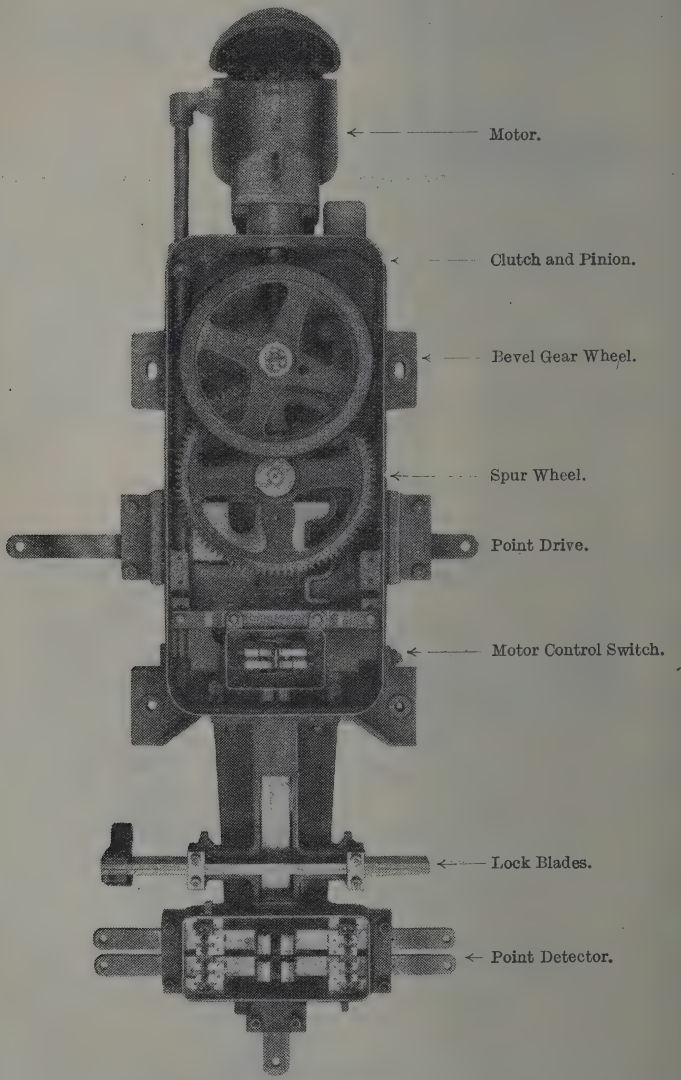


FIG. 11.—British Power Railway Signal Co.'s patented Point Operated Machine.

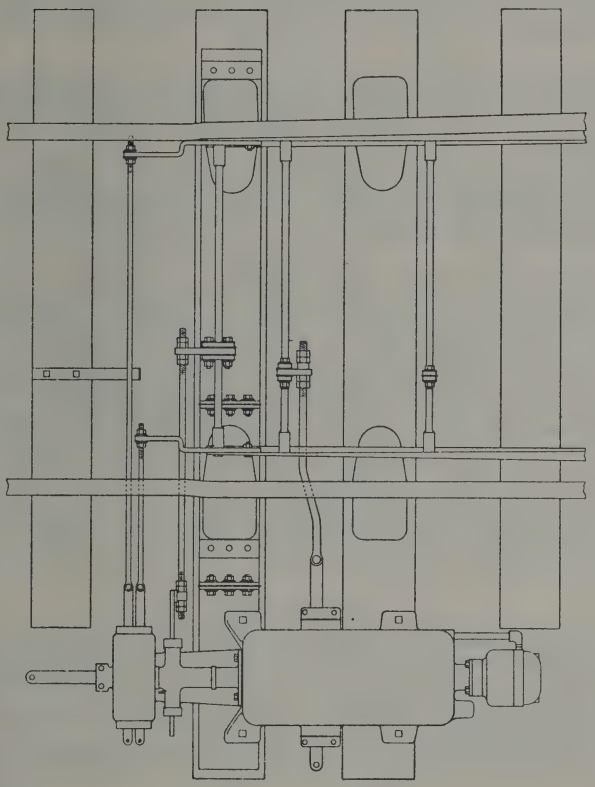


FIG. 12.—Low-Volt Quick-Acting B.P. Point Operating Mechanism, with Outside Point Lock and Detector Attachment.

ALL-ELECTRIC POWER SIGNALLING.

(The British Power Railway Signal Company, Ltd.)

Amongst signal engineers the all-electric system of point and signal operation has met with more favour generally in recent years than those systems, such as the electro-pneumatic, where two sources of power are required for operation. Each system has its own advantages and disadvantages, and the choice between the two systems depends on the circumstances at the particular station or yard where an installation is contemplated.

The system of all-electric signalling adopted by the British Power Railway Signal Company, Ltd., is based on the principles of dynamic indication in combination with an automatic stroke completion movement of the signal or point lever, and also a complete cross protection system. The following is the arrangement :

Locking Frame.

The lever slides are arranged in easily detachable units at 3 in. pitch, each slide having cam-shaped slots cut therein for the operation of the interlocking, which is arranged vertically at the front of the machine. A further cam slot is also cut in each lever for the purpose of obtaining the automatic lever movement by solenoid action acting on the diagonal portion of the cam slot for indication purposes.

An extension of the lever slide carries a contact maker which makes and breaks with ' normal ' and ' reverse ' contact springs for operation of the points and signals. A horizontal rod extension from the lever slide operates the combination circuit closer arranged vertically at the back of the frame for the control of the various circuits. The safety and indication selector relays are fixed conveniently at the back and below the lever slides, as also the polarised relays for cross protection purposes.

Point Mechanism.

The power point mechanism comprises a 110-v. motor in weatherproof casing and bolted solidly to the gear-case. The motor operates the train of spur gears and the main cam gear for unlocking, throwing the points and relocking. A friction clutch is provided to protect the mechanism from shock in case of obstruction. A pole-changing device is provided, all self-contained in its own casing within the main gear-case. The pole-changer is required for the changing of the motor connections at the end of each point operation ; this is effected by a cam slot on the lock bar connection, and in addition is also operable by solenoid magnets, in order that the points may be reset in their previous position in the event of any obstruction in the points. Connections from the lock bar may be arranged to work a combined facing point lock with point and lock detector, or the design of point mechanism is arranged for an outside lock or combination of outside lock and point detector attachment bolted securely to the end of the mechanism casing to meet varying conditions and requirements. Energy for the dynamic indication stroke of the lever is obtained by the overrun of the point motor after the completion of the movement of point function, and in addition the generated indicated current provides an automatic snubbing action to the motor and all parts are brought to rest without shock. Two wires are used for operation, ' normal ' and ' reverse,' and these are used for the return indication current ; the ' normal ' operating wire is used for the ' reverse ' indication, and the ' reverse ' operating wire for the ' normal ' indication.

For detection, one ' normal ' and one ' reverse ' wire is used.

Signal Mechanism.

The signal mechanism comprises a 110-v. motor with a train of gears operating a circuit controller and main driving shaft. A spring attachment is operated by this driving shaft and is placed under tension when the signal lever is operated. When a train enters a track section governing the signal the operating current is broken and the signal falls by gravity to the ' stop ' position. The spring tension comes into action, when the lever is returned to ' normal,' for the purpose of rotating the motor armature, which generates the dynamic indication current and automatically completes the indication stroke of the lever.

The design of mechanism is similar for running signals or dwarf signals ; for the latter an alternative signal of the solenoid type is sometimes used, in which case battery indication is provided.

D.C. OR A.C. LOW-PRESSURE ELECTRO-PNEUMATIC SIGNAL SYSTEM.

The British Power Railway Signal Co., Ltd., specialises in d.c. or a.c. electro-pneumatic systems for terminal or through stations, in which the principles of the automatic indication of the stroke completion of the lever, and cross protection, are retained, as in the All-Electric Signalling System. The points are operated by 8-in. diameter cylinders controlled by electro-pneumatic valves, the operating air pressure varying from 15 to 20 lbs. The signal operating cylinders are 4 in. diameter.

For gravity or sorting yards, the point operating cylinders are 7 in. diameter and are controlled by electro-pneumatic valves energised from a push-button machine placed in the control cabin.

Mechanically Operated Points.

The limit of distance from levers working points to be 350 yds., unless the points are power worked and occupation of the lines is electrically indicated in the signal-box, in which case the distance may be indefinitely extended. *(Ministry of Transport.)*

SECTION XIII

PART IV

UNITED KINGDOM RAILWAY EXPENDITURE AND RECEIPTS—STANDING ORDERS WITH REFERENCE TO RAILWAY BILLS.*

Financial Statements.

The capital expenditure of the railways in Great Britain at 31st December, 1926, amounted to 1,206,216,723*l.*, as compared with 1,198,637,386*l.* at the end of 1925, an increase of 7,579,337*l.* Capital receipts at 31st December, 1926, amounted to 1,153,888,312*l.*, the amount received during the year 1926 being 2,141,079*l.* The excess of capital expenditure over capital receipts was thus increased from 46,890,153*l.* to 52,328,411*l.*

The net income for the year was 26,548,137*l.*, as compared with 44,771,081*l.* in 1925, a decrease of 18,222,944*l.* 17,199,139*l.* was added to the net income of the year by transfer from Reserve Funds, and from Profit on Realisation of Investments, compared with 6,892,887*l.* brought in from similar sources in 1925.

The amount appropriated for the payment of interest and dividends in 1926 was 41,959,515*l.*, as compared with 49,324,331*l.* in 1925, representing 3·63 per cent. upon the receipts from capital issued as compared with a corresponding figure of 4·28 per cent. in 1925.

The Reserves and Depreciation Funds of the companies, which in 1925 amounted to 103,341,313*l.*, were reduced to 86,430,675*l.* in 1926.

Way and Works.

Mileage of Lines.—The total length of road open for traffic at the 31st December, 1926, was 20,396 miles, an increase of 5 miles during the year. Expressed as single track, the total mileage of running lines was 37,058 miles (an increase of 40 miles) and of sidings 15,274 miles (an increase of 60 miles), representing a total increase of 100 miles during 1926.

Rolling Stock.

Locomotives.—The number of steam, electric, and petrol locomotives owned, excluding those employed solely on departmental services, at the 31st December, 1926, was 24,045, a decrease of 171 during the year.

Coaching Vehicles.—The number of electric coaching vehicles was 4,497, an increase of 262 during the year, and of carriages worked by steam power 46,617, an increase of 131.

The total number of passenger-carrying vehicles owned was 51,210, an increase of 387, or 0·76 per cent., and the seating capacity of these vehicles was 2,759,581, an increase of 44,444, or 1·64 per cent.

The stock of Pullman cars in use remained at 177.

Merchandise, Mineral, and Railway Service Vehicles.—The number of merchandise and mineral vehicles owned at the 31st December, 1926, was 720,860, a decrease of 499. The total tonnage capacity was 7,665,856, an increase of 62,914 tons, or 0·83 per cent. The replacement of smaller wagons, as they are withdrawn from traffic, by wagons of a capacity of 12 tons and over is reflected in an increase in the average capacity per wagon from 10·75 tons to 10·84 tons.

The stock of railway service vehicles decreased during the year from 53,138 to 52,435.

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* 'Returns of the Capital, Traffic, Receipts, and Working Expenditure, etc., of the Railway Companies of Great Britain for the Year 1926.' (Ministry of Transport.) H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*l.* 1*s.* net.

Road Vehicles, Horses, and Miscellaneous Property.

The number of passenger road-motors owned by the railway companies in Great Britain at the 31st December, 1926, was 282, as compared with 303 at 31st December, 1925. Parcels and goods motor vehicles increased by 219 to 2,501.

There has been a decrease of horse-drawn road vehicles, from 18,512 to 18,481, and horses for shunting, from 978 to 917.

Operation.

Engine-Mileage.—There was a decrease in the total engine-miles run, of 88,156,602, or 14·94 per cent. Coaching train-miles were reduced by 28,129,579 (10·75 per cent.), freight train-miles by 28,182,789 (19·98 per cent.), shunting miles by 1·24 per cent., coaching and freight shunting-miles by 21,847,096 (17·2 per cent.), and other miles (assisting, light and departmental) by 9,997,138 (16·6 per cent.).

The mileage worked by steam tender and tank engines showed a decrease of 89,820,649 miles, or 16·35 per cent.; by electric engines and motor vehicles, an increase of 1,933,747 miles, or 4·99 per cent.; and by steam, petrol, etc., rail-motors a decrease of 269,700 miles, or 16·77 per cent.

Coal and Lubricating Oil Consumed.—For all services combined, the consumption of coal increased from 54·43 lbs. to 56·04 lbs. per engine-mile, and the consumption of lubricating oil increased from 6·86 pints to 6·90 pints per 100 engine-miles. The total tonnage of coal consumed and pints of lubricating oil used by steam locomotives and steam rail motors on standard gauge railways were 11,429,197 tons and 31,727,063 pints respectively, as compared with 13,357,123 tons and 37,749,827 pints in 1925.

Wagon-Load.—The average wagon-load for all descriptions of freight decreased from 5·50 tons to 5·06 tons, and the average train-load from 130·02 tons to 124·47 tons.

Traffic.

Passenger Traffic.—The total number of ordinary and workmen's journeys was 1,068,984,227 as compared with 1,232,580,914 in 1925.

The total number of passenger-journeys, including season-ticket holders on the basis of 600 journeys per annual ticket, was 1,541,879,621, a decrease of 201,438,639, or 11·55 per cent. compared with 1925.

Parcels and Miscellaneous Traffic—The gross receipts from parcels and miscellaneous passenger-train traffic (excluding parcels post and mails) on standard gauge railways were 13,792,939*l.*, a decrease of 3·93 per cent. compared with 1925.

The average receipt per coaching train-mile from passenger-train traffic, including mails, parcels, etc., and other merchandise conveyed at passenger train rates during 1926 was 7*s.* 3*d.* as compared with 7*s.* 2*d.* in 1925.

Freight Train Traffic.—The total tonnage of goods and minerals conveyed (excluding companies' free-hauled traffic) was 215,597,027, as compared with 315,951,240 tons in 1925.

The total tonnage and net ton-miles of freight traffic (including live stock and companies' free-hauled traffic on standard gauge railways amounted to 233,850,313 tons and 14,044,751,197 ton-miles, representing decreases of 31·18 and 23·40 per cent. respectively compared with the year 1925.

On standard gauge railways the average lengths of haul were for general merchandise 89·20 miles, for coal, coke, and patent fuel 48·61 miles, and for other minerals 55·16 miles, in 1926, compared with 85·61 miles, 44·57 miles, and 52·58 miles respectively in 1925. For all descriptions of traffic the average haul was 60·05 miles, compared with 53·95 miles. The net ton-miles per route-mile were 695,963, compared with 909,785, and the net ton-miles per engine-hour 405·55, compared with 434·37.

The average receipts per freight train-mile from all freight were 15*s.* 1*d.* during 1926, compared with 14*s.* 8*d.* in 1925.

The average receipts per ton-mile on standard gauge railways were 2·277*d.* for general merchandise, 1·062*d.* for coal, coke, and patent fuel, and 1·157*d.* for other minerals in 1926, compared with 2·307*d.*, 1·009*d.*, and 1·130*d.* respectively in 1925.

Supplementary Information.

Electrical Working of Railways.—The total length of road over which electrical trains were run increased from 466 miles 6 chains to 527 miles 27 chains in 1926.

The car or wagon miles for passenger and freight services for 1926 compared with 1925 were as under :—

Service.	Car or Wagon Miles.	
	1925.	1926.
Passenger	188,520,172	197,293,182
Freight	4,131,559	1,828,675

RAILWAY STATISTICS OF THE UNITED STATES AND TWENTY OTHER COUNTRIES OF THE WORLD.

Year.	Country.	Miles of Line.	Capital, or Cost of Construction.	Receipts from Passenger Traffic.	Receipts from Freight Traffic.	Receipts from other Sources.	Total Receipts.
			£	£	£	£	£
1906	United Kingdom	23,063	1,253,424,374	48,585,823	56,875,967	8,718,213	114,180,005
1904	Russia in Europe	30,800	580,820,600	11,431,042	47,810,400	5,872,699	65,114,141
1906	German Empire	34,563	722,698,741	34,033,000	79,516,147	12,846,450	126,395,598
1904	France	24,755	662,396,000	26,482,802	31,057,550	928,035	58,468,388
1905	Austria	12,976	282,098,809	7,248,518	20,935,807	1,088,474	29,272,799
1905	Hungary	11,259	143,746,328	3,494,840	9,232,920	501,520	13,228,080
1903	Italy	10,022	222,851,200	5,190,309	7,690,384	623,998	13,904,689
1902	Spain	8,559	113,243,200	—	—	—	11,321,380
1904	Sweden	7,708	48,987,234	1,923,162	3,662,011	112,072	5,697,245
1906	Norway	1,575	11,795,544	395,882	523,925	18,491	938,295
1906	Denmark (State only)	1,164	11,249,700	924,993	952,448	146,688	2,024,129
1905	Belgium	2,844	95,849,477	3,483,859	7,052,261	209,143	10,745,265
1905	Holland	2,100	34,769,800	2,025,760	1,956,400	221,920	4,212,880
1905	Switzerland	2,644	55,190,014	2,820,362	3,481,983	310,381	6,612,727
1905	Portugal	1,425	32,477,056	802,839	1,064,575	84,787	1,952,501
1904	Roumania	1,974	30,115,975	750,932	1,492,786	78,627	2,322,365
1907	Canada (companies)	20,660	234,387,561	9,146,130	19,147,653	1,053,869	29,347,652
	Canada (Government)	1,792	16,548,987	412,477	832,757	56,603	1,301,837
1904	Argentine	12,065	113,579,198	2,584,375	8,450,887	1,138,774	12,074,036
1906	Japan	4,783	41,155,903	3,413,162	2,869,950	620,203	6,903,313
1907	New South Wales	3,452	43,538,024	1,448,998	2,847,047	290,915	4,586,980
	Total	220,183	5,751,323,729	166,499,269	307,453,850	34,921,867	520,607,982
1906	United States	222,340	2,612,855,861	102,006,516	328,077,331	35,069,186	465,153,033

Year.	Country.	Total Expenses.	Ratio Receipts to Expenses.	Passengers Carried.	Mean Journey.	Tons of Freight Carried.	Mean Haul.
		£			Miles.		Miles.
1906	United Kingdom	70,889,525	62·09	1,240,347,000	7·95	488,790,683	24·86
1904	Russia in Europe	42,663,090	65·40	123,208,000	68·58	170,039,234	152·49
1906	German Empire	81,637,773	64·55	1,209,224,072	14·21	479,226,874	62·48
1904	France	30,377,544	51·90	433,912,983	19·59	130,143,810	78·86
1905	Austria	19,592,404	66·91	189,931,211	23	133,764,959	65
1905	Hungary	8,122,560	61·40	86,485,000	25	51,948,000	83
1903	Italy	10,058,508	72·30	68,031,232	27	23,688,410	66
1903	Spain	5,558,400	49·10	39,600,000	34	—	—
1904	Sweden	3,773,554	66·22	39,354,777	16·47	27,624,444	44·64
1906	Norway	691,525	73·71	10,074,372	15·37	4,273,189	34·10
1906	Denmark (State only)	1,572,676	77·70	19,467,616	21	4,530,833	53
1905	Belgium	6,717,124	62·13	163,422,017	14·03	65,515,247	—
1905	Holland	3,527,440	83·74	38,810,000	18 66	13,936,000	56·97
1905	Switzerland	4,294,574	64·95	82,424,588	12	13,971,540	44
1905	Portugal	885,247	45·34	13,446,043	20	3,775,559	89
1904	Roumania	1,327,509	57·10	5,234,683	42	4,731,195	89
1907	Canada (companies)	20,749,734	70·70	32,137,319	64	63,866,135	183
	Canada (Government)	1,265,779	97·23	2,277,218	54	2,673,217	234·60
1904	Argentine	6,408,815	53·05	23,312,987	24	20,123,575	104
1906	Japan	3,215,517	46·58	113,675,403	22	21,530,064	63
1907	New South Wales	2,434,746	53·08	41,413,084	9·96	8,793,832	66·66
	Total	325,764,047	62·60	3,975,789,605	15	1,732,946,800	65
1906	United States	307,489,740	66·08	797,946,116	31·54	1,631,374,219	132·33

(*Slason Thompson.*)

Census of Staff.—The total number of persons employed by the railway companies in Great Britain (including the Railway Clearing House, but excluding the Manchester Ship Canal Co.) during the week ending 27th March, 1926, was 689,264, compared with 902,062.

Canals.—The tonnage originating on railway-owned canals in Great Britain in 1926 was 1,712,716 tons, as compared with 2,030,675 tons in 1925. Traffic originating on canals, other than railway-owned, in 1926, amounted to 11,249,524 tons, as compared with 13,540,266 tons in 1925.

Ministry of Transport Regulations with Reference to Railways.

(See 'Requirements for Passenger Lines and Recommendations for Goods Lines of the Ministry of Transport in regard to Railway Construction and Operation.' H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 3*s.* net.)

Cost of Renewal of Railway Tracks.

At the Railway Rates Tribunal (1925) it was stated that on the Great Western Railway it was the general practice to renew the track on the main and principal lines with new materials; the serviceable materials recovered were used on secondary and branch lines. The mileage of the G.W.R. system which must be renewed with new materials was 4,194. The cost worked out at £3,000 per mile. In 1913 the total mileage maintained was 6,709, and this was increased in 1924 to 6,915.

STANDING ORDERS OF THE HOUSE OF COMMONS WITH REFERENCE TO RAILWAY BILLS.

The following are the principal Orders relating directly to railways.

Estimate.

37. The estimate for any works proposed to be authorised by any railway, tramway, tramroad, subway, canal, dock, or harbour Bill shall be in the following form, or as near thereto as circumstances may permit :—

ESTIMATE of the proposed (Railway).

Line, No.				Whether Single or Double.	
Length of line	*Miles.*	*Fgs.*	*Chs.*		
Earthworks :	*Cubic Yds.*	*Price per Yd.*		£ *s.* *d.*	£ *s.* *d.*
Cuttings—Rock					
Soft Soil					
Roads					
Total					
Embankments, including roads	*Cubic yds.*				
Bridges—Public roads	*Number*				
Accommodation bridges and works					
Viaducts					
Culverts and drains					
Metallings of roads and level crossings					
Gatekeepers' houses at level crossings					
Permanent way, including fencing :					
Miles. *Fgs.* *Chs.* at	*Cost per Mile.* £ *s.* *d.*				
Permanent way for sidings, and cost of junctions					
Stations					
Contingencies				per cent.	
Land and buildings : A. R. P.					
TOTAL .. .. £					

The same details for each branch, and general summary of total cost.

Plans.

42. In all cases where it is proposed to make, vary, extend, or enlarge any railway, the plan shall exhibit thereon the distances in miles and furlongs from one of the termini; and a memorandum of the radius of every curve not exceeding one mile in length shall be noted on the plan in furlongs and chains; and where tunnelling as a substitute for open cutting is intended, the same shall be marked by a dotted line on the plan, and no work shall be shown as tunnelling in the making of which it will be necessary to cut through or remove the surface soil.

43. If it be intended to divert, widen, or narrow any public carriage-road, navigable river, canal, or railway, the course of such diversion and the extent of such widening or narrowing shall be marked upon the plan; and if it be intended to divert any public foot-path, the course of such diversion shall be marked upon the plan.

44. When a railway is intended to form a junction with an existing or authorised line of railway, the course of such existing or authorised line of railway shall be shown on the deposited plan for a distance of 800 yards on either side of the proposed junction, on the same scale as the scale of the general plan.

Sections.

47. The section shall be drawn to the same horizontal scale as the plan, and to a vertical scale of not less than one inch to every one hundred feet, and shall show the surface of the ground marked on the plan, the intended level of the proposed work, the height of every embankment and the depth of every cutting, and a datum horizontal line, which shall be the same throughout the whole length of the work, or any branch thereof respectively, and shall be referred to some fixed point (stated in writing on the section), near some portion of such work, and in the case of a canal, cut, navigation, public carriage-road or railway, near either of the termini, the distance of such fixed point above or below an ordnance bench mark in the locality of the proposed works, and near one of the termini, and the height of such bench mark above ordnance datum shall also be stated.

48. In cases of Bills for improving the navigation of any river, there shall be a section which shall specify the levels of both banks of such river; and where any alteration is intended to be made therein, it shall describe the same by feet and inches, or decimal parts of a foot.

49. In every section of a railway the line of the railway marked thereon shall correspond with the upper surface of the rails.

50. Distances on the datum line shall be marked in miles and furlongs, to correspond with those on the plan; a vertical measure from the datum line to the line of the railway shall be marked in feet and inches, or decimal parts of a foot, at the commencement and termination of the railway, and at each change of the gradient or inclination thereof; and the proportion or rate of inclination between every two consecutive vertical measures shall also be marked.

51. Wherever the line of the railway is intended to cross any public carriage-road, navigable river, canal, or railway, the height of the railway over or depth under the surface thereof and the height and span of every arch of all bridges and viaducts by which the railway will be carried over the same, shall be marked in figures at every crossing thereof; and where the railway will be carried across any such public carriage-road or railway, on the level thereof, such crossing shall be so described on the section; and it shall also be stated if such level will be unaltered.

52. If any alteration be intended in the water level of any canal, or in the level or rate of inclination of any public carriage-road or railway which will be crossed by the line of railway, then the same shall be stated on the section, and each alteration shall be numbered; and cross-sections, in reference to the numbers, on a horizontal scale of not less than one inch to every three hundred and thirty feet, and on a vertical scale of not less than one inch to every forty feet, shall be added, which shall show the present surface of such road, canal, or railway, and the intended surface thereof when altered; and the greatest of the present and intended rates of inclination of the portion of such road or railway intended to be altered shall also be marked in figures thereon; and where any public carriage-road is crossed on the level a cross-section of such road shall also be added, and all such cross-sections shall extend for two hundred yards on each side of the centre line of the railway.

53. Wherever the extreme height of any embankment, or the extreme depth of any cutting, shall exceed five feet, the extreme height over or depth under the surface of the ground shall be marked in figures upon the section; and if any bridge or viaduct of more than three arches shall intervene in any embankment, or if any tunnel shall intervene in any cutting, the extreme height or depth shall be marked in figures on each of the parts into which such embankment or cutting shall be divided by such bridge, viaduct, or tunnel.

54. Where tunnelling as a substitute for open cutting, or a viaduct as a substitute for solid embankment, is intended, the same shall be marked on the section, and no work shall be shown as tunnelling in the making of which it will be necessary to cut through or remove the surface soil.

55. When a railway is intended to form a junction with an existing or authorised line of railway, the gradient of such existing or authorised line of railway shall be shown on the deposited section, and in connection therewith, and on the same scale as the general section, for a distance of 800 yards, on each side of the point of junction.

SECTION XIV

ELECTRIC TRACTION

ELECTRIC TRACTION ON LONG-DISTANCE RAILWAYS—ELECTRIC LOCOMOTIVES — LOCOMOTIVE BRAKES — SUBURBAN RAILWAYS — TRAMWAYS — RAILS — RAIL JOINTS—FOUNDATIONS—POINTS AND CROSSINGS—COST OF CONSTRUCTION — TRACTIVE RESISTANCE — CROSS-OVERS AND TURNOUTS—TRAMWAY MOTOR CONTROL—BRAKES — ELECTRIC EQUIPMENT OF TRAMWAYS — TROLLEYS — OVERHEAD CONSTRUCTION — POLES — CURVES—TROLLEY WIRE—RAIL BONDING — CABLES—MINISTRY OF TRANSPORT REGULATIONS — SPECIFICATIONS — RAILLESS ELECTRIC TRACTION — BATTERY VEHICLES.

(Revised and Amplified by Prof. S. Parker Smith, D.Sc., Assoc.M.Inst.C.E., M.I.E.E.)

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ELECTRIC TRACTION ON LONG-DISTANCE RAILWAYS.

There are at present four systems for electric traction on long-distance railways: (1) Direct-current, (2) Three-phase, (3) Single-phase, and (4) Split-phase—a combination of (2) and (3). The Three-phase system, although a complete success, has made considerable headway in but one country—Italy; its drawback is the double overhead conductor. The Direct-current, Single-phase, and Split-phase systems only are in active conflict to-day.

In most European countries the choice of system has been definitely decided by national commissions: these bodies, after weighing the facts, have set forth the details of the system most suited to their needs. Thus, in Great Britain the well-known report of the Electrification of Railways Advisory Committee has recommended the adoption of Direct-current at 1,500 volts. The same conclusion has been reached by the authorities in Holland, Belgium, Czecho-Slovakia, and France; whereas Switzerland, Germany, Austria, Sweden, and Norway have standardised the Single-phase system at low frequency. In the U.S.A. the electrification of the Chicago, Milwaukee, and St. Paul Railway, a large trans-continental route, on the Direct-current system at the high pressure of 3,000 volts, has had a considerable influence on some European decisions. The more recent adoption by the Virginia Railroad of the Split-phase arrangement for one of the heaviest freight services in the world has, however, again drawn attention to the capabilities of A.C. for electric train-haulage.

The motors employed for Direct-current traction are universally of the Series type, yielding a torque which is greatest at starting, falling off as the speed rises. (See Section XXXV.) *Speed regulation*—a very important matter for locomotive work—is obtained by series-parallel grouping of the motors—the standard method employed in traction to vary the motor terminal voltage. Further speeds entail weakening of the motor field flux: a method, while economical, resulting in the reduction of the useful torque per ampere of armature current. Starting is

effected by the insertion of resistance in the motor circuit. For passenger and express work the losses in the rheostats may well be insignificant, but for goods and shunting operation, or where stops are frequent, these losses may become important.

For Single-phase traction in Europe, the Single-phase neutralised series motor is used almost universally; this machine is similar in principle and performance to its D.C. prototype, but has some inherent defects; these have now been overcome by sound design, although compromise and cost have figured largely in the solution, which involves the adoption of a low frequency ($\frac{2.0}{3}$ = 16$\frac{2}{3}$ periods). The decisive advantage, however, is the feasibility of a high pressure on the contact line: 20,000 volts has been successfully tried, and 16,000 volts is standard practice. The stationary transformer is largely responsible for the success of Single-phase traction, both in its capacity of voltage transformation and of providing simple speed-regulation for the motors. No series resistance is required in the armature circuit, as the motor can be switched on to various tappings on the secondary side of the main transformer. This is of especial value for goods locomotives; while, in addition, starting can be economically graded to take up the slack in the wagon couplings.

In America the later developments in Single-phase train-haulage have been with the Split-phase arrangement. Here a higher frequency can be used on the lines with advantage. The high-voltage Single-phase energy taken from the trolley wire is transformed down on the locomotives and passed through a phase-converter, which supplies two- or three-phase energy to the induction motors used for traction. The use of these robust and efficient motors is a great advantage, and commutators are avoided. This is important in the U.S.A., where 25 cycles has become the standard frequency for A.C. traction. Polyphase induction motors are lighter than either D.C. or Single-phase machines, but speed regulation is difficult, complex pole-changing and cascading devices being required. Rheostatic starting is essential. The recuperation of energy by the motors when descending a grade is automatic, and this explains the adoption of the Split-phase system on lines dealing with heavy mineral trains on steep gradients; moreover, braking is positive; energy is returned to the line; tyres, brake blocks, and rails are subjected to less wear; and the high line-voltage makes the collection of large quantities of energy a simple matter.

The straight Three-phase system possesses the disadvantage of requiring two overhead conductors, the track forming the third phase. The result is that the voltage between phases is limited, and the load is always more or less unbalanced. Even here, however, modern developments have improved the conditions, and the phase voltage has, experimentally, been trebled. Induction motors are used as for the Split-phase system, and three or four speeds are becoming common practice.

The systems employed for electric traction which have proved to be technically sound are shown in the following table, which traces the connection from locomotive to power-station:—

Equipment of			Supply.
Locomotive.	Track.	Substation.	
D.C. motor	Overhead wire or Third rail	Rotary converter or Motor generator or Mercury rectifier and transformer	Three-phase at normal or low frequency.
Polyphase induction motor	Two overhead wires	Transformer	
Polyphase induction motor, with phase converter	Overhead wire	Transformer	
Single-phase series motor and transformer	Overhead wire	Motor generator and transformer	Single-phase at low frequency.
		Transformer	

The choice of an electrification system in any specified case is first and foremost a matter of finance. In the main, the installation which is cheapest when taken from every standpoint is the system to be installed. An important secondary matter is interference with communication circuits. The following table will give some idea of the comparative advantages of the several systems:—

Item.	D.C.	Three-phase.	Single-phase.
Locomotives—			
Speed regulation	fair	worst	best
Starting economy	poor	poor	good
Motor transformer	none	optional	essential
Power factor	unity	good	fair
Efficiency	good	best	lowest
Recuperation of energy	fair	simple	fair
Current collection	worst	medium	best
Weight	heavy	light	heavy
Cost	medium	cheapest	dearest
Substations and Track Equipment—			
Contact line	good	complex	best
Interference (telephonic)	may be bad	may be bad	safeguards essential
Number and size of substations	largest	medium	smallest
Cost	greatest	small	lowest
Transmission lines—			
Cost	high	high	low
Power Stations—			
Generators	cheapest	cheapest	dearest
Overall cost	least	least	most
Complete Installation—			
Overall efficiency	47–61 per cent.	45 per cent.	50–68 per cent.
Overall cost	not much difference		

The following summary shows the chief developments in Long-distance and Main-line electric traction. Unless otherwise indicated the lines are now running electrically.*

Austria.—The decision on July 23, 1920, by the National Assembly to electrify 650 km. of route was influenced by the urgent need of reduction in the consumption of imported coal and utilisation of available water-power resources to assist in restoring economic independence. The system of electrification has been under consideration for many years, and the commission formed for that purpose has decided to adopt the Single-phase system at 15,000 volts, 16⅔ periods. The chief lines running or under construction, together with some privately owned lines, are noted in the table below :—

Railway.	Section.	Route Length. Km.	System.	Remarks.
Austrian Federal Railways	Innsbruck–Lindau	235	Single-phase, 15,000 volts, 16⅔ periods.	Mountain line.
	Salzburg–Worgl	192		Heavy traffic.
	Schwarzach–Villach*	117		Mountain line.
	Stainach–Attnang	107		—
Mittenwald	Innsbruck–Reutte	105	Single-phase, 15,000 volts, 16⅔ periods.	Connects Tyrol–Bavaria.
Lower Austrian Railways	Vienna–Pressburg	68	Single-phase, 15,000 volts, 16⅔ periods.	D.C. in Vienna and Pressburg.
	St. Polten–Mariazell	91	Single-phase, 6,600 volts, 25 periods.	Tourist traffic.

The present work on the Federal Railways was due for completion in 1925, after which a further group, totalling 1,135 km., was to have been converted: financial difficulties have delayed progress. Cheap coal may also retard development.

* An asterisk denotes lines at present under construction.

France.—Although the coal situation in France is not so critical as in some other parts of Europe, it is nevertheless serious. The question of main-line railway electrification has been much to the fore since 1918, when a commission investigated existing railways in Switzerland, Italy, England, and the U.S.A. The operation of the Chicago, Milwaukee, and St. Paul Railway, in the Western States of the Union, was closely studied, and a report was made in favour of the D.C. system, but at 1,500 volts. Three of the French railway companies, as detailed below, have embarked on large electrification schemes. Supply will be obtained solely from hydro-electric stations, except in the case of the Paris–Orleans line, for which a supply will also be taken from parallel-working steam stations near Paris.

Railway.	Section.	Route Length. Km.	System.	Remarks.
Paris–Orleans	Paris–Vierzon Vierzon–Brive* St. Sulpice–Gannat* Brive–Clermont*	916	D.C., 1,500 volts	Heavy traffic—partly completed. Mountain lines.
Paris–Lyons–Mediterranean	Culoz–Modane*	149	D.C., 1,500 volts	Mountain line.
	Nice local lines*	174		Suburban.
Midi	Bordeaux–Toulouse and branches. Part now working.	1,782	D.C., 1,500 volts	Main line connecting with mountain branch lines, partly converted from one-phase system.

As it is still an open question whether the overhead wire or the third rail should be used, locomotives, etc., are being provided with two types of collecting gear.

Germany.—Electrification on a large scale had already begun in Germany previous to the war, and several experimental tracks had been equipped. The Leipzig–Magdeburg line, in the plains of the Elbe, the Silesian Mountain Railway, the Wiesenthal Railway, in Baden, and some of the South Bavarian lines were already electrified. After 1918 it was realised that the natural resources of the country had to be conserved. For districts lacking in water-power, large steam-stations capable of using inferior lignite coal were proposed. For Bavaria, an extensive scheme is being carried out, the electric power network being fed from hydro-electric stations at Walchensee and on the Middle Isar River: a separate supply network will feed the railways. The question of system was investigated both before and after the war, and in the report of December 1921 it was unanimously decided that the system best suited to the governing conditions was the Single-phase at 15,000 volts, $16\frac{2}{3}$ cycles, with a separate supply for the railways.

Railway.	Section.	Route Length. Km.	System.	Remarks.
German Federal Railways	Silesian Mountain Rly.	259	Single-phase, 15,000 volts, $16\frac{2}{3}$ periods.	Mountain lines.
	Magdeburg–Leipzig	177		Heavy traffic.
	Bavarian lines*	672		Hydro-electric supply.
	Wiesenthal Railway†	49		

Electrification is sufficiently far advanced in Germany to enable a decision to be reached as to rolling-stock standardisation, and the administration have standardised six locomotive types to suit all the conditions met with. Regarding route length, including work in hand, Germany is second only to the United States.

* An asterisk denotes lines at present under construction.
† 15 periods.

Great Britain.—Great Britain has comparatively little to show in the way of long-distance railway electrification, although there are numerous schemes and projects under consideration.

Standards for British Railway Electrification.—An attempt has been made to standardise the system, etc., for future developments, but a certain amount of latitude has been allowed, as the following will show :—

The Electrification of Railways Advisory Committee, appointed by the Minister of Transport in March 1920, issued its final report in September 1921, recommending that all new electrification should be on the direct-current system, and that the standard pressure should be 1,500 volts, except in the case of railways already operating at 600 or 1,200 volts D.C., or with alternating current. The adoption of 750 or 3,000 volts should be permitted where approved by the Minister. Both overhead and rail conductor collection were recommended, provided that the form and design of the conductors and structures were in accordance with specified regulations. Current should be generated on the three-phase system, at the frequency in general use in the district concerned ; 50 cycles could be used satisfactorily. Suggested regulations were given, with drawings, for the standardisation of contact rails, the centres of which were to be 16 in. from the gauge line of nearest track rail, and for top-contact 3 ins., for under-contact 1½ ins., above the plane of the top table of the track rails. The clearance of the contact shoe in the free position over the track rails was not to be less than 1½ ins. For overhead collection, the clearance between the overhead conductor and the maximum load gauge was to be 3 ft. in the open and 10 ins. in tunnels and under bridges ; between the conductor and any part of the structures, 6 ins. ; between the conductor and the rail level 18 ft. at crossings, 20 ft. where men might have to stand on the roofs of vehicles ; and between any part of the collector gear and any structure, 3 ins. Exceptions were made in the case of the equipment of existing lines : for instance, the Brighton Railway is permitted to retain and extend its single-phase system.

The contact wire was to be not more than 15 ins. from the vertical plane through the centre line of track at 18 ft. above rail level, and provision should be made for an upward pressure of 25 to 40 lbs. The contact surfaces of collectors were to be not less than 4 ft. wide, and the extreme width of collectors not more than 7 ft. 6 ins. The Committee considered it undesirable to set limits to the drop of pressure in uninsulated return conductors.

Holland.—In consequence of the recent decision of the Dutch commission on the subject the future development of electric traction will be on the high-voltage D.C. system. The railways will be fed from a unified network of steam power-stations, and it is considered that for this purpose D.C. offers the most decided advantages. At the same time, the only long-distance line at present in operation is the Rotterdam–Scheveningen Railway, which employs single-phase energy at 10,000 volts, 25 cycles. The line intended for the first step in future D.C. electrification is the Rotterdam–Haarlem–Amsterdam railway.

Railway.	Section.	Route Length. Km.	System.	Remarks.
Dutch State	Rotterdam-Scheveningen	36	Single-phase, 1,000 volts, 25 periods.	Semi-suburban traffic.
	Rotterdam – Haarlem–Amsterdam* . .	—	D.C., 1,500 volts.	Main route.

Hungary.—The rearrangement of the international boundaries after the war lost to Hungary her complete oil and natural gas resources, two-thirds of her coal-fields, and nearly the whole of her water-power. The railways must, therefore, be electrified, in order to reduce imports, to conserve what coal and peat remain, and because the available fuel is only suitable for power-station combustion. While plans are ready for the eventual conversion of 1,385 km. of route, only a short 15-km. line has at present been equipped between Budapest and Dunakeszi–Alag. The system proposed is the split-phase arrangement with 15,000 volts, 50 periods on the track, in order to supply the line from phases of the industrial network, and tests under these conditions have proved satisfactory.

Italy.—The electrification of the Italian railways dates back to the beginning of the present century, and provides practically the earliest example of main-line electrification in Europe. This fact largely explains the adoption of the three-phase system at 3,000 volts, 15 periods, at

* An asterisk denotes lines at present under construction.

the outset, for at the time the high-voltage D.C. and Single-phase systems were in their infancy. Although it seems likely that Italy will adhere to the three-phase system, yet there are indications that the line voltage will be raised to 10,000 volts, and the frequency to that commonly met with in the surrounding industrial districts. The reasons for electrification here, as elsewhere, were economical, owing to lack of coal and the existence of abundance (in some districts) of water-power. The Valtellina line in Northern Italy was the first electrified, and other lines have been added from time to time, until now about 670 km. of route is in operation, while very extensive programmes exist for future developments. High-voltage D.C. traction is being tried in the south.

Railway.	Section.	Route Length. Km.	System.	Remarks.
Italian State Railways	Milan–Varese	73	D.C., 650 volts.	Third rail: date 1901.
	Valtellina lines	143		First 3-phase line.
	Giovi lines Savona–Sampierdarena Savona–Ceva Alessandria–Voghera Novi-Tortona–Ronco	241	Three-phase, 3,000–3,700 volts, 15–17 periods.	Among the most heavily worked lines in Italy. Steep gradients and long tunnels.
	Mt. Cenis line	113		Through Mt. Cenis Tunnel.
	Turin lines	173		
	Rome–Tivoli	40	Three-phase, 10,000 volts, 45 periods.	Industrial frequency.
	Benevento–Foggia	—	D.C., 3,000 volts.	Experimental.

Scandinavia.—In Sweden the question of main-line railway electrification has been discussed since 1899. In 1915 the first section of the Riksgransen Railway was put into operation. This line carries heavy mineral trains from the iron-ore mines of Kiruna and Gellivare to the coast at Narvik and Lulea. The line is run at 16,000 volts, single-phase, 15 cycles, under the most severe climatic conditions. Since 1918 the Swedish State Railways Electrification Commission have considered afresh the question of system, and the choice of Single-phase has been confirmed. The Norwegian authorities have come to a like decision. The Swedish Stockholm–Gothenburg line is in process of conversion to electric traction: this line will be fed from the three-phase industrial network through converter stations at 15,000 volts, $16\frac{2}{3}$ cycles. The Norwegian developments comprise the completion of the Riksgransen Railway to Narvik and the equipping of the Kristiania–Drammen Railway.

Railway.	Section.	Route Length. Km.	System.	Remarks.
Swedish State Railways	Narvik–Riksgransen–Lulea*	472	Single-phase, 16,000 volts, 15 periods.	Mineral line.
	Stockholm–Gothenburg	458	Single-phase, 15,000 volts, $16\frac{2}{3}$ periods.	Main line traffic.
Norwegian State Railways	Kristiania-Drammen	53	Single-phase, 15,000 volts, $16\frac{2}{3}$ periods.	Semi-suburban.

Switzerland.—Up to the present there is probably no country which has electrified so large a proportion of its main-line railways as Switzerland. The need for utilising water-power instead of importing coal has long been recognised. While a few local railways are operated with D.C., and two important lines with three-phase, the main bulk of the electrified railways use the Single-phase system, at $16\frac{2}{3}$ cycles, which, after a protracted study, was recommended by the

* The Narvik–Riksgransen part is in Norway.

Administration of Railways in 1912. The single-phase lines comprise the Federal Railways, the Loetschberg Railway, and the metre-gauge Rhaetian Railways. The latter are operated at 11,000 volts, and the others at 15,000 volts. All the power is obtained from hydro-electric stations fed from rivers or lakes in such a way that the supply is maintained reasonably constant all the year round. On the Federal lines considerable extensions are in hand, totalling about 1,110 km. of route: the work is being accelerated to ease the unemployment situation.

Railway.	Section.	Route Length. Km.	System.	Remarks.
Loetschberg and Bernese Subsidised Railways	Berne–Thun–Brieg and branches	194	Single-phase, 15,000 volts, $16\frac{2}{3}$ periods.	International through route.
Rhaetian Railways	Chur–Landquart–Klosters–Filisur, etc.	277	Single-phase, 11,000 volts, $16\frac{2}{3}$ periods.	Metre-gauge.
Swiss Federal Railways	St. Gothard line, Rhone Valley, etc.	429	Single-phase, 15,000 volts, $16\frac{2}{3}$ periods.	International routes.
	Simplon Tunnel	22	Three-phase, 3,000 volts, 15 periods.	Continuation of Loetschberg and Rhone Valley lines.

United States of America.—Largely on account of its immense size and development most of the important and extensive railway electrification projects are to be found in the United States.

Chicago, Milwaukee, and St. Paul Rly.—At present the C.M.S.P. Railway is the largest electrified line in the world as far as route length is concerned. It is a trans-continental road, operating electrically the single line over the Rocky Mountains, with very heavy trains on long gradients. The system employed is the direct-current at 3,000 volts on the contact line. On the down-grades regenerative braking is extensively used—on the whole, quite successfully. Both geared and gearless types of locomotive are employed.

Butte, Anaconda, and Pacific R.R.—This road is engaged principally in the haulage of copper ore by locomotives, on the 2,400-volt direct-current system. It was the original example of high-voltage D.C. applied to heavy railway operation, and served as a model for the C.M.S.P. Railway.

New York Central R.R.—The electrified portion comprises a 30-mile zone in the Hudson River and Haarlem Divisions, both locomotives and multiple-unit trains being employed. The system is D.C., 650 volts, with third rail.

Pennsylvania R.R. (New York terminal).—This line is of a type exactly similar to the N.Y.C. electrification and interchanges with the Long Island R.R., an extensive suburban system.

New York, New Haven, and Hartford R.R.—A great deal of pioneer work has been done by this company, which now operates an 11,000-volt network running out to New Haven. The trains, hauled by locomotives or motor-coaches, run into New York over the N.Y.C. tracks D.C., 650 volts), with the result that the equipment in many cases is very complicated.

Pennsylvania R.R. (Philadelphia terminal).—In order to relieve congestion at the Broad Street Station, Philadelphia, due to the heavy passenger services, single-phase electric traction has been installed for some distance out on the main line and a branch at 11,000 volts, 25 cycles. This is intended as a step in the large scheme of electric haulage over the Washington–Philadelphia–New York main line.

Norfolk and Western Rly.—Mineral traffic of a very heavy character is hauled on this line. The locomotives are of the split-phase type, taking single-phase energy from the contact line at 11,000 volts, 25 periods, and supplying three-phase induction motors through a phase converter: the ease with which regenerative braking is effected is a very noticeable feature

Virginia R.R.—A recent contract of 15 million dollars has provided for the electrification of the Va. R.R. between Mullens and Roanoke, over a mountainous route of 135 miles. At

present, with steam haulage, the company is moving 7 million tons of coal per annum, and the limit has been reached. Electrification (single-phase, 11,000 volts, 25 cycles) will enable 6,000-ton trains to be hauled up the 2 per cent. grades at 14 m.p.h. The locomotive units will weigh 200 tons each, and will provide, when coupled in sufficient numbers, 12,000 h.p. The regenerative braking of the split-phase system to be installed is of paramount importance.

Detroit, Toledo, and Ironton R.R.—This railway, in which Mr. Henry Ford has the controlling interest, has a length of route under conversion to electric traction. A 22,000-volt, 25-cycle, single-phase, contact-line pressure will be used. The locomotives will carry transformers and motor-generators for supplying normal D.C. series traction motors.

Railway.	Section.	Route Length. Miles.	System.	Remarks.
Chicago, Milwaukee, and St. Paul Rly.	Harlowton–Avery Avery–Othello* Othello–Seattle	874	D.C., 3,000 volts	Transcontinental.
Butte, Anaconda, and Pacific R.R.	Butte–Anaconda	25	D.C., 2,400 volts	Mineral line.
New York Central R.R.	Hudson River and Haarlem division	58	D.C., 650 volts	Heavy suburban.
Pennsylvania R.R. (New York)	New York Terminal and Long Is. R.R.	103	D.C., 650 volts	Extensive suburban.
New York, New Haven, & Hartford R.R.	New York – New Haven, etc.	88	Single-phase, 11,000 volts, 25 periods.	Suburban and main line traffic.
Norfolk and Western Rly.	Bluefield–Vivian	29		Heavy coal trains.
Pennsylvania R.R. (Philadelphia)	Philadelphia – Paoli and branch	30		Suburban: proposed extension.
Virginia R.R.	Mullens–Roanoke	135		Record train weights.

Other Developments.—In many other countries the railway electrification movement has begun. In Morocco a 416-km. line is to be electrified at 3,000 volts, D.C.: motor-coaches will work at this pressure. In New Zealand, the Arthur's Pass section of the Government Railways was opened on August 6, 1923, using the 1,500-volt D.C. overhead system. Important installations have been completed, or are under construction, in Brazil (Paulista Railway, 28 miles, 3,000 volts D.C.); Chile (Bethlehem–Chile Railway, 15 miles, 2,400 volts D.C.); Japan (Tokio–Yokohama–Kozu, 65 km., 1,500 volts D.C.); and in South Africa (Glencoe–Pietermaritzburg, 3,000 volts D.C.); Java (Tanjong Priok harbour–Weltevreden, 16 km., 1,500 volts D.C.); Spain (Northern Rly., Pajores gradient, 40 miles, 3,000 volts D.C.).

Electric Locomotives.

The first electric locomotives were developed directly from the street tramway, and had bogie tracks provided with nose-suspended motors. Progress in America has in general avoided mechanisms involving reciprocating motion, and the nose-suspension and the quill drives have been widely applied to passenger, freight and shunting locomotives. On the Continent of Europe there was a widespread tendency at first to apply the steam locomotive side-rod mechanism to the electric locomotive. Many difficulties were encountered and generally overcome, but the continuous torque of the electric motor was fundamentally unsuited to the reciprocating nature of the drive, whilst the effect of steam cushioning in the steam locomotive cylinders had no counterpart in the electric drive. Subsequent designs introduced springs and similar elastic members to provide for this, and to obviate the troublesome oscillatory phenomena in side-rod drives so damaging to the bearings. The present tendency in Europe is to return to individual-axle drives with nose-suspended motors or with some form of special gearing enabling the motors to be entirely spring-borne. Among these are the Westinghouse (geared-quill, with spring connection between gear wheel and driving wheel) and the Buchli (link connection) drives. Individual-axle drives allow greater freedom in the running-gear design and are adaptable to most classes of service, tending to simplification of spare parts and maintenance. The locomotives built in Great Britain have been mostly fitted with nose-suspension drives.

* To be undertaken later.

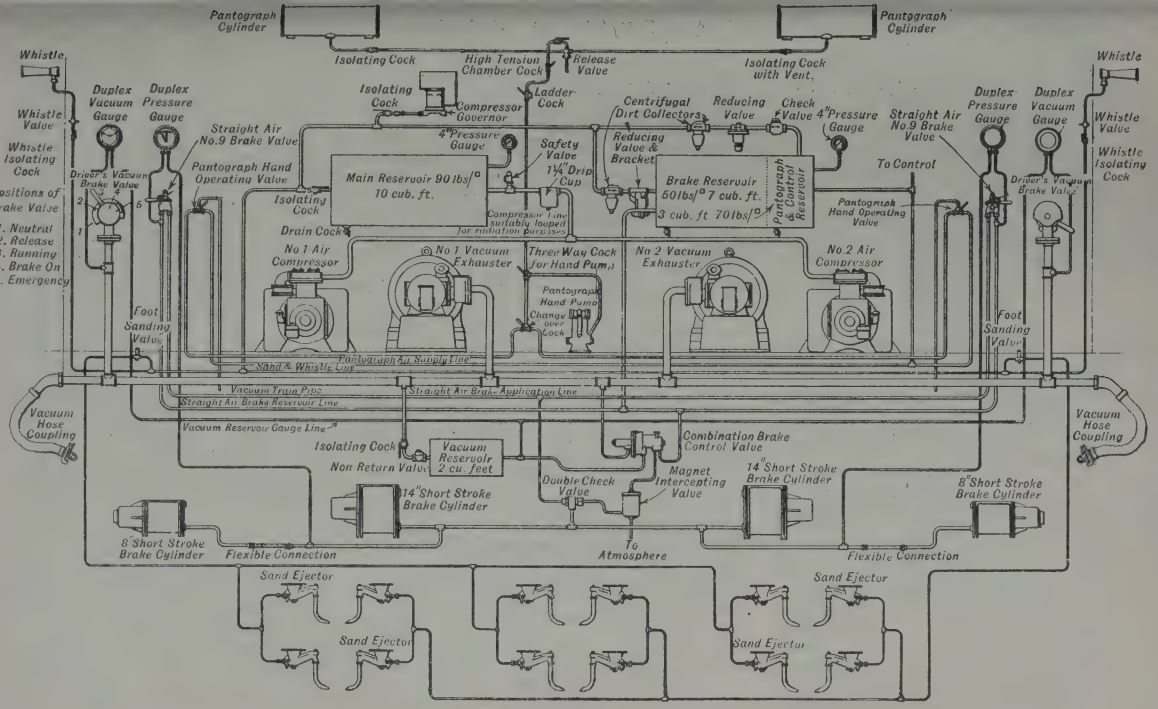

Pantograph Cylinder
Pantograph Cylinder
Whistle
Whistle
Isolating Cock
High Tension Chamber Cock
Release Valve
Isolating Cock with Vent.
Duplex Vacuum Gauge
Duplex Pressure Gauge
Isolating Cock
Compressor Governor
Ladder Cock
Centrifugal Dirt Collectors
Reducing Valve
Check Valve
4" Pressure Gauge
Straight Air No.9 Brake Valve
Duplex Pressure Gauge
Duplex Vacuum Gauge
Whistle Valve
Whistle Isolating Cock
Whistle Valve
Whistle Isolating Cock
Straight Air No.9 Brake Valve
4" Pressure Gauge
Reducing Valve & Bracket
Safety Valve 7¼" Drip Cup
Pantograph Hand Operating Valve
Main Reservoir 90 lbs/□ 10 cub. ft.
Brake Reservoir 60 lbs/□ 7 cub. ft.
3 cub. ft 70 lbs/□
Pantograph & Control Reservoir
To Control
Driver's Vacuum Brake Valve
Driver's Vacuum Brake Valve
Positions of Brake Valve
1. Neutral
2. Release
3. Running
4. Brake On
5. Emergency
Isolating Cock
Compressor Line suitably looped for radiation purposes
Pantograph Hand Operating Valve
Drain Cock
No 1 Air Compressor
No 1 Vacuum Exhauster
Three Way Cock (for Hand Pump)
No 2 Vacuum Exhauster
No.2 Air Compressor
Pantograph Hand Pump
Change over Cock
Foot Sanding Valve
Foot Sanding Valve
Pantograph Air Supply Line
Sand & Whistle Line
Vacuum Train Pipe
Straight Air Brake Application Line
Straight Air Brake Reservoir Line
Vacuum Hose Coupling
Vacuum Hose Coupling
Vacuum Reservoir Gauge Line
Isolating Cock
Vacuum Reservoir 2 cu. feet
Non Return Valve
Combination Brake Control Valve
Double Check Valve
Magnet Intercepting Valve
14" Short Stroke Brake Cylinder
8" Short Stroke Brake Cylinder
14" Short Stroke Brake Cylinder
8" Short Stroke Brake Cylinder
Flexible Connection
To Atmosphere
Flexible Connection
Sand Ejector
Sand Ejector
Sand Ejector
Sand Ejector

FIG. 1.

Brakes for Electric Locomotives.

(*The Consolidated Brake and Engineering Co., Ltd.*)

The diagram (fig. 1) shows a brake equipment for electric passenger locomotives for heavy duty on steep grades, operating vacuum-braked trains, the locomotives being fitted with an air-pressure brake.

To synchronise the brakes on the locomotive and the train and also to give proportionate control, a combination brake-control valve is provided. This valve is governed by the vacuum in the continuous train pipe of the vacuum brake and directly admits a corresponding air pressure to pass to the air-brake cylinders upon the locomotive, giving a perfectly synchronised and balanced braking effect throughout the train and avoiding bunching at the forward end, and shocks.

The air brake can be used independently if desired, by use of the straight air-brake valve; this is useful in shunting operations. The vacuum brake can also be operated upon the train independently of the air brake, for which purpose a magnetic intercepting valve is provided.

The vacuum exhausters are of the rotary drum type directly coupled to the motors with a two-speed control. The full speed is for quickly releasing the brakes or charging up the system rapidly if time is limited. The slow speed is for maintaining vacuum and for brake control generally, the full speed only being used as circumstances require. The two speeds are suitably controlled by contacts on the spindle of the driver's vacuum brake valve, which allows slow speed in all positions except full release, in which position the exhausters run at full speed.

The motor-driven air compressors, in addition to providing compressed air for the locomotive brakes, also supply the necessary air for the sanding gear, pantograph operating apparatus, pneumatic control, and whistles.

ELECTRIC TRACTION ON SUBURBAN RAILWAYS.

Much of the electrification work hitherto has been in connection with suburban railways around large cities like London, New York, and Paris. Such lines form a most promising field for the utilisation of electric power, as they usually carry heavy and dense traffic, a condition very favourable to electric traction. Of course, on tube and similar underground railways anything but electric haulage in the light of modern requirements is unthinkable. For suburban and urban traffic the single-phase system is seldom considered unless some ulterior condition makes this advisable: in practically all cases the direct-current system is used, at voltages of 600 to 1,500, with third-rail collection. It is standard practice to generate three-phase energy in the power stations, transforming to suitable pressures for transmission to the substations. The motor-generators formerly used for A.C.-D.C. conversion are now displaced by the rotary converter, which has higher efficiency and overload capacity. The mercury vapour rectifier is also coming into use. (See Section XXXV., Electrical Engineering.)

With the use of 600 volts (or more) for traction on lines of a suburban character, it is usual to replace the hand controller suitable for tramway operation by the multiple-unit control which consists of small manual or automatic 'master-controllers' operating separate switches or 'contactors,' connected to the motors and to the tappings of the resistance grids. The contactors may be either electro-magnetically or electro-pneumatically operated. Electric coupling between the adjacent coaches permits the use of any one master-controller for the control of the train. The advantages of this so-called multiple-unit control lie in the flexibility of train length, the provision of a motor capacity always suitable to the load (for the maintenance of a uniformly fast service), and the efficient utilisation of the available adhesion (for rapid acceleration).

For leading the current to the moving trains a third rail is provided for each track, the motor coaches being equipped with cast-iron contact shoes for current collection. In England, where the Board of Trade regulations require a very small drop in the earth return, it has been necessary on occasion to add an insulated fourth rail in order to avoid the drop in the running rails which elsewhere serve as a return. This may often be of considerable advantage in cases where track circuiting is required for automatic train-signalling.

On most city and suburban electrified railways dealing with heavy traffic, automatic signalling is employed; indeed for many of the congested services it is essential. Where a fourth-rail return is used, the running rails are used to convey direct or alternating current for the track circuits. Where, however, the running rails carry the power current, alternating current alone may be employed for signalling. For automatic signalling the reader should consult Section XIII.

For lines with infrequent service the efficiency of the substations is comparatively low, while the running costs are high in consequence of the fact that the numerous substations must be capable of supplying the peak load. The transmission losses in the conductor rails are also considerable. In such cases automatic or semi-automatic substations, with higher line voltages, may be used.

Low-pressure traction motors are now standardised, as also is their control. Series-parallel arrangement of the motors of each bogie (of the motor coach) is universal practice. In special cases field-shunting is used, as, for instance, when trains make occasional runs to outlying districts. The diagram of tram-motor control given in fig. 4, p. 781, is typical also of motor coaches, except that switching operations, as already indicated, are performed by contactors operated from the master controller.

LONDON TUBE RAILWAYS SYSTEM.

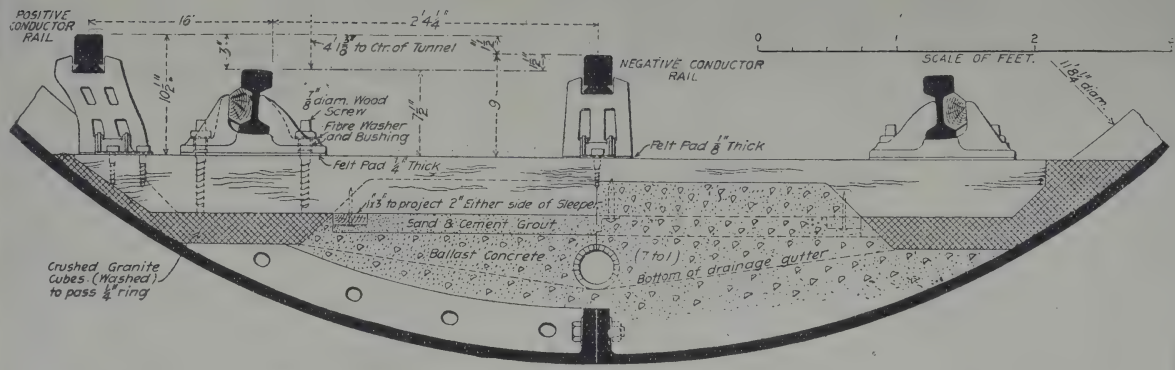


FIG. 2.—Type of Construction of Permanent Way and Conductor Rails on the tube lines of the underground railways of London..

Train units are usually made up of motor-coaches and trailer coaches. A common arrangement is one motor-coach semi-permanently coupled to one or more trailers. In such a case the end trailer is a driver trailer, and is provided with a driver's cabin with a master controller and the necessary apparatus for reversed operation. One, two, three, or more units may be coupled and controlled by one driver to form a train of any desired size according to traffic needs, and the same schedule may be maintained regardless of the train-length, since the power/weight ratio remains constant.

The following details refer to typical motor-coach equipments with multiple unit control:

(*Messrs. British Thomson-Houston Co., Ltd., Rugby.*)

Details.	Metropolitan-District Rly.	L.N.E.R. (Newcastle).	L.M.S.R. & L.E.R. (Bakerloo–Watford).	Bombay–Baroda Cent. Ind. Rly.
Motors per coach	4	2	2	2
Line voltage	600	600	600	1,500
Motor h.p. (1-hr.)	195	145	235	275
Current collectors	Shoes	Shoes	Shoes	Pantographs
Gauge	4 ft. 8½ in.	4 ft. 8½ in.	4 ft. 8½ in.	5 ft. 6 in.
Length over head-stocks	49 ft. 2 in.	55 ft. 0 in.	50 ft. 10 in.	68 ft. 0 in.
Bogie centres	34 ft. 0 in.	40 ft. 0 in.	34 ft. 0 in.	48 ft. 0 in.
Bogie wheel-base	7 ft. 10 in.	7 ft. 0 in.	7 ft. 0 in.	10 ft. 0 in.
Wheel diam.	36 in.	36 in.	40 in.	43 in.
Weight empty, tons	44·5	34	32·5	69
Seating capacity	64	64	36	80
Control	electromagnetic	electromagnetic*	electromagnetic*	electropneumatic-camshaft*

* With automatic acceleration.

The following are brief details of some important suburban electrification systems:

London.—A large network of electrified lines exists in the south and west of London. The north-east district has hitherto been largely neglected.

Line.	Route.	Route Length. Miles.	System.	Remarks.
Underground	Metropolitan-District Rly.	28·5	D.C., 550–600 volts, third or third and fourth rail.	Surface and sub-surface.
	Bakerloo Rly.; Piccadilly Rly.; Edgware, Highgate & Morden Rly.; City Rly.	44		Deep-level tubes with surface extensions.
	Central London Rly.	11·1		
Metropolitan	N. side of 'Inner Circle'; Harrow main line	29·5		Surface and sub-surface.
L.M. & S. Rly.	Euston and Broad St. to Kew, Watford, etc.	38·5		Surface, main-line terminus.
Southern Rly.	Western section	47		Surface, main-line termini.
	Eastern section	94		
	Central section	22·4*		

* To be converted to d.c. from 6,600 volts, 25 cycles.

Paris.—The C. de F. Métropolitain and Nord-Sud operate sub-surface lines covering the area bounded by the old city walls. Stations are closely spaced, allowing of competitive services with street transport. The C. de F. de l'État (Ouest) works two suburban lines and a short local city

branch to Auteuil Boulevard. The electrification of the C. de F. de Paris-Orléans embodies the main line out of Paris.

Line.	Route.	Route Length. Miles.	System.	Remarks.
Métropolitain	Route Nos. I.–X.	62 *	D.C., 600 volts, third rail.	Sub-surface city lines.
Nord-Sud	Clichy, St. Ouen, and la Chappelle to Porte de Versailles.	10 *	D.C., 700 volts, third rail and overhead line.	
État (Ouest)	Invalides–Versailles, St. Lazare–St. Germain, etc.	30 *	D.C., 750 volts, third rail.	More lines in process of electrification.
Paris-Orléans	Quai d'Orsay–Juvisy, etc.	14·6	D.C., 1,500 volts, third rail and overhead line.	Part of extensive main-line electrification.

* Further lines projected.

Berlin.—The Hoch- und Untergrundbahn, serving city districts, was begun in 1902. The lines of the Reichsbahngesellschaft round Berlin, including the Stadt- und Ringbahn, are now being converted to electric haulage.

Line.	Route.	Route Length. Miles.	System.	Remarks.
Hoch- u. Untergrundbahn	City lines.	31·5	D.C., 800 volts, third rail	Sub-surface and overhead.
Stadt-, Ring u. Vorortbahnen	Stettiner Bahnhof, Bernau, Oranienburg and Velten.	45·7 *		Extensive programme of electrification in hand.

* Further lines projected.

Melbourne and Sydney.—These two capital cities of Australia have modern electrification systems (complete or projected) of a very extensive nature, since far-seeing town planning has led to a wide distribution of suburban population.

Line.	Routes.	Route Length. Miles.	System.	Remarks.
Victoria Govt. Rlys.	Melbourne City and suburban lines.	154	D.C., 1,500 volts, overhead line.	
N.S. Wales Govt. Rlys.	Sydney Central – Sutherland.	23		Extensive scheme under conversion.

New York.—On account of its geographical peculiarities the city of New York has for many years been subject to traffic congestion in a north-south direction along the line of Manhattan

Island. In addition, there is a heavy traffic movement east and west between Manhattan and Long Island (Brooklyn, Queens, etc.). The following are details of the principal lines:

Line.	Routes.	Route Length. Miles.	System.	Remarks.
Brooklyn Rapid Transit Co.	Manhattan–Brooklyn and Coney Island lines.	89·2	D.C., 600 volts, third rail.	Surface and elevated along main streets.
Hudson and Manhattan R.R.	Newark – Hoboken – South Manhattan.*	7·9		Surface and tunnel lines.
Interborough Rapid Transit Co.	Manhattan – Bronx and connection with B.R.T. Co.	114·7		Subway and elevated lines.

* Partly over Pennsylvania R.R. Co.'s tracks.

ELECTRIC TRACTION ON TRAMWAYS.

The technical arrangements for electric tramways are practically standardised all over the world. Two 4-pole totally-enclosed series motors are used, either with or without interpoles. The nominal rating of each motor is 30 to 50 h.p. with double-decked cars. The current transmission is effected by means of an overhead trolley-wire and rail return, collection being performed with a wheel trolley or sliding bow-collector. The voltage is most commonly 500 to 600, although a few American inter-urban roads have adopted a pressure of 1,200 volts. For control, a drum-controller is used, allowing of series-parallel and field-weakening methods for the regulation of the speed. Braking is by air or electric devices, the latter including rheostatic and magnetic track-brakes. Hand-controlled braking is used as a standby. In Glasgow and places where air-brakes are not used, the hand brakes are used for ordinary service stops and the electric only when going down steep hills or for emergency stops. For tramway substations, rotary converters have replaced the older motor-generator sets, but mercury-vapour rectifiers are coming into use for modern installations (see Section XXXV, Electrical Engineering).

Tramway Tyres and Axles.

The British Engineering Standards Association has issued standard specifications Nos. 101—1921 for tramway tyres and 102—1921 for axles. The former includes particulars of the tests to be applied, and a drawing showing the shape and dimensions of the tyre of standard section. The latter specifies that the steel shall not contain more than 0·05 per cent. of sulphur or phosphorus, and defines the tests to which the axle shall be subjected.

New tyres should be turned to the same angle of inclination as the worn head of the tramway rails has assumed, and care should be taken to ensure that the tyres fixed on the same axle should be of equal hardness, in order to ensure the maintenance of equal diameters in service.

Tramway Rails.

In Great Britain the grooved girder rail is practically the only type employed for tramways constructed in public roadways.

On some inter-urban tramways, with tracks laid on private lands, 'tee' section rails have been used, loose guard-pieces being bolted on at curves; on single lines, having passing places with automatically worked points, 'tee' rails present practical difficulties, and the later tendency is to use a special type of the ordinary grooved girder rail for such lines.

Twenty to thirty per cent. more power is required to run cars on a grooved rail than on a 'tee' rail, due to side friction, dirt in grooves, &c.

When gauge is 4 ft. or less, in order to allow room for removing motors, special rails, without overhang, should be fixed at car pits.

Weight of straight-track rails used in this country varies from 65 lbs. per yard, as at Coventry and Norwich, to 108½ lbs. per yard, as at Sheffield, Leeds, Wigan, &c. Rails of from 90 to 105 lbs. per yard are now generally adopted, with depth from 6 ins. to 7 ins., and width of base 6½ ins. to 7½ ins. The rail now used in Glasgow is 'B.S.' section No. 8, the weight being 112·9 lbs. per yard. No. 8c, weighing 119·2 lbs. per yard, is used at curves. The depth is 7 ins. In America, rails weighing as much as 137 lbs. per yard are now being used.

The Board of Trade has made a pronouncement against the employment of rails less than 90 lbs. per yard.

For a wheel flange ¾ in. thick, groove width should be 1⅛ in. on straight, and 1¼ in. on curves less than 75 ft. radius.

It is of importance that the profile of wheel tread and flange should accord to the shape of rail table and groove.

On curves of less radius than 50 ft. there is much grinding of wheel flange against both sides of groove which quickly widens under such wear; to allow for this the guard or lip on curve rails should be made thicker and higher and rails should be preferably of manganese steel.

Curves less than 100 ft. radius should be of spiralised or other easement form.

The top of guard or lip for straight-track rails is usually made slightly lower than the table, to allow for greater wear on latter, but the effect of this is very objectionable to vehicular traffic where the rail table is not sloped or coned.

The rail web should be as nearly as practicable under the centre of rail table, so that the resultant of forces, due to rolling load of car and lateral pressure of wheel flange, shall fall well within the rail base, otherwise there is a tendency for the rail to tilt sideways.

The base should be sufficiently wide to spread the superincumbent weight on to the underbed, and to resist the side-tilting motion.

The British Engineering Standards Association has issued a series (No. 2—1927) of fully dimensioned drawings for 'British Standard' tramway-rail and fishplate sections, and also (No. 101—1921) for corresponding standard tyre profiles for tramcar wheels. A Report (No. 79—1919) has been issued by the Association on British standard special track-work for tramways.

Fig. 3, page 772, shows a section of a 103·7 lb. (No. 7) rail.

(Expert opinion, and the actual practice of some authorities, now favours the use of a deeper groove, viz. 1½ in., than is shown in fig. 3.)

There are four sections of rails for straight tracks, with corresponding sections for curved tracks. Their general particulars, and those of fishplates, are as shown by the table below.

The affix C to the 'B.S.' number denotes that the rail is for use on curves, the difference between the straight-track and curve rails being that the groove is ⅛ in. wider and the guard or lip thicker and higher in the latter. All the sections have heads of similar profile as regards the groove and the angle of the rail-table. This profile gives a groove 1⅛ in. wide by 1¼ in. deep, measured from the highest point of the table, which has a radius of 9 ins. The guard or lip is $\frac{3}{16}$ in. below the highest point of the table. In the curve rails the groove is 1¼ in. wide, and the lip is brought up level with the table.

TABLE OF TRAMWAY RAILS AND FISHPLATES.

'B.S.' Section.	Rails.			Fishplates.	
	Height.	Width of Flange.	Calculated Weight per Lineal Yd.	Weight of Inner.	Weight of Outer.
Number	Ins.	Ins.	Lbs.	Lbs.	Lbs.
6 } 6C }	6½	6¾	{ 96·4 } { 103·2 }	22½	27
7 } 7C }	7	6¾	{ 103·7 } { 109·7 }	26	30½
8 } 8C }	7	7	{ 112·9 } { 119·2 }	25	30½
10 } 10C }	5	6	{ 95·4 } { 101·8 }	10½	18½

The Association has likewise drawn up a Standard Specification for the manufacture of tramway rails, prescribing the chemical constituents, physical tests, etc. The principal provisions are briefly as follows:

Chemical composition.—Steel to conform to following limits:

	Bessemer Process.	Open-Hearth Process.	
	Acid.	Acid.	Basic.
	Per Cent.	Per Cent.	Per Cent.
Carbon	0·50 to 0·60	0·60 to 0·70	0·60 to 0·70
Manganese	Max. 1·0	Max. 1·0	Max. 1·0
Silicon	,, 0·10	,, 0·10	,, 0·30
Phosphorus	,, 0·075	,, 0·06	,, 0·06
Sulphur	,, 0·07	,, 0·06	,, 0·06

British Standard Section Tramway Rail.

'B.S.' Section No. 7.—103·7 lbs. per yd.* (Superseding 'B.S.' Section No. 4.)

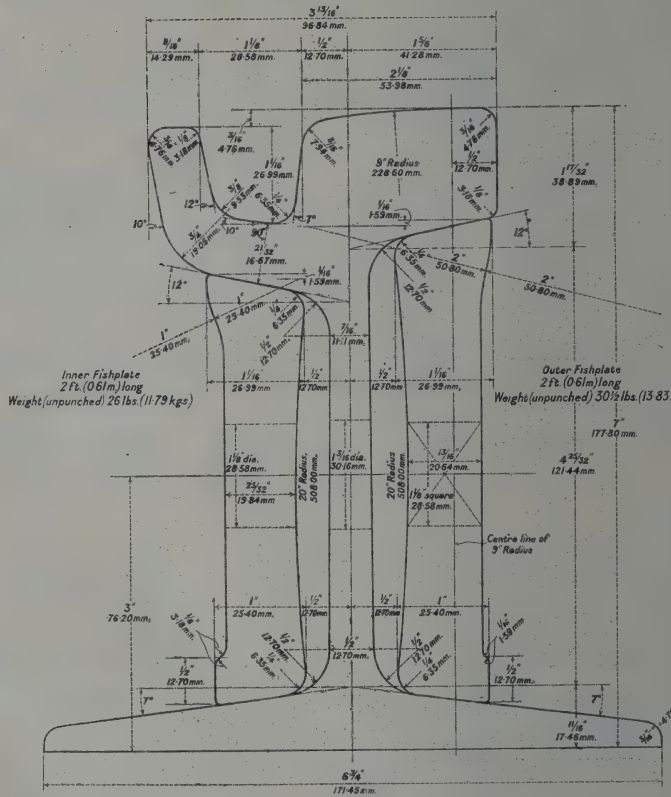


FIG. 8.

* 51·44 kgs. per metre.

Electrical resistance per yard of rail (single) = ·0000277 ohm = ·0487 ohm per mile = 11·8 times resistance of a copper conductor of same section.

Manufacturer to furnish carbon and phosphorus determinations of each cast, and a complete chemical analysis for each rolling, or, if a rolling exceeds 100 tons, for each 100 tons or part thereof. Engineer may make independent analyses; in case of difference, samples may be analysed by an independent metallurgist, to be appointed by the Chairman of the B.E.S.A.

The following are abbreviated requirements :

Templates.—Two complete sets of templates are to be furnished, properly engraved with names of purchaser and manufactusrer, ' B.S.' number of section, and date of contract.

Limits of variation.—Permissible variations are $\frac{1}{32}$ in. under or over total height, but $\frac{1}{64}$ in. only between fishing-angles.

Lengths.—Standard length of rail to be either 35 ft., 45 ft., or 60 ft., maximum proportion of short lengths being 5 and 2½ per cent. for the 35-ft., 5 and 2½ per cent. for the 45-ft., and 5 per cent. for the 60-ft. lengths.

A variation of ¼ in. either way is permitted in the lengths. All short lengths to be painted at each end, the colour indicating the length.

Straightness and squareness.—All rails to be made properly straight and true in all directions when cold, and to be sawn or planed true and square, and burrs removed before leaving the works.

Branding.—A special brand is to be rolled on the web of every rail, to indicate that the rail is of ' British Standard ' section and made under the conditions of the Standard Specification; also the number of section, weight, process of manufacture, manufacturer's name or mark, and year of manufacture. The number of cast or blow is also to be stamped near the end of each rail.

Falling Weight test.—A 5-ft. test-piece, head uppermost, is to be supported horizontally on steel bearings 3 ft. 6 in. apart at centres, and a tup, having 5 ins. radius face and weighing 1 ton, dropped on to it, midway between the bearings, from a height of 10 ft. If the rail fractures all from that cast may be rejected.

Tensile test.—From each 100 tons of rails a rail may be selected and a test-piece cut therefrom. It is to show an ultimate tensile strength equal to not less than 45 tons per sq. in., with an elongation of not less than 10 per cent. In case of failure the whole of the 100 tons may be rejected.

Bending.—From each 100 tons of rails a selected rail is to be tested by bending sideways to a curve of 30 ft. radius, and shall not show signs of cracking; if it does, the whole rolled from that cast may be rejected.

Holes in rails.—If required, each rail is to have holes made in it, without extra charge, for fish-bolts, electric bonds, and tie-bars. Those for the tie-bars may be punched, but all others must be drilled.

Notice and facilities for inspection.—Seven clear days' notice of the rolling of the first lot and three days for subsequent rollings is to be given; the inspector is to have access at all working hours to those parts of the mill where work under his inspection is being performed. The manufacturer is to provide all necessary apparatus in complete working order, and to provide all labour and reasonable assistance for making the specified tests. All rails accepted are to be stamped in the presence of the inspector.

Payment by weight.—Rails are to be paid for according to calculated weights before drilling or punching.

Fish-plates.—The chemical composition of the steel, tensile tests, and general conditions as to manufacture of fish-plates, are specified. Accuracy of fit between rails and fish-plates is regarded as of special importance, and sample joints are to be made whenever the engineer or inspector desires to test this.

Bending.—When cold and before being punched, the fish-plates shall be capable of being bent to a right angle round a bar 4 ins. in diameter without showing fracture.

Size.—Length for rail sections Nos. 6, 7, and 8, 24 ins., for No. 10, 18 ins., ends sawn square.

Holes are to correspond with those in the rails. All burrs are to be removed, and if fish-plates have been punched cold they are to be afterwards annealed. They are to be dipped into hot boiled linseed oil, and if required wired up in bundles. Payment is to be according to actual weight after punching.

(Copies of the complete specification and drawings can be obtained (post free, 5*s.* 4*d.*) from the offices of the British Engineering Standards Association, 28 Victoria Street, S.W. 1.)

Notes on Chemical Constituents and Physical Tests of Tram-Rails.

Generally speaking, there are very wide variations in the specified stipulations as to the chemical constituents of steel for tramway rails, particularly with regard to the proportion of *carbon*, which may be regarded as the main hardening constituent, some engineers specifying this to be as low as from ·28 to ·40 per cent., while the highest extreme is from ·60 to ·70 per cent. It is questionable whether the latter stipulation always meets with full compliance.

Where British ores are employed, there are limitations in practicability of manufacture of very high carbon tramway rails.

If carbon is over ·55, and especially if combined with high silicon, a somewhat brittle rail is likely to result.

Practical experiments under everyday conditions have shown that high carbon tram-rails have not given as good wear as those with moderate carbon.

Rails vary in hardness among themselves even when manufactured to the same specification and subjected to the same tests, and they show corresponding irregularities in their wear, which also varies greatly according to the situation in which rails are placed.

High carbon rails are specially liable to injury by injudicious thermal treatment in rolling.

Carbon and *Manganese*, particularly the latter, notably affect the electrical conductivity of steel, which in tramway rails usually varies from one-twelfth to one-fourteenth that of copper.

High manganese tends to coarse crystallisation, with resulting abrasion and flow of metal, or 'rolling out,' under heavy car traffic. This is often the cause of much trouble from hog-backing, &c.

Sulphur, when in moderate excess, is not particularly harmful, as hitherto generally supposed, but an excess of *Phosphorus* tends to brittleness.

A high percentage of sulphur mainly affects the rail-maker, causing red shortness and seamy metal with attendant difficulties in rolling.

In American standard specifications no limit of sulphur is specified.

Copper.—No limit necessary. It has been conclusively proved that it exercises no deleterious influence even when present in greater proportions than usually found in tram-rail steel.

Arsenic and Nickel.—Limiting proportions are occasionally specified, but for present processes of manufacture it is superfluous to mention these elements. There are proposals, however to employ nickel to a greater extent in rail-steel making.

The processes usually employed in analysing the chemical constituents of steel are not so exact as for the physical tests. There is also considerable liability to personal error. The effects of segregation of the constituents often have an important bearing in the consideration of this question. Carbon is sometimes judged by the colour test, but more exactly by the combustion test.

Physical Tests.—The impact, or drop, test when conducted by a thoroughly competent inspector is perhaps the most valuable of all tests for ascertaining the general quality and characteristics of the steel in tramway rails.

As deflection is in the nature of a measure of ductility of a rail, and as tramway rails are composed of chemical constituents with a view to securing extreme hardness in the steel—which is not compatible with great ductility—it is not usually considered desirable to exact a deflection test.

Steels of similar chemical constituents, but manufactured by different processes, will give somewhat different results in the physical tests. A high elastic limit is one of the most important properties of tram-rail steel, and can be obtained, combined with toughness, by suitable heat treatment.

The physical tests stipulated by specifications are often incompatible with the required chemical constituents of the steel and the processes to be employed in its manufacture.

The results of the chemical analyses and physical tests should be considered in conjunction.

Inspection.—It is of very great importance that there should always be careful inspection and testing of tramway rails, conducted by a thoroughly competent and reliable inspector, at the rolling-mills, before acceptance of deliveries.

Sandberg Rails.

The use of Sandberg silicon steel (silicon 0·3, carbon 0·5, manganese 1·1 per cent.) increases the life of rails by at least 25 per cent. If steel of the same composition is treated by a special process (Sandberg air-cooled steel), the life is said to be increased by 100 to 200 per cent., so far as experience has been obtained (*R. B. Holt*). The surface of rails can be hardened *in situ* by a patented process which has been adopted on several British tramways; this process diminishes the tendency to corrugation. The Sandberg sorbitic process has also been applied to tram-car tyres. The process needs to be correctly applied in order to obtain the best results.

Rolling-Mill Memoranda.

The Bessemer basic process of steel-making is now generally employed for the manufacture of tramway rails at English and Continental rolling-mills.

Rails are cut, while hot, by circular saw, to specified lengths, with a certain margin for shrinkage in cooling. They should be cut off quite square at the ends; the practice of undercutting below the head should not be permitted.

Very exact or dead lengths require to be planed in an ending or milling machine, and are usually subject to a slight extra charge.

Rails are straightened, while in a cold state, in a press.

45 ft. or 60 ft. are the most usual lengths. With the latter there are fewer joints, and they are generally preferred.

Density of Steel for Girder Tram-rails.

As a result of very careful and complete experiments and tests, undertaken at the instance of the Engineering Standards Association at the National Physical Laboratory, it was found that the average density of the steel in a large number of specimens of English-made tram-rails was 0·283 lb. per cubic inch.

Sectional area of rail in square inches=approximately one-tenth the weight of rail in lbs. per yard.

Rail Joints.

This detail is of the first importance, as the rail joints are the weakest part of the track and determine its life, being also the main factor in the cost of maintenance of the permanent way, and largely affecting the cost of upkeep of the rolling-stock and equipment.

A thoroughly strong and permanently rigid joint will maintain a smooth and quiet running surface, and will greatly lengthen the life of the rails, while assisting the electrical conductivity.

Fishplates alone, even when of the heaviest type, have proved inadequate to withstand the stress from the great vibration and pounding effect experienced from the running of heavy electrical cars, and the addition of flat plates under the rail-base has proved of no permanent advantage.

The very best type of joint should be employed, such as an efficient form of bridge joint. A type frequently adopted is the Cooper patent 'Anchor' joint, which is in the form of an inverted rail or joist riveted to the under side of the rail-base, thereby having the effect of doubling the depth of the rail about its weakest part. This device, in addition to providing an efficient connection between the rail-ends, also securely holds the rails down to the concrete foundation, thus keeping them rigidly in position and preventing springing, creep, etc. It is also of considerable value in providing a path for the electric return current.

Allied to the question of rail-joints is that of fixing down or anchoring the rails to the concrete under-bed, not only at the rail-ends, but at intervals intermediately. When rails are welded together, anchorage at close intervals is certainly a necessary accompaniment. With 'thermit welds,' anchors are placed 3 ft. from joints and then at distances of 13 ft. 6 ins. apart. At Leeds, with the 'thermit' process, the rails are anchored at 8-ft. intervals.

Taking into consideration the increased length of rails, the close-butting of ends, and other circumstances, this course is undoubtedly essential to provide against the effects from expansion and contraction, hog-backing, creep, springing, undulation, vibration, water-pumping, cold-rolling, spreading of gauge, and other causes tending to create movement in the rails.

The distance apart for intermediate anchors or holding-down devices varies from 3 ft. 6 ins., as at Hull, to 30 ft. There should be at least one intermediate with 45-ft. rails, and two with 60-ft. rails.

Rails should not be rigidly connected to each other across the track—as, for instance, by steel cross sleepers fixed under rail-base from rail to rail—as this is liable to cause waviness in the rail-table, due to unequal flexure in the rails.

Worn rails can be ground to shape *in situ* by a travelling apparatus, thus prolonging their life by several years. Worn joints, crossings, etc., can be built up to level by adding metal with the metallic arc.

Foundation.

In the most approved British methods of electric-tramway construction, the base of the rails is bedded on a foundation of concrete, composed of 4 parts of stone, 2 of sand, and 1 part of Portland cement, laid about 20 ins. wider than the gauge of the track, and 6 ins. in depth, a short length of some 3 ft. under the rail-joints being usually made from 3 ins. to 6 ins. deeper and of better quality concrete. The latter should be of clean aggregate mixed with good quality cement having somewhat quick-setting properties.

Sometimes the concrete is first laid, the rails being afterwards set, and packed to the required level with small crushed stone and cement, mixed dry. A more approved method is first to set the rails on blocks to the proper alignment and level, and to fit all the fastenings, afterwards placing the concrete in position under and around the rail-base, care being taken that there shall always be a sufficient 'head' on the upper surface of concrete above the rail-base.

At Hull, a longitudinal timber, 4 ins. thick and the width of rail-base, is interposed between the rails and the concrete. At Aberdeen, Birmingham, and Liverpool, on part of the track, cross-sleepers are used. Sleepers are no longer used in Glasgow.

The hollow on each side of the rail-web should be filled with a 'parging,' or rendering composed of 1 of cement to 4 of sand, laid to a vertical surface to pave against.

Rails should be laid so as to butt quite close at ends.

Paving.

Tar macadam and other forms of well-rolled smooth paving are coming much into use. Reinforced concrete is also being employed.

Points and Crossings.

Points and crossings should be of manganese steel throughout, or, if of the best crucible cast steel, then with specially hardened tongues. Renewable parts are of questionable value. Points should be about 12 ft. in length, having one road curved. The tongues should be at least 6 ins. longer than maximum wheel-base length of cars. Movable points should always be drained. Crossings should be of the 'leg' type, and from 7 ft. to 8 ft. long, according to angle number.

Drain-rails should never be used, but slots 9 ins. long cut in rail-groove at every low point, and trapped drain-boxes fixed and connected to sewer.

Cost of Construction.

Where the overhead running or trolley principle was adopted, the pre-war cost of construction of the permanent way varied approximately between 4,500*l.* and 6,500*l.* per mile of single track; this variation being mainly due to the different classes of paving used. Present prices are about 150 per cent. higher.

A fair general average of proportionate costs over a system may be taken as follows:—Rails and fastenings, including points, crossings and special work, 30 per cent.; paving (sett or wood) including concrete underbed, 45 (to 50) per cent.; labour, including cartage, 20 per cent.; bonding, 2 per cent.; watching and sundries, 3 per cent.

Tractive Resistance on Tramways.

The average pull required per ton of load to keep a car moving is 30 lbs. With exceptionally clean rails, as during a heavy rainfall, and with the rail grooves void of dirt, the pull may be as low as 20 lbs. per ton, or below this figure, approximating to the 10 or 12 lbs. of railway work. Again, a very dirty, clogged rail may demand more than the 30 lbs. Multiplying the pull by the speed in feet per minute gives the power in foot-pounds per minute, so that the horse-power is H.P. $= \frac{T \times W \times S}{33{,}000}$, where T is the pull per ton necessary, W is the load in tons, and S the speed in feet per minute. This rule gives the horse-power on the level. To find the power on a grade, the vertical rise of the car is found by dividing the speed of the car in feet per minute by the length of road in which there is a rise of 1 foot. The number of feet of vertical lift multiplied by the total weight in pounds gives the work done per minute against gravity, or $\frac{S \times W}{F}$, where W is the load, S is the speed, and F is the distance in which the road rises 1 foot. Thus on a 1 in 30 grade, F = 30. The addition of the two results gives the total horse-power. Track resistance is increased at curves, also increased horse-power is required during acceleration. The latter depends not only on weight of car as a whole, but also on moment of inertia of rotating parts.

HADFIELDS' CROSSOVERS AND TURNOUTS.

STANDARD LATERAL TURNOUTS (Gauge 4′ 8½″).

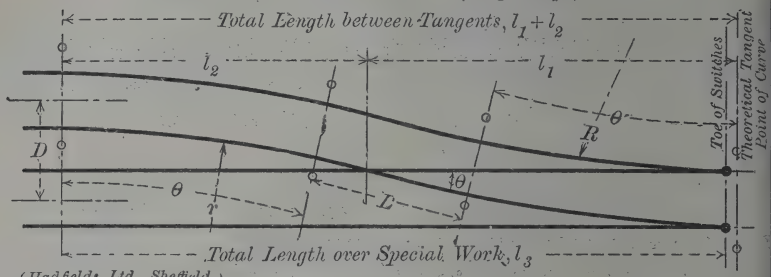
Radius of Switches.	Angle of Crossing.	Lead of Crossing in Feet.	Radius of Plain End.	Distance between Centres of Tracks.	Lead of Plain End.	Total Length over Special Work.	Variation in Inches of l_2 and l_3 for each Inch in Width D.	Length of Straight Through Crossing.	Variation in Inches of L for each Inch in Width D.
R	$\theta°$	l_1	r	D	l_2	l_3		L	
100′ 0″	1 in 5 11° 29′	33·7047	100′ 0″	8 0	26·2581	59·9628	4·9225	19·6013	5·0230
			150′ 0″	8 6	33·7468	67·4515		17·0354	
				9 0	36·2080	69·9127		19·5969	
				9 6	38·6693	72·3740		22·1084	
				10 0	41·1305	74·8352		24·6199	
100′ 0″	1 in 5½ 10° 26′	35·1296	150′ 0″	8 0	31·5715	66·7011	5·4308	20·9217	5·5221
				8 6	34·2869	69·4165		23·6828	
				9 0	37·0023	72·1319		26·4438	
				9 6	39·7177	74·8473		29·2049	
				10 0	42·4331	77·5627		31·9659	
100′ 0″	1 in 6 9° 34′	36·6979	150′ 0″	8 0	32·0827	68·7806	5·9333	26·8224	6·0170
				8 6	35·0494	71·7473		29·8309	
				9 0	38·0160	74·7139		32·8394	
				9 6	40·9827	77·6806		35·8479	
				10 0	43·9493	80·6472		38·8564	

STANDARD LATERAL TURNOUTS (Gauge 4′ 8½″)—*continued.*

Radius of Switches.	Angle of Crossing.	Lead of Crossing in Feet.	Radius of Plain End.	Distance between Centres of Tracks.	Lead of Plain End.	Total Length over Special Work.	Variation in Inches of l_2 and l_3 for each Inch in Width D.	Length of Straight Through Crossing.	Variation in Inches of L for each Inch in Width D.
R	$\theta°$	l_1	r	D	l_2	l_3		L	
100′ 0″	1 in 6½ 8° 49′	38·4276	150′ 0″	8 0	32·7860	71·2136	6·4472	32·5583	6·5243
				8 6	36·0096	74·4372		35·8204	
				9 0	39·2332	77·6608		39·0826	
				9 6	42·4568	80·8844		42·3447	
				10 0	45·6804	84·1080		45·6069	
100′ 0″	1 in 7 8° 12′	40·1789	150′ 0″	8 0	33·5949	73·7738	6·9395	37·8319	7·0112
				8 6	37·0646	77·2435		41·3375	
				9 0	40·5344	80·7133		44·8431	
				9 6	44·0041	84·1830		48·3487	
				10 0	47·4739	87·6528		51·8543	
100′ 0″	1 in 7½ 7° 39′	42·0543	150′ 0″	8 0	34·5357	76·5900	7·4451	43·0662	7·5119
				8 6	38·2582	80·3125		46·8221	
				9 0	41·9808	84·0351		50·5781	
				9 6	45·7033	87·7576		54·3340	
				10 0	49·4259	91·4802		58·0900	
100′ 0″	1 in 8 7° 10′	44·0023	150′ 0″	8 0	35·5723	79·5746	7·9530	48·1747	8·0156
				8 6	39·5488	83·5511		52·1825	
				9 0	43·5253	87·5276		56·1903	
				9 6	47·5018	91·5041		60·1981	
				10 0	51·4783	95·4806		64·2059	
150′ 0″	1 in 5 11° 29′	38·7321	150′ 0″	8 6	33·7468	71·4789	4·9225	12·0581	5·0230
				9 0	36·2080	73·9401		14·5696	
				9 6	38·6693	76·4014		17·0811	
				10 0	41·1305	78·8626		19·5926	
150′ 0″	1 in 5½ 10° 26′	39·6946	150′ 0″	8 0	31·5715	70·2661	5·4308	16·3566	5·5221
				8 6	34·2869	72·9815		19·1177	
			200′ 0″	9 0	41·5673	80·2619		17·3137	
				9 6	44·2827	82·9773		20·0747	
				10 0	46·9981	85·6927		22·8358	
150′ 0″	1 in 6 9° 34′	40·8819	200′ 0″	8 6	39·2333	79·1152	5·9333	21·4629	6·0170
				9 0	42·2000	82·0819		24·4714	
				9 6	45·1666	85·0485		27·4799	
				10 0	48·1333	88·0152		30·4884	
150′ 0″	1 in 6½ 8° 49′	42·2822	200′ 0″	8 0	36·6405	77·9227	6·4472	24·8491	6·5243
				8 6	39·8641	81·1463		28·1112	
				9 0	43·0877	84·3699		31·3734	
				9 6	46·3113	87·5935		34·6355	
				10 0	49·5349	90·8171		37·8977	
150′ 0″	1 in 7 8° 12′	43·7629	200′ 0″	8 0	37·1790	79·9419	6·9395	30·6638	7·0112
				8 6	40·6488	83·4117		34·1694	
				9 0	44·1185	86·8814		37·6750	
				9 6	47·5883	90·3512		41·1806	
				10 0	51·0580	93·8209		44·6862	
150′ 0″	1 in 7½ 7° 39′	45·3972	200′ 0″	8 0	37·8785	82·2757	7·4451	36·3804	7·5119
				8 6	41·6010	85·9982		40·1363	
				9 0	45·3236	89·7208		43·8923	
				9 6	49·0461	93·4433		47·6482	
				10 0	52·7687	97·1659		51·4042	
150′ 0″	1 in 8 7° 10′	47·1334	200′ 0″	8 0	38·7035	84·8369	7·9530	41·9125	8·0156
				8 6	42·6800	88·8134		45·9203	
				9 0	46·6565	92·7899		49·9281	
				9 6	50·6330	96·7664		53·9359	
				10 0	54·6095	100·7429		57·9437	

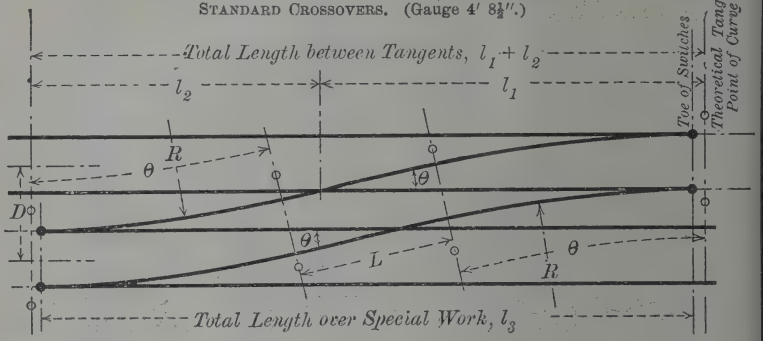
HADFIELDS' CROSSOVERS AND TURNOUTS.

STANDARD LATERAL TURNOUTS. (Gauge 4′ 8½″.)



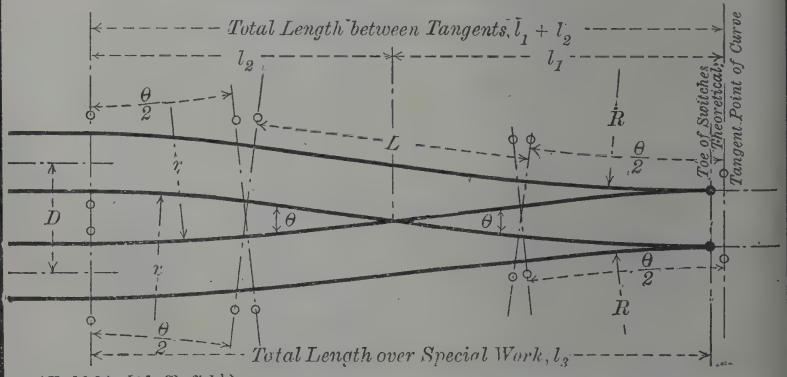
(*Hadfields Ltd., Sheffield.*)

STANDARD CROSSOVERS. (Gauge 4′ 8½″.)



(*Hadfields Ltd., Sheffield.*)

STANDARD EQUILATERAL TURNOUTS. (Gauge 4′ 8½″.)



(*Hadfields Ltd., Sheffield.*)

STANDARD CROSSOVERS. (Gauge 4′ 8½″.)

Radius of Switches.	Angle of Crossing.	Lead of Crossing in Feet.	Distance between Centres of Tracks.	Lead of Plain End.	Total Length over Special Work.	Variation in Inches of l_2 and l_3 for each Inch in Width D.	Length of Straight through Crossing.	Variation in Inches of L for each Inch in Width D.
R	$\theta°$	l_1	D	l_2	l_3		L	
ft. ins.			ft. ins.					
	1 in 4		9 0	29·3589	60·9377		10·4716	
100 0		31·5788	9 6	31·3110	62·8898	3·9042	12·4867	4·0302
	14° 22′		10 0	33·2631	64·8419		14·5018	
			8 0	25·7149	58·2086		13·3008	
	1 in 4½		8 6	27·9216	60·4153		15·5634	
100 0		32·4937	9 0	30·1283	62·6220	4·4134	17·8261	4·5253
	12° 46′		9 6	32·3350	64·8287		20·0887	
			10 0	34·5417	67·0354		22·3514	
			8 0	26·2581	59·9628		19·6013	
	1 in 5		8 6	28·7194	62·4241		22·1128	
100 0		33·7047	9 0	31·1806	64·8853	4·9225	24·6243	5·0230
	11° 29′		9 6	33·6419	67·3466		27·1358	
			10 0	36·1031	69·8078		29·6473	
			8 0	27·0066	62·1362		25·4866	
	1 in 5½		8 6	29·7220	64·8516		28·2477	
100 0		35·1296	9 0	32·4374	67·5670	5·4308	31·0087	5·5221
	10° 26′		9 6	35·1528	70·2824		33·7698	
			10 0	37·8682	72·9978		36·5308	
			8 0	27·8988	64·5967		31·0063	
	1 in 6		8 6	30·8655	67·5634		34·0148	
100 0		36·6979	9 0	33·8321	70·5300	5·9333	37·0233	6·0170
	9° 34′		9 6	36·7988	73·4967		40·0318	
			10 0	39·7654	76·4633		43·0403	
	1 in 4½		9 3	36·8255	72·9128		7·7700	
150 0		38·0873	9 6	37·9289	74·0162	4·4134	8·9013	4·5253
	12° 46′		10 0	40·1356	76·2229		11·1639	
			8 6	33·7468	70·4789		12·0581	
	1 in 5		9 0	36·2080	72·9401		14·5696	
150 0		38·7321	9 6	38·6693	75·4014	4·9225	17·0811	5·0230
	11° 29′		10 0	41·1305	77·8626		19·5926	
			8 0	31·5715	69·2661		16·3566	
	1 in 5½		8 6	34·2869	71·9815		19·1177	
150 0		39·6946	9 0	37·0023	74·6969	5·4308	21·8787	5·5221
	10° 26′		9 6	39·7177	77·4123		24·6398	
			10 0	42·4331	80·1277		27·4008	
			8 0	32·0827	70·9646		22·6384	
	1 in 6		8 6	35·0494	73·9313		25·6469	
150 0		40·8819	9 0	38·0160	76·8979	5·9333	28·6554	6·0170
	9° 34′		9 6	40·9827	79·8646		31·6639	
			10 0	43·9493	82·8312		34·6724	
			8 0	32·7860	73·0682		28·7037	
	1 in 6½		8 6	36·0096	76·2918		31·9659	
150 0		42·2822	9 0	39·2332	79·5154	6·4472	35·2280	6·5243
	8° 49′		9 6	42·4568	82·7390		38·4902	
			10 0	45·6804	85·9626		41·7523	

STANDARD EQUILATERAL TURNOUTS. (Gauge 4′ 8½″.)

Radius of Switches.	Angle of Crossing.	Lead of Crossing in ft.	Radius of Plain End.	Distance between Centres of Tracks.	Lead of Plain End.	Total Length over Special Work.	Variation in Inches of l_2 and l_3 for each Inch in Width D.	Length of Straight through Crossing.	Variation in Inches of L for each Inch in Width D.
R	$\theta°$	l_1	r	D	l_2	l_3		L	
200′ 0″	1 in 5 11° 29′	33·6794	200′ 0″	8′ 0″	26·3977	60·0771	4·9728	19·6877	4·9978
				8′ 6″	28·8841	62·5635		22·1866	
				9′ 0″	31·3705	65·0499		24·6855	
				9′ 6″	33·8569	67·5363		27·1844	
				10′ 0″	36·3433	70·0227		29·6833	
200′ 0″	1 in 5½ 10° 26′	35·1107	200′ 0″	8′ 0″	27·1373	62·2480	5·4764	25·5570	5·4992
				8′ 6″	29·8755	64·9862		28·3066	
				9′ 0″	32·6137	67·7244		31·0562	
				9′ 6″	35·3519	70·4626		33·8058	
				10′ 0″	38·0901	73·2008		36·5554	
200′ 0″	1 in 6 9° 34′	36·6335	200′ 0″	8′ 0″	28·0212	64·7047	5·9752	31·0653	5·9961
				8′ 6″	31·0088	67·6923		34·0634	
				9′ 0″	33·9964	70·6799		37·0614	
				9′ 6″	36·9840	73·6675		40·0595	
				10′ 0″	39·9716	76·6551		43·0575	
200′ 0″	1 in 6½ 8° 49′	38·4165	200′ 0″	8′ 0″	29·0462	67·4627	6·4858	36·4634	6·5050
				8′ 6″	32·2891	70·7056		39·7159	
				9′ 0″	35·5320	73·9485		42·9684	
				9′ 6″	38·7749	77·1914		46·2209	
				10′ 0″	42·0178	80·4343		49·4734	
200′ 0″	1 in 7 8° 12′	40·1702	200′ 0″	8′ 0″	30·1190	70·2892	6·9754	41·4598	6·9932
				8′ 6″	33·6067	73·7769		44·9564	
				9′ 0″	37·0944	77·2646		48·4530	
				9′ 6″	40·5821	80·7523		51·9496	
				10′ 0″	44·0698.	84·2400		55·4462	
200′ 0″	1 in 7½ 7° 39′	42·0474	200′ 0″	8′ 0″	31·2946	73·3420	7·4786	46·4481	7·4952
				8′ 6″	35·0339	77·0813		50·1957	
				9′ 0″	38·7732	80·8206		53·9433	
				9′ 6″	42·5125	84·5599		57·6909	
				10′ 0″	46·2518	88·2992		61·4385	
200′ 0″	1 in 8 7° 10′	43·9968	200′ 0″	8′ 0″	32·5373	76·5341	7·9844	51·3404	8·0000
				8′ 6″	36·5295	80·5263		55·3404	
				9′ 0″	40·5217	84·5185		59·3404	
				9′ 6″	44·5139	88·5107		63·3404	
				10′ 0″	48·5061	92·5029		67·3404	
300′ 0″	1 in 6 9° 34′	40·8602	300′ 0″	8′ 0″	32·1978	72·0580	5·9752	22·7120	5·9961
				8′ 6″	35·1854	75·0456		25·7101	
				9′ 0″	38·1730	78·0332		28·7081	
				9′ 6″	41·1606	81·0208		31·7062	
				10′ 0″	44·1482	84·0084		34·7042	
300′ 0″	1 in 6½ 8° 49′	42·2654	300′ 0″	8′ 0″	32·8951	74·1605	6·4858	28·7656	6·5050
				8′ 6″	36·1380	77·4034		32·0181	
				9′ 0″	39·3809	80·6463		35·2706	
				9′ 6″	42·6238	83·8892		38·5231	
				10′ 0″	45·8667	87·1321		41·7756	
300′ 0″	1 in 7 8° 12′	43·7497	300′ 0″	8′ 0″	33·6985	76·4482	6·9754	34·3008	6·9932
				8′ 6″	37·1862	79·9359		37·7974	
				9′ 0″	40·6739	83·4236		41·2940	
				9′ 6″	44·1616	86·9113		44·7906	
				10′ 0″	47·6493	90·3990		48·2872	
300′ 0″	1 in 7½ 7° 39′	45·3866	300′ 0″	8′ 0″	34·6338	79·0204	7·4786	39·7698	7·4952
				8′ 6″	38·3731	82·7597		43·5174	
				9′ 0″	42·1124	86·4990		47·2650	
				9′ 6″	45·8517	90·2383		51·0126	
				10′ 0″	49·5910	93·9776		54·7602	
200′ 0″	1 in 8 7° 10′	47·1248	300′ 0″	8′ 0″	35·6653	81·7901	7·9844	45·0843	8·0000
				8′ 6″	39·6575	85·7823		49·0843	
				9′ 0″	43·6497	89·7745		53·0843	
				9′ 6″	47·6419	93·7667		57·0843	
				10′ 0″	51·6341	97·7589		61·0843	

Tramway Motors.

For a description of modern practice in tramway motor design and construction, see Section XXXV., 'ELECTRICAL ENGINEERING.'

Tramway Motor Control.

CONNECTIONS OF MOTORS IN SERIES-PARALLEL, WITH CUT-OUT OF RESISTANCES, ON METROPOLITAN-VICKERS CO.'S 'T' TYPE TRAMWAY CONTROLLER.

The method now universally used for controlling the motors on an electric tram-car is that known as the series-parallel system. With this system the two motors are first thrown on to the line in series with one another and with a resistance. This resistance is gradually cut out by the operation of the controller until the two motors are left in series without any resistance in the circuit. The motors are then thrown in parallel with a resistance in the circuit, and when this resistance is finally cut out the motors are in full parallel.

Fig. 4 shows the various combinations as the handle of the controller is moved over.

First Point.—Current passes from the trolley through six sections of resistance, through Armature No. 1, and Field No. 1, thence through Armature No. 2, and Field No. 2 to earth.

Second Point.—Two sections of resistance are cut out.

Third Point.—Two more sections of resistance are cut out.

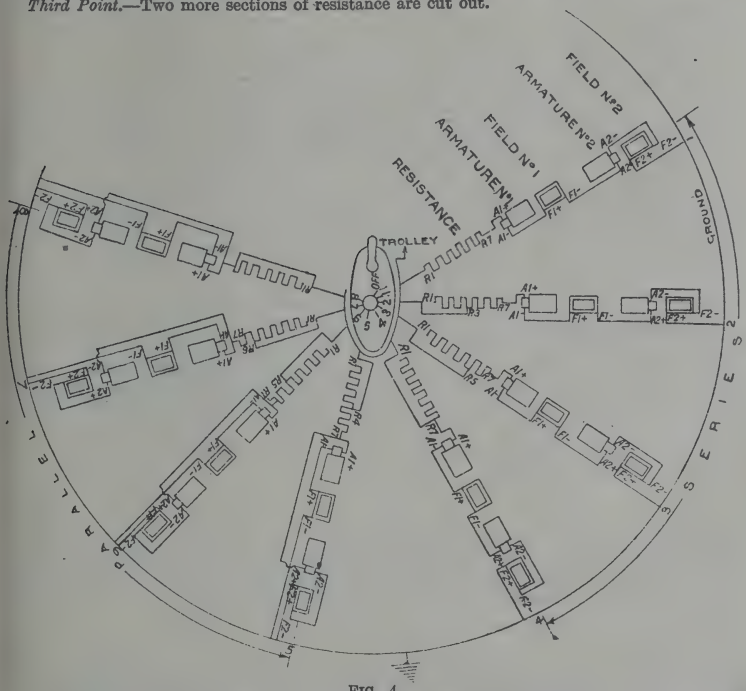


FIG. 4.

Fourth Point.—Two more sections of resistance cut out. The motors are now in full series on the line with no resistance in circuit.

Fifth Point.—Current passes from the line through three sections of resistance and thence to earth through the two motors inparallel. The armature and field of each motor remain of course permanently in series with one another on all combinations of the controller.

Sixth Point.—One of the sections of resistance is cut out.

Seventh Point.—Another of the sections of resistance is cut out.

Eighth Point.—The remaining section of resistance is cut out, leaving the two motors in full parallel on the line with no resistance in circuit.

General Electric Co.'s Tramway Controller Type TE5/R2Z.

This drum type controller is arranged for the series-parallel control of two motors having a capacity not exceeding 70 B.H.P. each at the one-hour rating. It has four series, four parallels and seven braking notches, thus ensuring even acceleration and retardation. Shunt transition is employed between series and parallel. The connections are so arranged that it is possible to operate with one motor cutout. Braking may be accomplished both by rheostatic control and by electro-magnetic track brakes. The controller connections are arranged to afford an automatic run-back electric brake which comes into operation entirely independently of the action of the motor-man when the main handle is in the 'off' position. This feature prevents the possibility of the car running backwards on an incline. The controller is designed for operation on systems with earth return.

Controller Drums and Handles.—The main handle is permanently fastened to the spindle of the main power drum, the reversing key only being removable. In order to render impossible improper operation of the controller, mechanical interlocking is provided which prevents the reverse spindle being moved unless the main power drum is in the 'off' position. It is impossible to move the main power drum unless the reverser is fully thrown into either the forward or reverse position. Arrangements are also provided which prevent the controller being moved on to the main power notches unless the motor cutout mechanism is positively locked in any one of its three positions.

The copper liners on the power drum are easily removable for replacement, and are provided with separately removable end segments where the arc rupturing takes place.

Contact Fingers.—The main contact fingers are of the compression spring type, the arrangement being such that the springs afford constant pressure between the contact tips and the segments of the drum while permitting of adequate variation in the depth of the stroke. This type of finger, being capable of individual adjustment, permits of the correct pressure being provided for each finger, thus eliminating undue wear and obviating heating of the contacts.

Magnetic Blowout.—The controller is provided with individual magnetic blowout coils to each finger. These coils are provided with steel cores which are connected to steel plates embodied in the blowout shield partitions. These plates form part of the iron of the magnetic circuit for the blowout coils, and as they extend throughout the greater part of the area of the shield partitions they distribute the magnetic flux between the partitions parallel to the shaft, and consequently at right angles to arcs formed between the fingers and drum segments irrespective of the position the arc may assume. This ensures the complete extinction of the arc under all operating conditions, and thereby reduces to a minimum the burning at the contacts.

Motor Cutout.—The controller is provided with an external motor cutout for the purpose of cutting out either motor without the necessity of removing the cover of the controller.

For this purpose an operating knob adapted to receive the reversing key is provided at the side of the controller, and by throwing this either up or down, No. 1 or No. 2 motor, as the case may be, is cut out of circuit, still leaving the other motor capable of being operated both for power and for rheostatic brake.

Weight.—The total weight of the controller complete is approximately 360 lbs., the overall dimensions being 42 ins. × 18 ins. × 9¼ ins. approximately.

BRAKING.

Electric braking consisted first of simple rheostatic braking, the drag on the motor armatures, acting as generators, causing the retarding force necessary. Resistance is inserted at first to prevent excessive currents and too severe strains on the motor windings, etc. This resistance is gradually cut out as the controller handle moves over the braking notches.

Electro-magnetic braking was added later, the braking effect being then partly electrical and partly frictional.

One weak point of electric braking was that, should the car be stopped when going up an incline, there was a tendency to run back, and then the electric braking had no effect unless the reversing handle was moved into the backward position. Omission to do this caused a number of accidents.

In the British Thomson Houston Co.'s type B.510 controller, electric braking is obtained irrespective of the forward or backward position of the reverse handle or the direction of motion of the car. In the braking position the connections are such that the armature of No. 1 motor is in series with the field of No. 2 motor and *vice versa.*

In the English Electric Co.'s new controller, when the handle is in the off-position, electric braking immediately comes into operation if the car begins to run back.

The Metropolitan Vickers Electric Co. have developed a new type of contactor-controller.

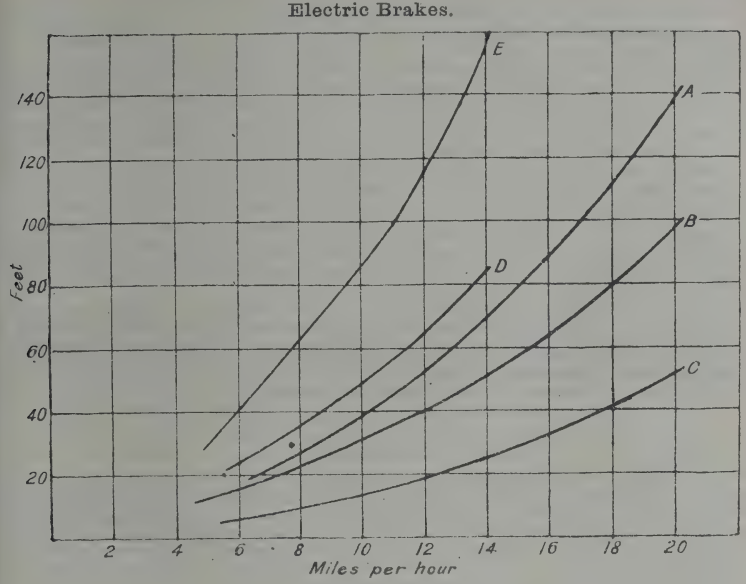


FIG. 5.

Fig. 5 shows the results obtained with tests on tramway cars fitted with various types of electric brakes. Tests A, B, and C were made under the supervision of the Special Committee on Brakes of the Tramways and Light Railways Association, tests D and E were made by Mr. A. L. C. Fell. Tests A, B, and C were made on a four-wheel car weighing 11 tons 9 cwt. loaded. Tests D and E were made on a bogie car weighing 13 tons with 6 persons. In every case the tests were made on a practically level track; in tests A, B, C, and D the rails were dry, in test E the rails were greasy. Tests A and E were made with a rheostatic brake, in tests B, C, and D the brake used was the Westinghouse electro-magnetic track brake, the track shoes being coupled to and acting with the ordinary brake shoes on the wheels. The results of each test are shown by a curve giving the speed in miles per hour at which the brakes were applied and the subsequent travel of the car in feet.

A comparison of curves D and B gives the relative effect of electro-magnetic track brakes acting under practically similar conditions on a bogie car and a four-wheel car. A comparison of curves A and B shows the behaviour of a four-wheel car under the action of a rheostatic brake and of a track brake in the case of ordinary service stops, while curve C shows the effect of a track brake on a four-wheel car in an emergency stop. In all these cases the rails were perfectly clean and dry. Curve E shows what may take place with a heavy car on a flat but greasy rail when controlled only by a rheostatic brake.

ELECTRIC EQUIPMENT OF TRAMWAYS.

Sectioning.

Trolley lines must be divided up into sections not exceeding half a mile in length by means of section insulators. The usual method of feeding the separate sections is to bring the supply cables to a small switch-board fixed in a cast-iron box near the poles carrying the section insulators. The supply cable is connected through a switch to a bus bar from which the four leads to the trolley lines are taken. Another method of feeding is to have a small section pillar in the middle of each section, into which the feeder is brought, and thence to feeder ears on the trolley wire. On the poles carrying the section insulators small iron boxes are fixed, carrying two single-pole switches connected to the section insulators. These switches are normally in the off position, so that in the event of a breakdown in the trolley line it is only necessary to go to one box in the centre of the section instead of two half a mile apart. In the event of failure on a cable, the section switches can be closed and the line run on the trolley wire alone.

All large and complicated junctions are generally isolated by means of section insulators on each line, placed as near the junction as possible, the junction being fed separately. This enables such a section to be isolated by the pulling out of one switch, and repairs can be made quickly and without shutting down the service.

Section boxes should be placed as close as possible to the poles up which the side-feed cables are carried. The simplest method of carrying the side-feeds from the box to the pole consists of a short piece of pipe passing from the section-box to the inside of the pole and held by lock-nuts to the section box. This method enables the cables to be easily withdrawn without disturbing the pavement, and also gets over the danger of the cables lying in water at the foot of the pole, as is frequently the case where they are carried underground.

The side-feed cables generally consist of rubber-insulated flexible-stranded cables, 2,500 megohm grade, and are protected by means of wooden brushes where they enter and leave the poles. The four cables should be tightly taped along their whole length to the span or bracket arm which carries them with 'P. & B.' tape or other weatherproof material. This gives them a neat appearance, and greatly increases the life of the cables. Paper-lead cables should on no account be used for side-feeds, as the lead frequently causes trouble. In some towns bare wires are used instead of rubber-covered cables, but the arrangement has an untidy appearance and possesses no advantages.

The system most in use at the present is known as the single-trolley system, the current being collected from the overhead wires and returned through the rails. In some few cases, where the earth-return current is likely to affect delicate scientific instruments, two overhead wires are carried over each track, one being the feeder and the other the return. This system, however, involves complications at junctions owing to the necessity of extra insulation between the feed and return wires, and the large number of wires required.

Trolleys.

The trolley with outside springs is the most simple form of trolley, as all springs are easily examined and adjusted. The cable is carried down the inside of the trolley arm to the bottom of the standard. The connection to the car leads is made by means of revolving rings or fixed-ring collector and a revolving brush, which allows the arm to make a complete revolution. In the Blackwell trolley with inside springs the springs are entirely enclosed, and are easily adjusted by means of one tension rod. This type has the advantage of taking up less room than the outside spring type.

The Trolley Wheel.

Trolley wheels should be of a good quality metal, but not too hard, as a worn wheel can be more easily replaced than a worn wire. Some trolley lines have been ruined by the manager, or other person responsible for the trolleys, endeavouring to get a high mileage out of the wheels.

The trolley wheel is usually about 4 ins. over all in diameter, of gun-metal or other copper alloy, and is fitted with a bush filled with some graphitic compound. The following are the dimensions recommended by the British Engineering Standards Association (No. 23—1905) as the section of the standard trolley wheel grooves (fig. 6): Width in inches = $1\frac{3}{8}$; depth in inches = $\frac{3}{4}$; radius in inches = $\frac{7}{32}$: angle in degrees = 65°.

Fixed or swivel trolley heads may be used. In Glasgow a fixed head is adopted.

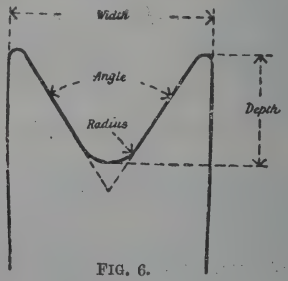


Fig. 6.

Sliding trolley heads are now being tried instead of wheels, with good results. The number of dewirements is greatly reduced, and less damage is done to the overhead equipment on dewirement. But the wear on the trolley wire is about doubled unless the wire is lubricated.

Overhead Construction.

The types generally in use are span, single-side bracket, double-side bracket, and centre pole. The span system is the best from the line point of view, as it allows the greatest flexibility, and also allows the wire to be placed centrally over each track, thus ensuring an even wear on the wire and a smaller tension on the trolleys. It has, however, the disadvantage of requiring standards

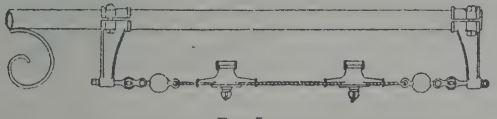


FIG. 7.

on both sides of the streets; and in many cases this is impossible owing to telegraph lines or other causes. Double bracket arms are used in some cases where the lines are laid close to the kerb on both sides and where span wires across the street would be of excessive length.

The single-side bracket is the form of construction most generally in use where economy is of importance and in cases where there are difficulties in obtaining room for structures on both sides of streets. Side brackets up to 22 ft. long have been used in some instances, but such long arms should only be used in very exceptional cases. The Board of Trade Memorandum (see page 790) limits the length of the arms to 16 ft. maximum. Where bracket arms are used, the trolley wire should be suspended by means of flexible suspensions, as in fig. 7. These consist of a short length of stranded-steel wire strained between two suitable malleable cast-iron or wrought-iron brackets bolted to the bracket arm. This length of wire should not be strained too tight, as it then becomes a practically rigid suspension; neither should it be left sufficiently slack for there to be any danger of the line being lifted by a trolley so that the insulator casting comes in contact with the bracket, and so cuts out the second insulation.

Trolley Wire Fittings.

The standard practice is to use double insulation in all cases on trolley lines, the usual method being an insulated bolt fitted into the hangers, the second insulator being at each end of the spans. All spans should be fitted either with one or two strain insulators in order to provide adjustment of the span wires. Triple insulation is now called for by the Board of Trade between any gas or electric lamp bracket attached to pole and trolley wire. Composition insulation is being largely replaced by porcelain. The most usual types of insulators are the straight line hanger and the double and the single pull-off for use on curves. The metal portion of the insulators is either of malleable cast iron or gunmetal, the latter being more expensive in first cost, but cheaper to maintain, as it does not require painting. In the Blackwell type of section insulator it is unnecessary to anchor the trolley wire over the top of the insulator.

The usual method of attaching the trolley wires to the suspension insulator is by sweating them into gunmetal ears. Where sweating is adopted the ears should be accurately milled out to take the wire, and the lips of the ears which clip round the wire should be carefully hammered over before soldering, and the ears dressed off to a feather edge after soldering, great care being taken not to notch the wire where it leaves the ear. In all cases it is absolutely essential that the wire should be held in a strong soldering clamp during the whole process of soldering until the ear is cooled. Unfortunately this practice is insisted on only in cases where the work is carried out by experienced contractors; and in many cases where corporations do their own work the sweating clamp is considered unnecessary, with the result that breakages of the wire at ears frequently occur. The sweating of the ears naturally causes the wire to be annealed, and this also is a cause of breakages.

The most satisfactory arrangement is to have the ears carefully hammered along the wire and the ends dressed off and left unsoldered. For some reason, however, this method is seldom specified, though not infrequently it is adopted in actual construction. In many cases mechanical bars are used. These are made in two halves, bolted together, and grip the trolley wire by means of a V-shaped groove drawn in the wire slightly above the centre line. This method facilitates erection, avoids softening the wire by sweating, and gives a straighter path to the trolley at the ears. It has, however, the disadvantage that the wire has to be annealed in order that the groove may be drawn into it, and the breaking strain of a grooved wire is less than that of a circular wire; there is also a tendency for the groove to turn over between the points of support, causing the wheel to run badly and frequently to leave the wire on curves.

Guards should be fixed at all frogs and on both sides of all crossings to prevent the trolleys jamming in the angles, as, in addition to their being a great safeguard, they help to preserve the wire, as the wear is taken up by the mechanical ears which support the roller bars, and these are easily renewable.

Poles.

Poles are usually 31 ft. long, and are planted 6 ft. in the ground, sufficient rake being allowed in erection so that the pole stands nearly vertical with a slight backward rake when the span and trolley wires are on. The amount of rake for a 36-ft. road in good ground should be about 6 ins., but the actual rake required varies with every class of ground, and can only be successfully estimated by experienced men. The holes should have a sufficient diameter to allow of six inches of concrete round the pole in good ground; this must be increased in bad ground or at places where additional loads are imposed due to bridles, extra long spans, etc. The poles should be planted on circular discs of concrete, or on flagstones or cast-iron plates dropped into the holes to prevent the poles cutting into the ground during erection. The holes should be filled in with 6 to 1 concrete, well rammed.

In order to prevent corrosion, all poles should be coated inside and for a distance of 8 ft. from butt outside with hot tar or Angus Smith composition.

In some coast towns corrosion, and a consequent loosening at the joints, sometimes occurs.

One-piece poles or poles welded smoothly at joints are being adopted, as in Edinburgh and Aberdeen.

In the specification for tramway poles, page 792, the light pole is suitable either for short side brackets or centre pole work, the medium pole for long brackets or span construction, and the heavy pole for anchors and pull-off poles. Three-section poles are generally used, as they are cheaper and more reliable than taper poles. Owing to the irregularity of the taper, the fitting of brackets, pole straps, etc., is extremely difficult with taper poles, and their appearance when erected hardly differs from the three-section pole.

Trolley Wire.

Trolley wire is usually 0 (·324 in.), 00 (·348 in.), or 000 (·372 in.) S.W.G., of hard drawn copper; conductivity should be 98 per cent. of pure copper; it should bear an elongation of 1½ per cent. in 10 inches, a breaking strain of 25 tons per square inch, and 20 twists in a length of 12 inches. Copper cadmium is also being used. Its conductivity is about 93 per cent. of Matthiessen's Standard and its breaking stress about 30 tons per square in. At curves and places where wear is severe, phono-electric wire is used; its conductivity is, however, low, usually 50 per cent. to 60 per cent. of Matthiessen's Standard.

The Engineering Standards Association recommends that the tensile breaking strength should be not less than 24 tons per square inch up to No. 00 S.W.G., and not less than 22 tons above that gauge.

If

L = distance in feet from pole to pole; l = actual length in feet of one span of trolley wire; d = dip in feet; T = tension in lbs. in trolley wire at point of support; w = weight in lbs. per foot of wire; then

$$d = \frac{L^2 w}{8T}\ ;\ T = \frac{L^2 w}{8d}\ ;\ l = L + \frac{8d^2}{3L}\ ;\ d = \sqrt{\frac{3Ll - 3L^2}{8}}.$$

If

e = expansion coefficient per F° = ·00001; $c°$ = change of temperature; then $l \pm c°e$ gives the new length on change of temperature = $c°$, from which the new dip d may then be calculated, or the tension T for any dip. In these formulæ the effect of wind pressure is neglected.

The lowest point of the wire should not be less than 17 feet from the road surface.

Span Wire.

The steel wire rope to form spans for carrying trolley wire is usually formed of a galvanised strand of 7 No. 12 S.W.G. or No. 7 No. 15's. The 7/12 is usually specified to bear a breaking strain of about 4,600 to 5,000 lbs. When the 7/15 wire is used it is of much harder material, and weighs 225 lbs. per 1,000 yards. The only objection to the small wire of high tenacity is the difficulty of forming the eyes over the thimbles and nozzling the ends.

Guard Wire.

Guard wire when single is No. 8 S.W.G. steel, and weighs 215 lbs. per 1,000 yards, but it is often of stranded steel. Guard wire brackets in their plainest form are Ts of ¾ in. iron pipe clipped on bracket arms. In span systems guard wire is carried by special guard wire spans. The Board of Trade have an explanatory memorandum on 'Guard Wires on Electric Tramways.'

STRENGTH AND CONDUCTIVITY OF WIRES.

Material.	Conductivity.	Breaking strain, Lbs. per Sq. In.
Commercial copper	98-99	33,000
Hard drawn „	96-97	60,000-65,000
(1) Silicon bronze	97	63,200
(2) „ „	80	76,000
(3) „ „	45	110,000
Phosphor „	26	101,000
Annealed iron	14	55,000
High carbon steel	10-12	120,000-130,000

Rail Bonding.

Except in those comparatively rare cases where a double trolley wire is employed, the rails are made use of as return conductor, and means have to be taken to connect adjacent rails so as to provide an unbroken electrical conductor. To effect this object the rails are bonded with copper, various types of bonds being employed.

The 'Chicago' Bond.

Fig. 8 shows the general design of this bond, which consists of a copper rod having tubular or thimble-shaped terminals bent at right angles to the rod, the whole being composed of one solid piece of copper. The terminals are inserted into holes in the web of the rail, and the slit in the end of the terminal is spread or clinched over the rail with a hammer and punch. A drift

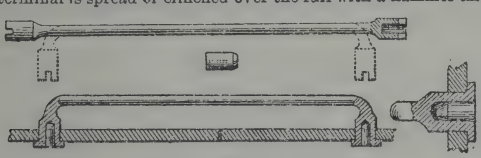


FIG. 8.—Chicago Bond.

pin, larger in diameter than the opening in the terminal by about one-sixteenth of an inch, is then driven in. This permanently expands the terminal and wedges it into contact with the surface of the hole in the web of the rail. The usual length of bond is 30 ins. The depth of the hole in the terminal in all sizes of bond is 1 inch. The size of conductor used depends upon the weight of rail and the current to be carried.

TABLE SHOWING STANDARD DIMENSIONS OF CHICAGO RAIL BONDS.

Size of Wire, B. & S. Gauge.	Diameter of Hole in Rail into which Terminal of Bond fits.	Diameter of Hole in Terminal.	Sectional Area of Rail Bond.	Diameter of Pin.
	Ins.	Ins.	Sq. Ins.	Ins.
0000	$\frac{7}{8}$	$\frac{7}{16}$	·166	$\frac{1}{2}$
000	$\frac{3}{4}$	$\frac{3}{8}$	·132	$\frac{7}{16}$
00	$\frac{5}{8}$	$\frac{5}{16}$	·104	$\frac{3}{8}$
0	$\frac{1}{2}$	$\frac{1}{4}$	·083	$\frac{5}{16}$

The 'Crown' Bond.

FIG. 9.

This is a development of the 'Chicago' bond, the conductors being stranded to afford the flexibility necessary for expansion in a conductor of considerable cross-section dimensions. Fig. 9 shows two of the many different designs in which this bond is made. The terminals have the same dimensions as those in the corresponding 'Chicago' bond.

The 'Neptune' Rail Bond.

FIG. 10.

Another form of bond, the 'Neptune,' fig. 10, is similar to the 'Chicago,' but the drift pin is driven in the same direction as the bond is inserted, thus safeguarding the bond against being driven out.

The 'Columbia' Rail Bond.

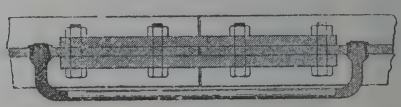


FIG. 11.

A feature in this bond (fig. 11) is the few parts of which it consists. When installed, owing to the pressure exerted between the head and the thimble, and also the fact that they are of the same kind of metal, the two become one, both electrically and mechanically. It therefore has all the advantages which may be claimed for a one-piece bond, and at the same time can be satisfactorily installed as no riveted bond can be. The contact of the rail and bond is made by a wedge expanding the thimble against the hole in the rail. By using a press, exactly the right pressure is exerted. One blow of a hammer too many or too few frequently spoils contact. As the bond is wedged both ways it cannot get loose, as, owing to the fact of its being pressed in, it is sure to make a perfect contact, and cannot be so over-stretched by hammering as to be ready to fall out at the end of a few weeks. It is essential that the hole in the rail should be clean, and the copper bright also. Bonds ought to be inserted at once after the rails are drilled, no time being allowed for rusting to commence.

WELDED BONDS.

The best of all methods of attaching bonds to rails is by electric welding. On this system short bonds can be used, welded into the head or base of the rails outside the fish-plates, or to the webs inside them; the cost of the bond and its attachment is small, and the high conductance of the joint is permanently ensured. Welding bends to rail is found to weaken the web of rail slightly.

Rail Welding.

Tramway rails are united into continuous lengths by welding. There are several systems in use for welding rails.

THE FALK CAST WELD.

This consists in casting round the cleaned ends of the two rails a mass of cast iron from a portable cupola. Being buried up to their top table, welded rails are held against contraction from cold, and the full stress does not come upon the weld. Expansion in hot seasons is impossible, and the rails are held against lateral buckling by the support of the paving.

ACETYLENE WELDING.

Acetylene welding by the D.A. system (*The Dissolved Acetylene Co., Ltd.*, now trading as *Allen-Liversidge Ltd.*) has been made considerable use of. The method consists essentially in reinforcing the joints by means of a pressed steel shoe placed on the flange of the rails at the joint and welded to the same so as to constitute a hollow beam which increases the moment of inertia about the joint, and correspondingly diminishes the bending caused by the passage of rolling stock. Many joints of this type have been fitted in France and Algiers and in South America.

Thermit Welding.

In Thermit welding a mould is fitted round the rails at the joint, and into it is run molten metal from a conical crucible, which is first filled with a mixture of powdered aluminium and iron oxide. The two are intimately mixed, and heated at a point by a special ignition powder. At the temperature produced by igniting this powder, the aluminium reacts very energetically with the oxygen in the iron oxide. The reaction spreads rapidly throughout the mass in the crucible, and produces a quantity of pure superheated liquid metal, covered with a slag of alumina. The temperature set up by the reaction has been ascertained to be about 5,400° Fahr. The crucible is a lined sheet-iron cone. It is suspended over the joint to be welded, and when the reaction is complete it is tapped, the metal running into the mould, followed by the superheated liquid slag, which covers the head of the rail, and raises it to a welding temperature. The rails are then drawn together by suitable clamps, with the result that the base and web of the rails are welded by fusion with the liquid Thermit metal, and the head is butt-welded.

For extra high-carbon rails, the difficulty of butt-welding has been overcome by the use of a special shim, which is inserted between the rail-ends, and ensures a perfect butt-weld at the head.

Thermit welding is often used on new work, partly because electric power is not available.

Electric Welding.

Electric welding has been very widely used, especially in the United States. Two methods have been developed—spot-welding and arc-welding. In the former, bars are placed on both sides of the rails at the joint, and are welded to the webs of the rails by heating them with a very strong current at low pressure, obtained from a transformer, after which the parts are tightly pressed together. These welds are made at several points along the bars. In the latter process, steel plates are welded to the head and foot of the rails with the electric arc, taking the place of fish-plates. In both cases additional bonds are unnecessary, but one 'Neptune' rail bond per joint is often provided. Manganese steel rails can be successfully welded with the electric arc.

(See also 'WELDING,' Section XL., Part II.)

Tramway Track Leakage.

Experiments made by the U.S. Bureau of Standards show that tramway tracks laid on concrete have a low resistance to earth—from 0·2 to 0·5 ohm per 1,000 ft. of single track. With crushed stone ballast under a concrete road-bed the resistance is about three times as great, while with crushed stone ballast with 'Tarvia' finish the resistance is 2 to 3 ohms. Track laid on wooden sleepers embedded in earth has a resistance of 1 to 1·5 ohms. Open track on sleepers laid on good stone ballast has a resistance of 10 to 15 ohms or more in dry weather, 3 to 5 in wet weather, per 1,000 ft. of single track. Chemical salts used to preserve the sleepers greatly reduce the resistance.

Cables.

In English tramway work the cables must be buried. There are four systems in use for buried cables. First, the system of drawing into buried cast-iron pipes. In this system spigot and socket pipes are employed, usually 2 ins. and 2½ ins. inside diameter. A 2-inch pipe 6 ft. long will weigh 48 lbs., a 2½-inch pipe 9 ft. long will weigh 81 lbs. About 2 to 2½ lbs. of lead are required to pour each joint. The pipes terminate in buried brick chambers in which they are finished with trumpet-shaped ends to facilitate drawing in. On curves the pipes may be slightly curved with advantage, but it is usual to lay the pipes round the curve in an equiangled polygon and to use manhole boxes at such intervals that no length of pipe has a versed sine above 12 ins. Soapstone powder is used as a lubricant. The brick chambers should be built on a good concrete bed with a cement collar joint, and they may advantageously be tarred over outside to render them waterproof. The pipes are bonded across the boxes with a stout iron wire to render them electrically continuous; the boxes have a cast-iron top frame with luted cover. These boxes must be placed at such distances apart that excessive stress is not brought upon the cables when hauling them in. The cables should be gripped by their cores. In place of pipes earthenware conduits are often employed of rectangular or hexagonal shape, in short lengths and cemented at the joints, also terminated in brick chambers. In the solid system the cables are laid in troughs of wood or sheet steel, and melted bitumen is poured over them so as to completely enclose them in a casing of bitumen. Cables are sometimes simply buried in the earth. The best cables are insulated with paper and sheathed in lead about $\frac{1}{12}$ in. to $\frac{1}{8}$ in. thick, squirted on under pressure. In whatever way laid the cables are brought up in their respective casings through the base of the section box, in which they are connected to the bus bars by switches, so that the cables may be switched out of the circuit in lengths of about half a mile. In the section box are placed the switch terminals of the trolley feeders, which can also be cut out of circuit in half-mile lengths. The trolley feeder cables are carried up inside the next pole, and in the Booth-Dickinson system, brought through the top finial, then down the pole and

along the span wire or bracket arm to the trolley wire terminals on the section insulator. Test and telephone wires are usually laid up in one cable and similarly laid in pipes, etc. Sometimes a telephone wire is carried overhead on insulators fixed to the poles. In laying cables and making joints the utmost care is necessary not to expose cable ends to the atmosphere excessively. Tents must be used in wet weather, but it is better to do the work in dry seasons. Cable ends must be well stoppered. It is preferable to have the cable ways under footpaths. The topmost pipe must not be nearer the surface than 18 ins. when laid in the road. Cast-iron pipes or sheet steel conduit must be dipped in Angus Smith compound of a non-brittle variety when cold, and cast-iron pipes should be dipped until they themselves are as hot as the boiling compound. The lead sheathing of cables must be electrically bonded past the manhole boxes and connected to the rails at the nearest point to the power station.

In Glasgow, cables are drawn into ducts, usually fire-clay ; sets of 3 or 6. Ducts are laid in the 4-ft. way between the tracks. Manholes are not more than 400 ft. apart. All solid laid cables are gradually being replaced by duct-laid.

Abstract of Board of Trade Memorandum, regarding Details of Construction and Equipment for Tramways and Light Railways Laid on Public Roads.*

Clearance.

There should be at least 15 ins. between the sides of passing cars and also a similar space between the side of a car and any standing work, such as lamp, telegraph and trolley wire posts in a street.

There should be at least 15 ins. between the side of a car and the kerb, whether on straight or curved roads.

The clearance between the top deck of cars and the underside of bridges should not, if possible, be less than 6 ft. 6 ins. Where this clearance cannot be obtained special precautions in working will be required, but in no case will less than 6 ft. be accepted with uncovered cars.

Posts and Brackets.

Where bracket arms 16 ft. in length will not suffice, it is desirable that span wire construction should be used.

The overhead conductors used in connection with the working of the tramways should be securely attached to supports, the intervals between which should not, except with the approval of the Board of Trade, exceed 120 ft., and the overhead conductors should be in no part at a less height from the surface of the street than 20 ft., except where they pass under bridges.

The overhead conductors should be divided up into sections not exceeding (except with the special approval of the Board of Trade) one-half of a mile in length, between every two of which should be inserted an emergency switch so enclosed as to be inaccessible to pedestrians.

Poles supporting gas lamp brackets should be efficiently bonded to the rails.

Permanent Way.

The weight of rails should not be less than 90 lbs. per yard, 100 lbs. being preferred.

The groove of the rail should not exceed 1⅛ in. in width, but a groove not exceeding 1¼ in. will be accepted on curves of less than 150 ft. radius.

Cars.

Of existing types of lifeguard, the ' trigger' is the pattern which is preferred. The hanging gate should be as close to the ground as possible, and there should be at least 3 ft. between it and the front of the guard. Both the guard and the gate should be at least as wide as the outside of the frame of the truck. The tray of the guard should be provided with a spring so as to hold the front edge down to the surface of the roadway when the tray is dropped.

All railings should be connected with earth.

All electrical conductors fixed upon the cars in connection with the trolley wheel should be formed of flexible cables protected by indiarubber insulation of the highest quality and additionally protected wherever they are adjacent to any metal so as to avoid risk of the metal becoming charged.

The trolley standard of every double-deck car should be electrically connected to the wheels of the car in such manner as either to prevent the possibility of the standard becoming electrically charged from any defect in the conductors contained within it or in the event of the standard becoming electrically charged to give a distinctive and continuous warning signal to the driver or conductor. The signal may be a red lamp bridged with a suitable fuse or (preferably) an audible signal. The signal device should be tested at least once a week.

* The functions of the Board of Trade are now exercised by the Ministry of Transport.

In the Board of Trade Memorandum dealing with guard wires on electric tramways the following regulations are laid down :—

Each guard wire must be well earthed at one point at least, and at intervals of not more than five spans. The resistance to earth must be such that a short circuit between a guard wire and a trolley wire will open the circuit breaker.

The earth connection should be made by connecting the support to the rails by means of a copper bond. When first erected, the resistance to earth of the guard wires should be tested, and periodical tests should be made to prove that the earth connection is efficient.

Guard wires should be, in general, of galvanised steel, but in manufacturing districts in which such wires are liable to corrosion bronze or hard drawn copper wires should be used.

The gauge of the guard wire must be such that it will carry, without fusing, a current 50 per cent. greater than that required to open the circuit breaker, and the guard wire must be maintained in such a manner that it will at all times meet these requirements.

The supports for the guard wires should be rigid and of sufficient strength for their purpose, and at each support each guard wire must be securely bound in or terminated.

The rise of the trolley boom should be so limited that if the trolley leaves the wire it will not foul the guard wires.

A Summary of the Board of Trade Regulations for Electric Tramways.

The following is a brief summary of the principal regulations affecting electric traction :—

When any rails on which cars run, or any conductors laid between or within 3 feet of such rails, form any part of a return, such part may be uninsulated. All other returns, or part of a return, shall be insulated, unless of such sectional area as will reduce the difference of potential between the ends of the uninsulated portion of the return below 7 volts.

Where any uninsulated conductor laid between or within 3 feet of the rails forms any part of a return, it shall be electrically connected to the rails, at distances apart not exceeding 100 feet, by means of copper strips having a sectional area of at least $\frac{1}{16}$ of a square inch, or by other means of equal conductivity.

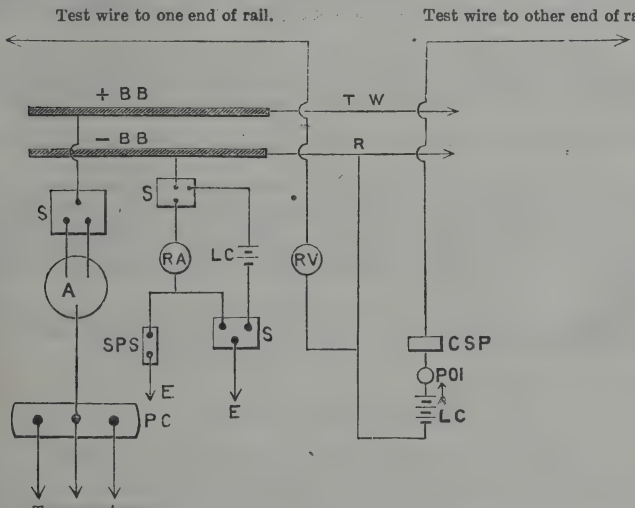


FIG. 12.—Diagram of Board of Trade Switchboard.

A, Ammeter reading $\frac{1}{10}$ — 3 and $\frac{1}{2}$ — 10 as.; B B, Bus bars; R, Return; T W, Trolley wire; S, Two-way switches; R A, Recording Ammeter 2 to 25 as.; R V, Recording voltmeter 2 to 10 v.; L C, Leclanché cells; S P S, S.P. switch; E, Earth; P C, Three-way plug connections; P O I, P.O. indicator; C S P, Contact of sensitised paper.

All uninsulated returns shall be connected to the negative pole of the generator; the negative terminal of the generator shall be also connected through a current-indicator, mentioned below, to two separate earth connections, which shall be placed not less than 20 yards apart. This clause enacts that the two earth connections may be replaced by making one connection to a water-pipe of not less than 3 inches internal diameter, provided that permission be obtained from the owner of the water-pipe and the person supplying the water.

The earth connections referred to in this regulation shall be constructed, laid, and maintained so as to secure electrical contact with the general mass of earth, and so that an electro-motive force not exceeding 4 volts shall suffice to produce a current of at least 2 amperes from one earth connection to the other through the earth, and a test shall be made at least once in every month to ascertain whether this requirement is complied with.

When the return is partly or entirely uninsulated the company shall, in the construction and maintenance of the tramway, (*a*) so separate the uninsulated return from the general mass of earth and from any pipe in the vicinity, (*b*) so connect together the several lengths of the rails, (*c*) adopt such means for reducing the difference produced by the current between the potential of the uninsulated return at any one point and the potential of the uninsulated return at any other point, and (*d*) so maintain the efficiency of the earth connections specified in the preceding regulations as to fulfil the following conditions, viz. :—

(i.) That the current passing from the earth connections through the indicator to the generator shall not at any time exceed either 2 *amperes per mile of single tramway line or 5 per cent. of the total current output of the station.*

(ii.) That if at any time and at any place a test be made by connecting a galvanometer or other current indicator to the uninsulated return and to any pipe in the vicinity, it shall always be possible to reverse the direction of any current indicated by interposing a battery of three Leclanché cells, connected in series, if the direction of the current is from the return to the pipe, or by interposing one Leclanché cell if the direction of the current is from the pipe to the return.

In order to provide a continuous indication that the condition (i.) is complied with, the company shall place in a conspicuous position a suitable, properly connected, and correctly marked current indicator, and shall keep it connected during the whole time that the line is charged.

The owner of any such pipe may require the company to permit him at reasonable times and intervals to ascertain by test that the conditions specified (ii.) are complied with as regards his pipe.

When the return is partly or entirely uninsulated, *a continuous record shall be kept by the company of the difference of potential during the working of the tramway between the points of the uninsulated return furthest from and nearest to the generating station. If at any time such difference of potential exceeds the limit of 7 volts, the company shall take immediate steps to reduce it below that limit.*

The current density in the rails shall not exceed 9 amperes per square inch of the cross-sectional area.

The insulation of the line and of the return when insulated, and of all feeders and other conductors, shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway. The leakage current shall be ascertained daily before or after the hours of running when the line is fully charged. If at any time it should be found that the leakage current exceeds *one-half* of an ampere per mile of tramway, the leak shall be localised and removed as soon as practicable, and the running of the cars shall be stopped unless the leak is *localised and removed within 24 hours.*

The insulation resistance of all continuously insulated cables used for lines, for insulated returns, for feeders, or for other purposes, and laid below the surface of the ground, shall not be permitted to fall below the equivalent of 10 megohms for a length of one mile.

Specification for Poles.

BRITISH STANDARD SPECIFICATION FOR TUBULAR TRAMWAY POLES.*

(No. 8—1927.) (*Abstract.*)

1. The poles shall be of wrought steel free of all defects, and shall be of four classes: light pole, medium pole, heavy pole, and extra-heavy pole.

2. The poles may be made of three separate sections (sectional poles) swaged together when hot so as to make a perfect joint; or they may be made in one piece with two reduced parallel steps

* By permission of the British Engineering Standards Association.

(stepped poles). Poles of both types shall be made either by the hot-rolled weldless process or the lap-weld process, of steel of a tensile strength of not less than 24 tons nor more than 42 tons per square inch. The lap-welded seams in the sections shall be set at an angle of one hundred and twenty degrees (120°) to each other.

3. The overall length of poles of all classes shall be 31 ft.

4. The length of the telescope joint in the sectional poles shall be 18 ins., and the upper edge of each step shall be chamfered off at an angle of not less than 30°.

5. The visible length of the sections or stepped portions shall be :—

Top section	7 ft.
Middle section	7 ft.
Bottom section	17 ft.

6. The outside diameters of the four classes of poles shall be as follows :—

Class.	Top Step or Section.	Middle Step or Section.	Bottom Step or Section.
Light	5½ ins.	6½ ins.	7½ ins.
Medium	6½ ins.	7½ ins.	8½ ins.
Heavy or Extra-Heavy	7½ ins.	8½ ins.	9½ ins.

The variation in diameter shall not exceed $\frac{1}{10}$ in.

7. The minimum thickness of metal in any pole shall be as follows :—

SECTIONAL POLES.

Class.	Top Section.	Middle Section.	Bottom Section.
Light	$\frac{9}{32}$ in.	$\frac{9}{32}$ in.	$\frac{5}{16}$ in.
Medium	$\frac{9}{32}$ in.	$\frac{5}{16}$ in.	$\frac{11}{32}$ in.
Heavy	$\frac{5}{16}$ in.	$\frac{11}{32}$ in.	$\frac{3}{8}$ in.
Extra-Heavy	$\frac{5}{16}$ in.	$\frac{7}{16}$ in.	$\frac{9}{16}$ in.

STEPPED POLES.

Class.	Top Step.	Middle Step.	Bottom Step.
Light	$\frac{5}{16}$ in.	$\frac{5}{16}$ in.	$\frac{5}{16}$ in.
Medium	$\frac{11}{32}$ in.	$\frac{11}{32}$ in.	$\frac{11}{32}$ in.
Heavy	$\frac{13}{32}$ in.	$\frac{13}{32}$ in.	$\frac{13}{32}$ in.
Extra-Heavy	$\frac{9}{16}$ in.	$\frac{9}{16}$ in.	$\frac{9}{16}$ in.

The tolerance shall be 5 per cent. under the above thicknesses.

8. The completed poles shall be straight and true over their entire length to within ¼ in.

9. Five per cent. of each class of sectional pole shall, if required, be subjected to the following drop test :—

The pole shall be dropped vertically, butt downwards, three times in succession, from a height of 6 ft. on to a hard wood block 6 ins. thick laid on a concrete foundation, without showing any signs of telescoping or loosening of joints.

10. Five per cent. of each class of pole shall be subjected to the following bending tests :—

The pole shall, in each case, be fixed horizontally and rigidly supported for 6 ft. from the butt, and loaded, as a cantilever, at a point 18 ins. from the top, the load being applied at right angles to the axis of the pole. Upon the application of the following loads, the temporary deflection and

permanent set, measured at the point of application of the load, shall not exceed the figures stated in the table.

Class of Pole.	Load in lbs. for temporary deflection not exceeding 6 ins.	Load in lbs. for permanent set not exceeding ½ in.
Light	750	1,000
Medium	1,250	1,750
Heavy	2,000	2,500
Extra-Heavy	2,750	3,250

11. In the event of any pole of the above-mentioned 5 per cent. not fulfilling the test requirements, a further 5 per cent. shall be subjected to the tests enumerated. Should any further failure occur, the whole parcel from which the poles have been selected shall be liable to rejection.

APPROXIMATE WEIGHT OF POLES.

The weight of the poles referred to in the Specification may be assumed to be approximately as follows :—

	Light.	Medium.	Heavy.	Extra-Heavy.
Sectional Poles	700 lbs.	872 lbs.	1,130 lbs.	1,437 lbs.
Stepped Poles	674 lbs.	851 lbs.	1,132 lbs.	1,538 lbs.

List of British Standard Specifications Referring to Tramway Work.

No.	*Title.*
2—1927.	Tramway Rails and Fishplates.
8—1927.	Tubular Tramway Poles.
23—1905.	Trolley Groove and Wire.
68—1914.	Steel Conductor Rails (Resistance of).
79—1919.	Special Trackwork for Tramways.
101—1921.	Tramway Tyres.
102—1921.	Tramway Axles.
149—1922.	Wrought-Iron Wheel Centres for Electric Tramway Cars.
150—1922.	Cast-Steel Wheel Centres for Electric Tramway Cars.
173—1923.	Electrical Performance of Traction Motors.

RAILLESS ELECTRIC TRACTION.

Where the traffic conditions do not justify the construction of an electric tramway, but where electric power is available, railless traction provides an alternative to the motor omnibus. Two overhead conductors are provided, as lead and return, and the vehicles carry trolley poles with under-running trolleys collecting the current from the conductors. These trolleys permit the vehicle to deviate at least 15 ft. from the centre-line on either side, so that they can pass other vehicles; on meeting a similar vehicle moving in the opposite direction the trolleys of one must be removed from the conductors whilst the other passes. Railless tramcars compared with motor omnibuses have higher acceleration, lower working costs, longer life, and greater elasticity as regards the number of passengers carried, while they give a more reliable service and a greater annual mileage, and can climb hills with greater ease. The cost of maintenance is about 1*d.* per car mile (exclusive of tyre renewals, which amount to about 1*d.* also), and the consumption of energy is about 1 kw.-hr per car mile. The life of a trolley omnibus is ten to fifteen years, *i.e.* about double that of a motor omnibus. The vehicle costs about 2,000*l.*, and the overhead construction about 2,700*l.* a mile. The seating capacity of a single-deck car is from 28 to 36, and the speed 16 miles per hour. Double-deck cars have been built to carry 59 passengers. Many installations of this class are at work in this country and abroad.

Mr. E. M. Munro states that the approximate cost of energy per passenger mile can be ascertained from the following data :—

Type of Car.	Energy per Car Mile.	Average Passengers carried per Mile on 38% Seats.	Cost of Energy per Car Mile at 1½d. kw.h.	Average Speed m.p.h.	Cost of Energy per Passenger Mile.
Railless single decker .	1·00 kw.h.	11	1·5*d.*	8·0	0·136*d.*
,, double decker	1·66 kw.h.	20	2·49*d.*	8·0	0·125*d.*
Tramcar . . .	2·00 kw.h.	24	3·0*d.*	7·5	0·125*d.*
Petrol Omnibus (petrol) .	0·166 gals.	13	4·359*d.*	8·0	0·335*d.*

The above results are averaged from a number of examples and types examined for this purpose.

The following municipalities operate railless traction vehicles to a greater or less extent:

Aberdare U.D.C., Birmingham, Bradford, Halifax, Ipswich, Keighley, Leeds, Ramsbottom U.D.C., Rotherham, Tees-side Railless Traction Board, West Hartlepool, Wolverhampton, York.

Industrial Electric Trucks.

For moving material about railway stations, factory premises, etc., electric battery trucks have been widely adopted, capable of carrying up to 5,000 lbs. and running at speeds up to 8 miles per hour; the net weight of the trucks is 1,600 to 2,500 lbs., and the mileage per charge 15 to 25 miles. In a railway warehouse 11 tractors and 600 trailers handled 130,000 tons per annum at an average cost of 15·1*d.* per ton. (*R. J. Mitchell.*)

Electric Battery Vehicles.

Useful data on electric battery vehicles was given by Mr. C. W. Marshall at the I.M.E.A. Convention in Glasgow, 1926, based on the experience of the Glasgow Corporation Electricity Department since 1913 with almost every available type of vehicle. The present position is that the lead battery is in favour, due in a great part to the fact that it is much cheaper in initial cost and at the same time gives service at least as good as that obtained from the alkaline battery. The question of the relative merit of thin and thick plate lead batteries is still an open one. The thin plate battery lasts only 12 to 15 months and costs about 60 per cent. of the price of the thick plate battery, which lasts 30 to 36 months. It is, however, possible to get a much greater capacity for a given weight and volume with the thin plate battery, and so in some cases the vehicle becomes much more useful. For example, vehicles in the service of the Glasgow Corporation Cleansing Department which could do only one shift on refuse collection when fitted with thick plate batteries can do two shifts with thin plate. Alkaline batteries cost from 2 to 4 times as much as the best lead batteries. Although they last at least 5 or 6 years under hard service conditions, and 8 or 10 years under easier conditions, their low watt-hour efficiency and high internal resistance counteract the long life to some extent. Battery data is summarised in Table I.

TABLE I.—BATTERY DATA FOR ELECTRIC VEHICLES.

Type of Battery.	Alkaline.	Lead.	
		Thin Plate.	Thick Plate.
Watt-hour efficiency in per cent.	59	75	75
Watt-hours per cubic inch .	0·74	0·8	0·6
,, ,, ,, pound .	15	12	9
Approx. initial cost in £ per kw.h.	30	4	8
Life in years	6–8	1	3
Life in cycles of charge and discharge .	1800–2400	300	900

The capital and operating costs of plain electric lorries of the very best quality of load capacities of 0·5 to 5 tons are given in Table II. The total distance covered is taken to be 10,000 miles per annum and the cost of electrical energy to be 0·75*d.* per unit. The daily distance covered by a battery vehicle should not exceed 35–45 miles.

Mr. Marshall also gives the following data concerning the costs of competing transport systems. For a horse-drawn vehicle, the annual operating costs work out at 239*l.*, with an average cost per vehicle mile of 10·7*d.* A comparison between petrol, steam, and electric vehicles can be obtained from Table III.

TABLE II.—FIRST COSTS AND RUNNING COSTS OF ELECTRIC LORRIES.

	Load Capacity in Tons . .	0·5	1	2	3·5	5
		£	£	£	£	£
First Costs	Cost of vehicle	455	500	552	710	816
	,, ,, battery	120	187	208	230	250
	,, ,, vehicle and battery . .	575	687	760	940	1066
Annual charges of mileage	Driver's wages	150	150	150	150	150
	Depreciation of vehicle (6¾ per cent.) .	30	34	37	47	54
	Interest on vehicle and battery (5 per cent.)	29	34	38	47	53
	Licence	21	21	25	28	30
	Garage charges	18	20	22	24	26
	Insurance	11	12	14	16	18
Annual charges proportional to mileage.	Battery renewals	40	62	69	77	83
	Electric energy	10	15	26	40	51
	Tyres	18	21	34	48	72
	Maintenance	16	17	19	21	23
	Total running costs	343	386	434	498	560
	Costs per vehicle-mile in pence . .	8·23	9·3	10·4	11·95	13·4

TABLE III.—WEEKLY OPERATING COSTS OF PETROL, STEAM, AND ELECTRIC VEHICLES.

Load Capacity in Tons.	Petrol.	Steam.	Electric.
0·5	117*s.*	—	137*s.*
1·0	146*s.*	—	153*s.*
2·0	176*s.*	—	173*s.*
3·5	212*s.*	249*s.*	198*s.*
5·0	246*s.*	275*s.*	224*s.*

RANSOMES' 'ORWELL' ELECTRIC BATTERY VEHICLES.

(Ransomes, Sims & Jefferies, Ltd., Ipswich.)

The main advantages of the electric propulsion of Ransomes' 'Orwell' electric vehicles and Ransomes' 'Orwell' electric industrial trucks are: simplicity of manipulation, efficiency of transmission of power to the wheels, silence, cleanliness, and low running costs. The vehicles are well suited for suburban and town work, where frequent stops are involved and busy thoroughfares have to be negotiated.

In the rear wheel drive applied to these vehicles, one motor is bolted firmly to each side of the chassis frame, and secured to the longitudinal and transverse members. The power of each motor is transmitted by totally enclosed helical gearing to an independent countershaft carrying a chain sprocket, which in turn transmits the power to the rear road wheel by means of a roller chain. Since all bearings, not only for the armature spindle itself, but also for the countershaft and rear road wheels, are of the ball- or roller-bearing type, it follows that the friction loss in this method of drive is reduced to a minimum.

Continuous day and night work.

On the move all day, transporting from one department to another loads of any description, a Ransomes' Electric Elevating Truck used in conjunction with stillages will frequently save its initial cost twice within a year. Moreover, by employing interchangeable batteries, a truck can be made to give a 24-hour service, if two or more shifts are being worked

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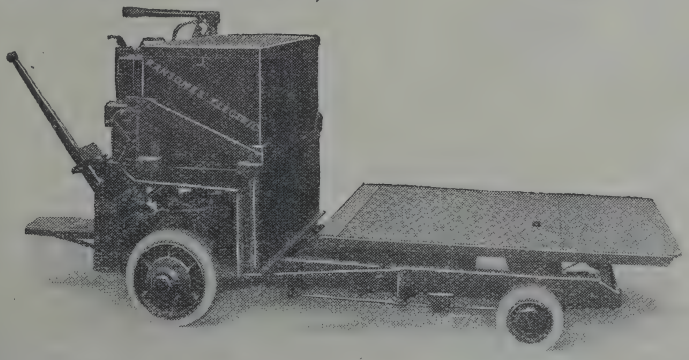

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In this type of drive the transmission is very simple, owing to the fact that use is made of the electric differential action between the two motors, so that mechanical differential gear can be omitted. Furthermore, cardan and universal joints are dispensed with, and, lastly, a change-speed gear box is not required, the speed being controlled by the use of various electrical connections of the motor armatures and fields. Four speeds in the forward direction and one in the reverse direction are obtained by series-parallel connections of the armatures and by the use of series and shunt windings in various combinations.

The fact that the motors are provided with shunt windings renders it possible to make use of the regenerative action of the shunt type of motor, so that on hills the motors may be run as generators, thus acting as an effective brake to the vehicle, and at the same time recharging the batteries.

The controller effecting the necessary changes in connections of the motors is situated under the driver's seat. It consists of two interlocked drums carrying segments, upon which rest the contact-making fingers. The main drum is operated by a hand lever which can be put into any of the running positions, and the rheostatic drum is operated by a foot pedal and inserts resistance steps, and finally interrupts the current, as the pedal is depressed, the breaking of the current without arching being achieved by the action of a magnetic blow-out. The interlocking of the drums is such that the hand lever can only be moved from one position to another when the foot pedal is depressed and the current is interrupted, and by this means it is impossible for sparking to occur on the main drum.

The foot pedal is used just as a clutch on a petrol vehicle, and by depressing and releasing it as obstacles present themselves or are removed from the road, the vehicle may be driven for long stretches without the necessity arising for using the change-speed hand lever.

The 'Orwell' vehicles are fitted with powerful hand and foot brakes, and these, together with the electric braking above referred to, provide a braking power sufficient for any emergency.

The range of action of the vehicles depends on the size of battery used and the nature of the roads to be traversed; on an average 25 to 45 miles may be run on one charge of the battery.

The number of units required to charge the battery is 30 to 35 units, so that at a cost of 1½*d.* a unit the battery may be completely charged for about 4*s.*, giving a cost of energy of about 1*d.* a mile.

The supply of current from the battery may be used to run auxiliary motors for tipping the bodies or for actuating pumps, cranes, or any auxiliary apparatus that may be required to add to the general utility of the vehicle.

Industrial Trucks.

Ransome's 'Orwell' electric industrial trucks are manufactured in 24 standard models, which can be readily adapted to cover all requirements, the leading types being: (*a*) fixed platform trucks; (*b*) elevating trucks; (*c*) tiering trucks; (*d*) crane trucks; (*e*) tipping hopper trucks. The trucks are intended to replace all types of hand trucks and wheel-barrows, and they have a large field of application in factories, on railway stations, and in all cases in which goods and materials have to be shifted for comparatively short distances in small bulk.

The electric industrial truck was originally simply a fixed platform vehicle, and this type has considerable value under certain working conditions. A later type of electric transport is known as the 'Elevating' truck. The main advantage of this truck is that it receives and discharges its load in a few seconds, and consequently it can be kept 'on the run' all day. The load is placed upon an independent loose stillage, which is picked up quickly at the loading point by the electric elevating gear and dropped at the discharge with equal facility and despatch.

The 'Tiering' truck is a pattern of especial value where it is required to load or unload goods at different heights. The whole platform can be raised or lowered by an electric device within easy control of the driver, while the tiering mechanism is fitted with automatic cut-out which operates when the load reaches either of the extreme positions, and eliminates any possibility of accident through over-running. These trucks have been found of great value in printing offices for unloading and storing paper.

The range of action is 10–12 miles per charge with a 2-ton load, and the trucks are capable of ascending gradients of 1 in 7 with this load. The trucks may also be used to drag loaded trailers. The small turning radius of 8 ft. for the type 'F' truck, and 10 ft. for the type 'C' truck, renders their use possible in congested workshops and tortuous passages.

Messrs. Ransomes manufacture a handy form of the electric industrial truck fitted with a swivelling and derricking crane, capable of dealing with a weight of 1,000 lbs. These trucks can run about a factory, picking up loads here and there, putting them on the platform and delivering where required.

In the type 'C' truck two of the wheels are used for driving, and the other pair of wheels are small rollers that enable the loading platform to be supported only 11 ins. from the ground, so as to facilitate the loading of heavy materials. This truck is manufactured in twenty standard models. This 'C' type truck can be supplied with large trailing wheels, thereby giving a higher platform, and an electrically operated elevating platform can also be fitted if desired.

In the 'F' type truck the rear wheels are driven, the battery is slung under the loading platform, and the driver's platform and tiller are capable of being folded back, thus making it specially suitable for working in factories and lifts.

The trucks may be equipped with auxiliary devices, such as end or side tipping hoppers, etc., to meet customers' special requirements.

In the 'C' type two independent brakes are provided. The control is effected by a hand switch giving the direction of motion, and a foot pedal varying the amount of resistance in series with the motors, and thus adjusting the speed. The same pedal, when completely released, cuts off the current from the motors and at the same time applies the brakes. The 'F' type truck is controlled by a hand-operating lever, a foot pedal being provided to release the brakes and interlock with the control lever.

The 'C' type truck can be supplied with four-wheel steering in lieu of two-wheel steering, in which case the turning radius is reduced from 10 ft. to 7 ft. 6 ins.

The cost of running an electric platform truck, including driver's wages, interest and depreciation, and current for charging, is about 200*l.* per annum, and as it is capable of displacing on an average about five workmen with hand-barrows, it will be seen that the truck offers considerable economy.

A range of 'Orwell' Electric Locomotives is also built for loads from 6 tons to 15 tons on gauges from 1 ft. 6 ins. to 3 ft. 6 ins., with draw-bar pulls varying from 180 lbs. normal and 720 lbs. maximum to 450 lbs. normal and 1,800 lbs. maximum.

Another type of 'Orwell' electric production is the 'Ransomes' Electric Runabout Crane,' which has been developed to fill the need for an expeditious, efficient, and mobile appliance to load, unload, and move about merchandise in docks, railway clearing-houses, warehouses, works and yards, and to supplement the working of the now familiar 'Orwell' Electric Industrial Trucks.

It consists of a crane jib provided with lifting and luffing mechanism mounted on a turntable provided with steering and power road wheels, capable of imparting at will to the whole appliance forward, reverse, and rotary movements.

The latest electrically driven vehicle produced by this company is their Electric Trolley Bus.

Ransomes' 'Orwell' electric vehicles and platform trucks are driven by the 'Exide-Ironclad' type of lead battery, which type has gained a high reputation in U.S.A., as well as in this country. The standard number of cells in each battery is forty. The capacities usually are as follows:—For 20–30 cwt., 40–50 cwt. and 3½-ton vehicles, 193, 226 and 258 ampere-hours respectively, and for industrial platform trucks 129 ampere-hours, at the five-hour rate of discharge.

The positive plates used in the 'Exide-Ironclad' battery are radically different from the flat plates usually employed. Each consists of a number of vertical pencils joined at the top and bottom to horizontal bars. Each pencil contains a core of antimonial lead, which is surrounded by the active material, peroxide of lead, which, in turn, is enclosed by an ebonite tube having a large number of horizontal slits. These slits allow the electrolyte (dilute sulphuric acid) access to the active material.

Each ebonite tube is provided with two vertical ribs projecting on opposite sides at right angles to the face of the plate, which serve not only to stiffen the tubes, but also act as insulating spacers, taking the place of the ribs on the wood separators used in the 'Exide' batteries, and allowing the use of a plain wood diaphragm. The ebonite tubes have a certain amount of elasticity, allowing them to compensate for changes in volume of the active material, due to expansion and contraction during charge and discharge. The cylindrical form of tube is peculiarly well adapted to perform its function, since no amount of expansion or contraction will tend to alter its shape and the internal strains are thus kept uniform. Another advantage is that most of the necessary electrolyte is carried within the confines of the plate itself. The negative plate used with the 'Exide-Ironclad' positive is of standard 'Exide' flat type, but is thicker than is usually employed.

The positive and negative plates are separated from one another by means of veneers of wood. The containers are of ebonite, and the cells being completely sealed in, there is little danger of leakage of the electrolyte. As the containers are not of metal, it is unnecessary to keep them apart or to place any special insulating material between them. The cells are usually made up in lots of twenty, these being fitted in an iron-bound wood tray. The tray is fitted with rollers so that one man can easily withdraw it for the purpose of inspecting and topping-up the cells.

The battery can be charged quickly and at any current rate that is obtainable, provided that the voltage per cell does not exceed 2·3, and the temperature is kept below 110° F. Its watt-hour and ampere-hour efficiencies are high. The internal resistance being very low, heavy currents, such as are called for when the vehicles are negotiating steep gradients, do not cause the voltage to fall very much, and so a good speed is maintained. The cost of charging the battery is low, as the efficiency is high. The capacity of the battery is not appreciably affected by the lowest temperatures experienced in this country. The manufacturers of the battery (the *Chloride Electrical Storage Co., Ltd.*, Clifton Junction, nr. Manchester), give a three-year guarantee with each battery, provided it is operated in accordance with their printed instructions and subject to certain records being sent to them regularly. Three years must not, however, be taken as the maximum life of the battery; many that have been heavily worked have been in commission over three years and are still giving useful service.

Petrol-Electric Lorries.

In the petrol-electric vehicle the motive power is provided by a petrol engine, but the mechanical gear and clutch are replaced by a very flexible electric transmission. In a recent type of Stevens petrol-electric lorry of 3 tons capacity, the generator driven by the engine gives from 300 amperes to 80 volts to 230 amperes at 110 volts, and in addition to driving the vehicle it can be used to supply power for charging a battery or electric lighting, welding, etc. The electric motor is supplied through a special controller which gives forward and reverse connections with a wide range of speed variation, and when put in the neutral position enables the generator to supply electricity for external use. In the last case the generator can be given any desired characteristic—under, level, or over-compounded. A 3-ton waggon can supply three arc-welding equipments at 60 volts.

Electric Battery Motors.

The development of the electrification of railway termini in large cities has been retarded by the complications and expense of equipping goods yards and sidings with overhead or third rail. To meet the problem, storage battery locomotives have been designed, the storage battery being particularly well suited to improve the economy of operation where the load is of a very fluctuating nature with high peak demands but with a low average demand, as the battery is capable of discharging at very high rates for short periods of time.

Many of these storage battery locos are in service, and favourable reports are furnished by the engineers operating them. The advantages in goods yards shunting service are as follows:

(1) The locos can be operated wherever there are rails and in buildings or yards where any form of smoke or exhaust gas is objectionable.

(2) A storage battery can deliver power at very high rates; it is capable of developing tremendous tractive effort for acceleration, which is of particular importance in shunting.

(3) Construction and operation are simple. A storage battery contains no moving parts and requires little attention.

(4) Economies will be effected in the total investment and in the cost of operation compared with that of steam locos.

The largest storage battery locomotive in the world has just been built by the General Electric Company at their Erie Works for shunting service by the Chicago and Northwestern Railways in Chicago. It is equipped with a battery of 120 Exide-Ironclad type FL-31 cells, and in addition it has an auxiliary gas engine and generator, and can operate off a third rail as a combination battery and trolley locomotive.

The power that can be developed by this locomotive at 25 per cent. adhesion is 55,000 lbs. tractive effort at over four miles per hour, which is equivalent to 600 horse-power at the wheel rim. A train of sixty 80-ton cars could be started by such a locomotive and brought up to a speed of 8 or 10 miles an hour.

Interesting data concerning this 110-ton storage battery locomotive are as follows:

Locomotive complete	237,000 lb.	Speed at one-hour rating	10 m.p.h.
Mechanical equipment	100,700 lb.	Tractive effort 30 per cent. co-efficient of adhesion	66,000 lb.
Battery	78,960 lb.	Maximum speed	30 m.p.h.
Motor	29,800 lb.	Time motors will carry maximum tractive effort	8 mins.
Engine and generator	7,850 lb.	Ampere-hour capacity at 6-hour rate	2,700
Radiator and fan	3,500 lb.	Average volts at 6-hour rate	228·0
Control	9,150 lb.	Kw.-hour capacity at 6-hour rate	616
Brakes	5,640 lb.	Max. discharge rate in amperes.	6,500
Heater	1,400 lb.	Max kw. discharge rate	846
Length overall	52 ft. 0 in.	Approx. weight of battery	78,960 lb.
Wheel base	39 ft. 0 in.	Approx. floor space	200 sq. ft.
Rigid wheel base	8 ft. 0 in.	Approx. over-all height of battery	38 in.
Height	14 ft. 8 in.		
Width	10 ft. 0 in.		
Tractive effort one hr. capacity.	20,000 lb.		

SECTION XV

HIGHWAY ENGINEERING

ADMINISTRATION — HIGHWAY AUTHORITIES — LEGAL POINTS — HIGHWAY STATISTICS — THE NEW ROADS — COSTS OF MAINTENANCE — REGULATIONS FOR WHEELS AND LOADS — RESISTANCE TO TRACTION — ROAD CONSTRUCTION — COUNTRY ROADS — ROAD CRUSTS AND WEARING LAYERS—STREET PAVINGS—SPECIFICATIONS—CONCRETE ROADS—ROAD STONE TESTS—COSTS DATA—ROAD CRUST WORK—VEHICLES AND PLANT.

Contributed and revised by **Reginald Ryves, Assoc.M.Inst.C.E., M.Cons.E.**

(*Author of 'The King's Highway; or the Nature, Purpose, and Development of Roads and Road Systems'; 'Preliminary Studies in Bridge Design.'*)

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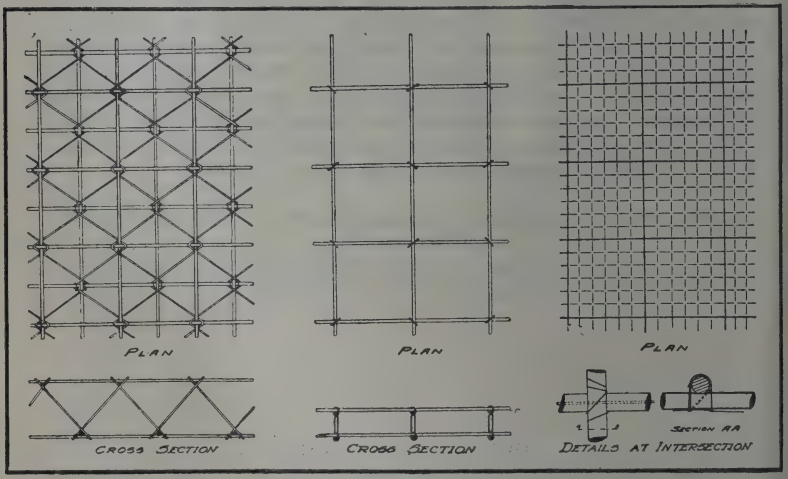

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(Contributed by Reginald Ryves, Assoc.M.Inst.C.E., M.Cons.E.)

ROADS AND STREETS.

ADMINISTRATION.

Road administration in the United Kingdom is carried out by individual local authorities, each of which appoints its own road surveyor. The financial arrangements are, however, such as to lead to relations between the council of a county and those of districts in the same administrative county, as regards some proportion of the roads, the extent to which this has occurred depending partly upon the circumstances of the area and partly upon the policy of the councils concerned.

Recent Grants.—For recent grants, see 'Revenue and Allotment of Funds,' pp 804 and 861.

Highway Authorities.

In all three countries the county councils are concerned with the maintenance of roads, but the arrangements differ, since there are no district councils in Scotland, while the relations between the county councils and the district councils are not the same in Ireland as they are in England and Wales. Subject to the financial modifications resulting from Government grants and the general supervision exercised by the Ministry of Transport in respect of the use of this money, the basis of highway administration is as follows:

England and Wales.—With some exceptions, applying to only a small mileage, the roads are maintained by the various authorities as follows. In cities and county boroughs all the public roads are maintained by the corporation or the borough council. In non-county boroughs and urban districts the urban council usually maintains all the roads, but the county council pays a considerable part of the cost of maintenance of such 'main' roads as pass through the area in question; and sometimes they are directly maintained by the county. With respect to rural roads it may be regarded as the normal arrangement for the more important roads, having been declared to be 'main' roads, to be maintained directly by the county council, and to be in charge of the county surveyor, while the other roads are maintained by the district councils, each council having its own surveyor. In effect there are wide differences, for the proportion of county roads to the whole may be very small or very large, the average being about 20 per cent.

In other cases the 'main' roads are maintained by the district councils under a contract with the county council; or the most important of the district roads are the subject of grants made by the county council. Since the roads directly maintained by the county must be technically 'main' roads, it follows that in counties having a large proportion of the total mileage under county management many technically 'main' roads are roads which are in fact 'secondary' in character or even less important; and conversely, there are many counties in which the main roads in fact are classed as 'assisted roads,' or are, some of them, district roads maintained at the cost of the local ratepayers.

Ireland.—The roads in Ireland are divided into 'main roads' and 'district roads.' The latter are maintained by, and at the cost of, the urban and rural districts in which they are situated, while the cost of main roads is equally divided between the district and the county. The sums for the maintenance of both classes of roads have first to be voted by the district councils, the power of the county council being almost entirely one of veto.

Administrative arrangements in the Free State are undergoing modification under the new conditions.

Scotland.—In Scotland there are no rural district councils. The urban roads within the burghs are maintained by the burgh councils and the rest of the roads by the county councils. Small counties, such as Elgin, Clackmannan, and Kinross, are each in charge of one surveyor, and Sutherland, where many of the roads are maintained by contract, has one surveyor. The larger counties are divided into districts, each in charge of a surveyor working under the district committee of the county council. Most of the counties are divided into two or three districts, but some large counties, such as Ayr, Perthshire, and Lanarkshire, into five. The mileage in a district ranges from about 120 miles in populous districts to some 500 or 600 miles in sparsely peopled districts. Each district committee of a county is composed of the county councillors representing that district. With their own officials they do all the county work for the district, and report their proceedings once a year to the county council, of which they are the component parts. In road matters the district councillors also report to the county road board, which is composed of members from each of the districts. It is recognised that the roads are better managed by persons intimately acquainted with the needs and resources of the relatively small area, and it is held that it is better to secure the services of qualified and experienced men for the direct management of the roads in each district than to employ less efficient local surveyors under a county surveyor. One of the most telling criticisms of the English system is that district councils cannot pay adequate salaries to their road surveyors. Midlothian is an exception to the rule in Scotland, the system of management resembling that of an English county in which a large proportion of the roads are directly maintained by the county. There are four districts, each in charge of a district surveyor, the whole being controlled by a county surveyor, through whom the reports from each district are made to the county road board. The traffic in this area is considerable and of a severe character.

Great Britain.—The Ministry of Transport contributes 50 per cent. towards the costs of maintenance of Class I. roads, and 25 per cent. towards the costs of maintenance of Class II. roads (raised to 33⅓ per cent. as from April 1927); sums are also allotted in aid of the maintenance of unclassified roads of a purely rural character. In 1926 the mileage of these rural roads scheduled for grants was nearly 36,000, the 1926–1927 total being not far short of 41,000; probable grant-in-aid, 50*l.* to 60*l.* per mile. This, at present, purely financial classification is independent of that under which 'main' roads are distinguished from roads not directly maintained by county councils. Since, however, the basis of it is the amount or severity of traffic, it is likely to prevail, the allotment of grants for unclassified rural roads creating in effect a third class. The result, if logical, will be four classes, unless the aided rural roads be added to Class II.

For mileages, see pp. 808–810.

Ministry of Transport: Roads Department.

Constituted under the Act of 1919, the Ministry of Transport took over the powers and duties of Government departments with respect to (*a*) railways; (*b*) light railways; (*c*) tramways; (*d*) canals, waterways, and inland navigations; (*e*) roads, bridges, ferries, and vehicles and traffic thereon; (*f*) harbours, docks, and piers. The powers and duties of the Road Board were also transferred to the new Ministry. These include: powers to acquire land for the making of new roads and for road improvements (Act of 1909), and the duty of allotting grants to local authorities for the purpose of road improvement. These functions are carried out by the Roads Department of the Ministry, which is 'charged with dealing in the ordinary course of departmental business with road construction, improvement, maintenance, and development.' The Ministry may, by agreement with the local authority, defray half the salary and establishment charges of the engineer or surveyor to a local authority.

The Ministry is also charged with the allotment of grants for road maintenance, acts in an advisory capacity as regards both financial and technical matters, and directs the general policy in the expenditure of the large sums allotted recently for special works intended to reduce unemployment.

Revenue and Allotment of Funds.

1927–1928. APPROPRIATIONS. (See p. 861.)

A. *Classified Roads.* (Class II. grants raised to ⅓ cost of maintenance as from April 1927.) (1) Class I. and Class II. roads and bridges, 10,000,000*l.* (2) Special Grants, Classes I. and II., 550,000*l.* (3) Grants in aid of loan charges, 15,000*l.* (4) Grants relating to improvements, 1,800,000*l.* Total, Class I. and Class II., 12,365,000*l.*

B. *Special Grants*, maintenance and improvement of rural roads:

(1) England and Wales: Towards improvement of classified roads before 'maining,' 500,000*l.*; towards improvement of unclassified roads, 500,000*l.*; towards maintenance of scheduled unclassified roads, 1,300,000*l.* Total, B (1), 2,300,000*l.*

(2) Scotland: Towards improvement, 250,000*l.*; towards maintenance, 100,000*l.* Total, B (2), 350,000*l.* Total rural roads, 2,650,000*l.*

C. Essentially rural unclassified roads for which other than district authorities are responsible, 200,000*l.*

D. London. Works, including Thames bridges, recommended by the Royal Commission on Cross-river Traffic, 1,000,000*l.*

E. London Area: Special schemes; works, 150,000*l.*; administrative expenses, 15,000*l.*

F. (1) Towards salaries, etc., local authorities, 200,000*l.*; (2) towards purchase of land, 15,000*l.*; (3) surveys and reports, 10,000*l.*; (4) building line surveys, 25,000*l.*; (5) experimental works, 35,000*l.*

G. Reserve, 35,000*l.*

Total appropriation in respect of liabilities, 1927–1928, 16,700,000*l.*

H. (1) Appropriation to meet liabilities taken over from the Unemployment Grants Committee, 875,000*l.* (2) Other outstanding liabilities, 1,680,000*l.* Grand total, 19,255,000*l.*

NORTHERN IRELAND.—The motor vehicles taxes are earmarked for road-making and maintenance. Recently the Government has paid 72 per cent. of the cost of Reconstruction of Class I. roads and, towards Maintenance, Class I. 60 per cent., Class II. 30 per cent. Contributions are also made towards the cost of maintenance of Class III. roads when used by motor vehicles.

LEGAL POINTS FOR ROAD ENGINEERS.

The same principles of law govern all highways, whether carriage roads, bridle paths, or footpaths. The widths of some roads have been fixed by legal enactments; in England, for instance, by awards under Inclosure Acts, and in Scotland a minimum width, with powers to take a further width was prescribed by the Roads and Bridges Act of 1878. The width of a highway may be greater than that set out in an award, but *prima facie* it is not. The width has often been determined by dedication, and in some cases the dedication was recent and the intended width may be clearly inferred; but in many cases the act of dedication is presumed, or the road is a legacy from ancient times. In such cases the usual presumptions are that the abutting owner of the soil is the owner of the soil to the middle line of the road, and that the right of public passage extends from fence to fence. Road engineers should note, however—when roads require widening—that there may have been recent encroachment and that a strip beyond the fence may be really a part of the highway. There have been many such encroachments. The principle 'once a highway always a highway' should not be lost sight of. The actual width of the highway and the nature and extent of the facility to which the public has a right may depend upon the manner in which and the extent to which the public has used the road and its margins as well as upon the extent to which and the manner in which the owner of the soil or his tenant has exercised rights of ownership, or has done things which tend to show that the dedication of the road is subject to reservations. It is important to note that a wayside ditch, though usually a part of the highway, may be outside the highway, and, especially when a road has been set out under an award, it should not be too readily concluded that a ditch lying beyond the width of the strip awarded is a part of the highway. The highway usually extends to a depth such as may be necessary for the proper maintenance of the road and to a height required for the passage of laden vehicles. The obstructions permitted on a highway are those which are authorised by Acts of Parliament, such as telegraph posts placed by the Postmaster-General, and pipes laid by water and gas companies in defined areas. No individual or society has the right to place any post or other obstruction on the highway, except the owner of the soil where he can clearly establish a claim to such a right. Failing this, the presumption is that he cannot place on the highway anything which amounts to an obstruction of public passage in its widest interpretation. The highway authority may erect direction posts, and, presumably, posts for cognate purposes, but it seems that such an authority may not erect lamp-posts unless they have powers as a lighting authority, even if the lamps are intended to facilitate the use of the road by the public. The highway authority has no powers enabling it to place posts or other obstructions upon the highway in the interests of certain classes of users of the road. The tendency is, however, for local authorities to go beyond their powers, and road surveyors will probably be required to carry out many works near the border line of those powers. Generally, as regards the placing of pipes, conduits, or wires along or across the highway, the persons doing so without statutory authority are likely to come into conflict with the public, or the owner of the soil, or both.

Width of Carriageway.—There is usually a presumption that the highway is dedicated in part as a carriageway, in part as footways, and grass margins which are regarded as occasional footways and rides, and in part as ditches, banks, and other enduring features necessary to the maintenance of the highway as established by use. It may, therefore, be desirable in some cases to obtain the formal consent of the owner of the soil to any radical alterations, such as the filling in of ditches. As regards trees and hedges it is important to distinguish between the powers of the highway authority as regards actual obstruction, and their further powers relating to the lopping of trees and cutting of hedges which injuriously affect the road, these powers being restricted to

the months of October to March inclusive. Similar powers, not restricted to any season and applying to cases in which the tree or hedge obstructs the view of drivers of vehicles, are conferred by Clause 23 of the Public Health Act, 1925, while cases in which trees or hedges obstruct the view of drivers but do not overhang the highway may be dealt with under section 4 of the Roads Improvement Act, 1925.

The Highway Authority.—Must maintain the road in a condition fit for the passage of the public; may enforce the lopping of trees and cutting of hedges in the manner already indicated; may recover damages for substantial injuries caused by 'extraordinary traffic'; may enforce the removal of obstructions from the highway; may enforce by-laws such as those regulating the locking of wheels and the use of skidpans, and the widths of tyres in proportion to the loads carried.

The Public.—The public rights affecting the maintenance of roads include—the recovery of damages caused by 'misfeasance' on the part of the local authority, such as the placing of heaps of stone within the limits of the highway or the fixing of manholes, in such a manner as to cause accidents.

Any member of the public who finds on a highway an object which is in fact an obstruction or a nuisance may take proceedings against the person responsible for its presence, unless it is placed there under statutory authority.

Ownership.—In certain cases the highway authority becomes owner of the soil to a greater or less extent. In boroughs and urban districts, streets taken over by the local authority are vested in that authority. In rural districts 'a main road and the materials thereof and all drains belonging thereto' vest in the county council, but this does not constitute the council owners of the soil or give them powers over roadside wastes beyond those proper to their duties as the guardians of the public right of passage. As regards new roads made by the Ministry of Transport, it has the same powers and duties as those of a county council (except that of levying rates); and it is clear that if the road is on land which the Ministry has bought outright, with powers 'to sell, lease and manage' it, the Ministry becomes owner of the soil; and the Development Act does not seem to contemplate the acquisition by the Ministry of limited rights. In rural districts, highways other than main roads are vested in the owners of the soil.

Extraordinary Traffic.—It has been held that, in the circumstances of a particular case, the haulage of 100 tons a week for five weeks was extraordinary traffic.

Heavy Vehicles on Bridges.—The owner of a bridge may prohibit the crossing of the bridge by a vehicle weighing more than 3 tons, but subject to confirmation, or an increase in the limit, by an umpire or arbitrator.

Bridges as 'Streets.'—By a legal precedent of 1926 (Mr. Justice Romer), a bridge may become a street within the meaning of the Public Health Act, 1875.

The Roads Improvement Act, 1925.

A highway authority may impose restrictions or enforce changes in respect of the use of land at or near a turning or a bend in a highway, in order to prevent danger arising from the obstruction of the view of persons using the highway. Relates especially to the height and character of a wall or hedge. Provision is made for the payment, by the highway authority, of the cost of alterations and compensation for losses sustained as the direct result of those alterations.

A highway authority may prescribe building lines on either or both sides of a highway.

On classified roads the approval of the Minister of Transport is required. Building lines prescribed by urban authorities must be approved by the county council. County councils must notify the local council of building lines prescribed for main roads, and plans must be open to inspection by the public. Compensation for injury to property may be claimed.

The Public Health Act, 1925.

Highway authorities are empowered to lop trees which overhang highways; in the case of a main road the power is exercised by the county council. Appeal may be made to the Petty Sessional Court.

Local authorities are empowered to prescribe improvement lines for widening streets. Compensation may be claimed. In respect of main roads county councils are given the same powers.

See the texts of the Acts, or Mr. E. J. Stead's presidential address to the Association of Somerset Engineers ('*The Surveyor*,' January 1, 1926).

Bus-Mileage Tax.—Under the Act of 1920, the local authority may, if the Minister of Transport approve, impose a tax of ¾*d.* per bus mile on regular services.

HIGHWAY STATISTICS.

Road Mileage in Relation to Population and Area.

Road Mileage, per square mile.—Norway, 0·17; Spain, 0·174; Sweden, 0·205; New South Wales, 0·223; Hungary, 0·253; Switzerland, 0·465; Austria, 0·641; United States Rural Roads—all rural roads, nearly 1·00; surfaced roads, including sand-clay, 0·175; not including sand-clay, but more than half the mileage of gravel, 0·151; macadam and durable materials, 0·056; Italy, 0·782; Canada, 0·014; Province of Quebec, rural roads (31,000 miles), not including trails and roads in remote colonisation districts, 0·044; Peru, 0·013; Brazil, about 0·003; Denmark, 1·724; Japan, 1·743; France, 1·750; Ireland, 1·755. *Class I., or First-Class Roads;* miles per sq. mile: England and Wales, 2·62; Scotland, 0·796; Great Britain, 1·98. [To reduce to km. per sq. km., multiply by $\frac{87}{140}$, or 0·6214.]

Population per Mile of Road.—New South Wales, 24·6; United States, whole population and rural roads only, 39·3; surfaced roads, 224; Denmark, 75·5; France, 108·0; Norway, 130; Sweden, 154·4; Japan, 210; Ireland, about 90; Italy, 451; Canada, 169; Province of Quebec, rural roads, whole population, 76; Brazil, about 3,800; Peru, about 1,400; England and Wales, 248; Scotland, 194; Great Britain, 240; Austria, 385; Switzerland, 504; Spain, 575·8; Hungary, 655. Nova Scotia, 1924, a mile to every seven families. See also 'Indian Roads,' p. 820. [To reduce to pop. per km., multiply by $\frac{87}{140}$, or 0·6214.]

Per Mile of Road.—Population—Acres; Bridgewater, 1214—71; Middleton, 1051—170; Burnley, 944—42; Huddersfield, 787—85; Blackburn, 772—47; Bridport, 758—87; Rochester, 917—81; Belper, U.D., 76—20; Bucklow, R.D., 107—64; Sheffield, 1067—64; Warwick, 684—280; Cambridge, 830—87; Aylesbury, 800—21.

Approximate Mileages (1909).—The British Isles, 231,330; England and Wales, 151,000; Scotland, 24,800; Ireland, 55,560; England and Wales (1920), 152,000 miles.

Mileages in England and Wales (1909).—Rural, 118,642; urban, 32,000; urban roads outside London, 29,837; roads maintained by rural district councils, 95,077; rural roads maintained by or at the cost of county councils, 23,565; county borough roads, 9,366; roads in urban districts and non-county boroughs, 20,471; roads closed as 'main' roads, 27,754.

Mileages in Scotland (1909).—County councils (rural roads), 22,663; burgh councils, 2,108.

Mileages, 1922.—Maintained by 62 county councils, 28,177; by 243 non-county boroughs, 4,656; by 812 urban district councils, 11,870; by 661 rural district councils, 94,628.

Ireland, 1926.—About 47,000 miles, of which 8,000 miles correspond to Classes I. and II. in Great Britain.

Classified Mileages.—See pp. 810 and 861.

EXAMPLES OF CLASSIFICATION.

Locality.		Class I.	Class II.	Unclassified.	Total.	Maintained by
Berkshire, main roads	Rural	249	56	46	352	County
	Urban	25	2	1	28	County
Nottinghamshire, main roads	—	273	124	57	454	County
	—	53	28	2	83	Other Councils
	—	319	126	47	492	County
Warwickshire, main roads	Urban	49	18	2	69	Other Councils
Kent, main roads	Urban	26	3	1	30	County
	Rural	381	173	50	604	County
Isle of Ely, main roads	Urban	36	25	9	70	County
	Rural	48	59	48	155	County
Surrey	Classified	402	232	—	—	All Councils
Blackburn, main roads	Urban	14	7	140	161	Borough

Widths of Important Roads.

Total Widths.—Essex county council has decided that, under the Roads Improvement Act and the Public Health Act of 1925, widths shall be: for Class I. roads, 60 ft. between improvement lines and 100 ft. between building lines for residences, 80 ft. for shops; Class II. roads, 50 ft., 90 ft., and 70 ft., respectively; unclassified roads, 40 ft., 80 ft., and 60 ft., respectively. *Midland*

Regional Advisory Council (committee for arterial roads and main drainage) advise: main and very important secondary arterial roads, 120 ft.; other secondary arterial roads, 80 ft.; other through routes, 65 ft.; minimum building lines, width on main arterial roads, 160 ft

Worcestershire.—Highways Committee recommend as least widths: between buildings, Class I. roads, 120 ft.; Class II., 100 ft.; highway widths, Class I., 60 ft.; Class II., 50 ft. *West Riding:* Highways Committee recommends, for widenings, when necessary and economically practicable, Class A, 80 ft.; B, 60 ft.; C., 45 ft.

Carriageway Widths.—Nottinghamshire, approximate average width, by calculation, of 361 miles of tarred and other surface-treated roads (in a total of 561 miles of main roads), the treated width, 18 ft. Similarly, Isle of Ely, average treated width of tarred roads, 15 ft. 8½ ins. Berkshire, Bradfield rural district, 196 miles, approximate metalled width, by calculation, 13 ft.

Costs of New Roads.

Recent Examples.—The Glasgow-Edinburgh main road, mostly 120 ft. wide between fences; estimated cost, 69,000*l.* per mile. Kingston by-pass road, 100 ft. between fences, 30 ft. carriageway; estimated total cost, 37,000*l.* per mile; tender for construction, 22,102*l.* per mile. Sutton by-pass road, 80 ft.; estimated total cost, 42,947*l.* per mile; tender for construction, 19,290*l.* per mile. Sheffield, widening of roads to 80 ft. and 100 ft., and entire reconstruction, 32,000*l.* per mile. Great West Road, London, 120 ft. wide between fences, 50 ft. carriageway, capable of being widened to 80 ft.; all mains crossing roads carried in subways; foundations, 12 ins. of ashes and hard core; road crust, 9 ins. of reinforced concrete; carpeting, 2 ins. of rock asphalt. Total estimated gross cost, 1,012,602*l.*, or nearly 197,000*l.* per mile. Edinburgh-Glasgow Road, 100 ft. (in parts 60 ft.) between fences, 40-ft. carriageway, two 10-ft. footpaths, some heavy excavation; about 40 miles, 24 m. new, 16 m. widenings; estimate 2,000,000*l.*, or about 50,000*l.* per mile. Whitehaven Loop Road, 41,700*l.* per mile. Tyne Coastal Road, between Heaton and Tynemouth, estimates, 175,000*l.*; length, 4¾ miles, nearly 36,800*l.* per mile. Sutton By-pass Road, 4·64 miles, 80 ft. between fences, 30-ft. carriageway, one 8-ft. footpath; estimate, nearly 44,000*l.* per mile.

Australia.—Under the Federal Aid Highway Act: graded earth roads, 5,008 miles, 1,712*l.* per mile; sand-clay, 2,541 miles, 1,730*l.*; gravel, 9,098 miles, 2,220*l.*; water-bound macadam, 608 miles, 4,500*l.*; bituminous macadam, 841 miles, 6,630*l.*; bituminous concrete, 757 miles, 7,270*l.*; Portland cement concrete, 4,075 miles, 8,570*l.*; brick, 318 miles, 10,000*l.* per mile.

Reconstruction.—Cardiganshire, including foundations and surfacing with tar macadam, 3,167*l.* per mile. Lincolnshire (Holland), 4,000*l.* Dorset, Wimborne, and Cranbourne R.D.C., 2,791*l.* A moorland road, 5,000*l.*

Jersey, Channel Islands: scarifying, cleaning old material, and mixing with 4½ galls. of bitumen to 11½ cu. ft. of stone for bottom coat of 3½ ins. (before rolling); rolling; preparing top coat of 10 galls. of bitumen to 11½ cu. ft. of dried destructor clinker, and spreading 1½ ins. thick; rolling; costs, 7*s.* per square yard. Cost of materials and their treatment for this work, 1*l.* 10*s.* 7*d.* per ton, of which labour accounts for 10*s.* 2*d.*, bitumen and its transport charges, 8*s.* 6*d.*, granite from parish quarry, 3*s.* 2*d.*, clinker from parish destructor, 1*s.* 7½*d.*, and capital charges, 2*s.* 7*d.* Relates to 1,756 tons.

Arterial and By-Pass Roads, Examples and Data: 1924–1925–1926–1927.

Ordnance Maps.—A special revision of roads has been made, and the results are being embodied on the 1-in. and smaller scale sheets as they become due for reprinting.

Dartford By-Pass Road, as another example; 3½ miles; carriageway, 30 ft.; 10-ft. footpaths; total width, 60 ft.; right-of-way, 100 ft.; maximum gradient, 1 in 30.

Middlesex.—Great Cambridge Road: 10 miles; total width, 100 ft.; prepared carriageway, 24 ft.; in reserve, 24 ft.; footpaths, 6 ft.; base, 3 ins. clinker; crust, 8 ins. reinforced concrete.

Great West Road, Greater London: 8½ miles; 5½ miles done; total width, 100 ft.; carriageway, 50 ft., flanked by 25-ft. grass margins, with forest trees; 10-ft. footways; parts of grass strip, available for widening of footways if needed; base, 12 ins. hardcore and ashes; strength crusts, 9 ins. reinforced concrete; carpet, 2 ins. rock asphalt.

Staines Extension: about 3 miles; total width, 100 ft.; present carriageway, 30 ft., flanked by grass strips 29 ft. each; two 8-ft. footpaths. Crust, 8 ins. reinforced concrete.

Greater London.—Works in hand or projected: 6 miles; 80 ft.; carriageway, 30 ft.; one footpath, 10 ft.; base, 6 ins. clinker; crust, 8 ins. concrete.

8¼ miles; 80 ft. average; carriageway, 30 ft.; footpaths, 8 to 10 ft.; crusts, uncarpeted, tar-macadam and bituminous clinker, in different parts of the length.

5½ miles; 80 ft.; carriageway, 30 ft.; footpaths, 8 ft. and 8 ft. Base, hardcore and flint; top course, bituminous.

2·6 miles; 80 ft.; 30 ft.; two 7-ft. footpaths.

1·5 miles; 60 ft.; 30 ft.; two 6-ft. footpaths; base, hardcore; carpeting, 2 ins. bituminous clinker.

North Circular Road, Greater London: partly carried out, includes widenings and reconstructions; widths, 100 ft. and 60 ft. New construction, 9½ miles; widenings, 5½ miles; estimated cost, nearly 1,164,000*l.*, or 77,000*l.* per mile; including crossings of 12 railways and many streams. Examples of the work: 3½ miles of widening to 60 ft.; costs, including all expenses, about 31,000*l.* per mile; widening to 80 ft. near Ealing, 55,000*l.* per mile; near Greenford, 60,000*l.* per mile.

Middlesex.—Schemes adopted in past five years for about 66 miles of new arterial roads, 47 miles of reconstruction involving considerable works, and 16 miles of improvement of existing roads; estimated cost, 7,735,000*l.*; or, averaging the classes of work, 60,000*l.* per mile.

Kingston By-Pass Road: 9·6 miles, 100 ft. wide; carriageway, clinker bottom course resting on clay; reinforced concrete 8 ins., of which the lower 6 ins. is 4½ : 2½ : 1, top 2 ins., 3 : 1½ : 1 aggregate, Thames Valley gravel.

East Ham and Barking By-Pass Road: 3¼ miles, 100 ft.; carriageway, 24 ft.; footpaths, 8 ft. and 10 ft.

Gravesend-Strood Road: 5·2 miles; 80 ft.; carriageway, 40 ft.; base, hardcore and flint; crust, bituminous clinker.

Farnham-Wrotham Road: 60 miles; 80 ft.; carriageway, 30 ft.; base, hardcore and flint; bituminous surfacing.

Bexley Heath: 80 ft.; 30-ft. carriageway.

Birmingham-Wolverhampton: 9¾ miles; 100 ft.; carriageway, 40 ft., with two optional additions of 20 ft. each; footways 10 ft. each; base, cinders and ballast; crust, 'Tarmac.'

Bolton: 2¼ miles; 70 ft.; carriageway, 50 ft.; base, hand-picked stone; strength crust, 6 ins. concrete; paving, 6 ins. granite setts.

County of Durham.—New Coast Road; minimum width, 60 ft.; carriageway, 24 ft.; crust, 4 ins. tar macadam; base in cuttings and on embankments, 12 ins. punning, 4 ins. ashes. Cost, about 37,000*l.* per mile.

Glasgow: 4½ miles; two carriageways of 30 ft. each, with middle grass strip, 40 ft.; footpaths, 12 ft. each; grass margins, 8 ft. each.

Leeds Ring Road: 30 miles; 10 miles made; right-of-way, 100 ft.; initial carriageway width, 24 ft.; bottoming, 4 ins. ashes; base, 12 ins. pitching; intermediate layer, 4 ins. 'dross'; carpet, 3 ins. tar-macadam.

Liverpool, 28 miles; 120 ft.; a middle grass strip, with tramway, flanked by privet hedges; a 25-ft. carriageway on both sides of the middle strip, and 10-ft. footways outside; partly, 4½ ins. pitch-grouted macadam, without foundation; partly a 9-in. concrete strength crust paved with 4-in. cubical setts of Welsh stone. Cost about 57,000*l.* per mile.

Nottingham: 2½ miles; 70 ft.; carriageway, 20 ft.; and 2 miles; 80 ft.; carriageway, 54 ft.; base, 12 ins. of slag on 2 ins. of ashes; crust, 4 ins. tar-macadam. The works include a 3-span bridge over the Trent.

Southport: 1¼ miles; 75 ft.; carriageway, 27 ft.; footpaths, 7½ ft. each; bottoming, 3 ins. clinkers; base, 9 ins. pitching; strength crust, 2½ ins. tar-macadam; carpet, 1½ in. asphaltic.

Other cases: Surrey East and West Road—nearly 5 miles; 60 ft.; carriageway, 30 ft., extendable to 40 ft.; base, 3 ins. to 6 ins. clinkers; crust, 8 ins. reinforced concrete.

Hartlepool: 1 mile 3 furlongs, and 1 mile; base, 4 ins. clinkers; intermediate layer, 9 ins. slag; crust, 4 ins. tar-macadam.

St. Austell By-Pass Road, 1¾ miles.

Essex: London-Yarmouth Road, 1¾ miles.

Mid-Glamorgan: Inter-valley road scheme: three portions of 2 miles apiece, and one portion of 1 mile; form a part of a 40-mile scheme; bottoming, ashes; base, 12 ins. of hand-picked stone; crust, 6 ins. water-bound mountain limestone; width, 30 ft.; carriageway, 20 ft.; footpath, 5 ft.

Whitby-Sandsend Road.—About 2 miles; 40 ft.; carriageway, 20 ft.; tar-grouted macadam; works include a cutting 125 ft. deep, an embankment 75 ft. high, and a bridge of 41 ft. span. Cost about 25,000*l.* per mile.

Sidcup By-Pass Road.—2½ miles; 80 ft.; carriageway, 30 ft.; two 10-ft. footways; 6 in. of clinker, 9 in. of hardcore; wearing carpet 3 in., 2-coat synthetic asphalt; cost about 50,000*l.* per mile.

Morecombe Ring Road.—2·21 miles; carriageway, 30 ft.; foundation, 14 ins. of hand-pitched rubble on ashes and clinker; cost about 41,000*l.* per mile.

London-Folkestone Road.—Maidstone to Charing; 12½ miles, 60 ft.; carriageway, 30 ft.; one 6-ft. footway; three-quarters of width is old carriageway, the remainder new, in concrete; bituminous carpet; estimated cost about 55,000*l.* per mile; estimated cost of the whole work, 400,000*l.*

Aberdulais-Resolven Road.—A county main road; 4·4 miles; 30 to 36 ft.; carriageway, 25 to 31 ft.; one 5-ft. footway; steepest gradient, 1 in 11; foundation, 8 to 12 ins. of ballast topped with mountain limestone; wearing crust, 4 ins. of tar macadam; cost about 10,000*l.* a mile.

Birmingham-Coventry Road.—Widening to 80 ft. or 60 ft., 10 miles; a spur, 6 miles to Castle Bromwich.

Daventry By-Pass Road.—A 20-ft. concrete carriageway; 60 ft. between fences.

York Ring Road.—Six-inch reinforced concrete with (1) 4-in. tar macadam; (2) 2-in. clinker asphalt.

Inverness-Perth Road.—To be finished 1928. Grant of 600,000*l.* Length, 78 miles, and 25 miles of widening; carriageway, 18 ft. between 'stone haunches'; 3-in. gravel bottoming; 9-in. stone; tar-macadam carpet, 3 in.; 35 new bridges.

Market Weighton By-Pass Road.—In the East Riding; about 3¾ miles; estimate, 7,630*l.* per mile.

Costs of Road Maintenance.

(Per Mile.)

ENGLAND AND WALES.

(1921–1923.)

Ordinary Maintenance: Costs per Mile.—Warwickshire, main roads, 284*l.*; Norfolk, main roads, 172*l.*; Northamptonshire, main roads, 371*l.*; Herefordshire, main roads (1920–1921), 163*l.*; Midlothian, (1) Lasswade, 149 miles, 229*l.*; (2) Calder, 156 miles, 159*l.*; (3) Gala Water, 150 miles, 83*l.* per mile. (1922–1923) Kent, 501*l.* (604 miles); Warwickshire, 204*l.* (458 miles); Gloucestershire, 324*l.* (1,002 miles). In Kent, 9*l.* 16*s.* per mile is under the head of 'plant, buildings, etc.,' and 2·6 per cent. of the cost of maintenance is the cost of administration. *Analysis of administration costs.*—Gloucestershire: central office, 0·92; salaries of main road surveyors, 1·35; county surveyor's salary, 0·27 per cent.

(1926–1927.)

Main Roads.—Kent, 458*l.*, including 74*l.* for improvements and tar-painting. Somerset, 880 miles, 308*l.* Essex, 812 miles, 796*l.* Herefordshire, 510 miles, direct control 471 miles; cost of the latter, 211*l.* Welland County, Canada, about 204*l.*

Sheffield, 492 miles of highways, range of altitude 1,400 ft., (100 to 1,500) motor omnibus traffic up to 1,000 ft., 231*l.* More than 11*l.* per mile has been spent on snow removal in one season. Durban, 160 miles of 'hardened' roads, 260*l.*

Italy.—Typical costs per mile, 1st class, 4,025 lire; 2nd class, 3,220 lire; 3rd class, 2,415 lire; 4th class, 1,610 lire.

Mileages in 1913–1914.—England and Wales: Metropolitan Boroughs, 2,168; County Boroughs, 10,304; Non-County Boroughs, main roads, 1,264; other roads, 4,867; Urban District Councils, main roads, 2,358; other roads, 11,871; Counties, main roads, 19,588 (English Counties, 16,831; Welsh Counties, 2,757); Rural Districts, main roads, 4,989; other roads, 94,628. The figures for 1922–1923 are substantially the same; the mileages, with the cost in different classes of local government areas, have been used for the tables given in succeeding pages, as forming a post-war basis for comparison with future returns and road expenditure abroad. (See p. 811.)

THE CLASSIFIED ROADS—1924–1925.

Miles: Class I. roads: England and Wales, 16,176; Scotland, 4,836; total, 21,012. Class II.: England and Wales, 6,880; Scotland, 3,173; total, 10,053. Total of both classes, 31,065. Road Fund contribution to Class I. road maintenance costs (50 per cent.): England, 4,952,000*l.*; Scotland, 527,000*l.* Class II. (25 per cent.): England 602,000*l.*; Scotland, 103,000*l.* Total, for both classes, 6,184,000*l.* Costs per mile, including bridges: Class I., England, 612*l.*; Scotland, 218*l.*; Class II.: England, 350*l.*; Scotland, 130*l.* These are the whole costs of maintenance, including respectively the one-half and three-quarters borne by the county councils in England, and by the county councils and district committees in Scotland.

(1926–1927.)

Miles: Class I. roads: England and Wales, 19,055; Scotland, 5,497; total, 24,552. Class II.: England and Wales, 12,048; Scotland, 3,577; total, 15,625. Total of both classes, 40,177. Including Class I. and Class II.; England and Wales: administrative counties; main roads, 29,574; district roads, 110,468; total, 140,042; county boroughs, 11,041; London, 2,206; total, England and Wales, 153,289; Scotland: Counties, 240,307; burghs, 1,043; total, Scotland, 25,073. Grand total, 178,362.

(1927–1928.)

See p. 861.

Costs of Maintenance and Other Expenditure.

Comparative Tables, 1922-1923.

(For figures relating to 1923–4, see p. 860.)

The chief sources of the essential figures in these tables are, as regards Tables I., II., and V., the 'Local Taxation Returns,' and for Tables III., IV., and VI., similar information tabulated by the Ministry of Health but not published. Other figures were derived from various sources. The editor is responsible for the figures given, and for the method of calculating and presenting the costs per mile; but, in Table V., the costs per mile of roads directly maintained by the counties are those given in the 'Local Taxation Returns.'

Outstanding Debts.—In many cases the loan charges form an important part of the total cost of maintenance, and in some cases exceed the amounts actually spent on the roads. The proportion of loan charges to expenditure is shown in some examples in the 'notes,' and in the totals for some of the tables.

Table I.—Roads and Streets: the Cities of London and Westminster, and Metropolitan Boroughs.

County or Metropolitan Borough.	Area. Acres.	Mileage of Roads and Streets.	Cost per mile: Maintenance, Repairs, and Improvements.	Cost per Mile: Scavenging and Watering.
(1)	(2)	(3)	(4)	(5)
			£	£
City of London	673	48	4,768	1,630
City of Westminster	2,502	99	1,489	1,152
Battersea	2,307	74	1,055	378
Bermondsey	1,560	51	1,199	861
Bethnal Green	759	40	682	571
Camberwell	4,480	122	862	332
Chelsea	660	34	1,105	472
Deptford	1,440	53	767	245
Finsbury	586	37	658	424
Fulham	1,701	65	904	296
Greenwich	3,852	63	850	217
Hackney	3,299	109	889	118
Hammersmith	2,240	60	605	295
Hampstead	2,240	64	643	347
Holborn	405	25	1,784	1,028
Islington	3,040	124	763	449
Royal Borough of Kensington	2,291	93	889	401
Lambeth	4,193	154	747	289
Lewisham	7,040	129	375	184
Paddington	1,356	60	742	399
Poplar	2,240	64	899	685
St. Marylebone	1,493	57	1,346	599
St. Pancras	2,703	89	945	583
Shoreditch	640	43	831	1,108
Southwark	1,120	65	801	762
Stepney	1,760	91	2,227	1,104
Stoke Newington	863	26	836	235
Wandsworth	9,199	197	475	184
Woolwich	8,986	89	830	312
Total, excluding the City of London	75,000	2,179	886	457
Total, including the City of London	118 sq. mls.	2,227	971	482

Total of loan charges, excluding the City of London, 273,421*l.*, or 125*l.* per mile, or 0·142 of maintenance costs.

Total of loan charges, including the City of London, 490,016*l.*, or 220*l.* per mile, or 0·226 of maintenance costs. Assessable value, nearly 49,000,000*l.*, or 10*l.* 17*s.* 9*d.* per head.

Notes on Table I.

City of London.—Loan charges amount to a little less than maintenance expenditure, or to 2,850*l.* per mile, the apparent discrepancy being due to recoupments. Outstanding loan debt at the end of the year, 1,287,754*l.*, in respect of highways, and 1,717,100*l.* in respect of bridges. The maintenance of bridges cost 44,300*l.* expended, and 78,366*l.* loan charges; recoupments in respect of rents, etc., from the Bridge House estates, 122,669*l.*

Bermondsey: Loan debt, 137,948*l.*; loan charges, 17,689*l.* *Hackney:* debt, 181,839*l.*; loan charges, 19,453*l.* *Hammersmith:* debt, 134,569*l.*; loan charges, 26,956, or 474*l.* per mile. *Lambeth:* debt, 135,946; loan charges, 21,592*l.* *Poplar:* debt, 100,972*l.*; loan charges, 23,781*l.*, or 371*l.* per mile. *Wandsworth:* debt, 129,862*l.*; loan charges, 32,292*l.*, or 163*l.* per mile. *City of Westminster:* debt, 261,483*l.*; loan charges, 22,045*l.*, or 122*l.* per mile.

Outstanding Loan Debts.—Less than 30,000*l.* in the cases of Chelsea, Deptford, Finsbury, Hampstead, Holborn, Islington, Paddington, St. Marylebone, Southwark (2,154*l.*), and Stoke Newington.

Public Lighting of Roads, Streets, Bridges, etc.—All these Metropolitan authorities, 265*l.* per mile.

Population.—City of London, 13,363 (census 1922), Administrative County of London, 4,483,249 (census 1921). The enumeration relates to persons who slept in the area the previous night. The day population, which is the significant figure in relation to streets, is much greater than the night population in the inner parts of the area, and in the area as a whole it is very considerably greater. The outer boroughs, however, contribute to the day population of the inner area.

Table II.—Roads and Streets: Cities and County Boroughs.

Reference to Notes.	Groups.	County Boroughs.	Officially Estimated Population: Middle of 1922.	Assessable Value: in Thousands of Pounds.	Produce of a Penny Rate per Pound.	Mileage April 1, 1923.	Expenditure per Mile.	
							Maintenance, Repair, and Improvement.	Scavenging and Watering.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				£	£	£	£	£
1	Sea-ports	Liverpool	826,400	6,378	23,230	472	950	312
2		Bristol	383,900	2,009	8,130	370	522	177
3		Kingston-on-Hull	294,000	1,575	5,961	135	941	290
4		Cardiff	203,700	1,236	5,361	168	672	161
5		Plymouth	211,500	1,115	4,584	180	454	186
6	In large industrial areas	Birmingham	945,100	5,430	20,736	620	645	176
7		Leeds	466,700	2,723	10,952	506	558	125
8		Bradford	291,300	2,370	9,510	252	720	144
9		Stoke-on-Trent	274,300	1,019	3,834	203	417	166
10		Bolton	182,700	1,050	4,180	330	245	—
11		Preston	120,900	582	2,253	99	316	160
12	Watering places	Bournemouth	81,500	853	3,411	113	442	204
13		Bath	68,500	419	1,667	86	561	92
14		Eastbourne	53,700	502	2,000	54	614	145

TABLE II.—ROADS AND STREETS: CITIES AND COUNTY BOROUGHS—*continued.*

Reference to Notes.	Groups.	County Boroughs.	Officially Estimated Population: Middle of 1922.	Assessable Value: in Thousands of Pounds.	Produce of a Penny Rate per Pound.	Mileage April 1, 1923,	Expenditure per Mile.	
							Maintenance, Repair and Improvement.	Scavenging and Watering.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
15	Towns not in large industrial areas	Leicester	238,800	1,191	4,704	149	619	143
16		Derby	132,400	596	2,932	100	599	151
17		Norwich	122,900	610	2,305	109	595	166
18		York	85,000	435	1,716	78	492	146
19		Exeter	59,700	357	1,437	70	683	117
20		Lincoln	66,900	321	1,283	60	460	108
21		Gloucester	52,200	287	1,213	46	545	156
22		Chester	41,200	243	916	44	722	129
23		Canterbury	23,700	133	538	36	483	91
24		Burton-on-Trent	49,630	303	1224	44	745	191
Totals and averages	All County Boroughs in England, 78.		12,283,880	71,310	280,339	10,234	543	155
	All County Boroughs in Wales, 4.		542,260	2,829	11,748	531	535	118
	In England and Wales, 82		12,826,140	74,139	292,087	10,765	542	153

NOTES ON TABLE II.

Population.—The census of 1921 was taken later in the year than that of 1911, and, presumably, the estimated populations in this table are referred to a normal census taken before the summer migrations. Thus, the 1921 census figures are higher for seaside resorts and lower in some industrial areas than those in the table: examples—Bournemouth, 91,800; Eastbourne, 62,000; Liverpool, 803,100; Birmingham, 919,400.

Areas.—The areas of boroughs are of less significance in relation to roads than are the areas of counties. The populations of the following boroughs, having areas between 18,000 and 23,000 acres may be compared: Stoke-upon-Trent, Bradford, Bristol, and Liverpool. Noteworthy cases are: Kingston-on-Hull (excluding the Humber), 9,042 acres; Plymouth, 5,711 acres; Birmingham, 43,600 acres; Leicester, 8,682 acres; Chester, 2,863 acres; and Preston, 3,964 acres.

England (all county boroughs).—Area, 611,238 acres; assessable value per head, 5·8*l.*; rates, all local authorities, 15*s.* 5½*d.* in the pound.

Wales (all county boroughs).—Area, 50,353 acres; assessable value per head, 5·2*l.*; rates, all local authorities, 16*s.* 2½*d.* in the pound.

England and Wales.—Area, 661,636 acres; assessable value per head, 5·8*l.*; rates, 15*s.* 6*d.* in the pound.

Bradford (No. 8).—Loan charges are slightly less than recoupments, and the calculation here made includes all money actually expended.

Lincoln (No. 20) *and Burton-on-Trent* (No. 24).—The same applies, the difference being also small in both cases.

Bolton.—Street scavenging and watering charges are included with the cost of house scavenging.

Groups.—England: Over 500,000, four county boroughs—Birmingham, Liverpool, Manchester (748,500), and Sheffield (522,600). Between 500,000 and 250,000, eight; between 250,000 and 100,000, twenty-six; between 100,000 and 23,680 (Canterbury), forty. *Wales:* Between 250,000 and 100,000, two—Swansea, 161,000; below 100,000, two—Merthyr Tydfil (82,680) and Newport, Mon. (94,880).

Public Lighting of Roads and Streets.—England and Wales—Annual expenditure, 1,631,435*l.*; loan charges, 6,391*l.* (total, 1,637,826*l.*; recoupments, 22,453*l.*; rates, 5·6 pence in the pound; outstanding loan debt, 45,280*l.* Cost per mile of lighting of roads and streets (cities and county boroughs, not metropolitan), 152*l.*

TABLE III.—ROADS AND STREETS: NON-COUNTY BOROUGHS.

Non-County Boroughs, and Carlisle.	Situated in the County of	Population, 1921 Census.	Assessable Value, in thousands of pounds. General District Rate.	Mileages.		Costs per mile.			Other expenditure on roads and bridges: amount
						Maintenance, Repairs, and Improvements.		Scavenging and Watering. (Here referred to the whole Mileage.)	
				Main Roads and Bridges.	Other Roads and Bridges.	Main Roads and Bridges.	Other Roads and Bridges		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
						£	£	£	£
Carlisle	Cumberland	53,300	293	(62 m. 7 f.)		(£374)		88	166
				m. f.	m. f.				
Bedford	Bedford	40,247	223	10 3	27 2	800	575	98	421
Harrogate	York, West Riding	38,938	387	4 1	56 7	1,010	303	149	719
Rochester	Kent	31,261	143	7 2	25 5	817	238	179	1,176
Heywood	Lancaster	26,691	166	5 3	20 5	1,187	549	36	—
Hereford	Hereford	23,324	138	15 7	34 0	1,221	190	31	—
King's Lynn	Norfolk	19,968	88	9 5	11 2	922	418	89	—
Chelmsford	Essex	20,761	135	7 0	14 6	2,613	322	1	—
Boston	Lincoln	16,100	58	3 4	19 0	1,597	119	81	539
Pontefract	York	16,763	90	5 2	25 0	1,020	329	27	—
Wenlock	Salop	13,712	542	26 4	78 6	182	37	—	—
Falmouth	Cornwall	13,318	58	1 4	4 4	1,121	1,084	288	—
Dorchester	Dorset	—	51	3 3	12 4	1,228	184	7·7	—
Clitheroe	Lancaster	12,204	51	2 2	15 6	437	290	41	—
Warwick	Warwick	12,862	72	9 0	10 3	1,075	261	76	—
Lewes	Sussex	10,798	64	3 5	11 3	595	189	95	—
Hertford	Hertford	10,712	60	2 6	7 2	2,124	651	—	—
Carnarvon	Carnarvon	8,298	32	7 1	10 0	218	44	1·8	102
Bideford	Devon	9,125	35	10 0	11 0	422	286	—	—
Lichfield	Stafford	8,394	44	8 0	20 0	1,425	348	17	—
Morpeth	Northd.	7,580	26	1 4	3 1	980	492	—	—
Sudbury	Suffolk	7,046	25	5 0	5 3	972	339	18	—
Chippenham	Wilts	7,757	45	4 2	6 3	1,008	482	132	—
Wells	Somerset	4,372	25	3 2	5 6	557	271	4·8	75
Totnes	Devon	3,982	20	4 6	8 0	610	91	21	106
Aberystwyth	Cardigan	11,220	51	2 6	8 6	894	172	45	109
Blandford	Dorset	3,194	15	1 6	2 0	314	230	87	—
Buckingham	Bucks	3,059	17	11 1	6 0	197	19	20	98
Woodstock	Oxford	1,510	4·3	—	1 0	—	62	55	—
NewRomney	Kent	1,605	6·3	3 4	3 4	181	51	15	—
All, 6	Chester		731	33 1	152 3	637	342	64	4,282
,, 10	Devon		432	116 0	177 7	306	147	33	322
,, 19	Kent		2,584	96 7	435 4	1,103	434	93	2,574
,, 19	Lancaster		2,627	118 1	507 6	971	379	70	17,774
,, 5	Stafford		394	17 5	86 4	1,485	413	37	4,348
,, 5	Suffolk		344	5 7	88 4	402	356	62	91
,, 11	York, West Riding		1,539	56 5	316 0	984	426	87	7,246
218 and 29 Total, 247	England and Wales	(Estimated 1922) 4,452,664	22,995 £5·4 per head.	about 5,000		£554		87	106,000

NOTES ON TABLE III.

England and Wales.—Expenditure, other than capital expenditure: main roads and bridges, 889,087*l.*, and loan charges, 119,991*l.*—total, 1,009,078*l.*; other roads and bridges, 1,287,607*l.*, and loan charges, 273,938*l.*—total, 1,561,545; scavenging and watering, so far as distinguishable, 432,615*l.*, and loan charges, 2,410*l.*; other highway and bridge services, 74,505*l.*; loan charges, 31,471*l.*—total, 105,976*l.*; total, all public roads and streets, 2,676,600*l.* Public lighting of roads,

streets, etc., 515,414*l.* Fees, repayments, and other annual incomes not being grants nor rates, 1,273,452*l.*; exchequer grants, 64,093*l.* Loan debt with respect to highways, bridges, and lighting (net outstanding), 4,428,000*l.*

Capital Expenditure during the year, over 1,400,000*l.* Average rate per pound of assessable value: for main roads and bridges, 1·0*d.*; other roads and bridges, 1*s.* 1·4*d.*; scavenging and watering, 4·4*d.*; other highway and bridge services, 0·8*d.*; lighting, 5·6*d.* These compare with—education (where applicable), 2*s.* 1·1*d.*; police, etc. (where applicable), 8·7*d.*

Population.—The census of 1921 was taken later in the year than that of 1911. This tends to reduce by a little the populations of industrial areas, and to increase by much those of seaside health resorts. Examples are furnished by taking figures from the 1913–1914 tables (the ten preceding issues of the 'Year-Book')—of the former, Heywood, 26,700; Clitheroe, 12,500; Lichfield, 8,626; and several which show less than the real increase; of the latter: Harrogate, 33,700; Aberystwith, 3,580; New Romney, 1,330; other places are slightly affected. In the case of health resorts the effect of the 'season' population is important, in relation to road maintenance.

Hereford: main roads, loan charges more than two-thirds the direct expenditure, or more than two-fifths the cost; other roads, loan charges exceed direct expenditure and account for nearly three-fifths of the cost.

Chelmsford: main roads, loan charges about one-sixth of the total cost.

Hertford: other roads, loan charges about one-sixth of total cost. In all these cases the figures relate to maintenance, repairs, and improvements.

Loan charges: other places, proportion of cost; Rochester main roads, nearly one-fifth, other roads, nearly one-fifth; Clitheroe, other roads, rather more than one-fourth; Heywood, main roads, about one-sixth; King's Lynn, other roads, a little less than one-third; Sudbury, other roads, about two-fifths; Warwick, main roads, 23 per cent., other roads, less than 11 per cent. In all cases, maintenance, repairs, and improvements.

Loan Charges: by the county boroughs in the counties selected; and as a proportion of the cost of maintenance, repair, and improvement for both classes of roads taken together, and including the loan charges—

Cheshire, more than 22 per cent.; *Devon*, less than 3 per cent.; *Kent*, over 26 per cent.; *Lancashire*, nearly 22 per cent.; *Staffordshire*, less than 9 per cent.; *Suffolk, East*, a little more than 10 per cent.; *Yorkshire, West Riding*, nearly 20 per cent.

England and Wales: loan charges, main roads, about 12 per cent.; other roads, about 18 per cent.; both classes, rather more than 15 per cent.

Outstanding loan debts: all non-county boroughs in England and Wales, 247 in number; on account of main roads, 1,166,925*l.*; other roads, 3,132,802*l.*; scavenging, watering, and other highway expenses, 432,128*l.*; total, 4,732,855*l.*, as an average, per borough, of 19,161*l.*

Notes on Table IV.

Assessable Value, is that of the General District Rate.

England and Wales.—Expenditure, other than capital expenditure: main roads and bridges, 1,586,746*l.* and loan charges, 162,965*l.*—total 1,711,711*l.*; other roads and bridges, 2,525,421*l.* and loan charges, 298,905*l.*—total 2,824,326*l.*; scavenging and watering, so far as distinguishable, 497,751*l.*, and loan charges, 4,684*l.*—total, 502,543*l.*; other highway and bridge services, 110,649*l.*, and loan charges, 11,080*l.*—total, 121,729*l.*; public lighting of roads, streets, etc., 799,847*l.*, and loan charges, 2,832*l.*—total, 802,679*l.* Fees, repayments, and other annual income, not being rates nor grants, 2,184,682*l.*; exchequer grants, 141,450*l.* Net outstanding loan debt with respect to highways, bridges, and lighting, 4,453,481*l.* *Capital expenditure* during the year (roads, etc.) over 2,200,000*l.* Average rate per pound of assessable value: for main roads and bridges, 0·8*d.*; other roads and bridges, 1*s.* 2·1*d.*; scavenging and watering, 2·9*d.*; other highway and bridge services, 0·5*d.*; lighting, 5·1*d.* These compare with—education, where applicable, 2*s.* 8·7*d.*

Upland Towns.—Numbers 1 to 4 are situated in mountain or moorland areas.

Coastal Towns.—Numbers 5 to 12 are situated on sea-coasts or estuaries.

Industrial Areas.—Numbers 13 to 18 are situated in large industrial areas.

TABLE IV.—ROADS AND STREETS: URBAN DISTRICTS.

Urban District Council.	County.	Population. Census 1921.	Area. Acres.	Assessable Value in Thous.	Mileages. Main Roads.	Mileages. Other Roads.	Costs per mile. Maintenance and Improvements. Main Roads.	Costs per mile. Maintenance and Improvements. Other Roads.	Costs per mile. Scavenging and Watering	Other Expenditure. Amounts.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
				£	m. f.	m. f.	£	£	£	£
1 Festiniog	Merioneth	8,143	16,323	32	30 4	9 6	109	26·5	—	—
2. Brynmawr	Brecon	8,062	1,454	17	—	3 0	—	623	140	605
3 Alnwick	Northumberland	6,691	4,777	30	6 1	12 1	373	139	30	—
4 Matlock	Derby	7,055	4,204	36	6 0	20 4	3,128	1,722	164	—
5 Whitby	York, North Riding	12,513	2,009	48	5 4	14 5	37·5	333	213	1,192
6. Bognor	Sussex	13.300	865	65	—	14 1	—	393	107	8
7. Brixham	Devon	7,782	5,626	28	6 2	24 1	224	67	21	—
8 Milford Haven	Pembroke	7,860	870	15	—	13 4	—	12	24	1,406
9 Cromer	Norfolk	5,435	1,062	31	4 4	4 5	302	153	25	—
10 Penmaenmawr	Carnarvon	4,480	3,814	20	4 0	10 3	500	130	—	—
11 Wyvenhoe	Essex	2,320	1,564	8	2 7	5 2	27	37	2·5	—
12 Wadebridge	Cornwall	2,319	864	8	2 3	5 3	240	46	3·5	—
13 Bedwellty	Monmouth	31,089	7,274	153	—	44 1	—	356	58	43
14. Atherton	Lancaster	19,863	2,264	112	2 7	11 6	644	247	65	1,732
15 Willenhall	Stafford	19,671	1,249	64	3 4	14 0	761	280	139	—
16 Mirfield	York, West Riding	12,131	3,394	59	4 6	17 2	1,021	288	65	—
17 Willington	Durham	9,197	3,793	29	10 6	7 6	256	89	11	—
18 Methley	York, West Riding	4,573	3,493	32	3 0	9 4	3,089	272	—	—
19 Tonbridge	Kent	15,929	1,403	86	4 7	9 1	2,567	307	—	—
20 Horsham	Sussex	11,413	1,277	58	0 5	15 2	—	351	6	—
21 Bishop's Stortford	Hertford	8,875	3,371	47	7 0	12 3	535	301	48	—
22 Cirencester	Gloucester	7,408	5,286	37	7 2	8 4	440	436	13	29
23 Sleaford	Lincoln	6,680	4,550	33	7 5	8 3	464	102	14	—
24 Sherborne	Dorset	6,394	923	30	6 5	6 0	218	245	57	189
25 Uttoxeter	Stafford	5,361	1,437	21	—	5 2	—	403	—	—
26 Woodbridge	Suffolk	4,500	—	18	—	11 7	—	161	(1·5)	32
27 Oakham	Rutland	3,327	2,055	17	3 4	6 1	269	149	16	141
All, 85	Lancaster	—	—	5,000	265	931	950	243	45	20,498
„ 111	West Riding	—	—	3,528	273	1,392	946	208	15·8	23,844
„ 10	Norfolk	—	—	164	64	114	330	67	7·8	227
„ 23	Kent	—	—	1,808	59	365	1,309	276	53	2,788
„ 9	Buckingham	—	—	321	10 7	69 3	1,746	210	45	—
„ 19	Hertford	—	—	986	32 3	220	1,670	262	44	3,160
„ 23	Devon	—	—	557	134	464	401	80	16	2,807
„ 16	Cornwall	—	—	236	38 2	251	273	61	8·8	730
„ 710	England	—	—							
„ 80	Wales	—	—							
„ 790	England and Wales	Estd. 1922 8,515,344	2,645,562	39,357 £5·1 per head	about 12,000		235		42	121,729

TABLE V.—ADMINISTRATIVE COUNTIES IN ENGLAND AND WALES.

Administrative County.	Area in Thousands of Acres.	Population in Thousands. Census 1921.	Mileages of Main Roads. Maintained by the County Council. In Urban Districts and Boroughs.	Maintained by the County Council. In Rural Districts.	Total: including Main Roads maintained by Town and District Councils.	Cost per mile of Cols. (4) and (5) only.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
						£
Bedford	303	206	9	728	786	178
Berks	455	203	—	351	379	341
Bucks	479	236	23	444	502	507
Cambs	315	130	—	242	257	283
Cheshire	641	625	31	480	637	491
Cornwall	868	530	14	533	625	230
Cumberland	968	220	47	434	513	255
Derby	645	585	40	511	653	639
Devon	1,660	444	5	1,125	1,376	254
Dorset	626	228	—	459	510	380
Durham	632	944	28	277	343	982
Essex	964	918	45	627	789	757
Gloucester	785	329	—	966	1,002	302
Hants	935	410	—	533	598	481
Hereford	539	113	—	464	502	196
Hertford	404	333	99	1,114	1,250	229
Hunts	234	55	—	527	561	166
Kent	972	1,118	19	585	756	516
Lancs	1,055	1,746	33	278	658	676
Leicester	524	260	17	327	395	407
Lincoln, parts of:						
Holland	263	82	2	155	194	544
Kesteven	469	108	—	106	259	394
Lindsey	963	260	—	283	313	459
Middlesex	149	1,253	19	23	107	3,907
Norfolk	1,304	323	2	1,382	1,467	164
Northants	582	212	10	271	318	393
Northumberland	1,279	407	39	532	614	360
Notts	529	378	24	340	427	324
Oxford	475	133	18	439	482	350
Rutland	97	18	—	12	67	125
Salop	862	243	12	663	756	314
Soke of Peterboro'	53	47	—	31	36	559
Somerset	1,032	397	—	20	966	1,507
Stafford	707	711	27	568	695	348
Suffolk E.	549	212	8	304	313	486
Suffolk W.	391	109	2	312	354	245
Surrey	453	740	12	20	223	603
Sussex E.	517	261	1	377	415	603
Sussex W.	402	196	6	172	189	635
Warwick	558	342	—	458	518	441
Westmorland	505	66	4	247	281	279
Wilts	864	292	—	689	761	343
Worcester	451	301	19	422	490	471
York, E.R.	741	174	12	138	154	572
York, N.R.	1,358	325	30	476	550	464
York, W.R.	1,641	1,473	153	598	1,075	779
English Counties, less London and Monmouth	31,198	18,606	852	20,203	25,331	395

TABLE V.—ADMINISTRATIVE COUNTIES IN ENGLAND AND WALES—*continued.*

Administrative County.	Area in Thousands of Acres.	Population in Thousands. Census 1921.	Mileages of Main Roads. Maintained by the County Council. In Urban Districts and Boroughs.	Maintained by the County Council. In Rural Districts.	Total: including Main Roads maintained by Town and District Councils.	Cost per mile of Cols. (4) and (5) only.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
						£
Anglesey	177	52	4	66	75	153
Brecon	469	61	11	166	178	179
Cardigan	443	61	—	242	257	202
Carmarthen	588	175	26	284	314	291
Carnarvon	366	131	6	225	270	136
Denbigh	426	155	6	250	283	242
Flint	163	107	—	163	214	379
Glamorgan	475	815	52	132	187	1,433
Merioneth	422	46	11	220	286	99
Monmouth	345	368	64	217	287	870
Montgomery	510	513	55	340	410	136
Pembroke	393	92	4	145	156	330
Radnor	301	24	11	123	136	112
Monmouth and Welsh Counties	5,078	2,137	252	2,573	3,052	349
English and Welsh Counties	36,276	20,743	1,104	22,776	28,383	390

NOTES ON TABLE V.

Mileages.—The mileages of main roads maintained by town and district councils in any county may be found by subtracting the sum of cols. (4) and (5) from col. (6). Total mileages, excluding London, are: maintained by county councils, England, 21,055; Wales, 2,825; maintained by town and district councils: in boroughs and other urban districts, England, 3,128; Wales, 193; in rural districts, England, 1,149; Wales, 34.

Rural Districts.—Only in nine counties do the published returns show that rural districts maintain more than a few furlongs of main roads, and in six only are more than four miles so maintained; these are: parts of Kesteven, 117; Rutland, 51; Somerset, 858; Surrey, 111; West Riding, 6; Flint, 32. The unpublished returns, however, show that the rural districts of Devon maintain 35½ miles of main roads.

Grand Totals.—The expenditure for the year, by county councils, on highways and bridges, was: In England, 12,964,147*l.*; Wales, 1,276,933*l.*—total, 14,241,090*l.* This includes 374,980*l.* for loan charges in England, and 27,398*l.* in Wales. Recoupments, 390,719*l.*, and government grants, 6,093,687*l.* The grand totals given above include: main roads maintained by county councils, England, 8,532,000*l.* (recoupments, 212,370*l.*; exchequer grants, 3,613,964*l.*); Wales, 1,012,442*l.* (recoupments, 26,272*l.*; grants, 476,399*l.*); roads maintained by town and district councils: England, 2,888,243*l.* (recoupments, 15,193*l.*; grants, 1,119,811*l.*); Wales, 115,520*l.* (grants, 71,117*l.*).

Bridges.—Included in the grand totals of expenditure are: bridges and approaches, England, 198,474*l.* (recoupments, 11,858*l.*); Wales, 24,127*l.* (recoupments, 157*l.*).

Other Roads.—The grand totals also include expenditure on roads other than main roads England, 939,377*l.* (recoupments, 5,534*l.*, grants, 676,467*l.*); Wales, 88,734*l.* (recoupments, 447*l.*; grants, 78,847*l.*).

Costs per Mile.—The full heading of col. (7) is, 'Average per mile, of expenditure falling on rates and grants in respect of main roads maintained by county councils.' The services include, maintenance, repair, improvement, and enlargement.

Capital Expenditure.—England, 2,386,523*l.*; Wales, 174,336*l.*; total, 2,560,859*l.*

Debt.—Outstanding loan debt, 2,974,713*l.*

Rates: Rough average, 1*s.* 4·4*d.* in the £; rates levied, 7,756,686*l.* (both excluding London).

Total Mileage.—See p. 860 for more recent figures.

TABLE VI.—RURAL DISTRICTS IN FIFTEEN COUNTIES, AND ENGLAND AND WALES MAINTENANCE, ETC., OF DISTRICT ROADS, COSTS IN £. NON-LOAN.

Rural Districts in the County of	Population in Thousands. 1921 Census.	Assessable Value in Thousands.	Number of Rural Districts.	Mileage of District Roads.	Cost per mile.	Improvements.	Bridges.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		£			£	£	£
Buckingham	136	470	10	1,202	85	659	—
Cornwall	182	796	14	3,197	46	4,457	—
Cumberland	99	744	9	1,867	41	—	427
Devon	219	1,426	18	5,657	40	5,971	735
Dorset	105	614	12	1,670	41	1,644	482
Essex	273	1,511	17	2,397	89	15,287	33
Gloucester	228	1,188	21	2,262	55	—	—
Norfolk	258	1,332	20	3,660	32	4,654	175
Stafford	215	1,219	16	2,174	64	6,921	1,420
Suffolk, West	68	295	8	903	48	1,935	—
Sussex, West	97	595	8	1,046	106	2,315	546
Wiltshire	159	970	18	2,206	52	2,394	349
Cardigan	40	148	6	1,109	27	—	—
Carnarvon	62	245	6	850	29	—	—
Glamorgan	180	1,033	8	932	207	—	88
All in England	—	—	580	—	—	216,889	11,568
All in Wales	—	—	78	—	—	53,936	1,319
England and Wales, area 33,149,615 acres	(1922) 7,851	Rateable value 58,992	658	about 94,000	71	270,825	13,412

NOTES ON TABLE VI.

'Non-loan' expenditure, but including loan charges.

England and Wales.—Total cost of rural district roads and some main roads maintained by rural district councils, 6,662,180*l.* Percentage analysis of this total, and, therefore, of average costs per mile; maintenance and other expenses, district roads and bridges, 93·6; main roads and bridges, 5·4; miscellaneous expenses, 0·6; scavenging and watering so far as distinguishable, 0·4; total, 100.

Public Lighting of roads, etc., 44,113*l.*, or an addition of 0·7 per cent. to the previous total.

Devon.—The mileage includes 35½ miles of main roads.

Relative Expenditure on Roads (H. R. Griffiths).—In 1925–1926; Local Rates in England and Wales; Analysis: Education, 20·9 per cent.; Public Health (including parks), 20·4; Relief of Poor, 19·8; Highways, 18·6; Police and Fire Brigades, 7·4; other items, 12·9 per cent.

Grand Total.—England and Wales: expenditure, main roads and bridges, 360,417*l.*; loan charges, 2,857*l.*: total, 363,274*l.*; fees, rents, repayments, not being grants or rates, 386,408*l.*; grants, 158*l.* District roads and bridges: expenditure, 6,148,764*l.*; loan charges, 84,788*l.*; total, 6,233,552*l.*; fees, rents, etc., 661,964*l.*; exchequer grants, 166,724*l.*; scavenging and watering, where distinguishable: expenditure, 25,830*l.*; fees, etc., 187*l.*; grants, nil. Miscellaneous: expenditure, 34,900*l.*; loan charges, 4,624*l.*; total, 39,524*l.*; fees, etc., 11,906*l.*; exchequer grants, 20,954*l.* Public lighting of roads, etc.: expenditure, 44,113*l.*; fees, etc., 220*l.*; grants, nil. Expenditure during the year to be met out of loans: main roads, 13,786*l.*; district roads, 421,275*l.*; lighting, 52,938*l.*

Wales and Monmouth.—The maintenance and repair of 31 miles of main roads in Welsh rural districts cost 76·9*l.* per mile, and of 13,058 miles of other roads, 14·2*l.* per mile.

The population of the 661 rural districts of England and Wales is about 7,733,000, and of the 78 rural districts in Wales and Monmouth about 808,000.

Indian Roads.—Since the expenditure upon the construction of Indian roads has in many cases been ample, usually adequate, and seldom recklessly parsimonious, and since, further, the work has usually been done by or under some control from the Royal Engineers or the Public Works Department, we cannot strictly compare the cost of their maintenance with the maintenance costs of English roads, some of which have been made a little at a time, and others developed from rough tracks, the first costs being very low, while the natural costs of maintenance have been increased by various embarrassments, such as insufficient width and obstructions to the natural land drainage. Looking at the matter more broadly, it must be borne in mind that average maintenance costs in India are influenced favourably by the low price of labour, and in some parts of the peninsula by plentiful supplies of first-class stone such as the gneiss of Madras, and second-class stone such as the 'laterite' of Madras and the 'kankar' of North-West India. On the other hand, the fact that there are in some parts of India numerous dry-weather cart tracks, which feed the roads, but are not classed as roads, reduces the mileage per square mile in relation to the traffic, and, in general comparisons with countries whose branch roads have more 'twigs,' increases the population per mile and the relative costs of maintenance. Comparisons within India are also affected by the proportion of metalled roads to unmetalled roads, and by the extent to which earthen tracks, having been 'partly bridged and drained,' have been added to the official mileage of unmetalled roads, some of which are bridged and drained throughout. A notable feature of Indian roads is the extent to which they are provided with shade trees on both sides, making it possible to travel on the roads, if necessary, during the sunny hours of the day. In a recent fiscal year the Punjab P.W.D. spent 80,000 rupees, or 6,000*l.*, on trees, and the Bombay Presidency P.W.D. planted 48,000 roadside trees.

REGULATIONS FOR WHEELS AND LOADS.

Traction Engines.

The regulations as to tyres of traction engines cited in the preceding issues of the Year-Book may be regarded as obsolete. The concerted action now being taken to encourage the use of tyres which will not damage the roads is leading to good results. New regulations will probably be withheld until some defined policy as regards the classification of these vehicles can be adopted, especially as relating to agriculture on the one hand and long-distance transport on the other. The tendency of practice as regards transport of goods is towards the use of small tractors with rubber tyres for work, such as local furniture removals, and the use of heavy vehicles of one of the two 6-wheeler types for higher-powered transport over long distances, except where ordinary steam waggons and lorries suffice. The scope of the old-fashioned heavy traction engine is becoming much reduced.

Heavy Motor-Cars.

This term applies to motor vehicles weighing more than 2 tons unladen, and refers to three distinct classes: (1) Motor waggons or lorries; (2) traction engines not exceeding 5 tons in weight and in other respects fulfilling the requirements; and (3) delivery vans and omnibuses, provided with rubber tyres and allowed to travel at 12 miles an hour.

Maximum Weight Heavy Motor-Cars.—The vehicle unladen, 7½ tons; vehicle and trailer, unladen, 9¾ tons; 'axle-weight' (any pair of wheels with their full load), 8 tons; axle-weight of trailer, 4 tons. An amending order of 1922 which, to meet special cases, allows 22 tons for the total of axle-weights and 6½ ton trailer axle-weight, will probably soon be superseded, but the necessary increases for tyre widths, in the table, can easily be calculated for such a case. This Order allows for a speed of 12 miles per hour if all the wheels have soft tyres, and the total length does not exceed 33 feet.

Tyre Widths.—These are: minimum for the vehicle itself, 5 ins.; minimum for the trailer, 3 ins. All wheels: ½ in. for each 'unit of axle-weight,' which is, 7½ cwt. for a 3-ft. diameter wheel, 1 cwt. more for every 12 ins. more, and 1 cwt. less for every 6 ins. less diameter. These rules do not apply to wheels with rubber tyres.

Heavy Motor-Car (Amendment) Order, 1927.

The chief provisions of the Heavy Motor-Car (Amendment) Order, 1927, may be summarised as follows:

Overall length of the vehicle not to exceed 27 ft. 6 ins. A vehicle more than 26 ft. in overall length may not draw a trailer. (See below.)

In the case of public service vehicles, one brake shall be applied by a pedal, and the operation of either brake shall not in any case disengage the engine from the transmission gear.

Public Service Vehicles: an axle-weight must not exceed 5½ tons, and the sum of such weights 9 tons. For other heavy motor-cars the figures remain 8 tons and 12 tons respectively. (See below.)

Six-wheeled Rigid Frame Vehicles: maximum overall length, 30 ft.; greatest unladen weight, 10 tons.

Axle-weights: the sum of the registered axle-weights shall not exceed 12 tons for a public service vehicle, nor 19 tons for other vehicles; individual axle-weights shall not exceed 4½ tons for public service vehicles, nor 7½ tons for other vehicles.

Tyre Width, Camber, and Pressures.—The value of width of tyre in reducing the pressure of the wheel upon the road crust is not fully operative even on flat roads, since the wider the tyre the more frequent are the occasions on which it fails to bear for its full width on the slightly uneven surface of the road. The effect of width in reducing pressure has a more definite limit on hard roads with a sharp camber, unless the road is wide, with sloped and not barrelled camber, and the vehicle travels wholly to one side of the middle line. On a barrelled camber, the vehicle does not rest upon the full width of its tyres even when keeping to one side of the road. Traction engines traversing narrow roads tend to wear them into a pair of parallel flat strips, with an exaggerated cambered part in the middle. Since the reduction of bearing width is a serious matter, and, apart from unusually troublesome vehicles and difficult roads, applies to many classes of vehicles on properly made roads, and even to tyres no wider than 3 ins. or 4 ins., it is necessary to take it into account in the development of vehicles and roads. In the first place, it is desirable to find what is the average relation between diameter and tyre width as regards pressure, a relation which depends upon the modulus of elasticity of the crust and other factors. Since, however, wheels of large diameter punish the road less than wheels of small diameter, even when the actual pressures (load per sq. in. of surfaces in contact) are somewhat higher, the position generally may be no worse even if we fail for some time to establish the true relation and make the tyres of large diameter wheels somewhat too narrow. A general increase in the diameters of the wheels of many vehicles is, then, to be aimed at. The principle is recognised in the regulations for heavy motor cars. Next, as regards tyres which are necessarily very wide, attempts should be made to design the vehicles so that some duly constrained side play, angular or bodily, is permitted to the wheels. The side play which the wheelwright, with centuries of experience behind him, gives to cart and wagon wheels, greatly tends to economy in the wear and tear of the vehicles and the road, side play taking place to a large extent between the greased axle and the hubs of the wheels instead of occurring as a rubbing of the wheels on the road. The play is partly axial, but to a small extent angular, and allows of a slight adjustment to the cambered road. Thirdly, dead flats on roads (no gradient) should, as opportunity arises, be converted to gradients of 1 in 200, or steeper, and the camber reduced. On steeper gradients, and with some road crusts and subsoils, a nearly flat camber is suitable, and in other cases a slight tilt to one side only may be given to the whole crust.

Tyre Widths for Horse-drawn Vehicles.—Under the Highways and Locomotives Amendment Act, 1878, a county authority may make regulations for tyre widths of vehicles drawn by animal power, in proportion to the loads carried. The following examples of such regulations are taken from 'The Surveyor and Municipal and County Engineer,' April 21, 1911.

Tyre Widths for Certain Loads: Horse-drawn Vehicles.

Four-Wheeled Vehicles.—Tyre width, 2½ ins., about 3 tons in several counties. Width, 3 ins., 2 tons 11 cwts.; 2 tons 19 cwts.; 3 tons 1 cwt.; 3 tons 11 cwts.; width, 3½ ins., 3 tons 1 cwt.; 3 tons 11 cwts. 3 tons 19 cwts. Width, 4 ins., 3 tons 1 cwt.; 3 tons 11 cwts.; 3 tons 19 cwts.; 4 tons 1 cwt. Width 4½ ins., 3 tons 11 cwts.; 3 tons 19 cwts.; 4 tons (summer ⊗). Width, 6 ins., 4 tons 1 cwt. (winter ⊗); 5 tons 1 cwt.; 6 tons 1 cwt. Width, 9 ins., 5 tons 1 cwt.; 6 tons 1 cwt.

Two-Wheeled Vehicles.—Tyre width, 2½ ins., 1 ton 1 cwt. Width, 3 ins., 1 ton 1 cwt.; 1 ton 11 cwts.; 1 ton 11 cwts. (winter); 1 ton 17 cwts. Width, 4 ins., 1 ton 11 cwts.; 2 tons 1 cwt.; 2 tons 11 cwts. Width, 4½ ins., 1 ton 11 cwts.; 1 ton 17 cwts. (summer); 2 tons 1 cwt.; 2 tons 11 cwts. (summer). Width, 6 ins., 2 tons 11 cwts.; 2 tons 17 cwts. (summer); 3 tons 1 cwt. Width, 8 ins. and 9 ins., 3 tons 1 cwt.; 9 ins., 2 tons 17 cwts. (winter).

TABLE VII.—LEGAL SPEED LIMITS OF MOTOR VEHICLES.

Class of Vehicle.	Miles per Hour.
Single vehicles under 2 tons weight	20
Single vehicles with rubber tyres, exceeding 2 tons :—	
With axle weights up to 6 tons	12
,, ,, ,, 8 tons	8
Single vehicles with hard tyres :—	
2 to 3 tons, unladen	8
Over 3 tons, unladen	5
With axle weights 6 to 8 tons (see page 803)	5
Any vehicle drawing a trailer ,, ,,	5

Passenger vehicles are not allowed to draw trailers.

Under the *Motor Car Act* of 1903 a county council may apply to the Ministry of Transport for an order closing any specified road (if of less than 16 feet width) to 'heavy motor cars.' This applies to large public passenger vehicles. There has also been provision of similar effect in recent legislation.

French Road-Surface Tests.

The following figures are given as those experimentally determined by the Paris police for the distances in which a motor-car weighing a ton and three-quarters, travelling on the level at 19 miles an hour, can stop on various kinds and conditions of road surface:—

Dry granite, 26 ft. 3 ins.; very wet granite, 32 ft. 10 ins.; greasy granite, 65 ft. 7 ins.

Dry wood, 26 ft. 3 ins.; very wet wood, 46 ft.; greasy wood, 65 ft. 7 ins.

Dry asphalt, 32 ft. 10 ins.; very wet asphalt, 59 ft.; greasy asphalt, 82 ft.

Table VIII.—Steam Rollers.

(Ordinary Loads and Dimensions in Working Order.)

Description of Roller.	Driving Wheels.				Front Rollers (as a whole).				Wheel Base.	Width Rolled.
	Diam. in Ft.	Tread of each, Ins.	Load on both, Tons.	Load per In., Cwts.	Diam.	Tread in Ins.	Load in Tons.	Load per In., Cwts.		
					Ft. In.				Ft. In.	Ft. In.
'Ten-ton'	5½	16	7·25	4·5	4 0	49	3·75	1·6	11 2	6 4
'Twelve-ton'	5½	16	7·9	4·9	3 10	49	4·3	1·7	11 3	6 4
'Fifteen-ton' or 'Sixteen-ton'	6	20 18	9·75	4·9 5·5	4 6	54	6·5	2·4	12 8	7 4

Six-wheeled Steam Waggon (Garrett): capacity, 12 tons; body, 22 ft. by 6 ft. 9½ ins. First wheel base 13 ft. 4 ins.; second wheel base, 3 ft. 10½ ins., the four driving wheels being driven by one differential gear.

Six-wheeled Omnibus (Daimler): rigid type; covered top; wheel base to midway between rear axles, 17 ft.; rear axles, 3 ft. 6 ins. apart; total wheel base, 18 ft. 9 ins.; rear overhang, 8 ft. 3½ ins.; maximum outside width of body, 7 ft. 6 ins.; turning circle, 60 ft.; rear axle clearance, 6¾ ins.; passengers, 104, 45 on lower and 59 on upper deck. (Used for transport of works staff.)

Passenger Chassis (Dennis): frame height, 24½ ins. ('one-step' type); wheel base, 16 ft.; rear axle clearance, 7 ins.; passengers, with omnibus body, 33, or less; with coach body, 30, or less.

Caterpillar Tractors, 10-ton and 5-ton: in use with street scrapers; as at Blackpool and at Lichfield, the latter drawing a train of three self-loading scrapers.

Resistance to Traction.

Table IX.—Influence of Diameter of Wheels.

The following figures are taken from the results of experiments by General Morin:—

Pull in lbs. per 2,000 lbs., at 3 miles an Hour.				
Nature of Road.	Cart without Springs. 4½-inch Tyres. Diameter of Wheels in Inches.		Waggon without Springs. 4½-inch Tyres. Diameter of Wheels in Inches.	
	64	80	36 and 60	44 and 78
	Lbs.	Lbs.	Lbs.	Lbs.
Earth road, very good, nearly dry	55	44	74	63
Gravel road, loose gravel on firm earth	143	114	190	163
	168	134	225	192
	180	144	241	206
Broken stone road:—				
In good condition, dry	30	24	40	34
Firm, little soft mud	55	44	74	63
Portion worn out, thick mud	80	64	107	92
Stone block pavement, fair condition, dry	25	20	34	29
Thick oak bridge floor	35	28	47	40

Influence of Width of Tyres.

Under some circumstances narrow tyres offer less resistance to traction than wide tyres, but these circumstances are unusual, or in themselves undesirable, or do not hold in all kinds of weather. For instance, narrow tyres will cut through stiff mud on a hard bottom better than tyres which, though wider, are not wide enough to ride over the mud by pressing it in a rut of moderate depth. Wheels will run along ruts made by wheels with wider tyres, but not in ruts made by narrower wheels. Narrow tyres will run through a layer of loose stones on a hard road better than wide tyres, and they allow of the vehicle being pulled out of a slough which would hold down wider felloes. Generally, however, tyres classed as wide offer less resistance than tyres classed as narrow, and the more so when their cumulative effects on soft roads are considered, as well as the comparison of the moment. It is important to note that a vehicle which, on soft roads, can be pulled more easily than a similar vehicle with narrower tyres, will still show some advantage on a hard and firm road, or will not be at a disadvantage; and it must not be overlooked that in hot weather the tractive effort with narrow tyres is very high on asphalt pavements and even considerably increased on tarred roads.

The following are extracted from a table in which 1½-in. tyres and 6-in. tyres are compared, the figures given being 'resistance to traction in lbs. per ton' (*Ira O. Baker*).

TABLE X.—INFLUENCE OF WIDTH OF TYRES.

Description of Road.	Width of Tyres. 1½-inch.	6-inch.
	Lbs.	Lbs.
Broken stone road, hard, smooth, no dust, no loose stones, nearly level	121	98
Gravel road, hard and smooth, few loose stones, size of black walnuts	182	134
Gravel road, new gravel, not compact, dry	330	260
Gravel road, wet, loose sand, 1 in. to 2½ ins. deep	246	254
Earth road, loam, dry, hard, no dust, no ruts, nearly level	149	109
Earth road, loam, stiff mud drying on top, spongy below	497	307
Earth road, clay, dry on top, but spongy below	618	464
Earth road, clay, stiff, deep mud	825	551
Earth road, loam, mud, 2½ ins. deep, very sticky, firm below	251	325
Earth road, clay, sloppy mud, 3 to 4 ins. deep, hard below	286	406
Earth road, loam, dry, loose dust, 2 ins. to 3 ins. deep	90	106

Tractive Effort on Different Pavements.

These experiments (*Ira O. Baker*) provide important comparisons between pavements differing only in condition as well as between pavements of different kinds. For instances the pulls in lbs. per 2,000 lbs. were: on considerably worn wood blocks, 36; on asphalt at 42° F., 34; on oak plank, nearly new, 32; and on smoothly-dressed granite blocks, 30; but the 32 for oak plank rose to 38 when it had been worn down ¼ in. in many places; and the 34 for asphalt rose by 3 lbs. with a rise of 10° in temperature, and was 70 lbs when the temperature was 84° F. On cedar blocks, a pull of 50 lbs. when they were covered with ¼ in. of crushed gravel, rose to 90 lbs. with a ¼ in. covering of silica pea gravel. On a brick pavement, ½ in. of dust raised the pull from 17 lbs. to 31 lbs. On a steel plateway a pull of 19 lbs. was raised to 28 lbs. by ⅛ in of fine dust, and to 40 lbs. by ¼ in. of powdered stone. Out of a number of brick pavements the best required a pull of 17 lbs. per 2,000 lbs., and a granite macadam crust only 18 lbs.

Rubber and Iron Tyres.

Experiments made in 1895 showed that the tractive effort is less with pneumatic tyres than with solid rubber or iron, and that the advantage increases with increase of speed. Iron tyres were better than solid rubber on good or ordinary pavements, but required a somewhat greater pull on bad, irregular pavements.

Effect of Speed.—Experiments by Morin showed an increase of tractive effort with increase of speed. The differences between the pulls required at a walk and those at a fast trot were considerable, as were those between the pulls at a 'trot' and 'a fast trot.' Other experiments showed a very small increase with pneumatic tyres and much greater increases with solid rubber and with iron tyres.

Undulations.—The effects of the passage of large numbers of heavy or fairly heavy vehicles of identical form, and the less serious effects of the same nature caused by the passage of many vehicles of similar weights and similarly sprung, have led to the forming of undulations of the same generic class as strings of puddles. Diversity in design and springing is favoured by road engineers, and 'fleets' of exactly similar vehicles are regarded as specially injurious. Direct action is hardly practicable, but the tendency to favour diversity seems likely to gradually effect some practical results.

ROAD CONSTRUCTION.

(By Reginald Ryves, M.Cons.E., Assoc.M.Inst.C.E.)

Country Roads.

Widths of Roads.—The total width given to a new road should include provision for: (1) the carriageway; (2) the supports for the edges of the crust, such as rough stone or gravel shoulders or 'water tables'; (3) such further strips of grass or other margin as may be necessary to hold drifted snow, to provide for the admission of air currents, or to keep sub-soil water at a suitable distance from the crust; (4) footways; (5) side ditches where necessary; (6) catch-water drains where necessary; (7) fences, and, where other parts of the width are not available, places for planting shade and shelter trees.

Width of Carriageway.

Width of Carriageway.—Maintenance is usually, or should be, the dominating factor. Under the item 'carriageway' in the provision for total width allowance may be made for probable future widening, having regard to the relative economy of widening alternative routes or making new roads. In hilly country, and especially on sidelong slopes, it is usually better to allow no such provision between fences, since the future can best be cared for by acquiring land only, the cost of obtaining a given width of flat strip by two earthworks being usually very much less than that of obtaining the same width by one earthwork. For the one wide strip the quantity of earthwork is much greater and the rate for cutting may be higher, while the retaining wall will cost much more than the two smaller ones. With flat earth slopes the total width required may be as great or greater.

Width in Relation to Maintenance.

Width in Relation to Maintenance.—The best width, having regard to the nature and amount of the traffic, will depend upon the materials available and their cost. One width will give a minimum maintenance cost with a hard and costly stone, a greater width may be the most economical for a softer stone. First decide the economical width for each material, and then compare costs. When the traffic is moderate the 'weathering' factor may be important and on little-used roads it may predominate. Usually the economic width for sandstone and flint crusts is greater than that for limestone crusts, partly because the more porous crusts made with sandstone and flint may have flatter cambers, tending to a good distribution of the traffic, and partly because the quartzy materials wear into large grains which are only removed by the heavier rains, while limestone crusts wear into fine stuff which is readily removed. The exposure of a wide surface is, therefore, usually undesirable with limestone crusts. Similar comparisons are furnished by harder stones, such as quartzites, compared with granites which contain much felspar. The nature of the subsoil affects the width, especially if the cost of construction or reconstruction has to be considered, because with soft subsoils, not tolerant of high pressures under heavy wheel roads, it may be better to reduce the pressure by making a deep crust than to reduce rutting of surface wear by making a wide crust.

Width and Traffic.

Width and Traffic.—The width may be decided, partly or wholly, from the traffic point of view. In making a mountain road, or widening a narrow lane, the ruling width may be that necessary for the passage of two loaded vehicles, and, as a matter of safety, a road with walls may be made somewhat wider than a similar road with hedges. In such cases it is important that the edges of the crust should not be steeply cambered or weak, since such conditions reduce the effective passing clearance. On roads of this kind the carriageway is that imposed by the total width, but it is often good economy to carry the actual crust right across, with such change in the nature of the materials near the edges, as may be suggested by the relative importance of the margin as a support to the crust or as a surface drain. Apart from such cases, and taking that of the normal carriageway on a road with suitable margins, the widths suitable are, for a very large mileage of country roads generally, either that required for one vehicle at a time, but sufficient

for the cautious passing of two vehicles, or that required for the frequent and convenient passing of two vehicles. In both cases, it is desirable to give ample support to the edges, either by under-trenching, with a filling of large-gauge stone, or by continuing the crust under the turf beyond the incidence of wheel loads. Using the word as applying to the measurement from surface margin to surface margin, the following widths are regarded as suitable. For single-line traffic, 12 ft. is a width largely adopted in many countries. Ten feet or even 8 ft. may be sufficient for roads with very little traffic if the soil is suitable and the margins readily accessible. A gravel soil, especially if these strips be sifted a little when the road is made, offers this advantage, as does, under some conditions, a sandy soil. On clay soils, the width of the crust itself should be such as to admit of the passing of vehicles, or the edges of the crust may be broken down by rutting of the clay just beyond. Clay is not easily brought back to its proper level. On account of its hardness in dry weather, however, it makes good margins for narrow 'fair weather' roads, which may be made with a very narrow metalled or gravelled width. For roads on which the passing of two vehicles must be readily accomplished, a width of 16 ft. is very usual, and 15 ft. is enough in countries in which the ordinary vehicles are narrow. In France a considerable mileage of important roads has a carriageway of about 16½ ft., but this may, in some cases, be the economical maintenance width. The usual width of the carriageways of the French Routes Nationales is from 5 to 7 metres, or say, 15½ to 23 ft. An important system of English county roads has an average width of 17½ ft. On very steep gradients it is often desirable to have very wide carriageways.

Except where local conditions demand a greater width, 30 ft. is a sufficient width for the carriageway of any but important arterial roads, other roads locally carrying very much traffic and parts of roads where vehicles are often standing. The best widths for traffic are not multiples of some unit even when such a unit can be decided upon. The best allowances for clearance depend upon the nature of the road. The necessary dimensions for clearances between vehicles depend on the nature of the margins and, in the case of a mountain road, may reasonably be small, having regard to the cost of construction and the moderate speeds which are proper to traffic on such roads. In the case of a road carrying much traffic, there is danger in having a carriageway less than some dimension depending upon how many lanes of traffic are provided for; but there may also be danger in providing a carriageway of a width considerably greater than that which is suitable. Thus, of two roads which are similar in other respects, the more costly may be the less efficient. The matter of width is one for judgment rather than for rules or formulas.

Camber.

Camber.—The amount of camber may be stated as the total rise in the width of carriageway or as the average slope of the sides. A rise of one-fiftieth is often recommended, or slopes of 1 in 25. Slopes of 1 in 32 have been recommended as an average. Actually, the amount of camber depends upon the nature of the crust, the gradient, the nature of the traffic, the widths and the climate, and no general rules can be laid down. It may be noted, however, that a rise of more than 1 in 50 should not be given without careful consideration to roads with much motor traffic, while there are some roads, especially those with quartzy crusts on steepish gradients, which require hardly any camber. The barrelled camber has the advantage that the support which the earth margins give to the edge of the crust is less nearly horizontal than in the case of a sloped camber (two slopes joined by a small arc in the middle of the road), and the barrel form resists somewhat better a tendency to the formation of ruts on each side of the middle line. The former advantage disappears, however, if the edges of the road crust are suitably designed, and the barrelled camber has the serious disadvantage that the slope becomes steeper near the edges where cyclists ride when they are being passed by motor cars. On roads with much motor traffic the mud is soon shifted to near the edges, this part being often somewhat slippery. An elliptic camber has sometimes the disadvantage that it is too flat in the middle, especially on roads with much motor traffic and of such width that a strip of about 5 ft. width in the middle gets the main part of the wear of the off-side wheels of cars going both ways. The camber with two slopes seems suitable for a greater range of roads than the barrelled form, and the advantage of a tilt to one side only must not be overlooked in the special cases to which such a device applies.

Drainage.

Specific works may come under one or more of the four heads: (1) interception of surface waters which would flow across the road, or along it, or would flood it; (2) interception of seepage water; (3) surface drainage of rain-water from the road and its margins; (4) under drainage of the road bed and crust. In a soil neither very stiff nor very porous, a side ditch may perform all four duties. When on the uphill side of a road it acts as a catch-water drain. It also acts as a channel to carry to suitable outlets the rain-water gathered by the road. It may also intercept seepage water from the hillside or the land above a sunken road; and, if near enough to the edges of the crust, and deep enough, it provides for the establishment of an hydraulic gradient from the crust and the road bed to the ditch bottom or water-level. On a stiff soil it does not perform this function, except to a very limited extent and when deep and close to the crust.

In a stiff soil, therefore, a deep ditch is not needed for this purpose, the water being dealt with by surface flow, aided by the filling of all hollows, and by evaporation. A deep ditch may, however, play the part of an interceptor of seepage water, forced through a fairly stiff soil from wet places on the hillside above. Apart from such a purpose a ditch on a stiff soil may be shallow if the necessary capacity can be given by the width available. The stiffer the soil the deeper the drain, up to a point at which it will no longer drain the road bed and may be quite shallow. It is then very important to fill hollows on all parts of the roadside which are above the level of the underside of the crust.

Catchwater Drains.—It is often desirable to have a catchwater drain clear of the uphill fence so that the bank may not be torn by water running down it. The outlets may be clear of the road, or lead to the larger cross culverts. Such a drain and, when necessary, side chains, may be provided with 'drops' or falls of hard materials, to reduce velocity and scour. Catchwater drains are much needed on many English roads.

Side Drains.—For a given soil there is a slope at which water hardly moves through it. To provide for flow, a slightly *steeper* slope, carried from the bottom of the side ditch or shoulder drain, should reach the edge of a waterproof crust, or the middle of a porous crust. This determines the depth of the ditch, or the depth at which the pipe drain in the shoulder trench lies; or it decides which of them will be the cheaper to make and maintain. On porous soils the natural slope of the land may provide drainage; but even then care must be taken that when the road runs directly down the slope there is some easier way for the water to flow than down the road bed and out through the crust; and sudden changes in the soil must be noted and provided for. On a long slope of this kind, on a porous soil, some diversion of subsoil water by trenches filled with clay may be useful, where the water can be turned to a depression in the ground outside the road. Pipe cross drains may be used for the same purpose, and if backed by clay on the downhill side will be very effective.

Drainage of the Crust.—This comes under one or two of the main divisions of drainage; surface drainage being the more important on stiff soils, and under-drainage on porous soils, while it may be necessary to make the most of both on soils such as those marls and silts which are at once receptive and retentive of water. If the crust is more porous than the road-bed and subsoil it will probably be desirable to provide a drainage course, or bottoming, such as a telford pavement. If the soil is more pervious than the crust such a provision is not likely to be necessary for drainage. When the crust or its bottom course allows of drainage to the sides, but not very rapid drainage, this may be aided by giving a camber to the road-bed, which may also be desirable so as to provide sufficient thickness of crust where it is most wanted, towards the edges. Cross-drains are seldom economical. If they are farther apart than the width of the road they are less effective than shoulder drains: if they are nearer together than the width of the road, they cost more than one shoulder drain, or, as they have to be placed deeper, as much as both shoulder drains. Cross drains require many more outlets than shoulder drains. Camber is given to a road so that water may drain from the surface of the crust. Too steep a camber may defeat its object by driving traffic to the middle, so that ruts are formed. When a road is puddled by much traffic in drizzly weather, camber is ineffective as the little ridges of mud hold up the water. On a slope of 1 in 24 a $\frac{1}{2}$-in. ridge of mud holds up a foot-wide puddle; on places worn flat very much wider puddles. Under such conditions the best drain, on an impervious road, is a broom. When the crust is porous and self-draining a very small camber is sufficient, but the outlets to the side ditches must be sufficiently numerous and effective, or the road will be flooded during rain. On a road with no gradient it may be necessary to have flush edges, that is, no raised water-tables; but with a very small gradient this is unnecessary as the water will flow to the outlets. To prevent scour and the cutting back of their beds till the crust and road-bed are attacked, the outlets through turf margins must not carry the water with too high a velocity. The formation of a delta with the road washings may be allowed, the stuff being cleared away when the level of the delta becomes too high and the outlet is ineffective. Generally, a porous road crust need not have a steep camber if any of the following conditions are fulfilled: (1) good drainage of the crust, with shoulder drains if necessary; (2) a porous subsoil with a low, normal subsoil water level; (3) a porous subsoil on an embankment, or drained by effective side ditches. An *impervious* crust need not have a steep camber—(1) on gradients, especially if fairly steep; (2) if kept clean; (3) in dry and in showery climates or where the rains are usually heavy, as opposed to damp and drizzly climates.

Drought.

Owing to the presence of clayey matter as a constituent of many important road stones the weakness of road crusts when too wet has received more attention than their weakness when too dry. Sandy materials, on the other hand, resist wheel loads and disturbance generally better when damp than when dry. Drought, therefore, injures such roads, including crusts made with quartzite, sandstones, and flints (apart from dust as a nuisance). Other roads may be seriously affected by droughts, which cause a crumbling of the margins, or the gaping of a clay soil, the effects being observed when heavy rains occur. Drought may be combated by shade, either of trees or hedges, and by care in carrying out drainage so that the soil is not made too dry. Dead

leaves are beneficial on sandstone and flint roads, and various materials, more or less imitative of the gummy decay of the leaf, have been used to lay dust, or to bind road crusts of a sandy character.

Roadside Trees.

For a fuller presentment of the subject see *The Surveyor*, August 9, 1907; and a summary of main points with notes relating to road surfacings of the new types, in the same journal, June 5, 1925.

The chief and prevailing influence exerted by trees on the road crust is a great reduction in daily or annual ranges of crust temperature, which facilitates design in some particulars. The effect in reducing maximum temperatures, separately considered, is next in importance in some cases. In other cases, notably with broken-stone, water-bound, and gravel or flint crusts, the effect of the trees in screening the road from loss of heat by radiation is the more important.

Shade in Summer.—The value of shade, apart from comfort, is in a reduction of evaporation from macadam and flint roads, reducing the tendency to disintegration in dry spells. On tarred roads it prevents licking up of the tar and the formation of ruts, and prolongs the life of the film. In the case of concrete roads the reduction of maximum crust temperatures reduces the tendency to the forming of cracks. On asphaltic and bituminous roads it either reduces the rutting and wearing effects of traffic, or, when its effect is taken into consideration in designing the crust or carpet, it is possible economically to construct a more efficient carpet, less hard and less slippery than one intended to withstand the effects of a whole day of hot sunshine.

Screening Effects.—While some trees, such as the elm, have a greater frost-screening effect than others, such as the ash, all have an important effect in decreasing the range of temperature to which the road crust is subjected, in one day or in one year. Generally, they reduce very much indeed the number of occasions on which a road is slippery because frozen. By lessening the severity of freezing and by afterwards screening the frozen surface from the full effects of sunshine, trees save macadam and flint roads from most of the licking-up after frosts. They also, by mitigating the effects of severe frosts, save such roads from disintegration due to the formation of ice within the crust. Slipperiness due to hoar frost, or to the freezing of condensed mist or drizzle on a cold road, is much worse on the new surfaces than it is on water-bound macadam, so that, in this respect, the value of the tree is increased by the new conditions in winter and early spring.

The Strength Crust and the Wearing Layer.

The word 'foundation' is often misapplied. It should properly be used for the special bottoming that is necessary on soft soils, and sometimes on clayey soils, in order that a distinction may be made between such preparatory work and the construction of the actual 'crust,' which plays the principal part, or is the sole agent, in distributing the load. The essential nature of the crust is the same, whether it distributes the wheel loads upon the natural soil or upon a bottoming of hard material, and whether it receives the wheel loads in their full intensity or partly distributed by a carpet of considerable strength and thickness. Thus, the so-called 'concrete foundation' of a wood-paved road is really the strength crust, and the wood-paving is the carpet or wearing layer, and on a bad natural soil the concrete crust will need something in the nature of a foundation proper.

These considerations are of special importance at the present time, because recent developments point to the value of an ordinary waterbound broken stone crust, as what is called 'a foundation' for a carpet of bituminous materials, or stone setts, wood blocks, or bricks; and it must be remembered that the extent to which the loads are spread by any of these carpeting materials is so small that the old crust should be brought up to its full strength, as a strength crust sufficient for the traffic. Further, in using materials with bituminous binders, it is possible to effect so good a bond with water-bound materials in the lower course that the whole thickness acts as one crust, the square of the depth of this crust being the measure of its beam or slab strength as well as of its effect in spreading the load as a cone. It is, therefore, very necessary that such a condition should not be confused with the condition when the wearing layer of relatively costly materials is quite thin, only thick enough to serve as a wearing carpet. There is a strong tendency towards the adoption of this plan, because the cost of making one set of materials quite effective in wear-resistance and another set effective in strength and resiliency tends to be less than that of using materials which have both qualities.

The Waterproof Carpet.

If a road-bed is so situated that no water will reach it from beyond the edges of the crust, and if a layer is spread over it, effective in preventing the access of water to it but not preventing the gradual escape of all moisture, the crust will become dry and be no longer water-bound. Tarred roads which are thus rendered very dry sometimes compare unfavourably as regards corrugations with other roads which have been less effectively waterproofed, or which are kept moist by the creep of water in the road-bed.

Water-bound Broken-stone Crusts.

In the ordinary water-bound, broken-stone road crust the wearing layer is simply the top part of the strength crust. Usually, the stone in this top portion is harder or tougher than that in the rest of the crust and differently graded, and it is therefore necessary to take care that the change in materials as the crust is built up from the first course of stone is not accompanied, at any stage, by the formation of a plane of division. There must be no hard surface and no parting layer within the crust when it is finished.

Binding Material.

One of the most frequent causes of the too rapid wear of both new crusts and repairs, especially repairs, is lack of sufficient binder. The use of too much earthy binder instead of a gritty binder, such as stone dust, is also a cause of too rapid wear. The former weakness, lack of binder, is, however, a much more serious and widespread weakness than is usually supposed, especially on secondary roads in some areas and by-roads and lanes in other areas. If no suitable binder is available when holes are filled with loose stones, it is better to use mud than to use nothing at all, and mud is better than dry earth, because the water comes to the top.

Segregation.

It is very necessary to avoid segregation. A mixture of stone and binder, supplied in the proper proportions, is ineffective, and fails to form a tough and durable crust if there are patches in which one size or another is in excess of its proper proportion. This applies also to the finishing of a road surface by filling considerable hollows with chips before the final rolling. The crust when finished should be practically mass concrete with its own true surface. The final touches should be of the nature of grouting, not rendering.

The Telford Road Crust.

In the case of a crust of the Telford type, in which large stones are placed with their lengths transversely to the road, the spaces packed with chips or gravel, and a layer of broken stone and binder formed over this, it is necessary either to treat the lower course as a foundation and to make the upper course adequate as the strength crust, or, which is usually better, so to form the upper course that its stones penetrate the gravel or chips of the lower course, and the whole thickness forms one strength crust. On very bad, wet ground the former plan is the better, that is, to treat the lower course as a foundation only, and make it not too compact for effective drainage.

Single Crust Roads.

In addition to the preceding notes, it may be pointed out that if the single crust is to have a fair chance of success, the road-bed should be carefully prepared. It should be brought to the correct shape, usually cambered, and it should be made of the same degree of hardness throughout, by ramming, and adding earth and ramming again, and, where necessary, by loosening before ramming. When a bottoming of gravel, or large stones, or a mixture of both, is used there should still be some preparation of the natural soil if it is of varying degrees of density; and it should always be brought to about the right camber. Otherwise, material is wasted, and the degree of resistance in the foundation varies, tending to the development of humps and hollows in the crust. Hollows in the road-bed should not be filled with the foundation material, but with material as similar as possible to that in the road-bed itself. Road crusts should *not* be thinner near the edges than they are in the middle part.

Tar Macadam.

There are in ordinary use two ways of forming a bituminous-bound road crust. If the stone is coated beforehand with the tar, and allowed to stand until the coating is tacky, the crust can be 'consolidated' with a moderate amount of rolling. The extent of consolidation will partly depend upon the extent to which the stone is graded. As a rule, very little grading is regarded as necessary, the surface being closed by rolling in ¾-in. to ½-in. material. The other kind of crust, formed by 'pitch grouting,' usually consists of stone graded through a wider range, the smallest material being sand, added with the pitch, which is poured in hot. The surface is closed with small material. For tar macadam the 'general directions' issued by the Road Board advised at least 60 per cent. of 2½-in. stone and not more than 30 per cent. of 2½ to 1¼ in., the remaining 10 per cent. not being in the body of the crust but being used for closing (¾ to ½-in. stuff). For pitch-grouting, the sizes are: 60 per cent. of 2½ ins. and 35 per cent. of sizes *graded* from 2½ ins. to 1¼ in. In addition 5 per cent. of chips are to be used for closing after the pitch has been grouted in. The body of the crust will, however, contain a proportion of sand, equal, by measure, to that of the pitch. The quantity of pitch varies according to circumstances, but ordinary quantities, noted in the 'general directions,' are 1¼ gall. per sq. yd. for a 2-in. layer, 1½ gall. for a 2½ in. layer, and 2 galls. for a 3-in. layer.

The pitch used (Road Board specification) is to be thinned with tar oil in the proportion of 10 to 12 per cent. (of the whole). The pitch itself should not have more than 22 per cent. and

must not have more than 24 per cent. of free carbon. The tar oil must have a specific gravity between 1·065 and 1·075 at 20° C. and must be commercially free from light oils and water.

Tar-macadam road crusts have been successfully made with stone of considerably smaller average sizes than the above.

Cost of Plant.—A plant at Stourbridge, including a 2-ft. revolving cylinder, 10 ft. long, inside a 3-ft. shell, and driven by a 5½ h.p. gas-engine, cost 350*l.*, and with it some 40 to 50 tons can be heated and mixed by three men in one day. The proportions of cost shown by a recently erected plant at Belfast are: broken stone and screenings, 60·67 per cent.; tar, etc., 11·49 per cent.; wages and cartage, 21·25 per cent.; tools, oil, etc., 1·94 per cent.; repairs and fittings, 4·65 per cent.

Limiting Gradient.—For ordinary tar macadam about 1 in 25 is regarded as the limiting gradient, but 1 in 30 or even 1 in 35 is sometimes preferred.

Material.—Emulsions of tar, of bitumen, or of both together, applied cold, are now being used to a considerable extent for both grouting and surface treatment. There are two kinds of emulsions, the natures of which have been studied. By one method there is produced an unstable product which, however, may be suitable if it is made for use on a specific job. By another process, or processes depending on one and the same principle, there is produced a material in which each particle of tar or bitumen is coated with a skin of some substance which isolates it, so that, for a very long time, the particles all remain suspended in the water without segregating. This is the kind to buy for general use. The material as supplied by the manufacturers is sometimes intended to be used neat, in which case two or more strengths may be supplied for grouting and for surface treatment. Other manufacturers supply a material which before use is to be mixed with water in a proportion depending on the purpose for which it is to be used. The former practice is likely to prove to be the better. These emulsions can be used for grouting and for surface work on damp or even wet crusts. A damp crust is better than a dry one, on the principle of the damp swab, resistance to penetration being less than when the materials are dry. If, however, a road crust is full of water it should be allowed to drain to a sufficient extent before being grouted. In the case of surface work it will be sufficient if the crust has begun to drain, being somewhat pervious, or if, it being impervious, water has ceased to drain from it and heavy rain is not immediately expected. Emulsions may, therefore, be used all the year round, saving in long periods of frost or wet. In the spring, summer, and autumn they may be used on many days on which the hot treatment is impossible. Their adoption must depend considerably on costs, but when the cost is higher than that with the hot treatment they may be used as a stand-by in order that work may be less often interrupted; thus, possibly, reducing the total cost or sparing the public from inconvenience. In grouting work the material, if not to be diluted, may be used directly from the barrel, which is then the unit related to road surface area; or it may be poured from cans. It is brushed into the road surface in order to effect an even distribution. The surface is then blinded with chippings which, as in other cases, should be of more even and somewhat smaller gauge than is usual in such work. The quantity to be used depends, as in the case of other grouting, upon the proportion of voids in the crust, and upon its thickness. If the crust is continuous and thicker than the depth which has to be grouted, precautions must be taken to prevent the absorption of too much emulsion per square yard. In the case of surface treatment, the procedure to be followed and the quantities per square yard may be found after a few trials by any person accustomed to hot tarring work.

A special purpose for which cold emulsions may be used is that of gradually strengthening an absorbent road crust, by small doses repeated at intervals. No generally conclusive results have yet been obtained in this practice (1927).

SURFACE TARRING

(Including similar treatment with bitumen, or with mixtures of bitumen and tar.)

General Policy.—At the present time the best results seem to follow the practice of tarring once only, except where the tarred surface is completely worn off before the autumn, and allowing the tar and some of the stony material of the crust to wear down by the winter. This prevents the road from becoming jolty and provides good foot and wheel-hold for the winter. Tar which remains below the surface is not harmful, but excess of tar, producing a greasy emulsion on a hard road, or thick, greasy mud in damp places, is to be avoided.

Conditions affecting Results.—Wind and free play for local air currents are needed to keep tarred roads cool. Roads exposed to wind and air currents will suffer little from sunshine; roads in airless places suffer much from sunshine. Roads in cuttings, and those flanked by walls and close palings, and especially if they run across the direction of prevailing winds, suffer from high temperatures in summer and from greasiness due to damp conditions in winter. Shade in itself is beneficial, both as regards the effects of sunshine and with respect to the frequency of frosts. Porous road crusts absorb more of the tar than impervious crusts, which reduces difficulties arising from high temperature or from greasy conditions. A dry and showery climate is much more favourable than a damp and drizzly climate, as regards both the work of tarring and the results obtained.

Cost of Tarring.—An ordinary cost is from 2*d.* to 3*d.* per square yard, in many cases about 2½*d.*, and in not a few well above 3*d.* In the year 1910–1911 the Buckinghamshire roads, 117 miles, cost ⅝*d.* per square yard. Main roads often cost about 100*l.* a mile per annum for tarring alone. One gallon of tar is usually sufficient for spraying 5½ square yards of road surface, and a gang of six men with a 320-gallon boiler will tar-paint 5,000 square yards in an ordinary day's work. For recent figures see p. 851.

Nature of the Tar.—Tar of the right consistency can be got by adding pitch to crude tar. It is better, however, to get the proper consistency by heating the tar until the lighter constituents are driven off, since their presence is in itself a source of trouble. The Road Board specifications describe two tars, No. 1 and No. 2, the latter which is the denser, for use only on warm, dry roads, and suitable for painting worn places. Tar No. 1 has a specific gravity of 1·16 to 1·22 at 15° C. (1·19 recommended). It must have not more than 1 per cent. of water and ammoniacal liquor. The free carbon should not exceed 16 per cent. by weight. Tar No. 2 has a specific gravity of 1·18 to 1·24 at 15° C. (1·21 recommended), and must be free from water. The free carbon should not exceed 18 per cent. by weight. Various bituminous preparations may be used instead of tar on most roads, except water-bound roads, for which tar is more suitable.

Method of Application.—The road should be dry and warm. The surface should be brushed hard to remove all dust and loose particles, the second brushing being in some cases done with soft brooms. The tar in the boiler should be at about boiling point, say 220° to 240° C. Its temperature when delivered on to the road will depend on the mode of application. Machines resembling water-carts do best on smooth roads which are true to shape. The spray, a fine rose at the end of a flexible tube, is used by hand, with the advantage that the quantity of tar applied to different parts may be varied if necessary. The spray is very effective in coating the stones with a clinging film, after which the required thickness can be sprayed on as desired. It works well on uneven roads. Tar can be successfully applied by hand, poured on and brushed in.

Blinding the Surface.—When the freshly tarred surface can be left for some hours undisturbed, this is usually done. On porous roads or where the quantity used is small, it may be sufficient to blind this somewhat hardened surface with dust only; clean dust from the preparatory sweeping or destructor dust. In other cases, varying quantities of sand are added, or stone chips, the quantities and method of application depending upon the extent to which these materials are intended to form a mat with the tar, or to act as a temporary protection. Chips may crush to a kind of filling coat, or they may be used so as to form a definite mat. Sand may be added so as to form a mat, or may be strewn a little at a time so as to avoid the forming of a too sandy and brittle mat, but at the same time to act as a parting layer between the tar film and the wheels of vehicles. Some of the sand, if not removed by rain, may be swept off when the tar has hardened and the road is becoming dusty. The true granites are not amongst the best of materials for blinding the surface.

Cold emulsions may be used when the road is damp and cold. (See under Tar Macadam, p. 828.)

SLIPPERINESS.

Some of the work done recently, on main roads especially, has produced very slippery surfaces. In some cases the road is regarded as dangerously slippery except when quite wet or quite dry, while there are some roads which are not satisfactory under any weather conditions. In the case of a surface which is, in the ordinary course, tarred from time to time in order to preserve it, it may be desirable to incorporate finely crushed flint or quartz with the tar; in other cases the rolling in of crushed flint in hot weather may be desirable. The treatment depends upon the nature of the crust or carpeting, and no general directions can be given. To prevent slipperiness by a suitable choice of materials and methods, care should be taken to avoid unsuitable grading, the use of too much very smooth stone in the aggregate, the use of an unsuitable bituminous or asphaltic binder, and, generally, the employment of materials which either separately or in combination tend to form a grease under traffic. The crust or carpet should be reasonably resilient, a surface which rings musically under blows being avoided.

Very good results in producing non-slippery surfaces have been reached by Mr. E. J. Lovegrove, who puts down crusts of a carefully graded aggregate of crushed destructor clinker, the bituminous binder being made of a substance having a somewhat low 'penetration,' under the usual test. The materials should be so chosen and so compacted that they will not wear too slowly. In the case of water-bound roads it has been found necessary to use a very gritty binder of siliceous material in order to correct the tendency towards the formation of a greasy slime, which is a feature under road conditions, of some limestones and most granites, including all true granites.

Non-Slippery Road Crusts.—Non-slippery road crusts can be made in the tar macadam and tar-slag macadam classes, using coated material or grouting with hot or cold preparations. Also in the cement grouted class, with a fairly wide range in the choice of stone and using rapid-hardening cement.

Silicated Roads.—Another class, of growing importance in this and other respects, is that of silicated roads—that is to say, roads in which the sodium silicate effects the binding of the whole crust. This method seems to be at present restricted to areas in which soft limestone is available, but it may be found worth while to modify it by importing the necessary proportion of such material to bind other stones. The French engineer Jacques-Thomas found that the proportion of silica to soda, initially 3·15 in a solution, was reduced by penetration into a piece of limestone after 24 hours soaking; at 1 to 2 cm. within the stone, 3·0; beween 2 and 4 cm., 2·9; between 4 and 6 cm., 1·5. (For data relating to the method, see p. 842.)

CONCRETE ROADS.

As regards country roads of ordinary width serious difficulties in the use of a concrete crust which is also the wearing layer, are: the necessity for allowing time to set; the practical difficulty in keeping one-half of the road closed for a month or more; and the resulting joint of hard to fresh concrete.

Alternatively, there is the difficulty, both in law and fact, of completely closing a road in long stretches for a period of a month *plus* the time it takes to get through with the concreting of the stretch of road in question.

The use of one of the rapid hardening or high alumina cements (such as 'Ferrocrete' and 'Ciment Fondu') with which rapid hardening concrete can be made has overcome this difficulty, and concrete strength crusts for arterial and by-pass roads are steadily growing in favour. The naked concrete road crust, though regarded as experimental in many specific cases, must now be considered as competing with other kinds of road surfacing.

Generally.—The weakness of joints, as regards strength and wear, is one of the chief difficulties in the adoption of the concrete wearing crust. It has been found that joints become 'frayed,' and open up. As in the case of strength crusts of concrete under paving or carpeting, the whole crust of concrete suffers from the effects of street openings and local repairs, but in a greater degree. These difficulties are not insuperable, but they are serious especially as regards country roads.

When joints are not provided, or are insufficient, concrete roads crack very badly, as is the case to a large extent in the United States.

REINFORCED CONCRETE ROADS.

When the slab is definitely a foundation, under a strength crust, light reinforcing is sufficient, and usually single reinforcement. In this case the lengthwise reinforcement may be more than the crosswise reinforcement in order to prevent the forming of temperature cracks across the road. When the slab is to be the strength crust, or the principal strength crust, double reinforcement is usually to be preferred, and in most cases is the proper method structurally. When the purpose of the slab is to extend the supporting area of an insufficiently firm but equally resisting foundation, the lower reinforcement may be stronger than the upper—more or thicker rods. When the purpose of the slab is to combine the unequal resistances of different parts of an unequally resisting foundation the upper and lower reinforcement should be about equally strong. Because the little piece of the slab under the wheel is supported from athwart the wheel as well as from fore and aft, the slab should be reinforced across the road about as strongly as it is along the road. Because a wheel close to the edge of the road slab is unsupported from one side, the slab must either be reinforced as a cantilever near the edges, or the lengthwise reinforcement must be increased to the actually necessary extent by closer spacing of the rods. There are alternatives, applicable under special conditions, such as extending the slab under the footway, or converting the edge of the slab into a kerb with the proper reinforcement in the vertical plane. When the calculations show that it it demanded, there should be diagonal reinforcement in the vertical planes of a road slab. A reasonable base should always be provided on very soft or treacherous ground, including otherwise firm ground which may suffer denudation by the action of trickling water. A slab cannot float as a raft nor sustain its own weight and the live loads if the average resistance of the soil is unequal to these. A slab provided with parapets, of a piece with it, may, however, be worth considering as a means of carrying a road across a bog.

Depth of Slab.

Much thinner slabs than those usually employed would be theoretically sufficient in most cases, and usually more economical of materials, but practically it is found to be better to have thicker slabs for the following reasons: (*a*) With a deeper spacing between the upper and lower grilles, less steel is needed, the mesh can be larger, larger stones may be used in the aggregate, and the filling in of the concrete is done more easily. (*b*) Any fairly large piece of road metal, left accidentally on the foundation or in the aggregate, may lead to the formation of a tension crack on

the under side of the slab. (*c*) In some cases the depth which must somehow be filled is not sufficient to make it worth while to provide a firmly rolled hard-core foundation, the cheaper solution being to employ a relatively low-stressed slab, with a somewhat reduced proportion of cement and relatively light reinforcement. (*d*) Lastly, 7 ins. of fairly tough concrete, with large-mesh reinforcement, is more easily cut through, for excavations, than 4 ins. of very tough concrete with a smaller mesh reinforcement.

NAMES OF ROCKS USED FOR ROAD METAL.

When a single word is employed as the name of a rock used for road metal or for paving setts the word may be definite in itself, denoting a rock of a particular composition which does not, as a rule, vary much from the average. In other cases, the general word, or word denoting the normal material, is compounded with another word, usually the name of a mineral which is present in an unusually large proportion, or which is an unusual constituent or one of several, any of which may be present. Thus, a diabase is usually composed chiefly of labradorite and augite, and sometimes olivine; and dolerite, though different in texture, is similar in composition. An olivine dolerite is a dolerite in which olivine is present in a considerable proportion, and a quartz-enstatite diabase is a diabase in which both quartz and enstatite (minerals, not rock names) are present in noteworthy proportions.

The following classification was suggested some years ago (*vide* 'The King's Highway') as a tentative grouping. It is here slightly altered.

Granites: True granites, horneblende granites (micro-granites).

Felstones: (*a*) Basaltic felstones:—Basalts, diabases, dolerites.

(*b*) Hornblendic felstones:—syenite, diorite, quartz-syenite, quartz-diorite.

Traps: (*a*) Whinstones—basic traps.

(*b*) Elvans—acid traps, quartz-felsites, quartz-porphyries (micro-granites).

Quartzites: both metamorphic and sedimentary.

Limestones: compact limestones, crystalline limestones.

Rags: calcareous sandstones, siliceous limestones.

Sandstones: true sandstones, grits.

Flints: flints, chert.

Pebbles: large broken pebbles to be named according to their class, small pebbles classed as gravels.

SOME IMPORTANT WORDS IN THEIR NARROWER APPLICATION.

The following are definitions of certain important rocks:—

Granite.—A coarsely-grained, wholly crystalline rock, mainly composed of alkali felspar, quartz, and a ferro-magnesian mineral.

Gneiss.—A metamorphic (altered) rock, usually resembling granite, but showing a foliated or banded structure.

Syenite.—A wholly crystalline rock, composed of orthoclase felspar, a ferro-magnesian mineral (usually augite or horneblende), and a small proportion of quartz.

Diabase.—A compact, dark rock, mainly composed of labradorite, augite, and sometimes olivine; is thoroughly crystalline and often ophitic (ophitic: a structure in which the crystals of one mineral inter-penetrate or are moulded upon those of another).

Dolerite.—Often classed as basalt, or as diabase. (The terms 'diabase' and 'dolerite' are often used synonymously.) Is more crystalline than basalt.

Diorite.—Consists essentially of oligoclase, andesine or labradorite felspar, and horneblende, augite, or biotite.

Basalt.—A black compact lava, basic (alkaline) in character. Consists essentially of plagioclase, augite, and olivine, is sometimes porphyritic, and often contains uncrystallised glass substance in the ground mass.

Porphyry.—Contains large crystals, usually of potash-soda felspar, in a ground mass of felspar, quartz, and other minerals.

Andesite.—A lava, intermediate between acid and basic, consisting principally of plagioclase felspar, and ferro-magnesian minerals, usually without olivine.

Quartzite.—Composed almost entirely of close-fitting quartz grains, the cementing material being itself quartzose, distinguishing it from sandstones.

Whinstones.—In its narrower and more correct use the term is applied to dyke or trap rocks. A typical whinstone may be classed as an andesitic dolerite, containing augite, or as a quartz diabase.

Recent Practice : Crusts and Carpets.

The advantages of having two layers of reinforcement are now being recognised, the value of the steel in two layers being greater than that of the same quantity in one layer. In some cases there is also reinforcement in vertical planes: an example of this being vertical triangular reinforcement, between an upper and a lower grille, in Paddington.

Road Crusts and Wearing Layers.

The macadam roadway is the prevailing structure throughout this and other countries; it is a cheap and easily attainable form of construction, but whenever it has been subjected to heavy traffic it has failed and has had to be substituted by asphalt, wood, or sett paving.

A wood-paved road under a certain amount of heavy traffic will wear probably $\frac{1}{8}$ in. per annum, whereas a macadam road would wear in the same period under the same traffic about 2 ins.; a granite sett pavement would wear to a lesser degree than the wood pavement.

The wear of a macadam roadway is due 10 per cent. to the traffic, 5 per cent. to the weather, and 85 per cent. to internal attrition. The stones in a macadam road are not bound together, they are merely consolidated, and the material which fills the interstices only aids in retaining the stones in their positions, but these become so loose that the traffic coming upon them causes them to grind on each other, so that they diminish in size until the structure largely becomes small material, the weather conditions then developing this fine material into a slimy mud.

The wear due to tractional resistance is extremely small, the wear to internal attrition extremely large, the presence of moisture aiding the latter process. This being the case, if the stones can be bound together by a good binding agent, so that this movement and grinding action is prevented, this form of wear will disappear and the cost of maintenance will materially decrease.

Tar spraying has in some slight degree assisted in this object, but 'tar macadam' is much more satisfactory.

Bituminous compounds of bitumen, sand, cement, etc., are still more effective, and the asphalt macadam which has been laid in Fulham and other places has had success up to a limit.

Investigation has demonstrated that large stones should not be included in the surface of a structure which is to be submitted to heavy traffic and which includes bitumen as a binding agent. The material is not at fault, but the large size of the stones causes the failure.

No constituent particle should be of greater size than $\frac{1}{4}$ in. diameter in the wearing surface, which in the ordinary road need not be more than 1 in. thick. But such a wearing surface has no inherent stability and would not have a satisfactory result unless provided with a substantial base. This can be provided by a bituminous concrete, which may be formed of the usual macadam sized stones and such fine material as would be found in the macadam portion of the structure of a road; this may be mixed with a pitch softened by tar oils to a state that is flexible when cold, or a composition of pitch, bitumen, etc., may be used. This base need be only $2\frac{1}{2}$ ins. to 3 ins. thick, and if it is placed on a substructure which is reasonably solid in all conditions of the weather and free from moisture, such a road will successfully withstand traffic of a heavy character for very many years and at a low cost of maintenance.

Roads on these lines have been built in Fulham and in the country (Surrey, etc.) at a cost of between 4*s.* 6*d.* and 5*s.* per sup. yard (pre-war prices).

APPROXIMATE GRADING ANALYSIS.

Base.		Wearing Surface.	
45 per cent.,	$1\frac{1}{2}$ in. stone	200 mesh,	18 per cent.
25 ,,	$\frac{1}{4}$ in. chippings	100 ,,	17 ,,
25 ,,	sand	80 ,,	17 ,,
5 ,,	200 mesh	50 ,,	35 ,,
		30 ,,	6 ,,
100 ,,		20 ,,	4 ,,
		10 ,,	3 ,,
			100 ,,

By weight the amount of bitumen would be 9 per cent. and 14 per cent. respectively.

The cost of wood paving in Fulham may be gathered from the fact that the Council allotted 10 years ago the sum of 4,000*l.* per annum to maintain 160,000 sq. yards; this has now been

increased to 202,268 sq. yards without increase in allotted sum. Any surplus not spent is placed to a reserve; this reserve at the end of 1916 was 12,000*l.*, sufficient to repave one-seventh of the whole area. The average cost is therefore 5*d.* per sup. yard per annum; the cost of the heaviest trafficked road does not exceed 9*d.* per sup. yard, even allowing for the concrete foundation. It has been stated in the Committee Rooms of the Houses of Parliament that local authorities have roads which cost over 2*s.* and which are of macadam.

The motor bus damages the road to no greater extent than the steam lorry, if as much, as many of these have steel tyres.

(Francis Wood.)

Bituminous Macadam Roads.

(Abbreviated from a description by A. W. Dean, Chief Engineer, Massachusetts Highway Commission.)

A gravel, or suitable sand, foundation may not be needed. If a stone foundation is made on a clay subsoil, the interstices should be filled with gravel to prevent the clay working up.

First course.—The thickness of the first course, of broken stone, depends on local conditions. For instance, if a 10-in. foundation is necessary, the first course of the crust need only be about 2 ins. thick. If no foundation is necessary, the first course of the crust should be not less than 4 ins. after rolling, or 6 ins. for heavy loads. The stones of this course may vary from ½ in. to 3 ins. in longest dimensions, but the percentage of the small size should be very small. For a course of 4 ins. or less a good size is 1½ ins. to 2½ ins. In a 6-in. course the maximum size may be 3 ins.

The voids must be well filled with fine material to prevent loss of bitumen from the upper course. The surface must be even. All surplus dust and fine material must be swept off, leaving the upper stones bare to receive the second, or bituminous, course.

Bituminous course.—The second, or bituminous, course to be 2 ins. thick, or 3 ins. for heavy vehicles in large volume. The stone must be of good quality and uniform in character, and the sizes not segregated. The best results are obtained with stone from ¾ in. to 2½ ins., the larger sizes predominating, although the course be only 2 ins. thick. The rolling should be thorough.

Application of bituminous material.—This is applied at a temperature of 250° to 300° F., with a mechanical distributor, with a force equivalent to that obtained under a pressure of 30 lbs. per square inch, or more. The amount per square yard is from 1½ gallons on a 2-in. course to about 2 gallons on a 2½-in. course. It should be very evenly spread.

Surfacing.—The surface should be lightly but completely covered with pea stone (½-in. stone) and thoroughly rolled with a 15-ton roller, if available, and if the stone is of hard quality, and a lighter roller for a poor quality stone.

Seal coat.—A seal coat of the same quality of bitumen is applied, half a gallon per square yard, covered with pea stone, and finished off with a heavy roller. When the bitumen is applied the stone must not be wet but may be moist. It must be clean and free from dust.

Bituminous Carpeting.

(Abbreviated from a description of work carried out in Kent. County Surveyor of Kent, H. T. Chapman, M.Inst.C.E.)

The work is done in two operations. The base coat of local stone, flint, scarified material, or clinker, mixed with bituminous material, is laid hot to form a nearly voidless concrete, not less than 3 ins. thick. For the carpet, sand, grit, or selected crushed clinker is graded between a 200 and a ½-in. mesh and mixed with from 13 to 15 per cent. of bituminous material, and laid at a temperature of 300° to 350° F.

In a specific case, 1914, the base coat was 3 to 4 ins. thick, of crushed shingle and flint, 1½-in. to ½-in. gauge, coated with a pitch and tar mixture, 8 parts soft pitch to 3 parts tar. The carpet was 1½ ins. thick, of grit 31 per cent., sand 56 per cent., and bitumen 13 per cent. All these ingredients were heated to 350° F. and mixed. The carpet was first cross-rolled and then consolidated with a 10-ton roller.

Costs.—Costs were, base coat, 2*s.* 6*d.*, carpet, 2*s.* 7*d.*, total, 5*s.* 1*d.* per square yard, the prices of the materials being at practically pre-war rates.

The results have been very satisfactory.

According to the remarks of several speakers at a meeting of the Institution of Municipal and County Engineers, asphalt macadam as a wearing surface for roads should be laid in one coat. It can apparently be laid in one thickness of 3½ ins. quite satisfactorily, whereas if put down in two layers the upper part creeps or peels off under traffic.

(See also notes from the Metropolitan Paving Committee's Report for 1923.)

SPECIFICATION OF WORKS TO BE DONE AND MATERIALS EMPLOYED IN CONSTRUCTING A WOOD-PAVED ROADWAY.*

Sand.

1. The sand is to be pit or Thames sand of the best quality, clean and sharp, and free from loam or clay.

Thames ballast.

2. The Thames ballast is to be clean, the stones are to be regular in size, and the proportion of sand to stones is to be to the satisfaction of the surveyor.

Cement.

3. The cement is to be best Portland cement, complying with the British Standard Specification, of a pale grey colour, specific gravity of not less than 3·15, or 3·10 one month after grinding, and capable of sustaining an average tensile stress of not less than 400 lbs. per sq. in. of sectional breaking area seven days after gauging and immersion in water twenty-four hours after gauging, and 500 lbs. per sq. in. of section twenty-eight days after gauging, and is to be delivered into the works in sacks, weighing 200 lbs. net, marked with the manufacturer's name. It is to be ground so that, when sifted in a sieve of 5,776 meshes to the sq. in., there shall not be a residue of more than 3 per cent. Sufficient cement is to be stored in or near the works for a fortnight's use fourteen days before the commencement of the work, and an equal quantity is to remain stored during the progress of the work until only sufficient work remains to be completed to use up the cement stored during the work. The cement will in all cases be tested by the surveyor with Adie's Testing Machine, and the average taken of at least six tests, and any rejected by him is to be at once removed from the work without any question being raised.

Concrete.

4. The concrete is to consist of one part of Portland cement and six parts of clean Thames ballast (large stone to be in no greater proportion than 60 per cent.), the parts being ascertained by measurement of their volume in proper measures, thoroughly mixed together in a dry state on a timber stage not less than 10 ft. by 10 ft. for half a cube yard of concrete; water is then to be added from water-can through a rose, and the whole again thoroughly mixed until a proper consistency is obtained. If the concrete has commenced to set before being used, it is not thereafter to be used except as ballast.

Cement grout.

5. The cement grout is to be made of one part of Portland cement, as described, and three parts of clean sand (the parts being ascertained by measurement of their volume in proper measures), thoroughly mixed together in a dry state on a proper banker, and made as previously described for concrete.

Cement mortar.

6. The cement mortar is to be composed of one part of Portland cement, as before described, and three parts of clean, sharp sand mixed on a proper banker, as previously described for the concrete, and used while fresh.

Thames ballast for top dressing.

7. The Thames ballast for top dressing is to be crushed and then screened through a ⅝-in. mesh sieve.

Excavation.

8. Excavate the whole of the carriageways as directed, including crossings, channellings, etc., wherever necessary, to the proper depths and levels as required, carefully separate the macadam, set aside for re-use, fill into contractor's carts, and deposit where directed within a radius of one mile from the job.

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* Extracted, by permission, from 'Modern Road Construction,' by Francis Wood, M.Inst.C.E.

Strip roads.

9. Carefully strip roads of all old wood blocks and cart away to wharf, depot, or where directed.

Existing channel.

10. The existing granite kerb, or sett channels, paved areas, binding courses, crossings, and concrete under, where described or necessary, is to be taken up and carted at the contractor's expense to the wharf, depot, or as directed. So much of the existing kerb as approved by the surveyor is to be set aside, rejointed, and relaid on Portland cement concrete 8 ins. thick, making out with new 12-in. by 8-in. kerb to be obtained from the Borough Council.

Floating.

11. The surface of all existing floating is to be picked perfectly free from all pitch, asphalt, old floating, soft concrete, etc., in such a manner that the new floating will not alter the existing contour or increase the height of existing foundations unless otherwise directed; the same is then to be brushed clean and free from dust, well drenched, and finished with a floated surface, $\frac{3}{4}$ in. in thickness, composed of one part Portland cement to three parts sand, as described for cement grout. The surface of new concrete to be finished in a similar manner with proper and approved contours and with satisfactory falls to gullies. The finished level of this surface to be exactly 5 ins. below and parallel to the intended surface of the wood pavement. All floating after completion to be left exposed for seven days or longer, as considered necessary by the surveyor.

Laying of wood blocks.

12. After the rendering specified above has been laid sufficiently long to become thoroughly hard and set, it is to be brushed clean, the block to be dipped in a hot mixture of pitch and creosote, or anthracene oil, and then to be quickly laid in position, butt-jointed, and in parallel courses across the road.

Wood blocks.

13. The timber from which the blocks are to be cut shall be carefully selected fourth Swedish close-grained, yellow deals, bearing the shipper's mark, and which must be described in the current *Timber Trades Journal List*. The blocks shall be of uniform size and weight and uniformly cut. The timber shall, before being cut, be submitted to the surveyor or his representative, and no blocks shall be sawn from timber of which the surveyor or his representative has not signified his preliminary approval. Four samples sealed and marked with the contractor's name and shipper's marks shall be left at the surveyor's office for his examination with the tender, and any blocks which may be brought on to the works and which may be inferior to these samples may be rejected by him. The surveyor or his representative shall have full power to reject any blocks, either at the cutting yard or at the creosoting works, and he shall also have power to reject any blocks after delivery on to the site of the proposed works, or at all or either of these places, whether creosoted or not, or which are not creosoted in a satisfactory manner, or to the extent of 10 lbs. of creosote to the cubic foot of timber, or with a satisfactory quality of creosote. The blocks when cut shall be truly square and shall measure 9 ins. by 5 ins. by 3 ins. off the saw. The annular rings shall not be less than 10 to the inch, not more than 2 ins. of sapwood shall appear in any block, and the percentage of such in bulk shall not exceed 15. They shall also be free from large, loose or dead knots, shakes or other defects, and shall not contain more than 5 per cent. of waney edges. Timber that has not been properly stored and become dry will not be accepted. Care must be taken to prevent the blocks from becoming wet, as any in such a condition either from rain, bilge water or other causes, must not be creosoted.

Creosoting and creosote.

14. The Council shall appoint a representative to examine the blocks, who shall have power to cause the blocks to be spread on the ground before being creosoted, and to cut or mark as arranged by the surveyor any block he may reject. The blocks after being approved may then be creosoted, a sample lot with each charge being weighed both before and after the process. The creosote to be forced under pressure into them until they have absorbed an amount of 10 lbs. to each cubic foot, and in such a manner that any block split open will show the creosote to have penetrated right through.

15. The creosote is to be a liquid heavy oil of tar, commonly called creosote, and is to contain not less than 8 per cent. of tar acid. It will be subjected to analysis, and the contractor is only to use such as may be approved by the analyst.

Expansion joint.

16. The contractor shall provide wooden battens $1\frac{1}{2}$ in. wide by the depths of the blocks, which shall be used in the channel against the kerb, and the blocks shall be paved up to it. After the paving has been grouted in, these battens shall be withdrawn and the space left shall be filled in with clay and gravel as directed.

Examination of blocks.

17. After the wood blocks are in position they will be examined by the surveyor, and no portion of the paving is to be grouted in with either the asphalt or cement until this examination has been made and sanction given for the grouting to commence.

Composition between joints.

18. Approved pitch or bitumen is to be heated and run between the blocks to a depth of 3 ins. as directed.

Cement grouting.

19. The blocks are then to be grouted with cement grout until the joints are thoroughly filled.

Protect for forty-eight hours.

20. After the completion of the grouting the work is to be protected for at least forty-eight hours before the road is thrown open for traffic.

Crossings.

21. At the intersection of other streets the crowns of the adjoining streets are to be adjusted to run into the crown of the roadway that is being paved for that purpose, and, whenever it may be necessary, the existing roadways or part or the whole of the crossings to the adjoining streets are to be taken up and relaid with similar materials or with new blocks as directed, making good with new where necessary in the opinion of the surveyor without any extra charge over the amount of the contract. At such intersections the wood blocks are to be laid diagonally as may be directed by the surveyor.

Binding Courses.

22. Two courses of 7 ins. by 5 ins. by 3 ins. granite setts laid on 6 ins. concrete are to be laid as a binding course wherever the wood pavement would otherwise abut against a macadam road. The contractor may retain, re-dress, and re-use sufficient of the old setts on the works for this purpose as approved by the surveyor.

Two coatings of siftings.

23. After the road has been inspected a coating of ⅜-in. crushed ballast for top dressing as specified is to be spread over the wood pavement, and the pavement is to remain fenced in as described before the road is thrown open to the traffic. An additional coating is afterwards to be spread over when directed.

Facilities to be afforded for traffic and passengers.

24. The work shall be done at such times and in such portions as the surveyor shall direct, and the workmen shall at all times afford such facilities for local traffic or the convenience of shopkeepers as may be directed by the surveyor.

Wood to be laid to proper falls.

25. The contractor must lay the blocks to such levels as are sufficient to satisfactorily convey away all water that may collect on the surface and in the channels at any time, and the work will not be taken over by the Council until this is done to the surveyor's satisfaction.

Contingencies.

26. Provide the sum of £ for contingencies. This sum to be deducted in whole or part from the contract as may be directed. The contractor must fill in the annexed schedule so far as the items refer to any portion of this contract.

Incidental Works.

27. The contractor's price per superficial yard for supplying and laying wood blocks 9 ins. by 5 ins. by 3 ins. off the saw is to include for all necessary cuttings, raising manhole tops, ventilators or other covers, stop-cock boxes, gully tops, making good to existing wood paving, relay crossings, binding courses, and all works incidental thereto and necessary in order to leave a perfect and satisfactory job.

CONCRETE ROADS, INCLUDING WEARING SURFACE.

Chelsea Embankment.—A naked concrete roadway, in slabs about 50 ft. long and four in the width of the carriageway. Upper and lower grille reinforcement. Much traffic, including very heavy vehicles. Lengthwise joints formed by laying fresh concrete against hardened concrete, and run with bitumen. Narrow transverse space joints filled with bitumen. Condition satisfactory after 15 months. Cracks appear, but do not give trouble except where they are across the sharper than right-angle corners, due to the skewing of the transverse joints.

Hendon.—Main roads, reinforced concrete with 2-in. asphalt carpet. Some private streets of concrete.

Swindon.—Reinforced concrete with 2-in. carpet.

Wallasey.—Reinforced concrete roads with mastic asphalt carpets.

Victoria, Australia.—Within a radius of 20 miles from Melbourne the standard construction is concrete with asphalt carpets. (See also 'Arterial and By-pass Roads,' p. 808, and 'Road Crust Work,' p. 849.)

Recent Costs.—Concrete roads have been made at the following costs: Southwark, 12*s.* 6*d.* per square yard; Chester, 10*s.* 6*d.*; Dunfermline, 10*s.* 6*d.*; Tilbury, 10*s.* 3*d.*; Dundee, 8*s.* 10*d.* per square yard.

Recent Facts and Figures, 1925.—Mileages of concrete roads: Manchester, 16; Surrey, 20; a hundred concrete streets in Tilbury and Southwark; a programme for nine streets in Weymouth; Isle of Portland, a concrete road to be made from the prison quarries; Esplanade, Weymouth, 2½ years' service, results satisfactory.

A Survey of Concrete Roads.—In 1925 Mr. E. J. Stead, A.M.Inst.C.E., County Surveyor of Somerset, prepared a report on concrete roads for his council, involving the inspection of a large number of such roads in all parts of England and Wales, as well as in France. He has stated: 'A large majority of the roads which I inspected showed many defects, to my mind indicating that the concrete surfaced road is not yet a satisfactory proposition.'

Without Expansion Joints.—A concrete road made, in Surrey, without expansion joints, was subject to expansion bursts in each of the three following summers, as many as 10 in 7,300 ft. There were also many cracks.

Steel-Mesh Road Reinforcement (Proprietary).—A series of metal strips bent into zigzag shape, laid on edge, side by side, and locked together by means of pins into a continuous mat of steel squares. Has been used on a tramway route in Birmingham. Is expected to be useful at omnibus stopping places. Imbedded in naked concrete at certain spots on Chelsea Embankment, its value cannot yet be estimated because that concrete crust is, so far, generally in good condition; but no signs of the steel-mesh doing any harm can be seen.

Life of Concrete Road Crusts.—New King Street, Deptford; laid 1917; 9-in.; double reinforcement; heavy traffic; in serviceable condition, 1927. Tilbury Dock Road; laid in 1917, in alluvium; 7-in.; single reinforcement; in good condition, 1927. Canmore Street, Dunfermline; laid 1916; in satisfactory condition, 1927. Southwark; 130 roads and streets laid since 1918 give satisfaction. Main Bridgewater Road; laid 1920; no expenditure on maintenance and very slight signs of wear, 1927.

Points from Ordinary Practice.

When making a reinforced concrete road slab in half-widths at a time, the transverse rods of the first half must be left projecting sufficiently to be effectively bonded into the second half. Unless there is a considerable margin of strength, the weakness across the middle line should be countered by providing additional lengthwise reinforcement on each side of it. The road-bed should be drenched before the concrete is laid. If it be clay, or a clayey soil, hard-core should be rolled in. The concrete must not be in the least sloppy; if excess water be removed by rolling, this should be done transversely, with a light roller. If the slab provides the wearing surface a tamping finish is nearly sufficient, and floating should be done very sparingly; the belt finish is better. The concrete should be protected by a tarpaulin for a day or two, and, anyhow, be amply protected from frost. It should be matured by waterings for ten to fourteen days, and not opened to traffic for two or three weeks under very favourable conditions, being kept closed for much longer periods under ordinary or adverse conditions. For the sake of economy of concrete the road-bed should be brought to the same camber as the surface. The proper proportions for the concrete can only be decided by the designer, but in order to provide a starting-point for the calculations, it may be noted that a fairly ordinary proportioning for slabs of about 6 ins. in thickness is 1 : 2 : 4, with 1 : 1⅔ : 3 for the surface, or, if the fine material be graded from ¼ in. to dust, 1 : 1½ : 3 throughout. Reinforcement should be accurately placed in position before concreting, and should be, preferably, not more than 2 ins. nor less than 1½ in. from the surface or bottom of the concrete. On clay soils a bottoming, such as clinkers, should be provided, and, generally, a suitable bed prepared for the concrete. Expansion joints should be provided at intervals of 50 ft. or so if the slab is reinforced, or at not more than 30 ft. if it is not reinforced.

See also p. 831.

Drying and Mixing Plant.

The principal essential parts of a Standard Plant are: (1) elevating skip, (2) drying drum or drums, (3) furnace, (4) flue and fan, (5) mixer, (6) driving pulley and gear, and (7) underframe, which also forms the operating platform. The plants can be hauled from place to place by a steam-roller or traction-engine, and they are almost invariably belt-driven by the same engine—a pulley being fitted for the purpose.

The smaller portable plants (Urban and No. 0) are sometimes fitted with a direct-coupled petrol engine, mounted on a platform, but the largest portable plant (No. 1) is driven by a separate power unit—usually the tractor that hauls it. The stationary plants are invariably belt-driven by a separate steam, petrol, or gas engine or electric motor though a direct-coupled power unit could be fitted to the platform if required.

The aggregate to be dried is either fed by chute direct into a fixed measuring hopper or shovelled or tipped into the skip, which measures a definite batch. The skip is hoisted by power, strikes the auto-knockout gear, and quickly and cleanly discharges the whole batch into the fixed receiving hopper without spilling.

In the Urban plant this receiving hopper has a counterbalanced door which automatically opens and passes the batch into the drying drum and then closes again. This means that once an Urban batch has been discharged from the skip, it must pass into the drum. On all the larger sizes the door of the receiving hopper must be opened by a hand lever, so that a batch can be kept in the receiving hopper any length of time, thus making it possible for *five* separate batches to be handled by the plant at the same time—one each in skip, receiving hopper, drying and heating drums, and mixer.

From the receiving hopper the batch is passed into the drying drum or drums; then, when all the moisture has been evaporated and the aggregate heated to the required temperature, it is passed by hand lever into the mixer, from which, after being *visibly* thoroughly coated with the hot binder that is poured in, the whole batch is discharged into the receptacle beneath.

The Urban plant takes 12 to 15 b.h.p., which is ample to drive the plant and any auxiliary equipment, such as a tar or bitumen pump.

APPROXIMATE AVERAGE OUTPUTS PER HOUR OF TAR AND BITUMINOUS MACADAM, GIVEN BY BATCH-TYPE COMBINED DRYING AND MIXING PLANTS.

TABLE XI.

Type of Plant	Portable or Stationary			Stationary only	
No. of Drying Drums	Single Drum	Double Drum		Double Drum	
Size of Plant	Urban	No. 0	No. 1	No. 2	No. 3
Batch Capacity	6 cu. ft. or 0·17 cu. metres	6 cu. ft. or 0·17 cu. metres	11·5 cu. ft. or 0·33 cu. metres	18 cu. ft. or 0·5 cu. metres	27 cu. ft. or 0·76 cu. metres.
Tar Macadam:—	Output per Hour.	Output per Hour.	Output per Hour.	Output per Hour.	Output per Hour.
2½ in. 5·7 c.m.	4 tons or 4,064 kilos.	6 tons or 6,096 kilos.	12 tons or 12,192 kilos.	16·5 tons or 16,764 kilos.	24 tons or 20,400 kilos.
1½ in. 3·8 c.m.	3·5 tons or 3,556 kilos.	5 tons or 5,080 kilos.	10 tons or 10,160 kilos.	14·5 tons or 14,732 kilos.	22 tons or 22,352 kilos.
¼ in. 0·635 cm.	3 tons or 3,048 kilos.	4·5 tons or 4,572 kilos.	9 tons or 9,144 kilos.	12 tons or 12,192 kilos.	19·5 tons or 19,812 kilos.
Bituminous Macadam	*Up to about 25 per cent. less than above figures given for Tar Macadam.*				

The above output figures are based on aggregate weighing 100 lbs. or 45 kilos. per cu. ft., and an output of one batch every 2½ minutes.

BRICK ROADS.

(By Alfred B. Searle, Author of 'Clays and Clay Products,' etc.)

Bricks used for roads should be so hard and tough that they will resist the crushing, vibration and abrading actions of the traffic. They must be made of suitable materials, such as marls and shales, which yield dense, heavy and impervious product when burned. The clays used for common building bricks are quite unsuitable, being too readily disintegrated. Bricks for roads should consist of a tough skeleton, the interstices of which are filled with a tough slag-like mass of

great viscosity when molten. When broken, such bricks show a dull, glassy structure, not readily affected by vigorous blows from a hammer. The modulus of rupture R should be at least 1,500 lbs. per sq. in. It is determined by supporting a brick on two knife edges 1 in. apart, and applying a pressure or load of W lbs. by means of a central knife edge. If the brick is b in. wide and d in. deep,

$$R = \frac{3Wl}{2bd^2}.$$

As bricks vary considerably, the test should be made on at least six bricks. When ten bricks are placed in a rattler with 10 cub. in. balls each weighing 7⅛ lbs. and 245–260 smaller balls of 1 lb. each (making a total of 300 lbs. of balls) and the rattler is rotated 1,800 times at 30 revs. per min., the pieces of brick more than 2 ins. diameter should not weigh less than 75 per cent. of the original weight of the bricks.

The size of bricks used for roads is of minor importance, provided that all the bricks used on a job are sufficiently uniform, i.e., with a variation of not more than ¼ in. in length and ¼ in. in depth and width. The size usually preferred is 9 ins. by 4¼ ins. by 3 ins.

The best results are obtained by using bricks with lugs (A, A, figs. 1 and 2) and a double bevel or bulge of $\frac{3}{32}$ in. at each end to ensure a joint at least $\frac{3}{8}$ in. wide at the top and the bottom

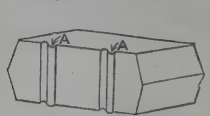

FIG. 1.

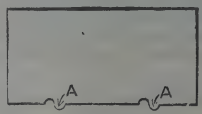

FIG. 2.

of the brick. These are no more expensive to make and they 'key' better than plain bricks. *Pressed* bricks should not, as a rule, be used for roads, as they are less durable than those made by the wire-cut process. Bricks should be laid with the rough, wire-cut sides vertical and in contact with the filler so as to ensure the latter being retained properly. This is almost impossible with the smoother surface possessed by pressed bricks.

The *foundation* of the brick road must be good and well drained. A 1 : 3 : 6 concrete foundation 6 in. thick is best, but an old macadam road, if well graded and rolled, is satisfactory.

The *cushion* or *bedding course* may be of (i) sand, (ii) sand and dry Portland cement, or (iii) mortar. A *sand bed* should not be more than 2½ ins. thick and consist of uniform grains, and the sand used must be quite dry. It may be consolidated by rolling under a pressure of 15 lbs. per sq. in. A *cement-sand bed* should consist of 1 part of dry Portland cement to 3 parts of sand, well mixed in a dry state and spread on the foundation to a thickness of ¾ in., any surplus material being removed with a straight-edge. This bed must not be rolled. The bricks are laid dry on this cushion and are then saturated with water so as to cause the cement beneath to set.

The *joints* should be filled with a 3 : 4 mixture of Portland cement and sand, the latter passing completely through a No. 20 sieve, but being wholly retained on a No. 100 sieve. The cement and sand should be mixed in the dry state, the mixture delivered to the road and mixed with water in a concrete mixer as required. The resultant slurry should be received in spouted cans and poured from these in a thin stream between the joints of the bricks, the fluid being well brushed into the joints. Two or even three applications of slurry may be needed, and are better than filling the joints at once. The second and subsequent quantities of slurry should be more viscous than the first one, and between each application any surplus slurry should be pushed (not drawn) into the joints with a rubber squeezer. The men should not walk or stand on the finished roadway when at work.

Maturing is effected by covering the road with sand which is kept well wetted for several days, so as to allow the cement to set properly. If this precaution is not taken the cement will be weak through a deficiency of water. The sand then may be allowed to dry, after which it can be used on another section of the road.

The road should not be used until three weeks after filling, as if the grouting is disturbed before it has hardened sufficiently the joints will be weak and the road will not be durable. If a road must be open for traffic in a much shorter time, a cement filling is little or no better than plain sand which is merely brushed into the joints, a small surplus being left on the surface of the road to be worked into the joints by the traffic; or a hot mixture of tar and sand may be poured into the joints. If time is less important, the cement-filled joints are far the best.

Brick roads laid on a concrete foundation are giving great satisfaction in the United States, and are being increasingly adopted in Europe.

POINTS FROM SPECIFICATIONS.

From Road Department Specifications.

(The first six paragraphs apply to the re-surfacing of water-bound macadam.)

Thickness of Crust.—On a good natural foundation, old and new crusts together not less than

4 ins.; nor under ordinary circumstances less than 5 ins.; on yielding subsoils not less than 9 ins. New coatings of more than 3 ins. should be applied in two courses, separately rolled.

Cross-fall.—The finished surface should have a cross-fall of 1 in 24.

Stone and Screenings.—The stone should be broken as cubically as possible. About 70 per cent. should pass through a 2½-in. ring, and not through a 1¾ in. ring. About 20 per cent. should pass through a 1¾-in. ring, but not through a screen with rods ¾ in. apart. The screenings from this screen should be kept for top-dressing.

Rolling.—The roller should weigh about 10 tons, and be worked from the sides towards the centre, the correct cross-fall being attained before adding water or binding.

Binding.—The binding should be the best obtainable. It should be either of the same material as the new coating or of granite, limestone, or slag chippings, or failing these, suitable pit-sand or gravel, and the largest stone in it should not exceed ¾ in. in its greatest dimension.

Re-rolling.—In some cases it is advisable that a steam-rolled water-bound macadam surface should be lightly watered and re-rolled from a week to a fortnight after the first rolling.

Surface-tarring a Water-bound Macadam Road.—The road should be scraped or brushed in the early months of the year, in wet weather. Tar No. 1., Road Department Specification, should be used and be heated to between 220° and 240° F. The spouts of pouring cans should be not less than 1½ inches in diameter at the orifice. A gallon should cover from 5 to 7 square yards. Delay before gritting is advisable. On roads with heavy traffic it is desirable to tar the road again, or a central strip of 9 to 12 ft., two or three months after the first tarring; a gallon to cover 8 to 10 square yards.

Pitch-grouted Macadam.—The finished thickness should be 2½ to 3 ins., or on very light trafficked roads 2 ins., for single grouting, and 4 to 4½ ins. for double grouting. The cross-fall of the finished surface should be 1 in 32. Of the broken stone aggregate, 60 per cent. should be 2½ ins. and 35 per cent. graded 2½ to 1¼ ins. For closing down after grouting, 5 per cent. of chippings, ¾ to ⅜ in. The pitch to comply with the Road Board Specification, the quantities applied being: for a 2-in. coating, 1¼ gallon per sq. yd.; for a 2½-in. coating, 1½ gal. per sq. yd.; for a 3-in. coating 2 gals. per sq. yd., but the quantities needed may vary, and the voids must be filled. The pitch must be raised to a temperature of 300° F. and the sand to 400° F., and the matrix formed by mixing the pitch and the sand in equal parts, and kept stirred till it is poured. The final rolling to begin immediately after the pouring of the matrix and carried on rapidly. The 5 per cent. of graded chippings should be spread in part previously to the rolling, and the remainder during its progress.

Double Pitch Grouting.—The lower layer should be the thicker and consist of large stones 3-in. to 2-in. gauge; a cheap local stone suitable for foundation work may be used. No chippings are required for the bottom layer. The upper layer aggregate of hard road stone 1½ in. gauge. The chippings should be graded from ½ in. to ¼ in. The quantities of pitch required are 3½ gals. per sq. yd. for 4-in. work and 3½ gals. for 4½-in. work.

Points from other Specifications.

Clinker Asphalte Paving (Sheffield: Mr. W. J. Hadfield).—Hard-burnt destructor clinker is used, crushed and screened; ½-in. mesh for the bottom coat and ¼-in. mesh down for the top coat. The rejections are used for ordinary tar macadam. The material is heated to 300° C. There is about 10 per cent. bitumen in the bottom coat and 17 per cent. in the top coat. The bottom coat is spread to rather more than 1 in. in thickness and slightly rolled. The top coat has a thickness of rather less than 1 in. when rolled, giving a total of 2 ins. Rolling is continued till no further impression can be made on the material. A 12-ton roller is preferred.

Manufactured Asphalt (A) ('Highway Engineering,' Blanchard and Drowne).—This is a combination of native bitumen and refined asphaltic oil. Specific gravity at 25° C. between 0·965 and 1·000. Ninety-nine per cent. soluble in carbon disulphide. To contain between 18 and 25 per cent. of bitumen insoluble in 88° Baumé paraffin naphtha. Between 5 and 10 per cent. of fixed carbon. Penetration between 150 and 200, with a No. 2 needle, weighted with 100 grammes; 5 seconds, 25° C.

Manufactured Asphalt (B) (Blanchard and Drowne).—This is manufactured by fluxing a refined native bitumen. Specific gravity 1·010 to 1·045 at 25° C. Ninety-two per cent. soluble in carbon disulphide. Between 18 and 25 per cent. of bitumen insoluble in 88° Baumé paraffin naphtha. Between 9 and 13 per cent. of fixed carbon. Penetration 100 to 200, with a No. 2 needle, weighted with 100 grammes; 5 seconds, 25° C.

Asphaltic Carpet.—British report to Fifth International Road Congress; type specification; bitumen soluble in carbon disulphide, 12 per cent.; aggregate passing: 200 mesh, 17; 100 mesh 15; 80 mesh, 15; 50 mesh, 25; 40 mesh, 8; 30 mesh, 4; 20 mesh, 2; 10 mesh, 2 per cent.

Granited Rock Asphalt.—(Same report): Type specification of gauging; fine powder, passing 100 mesh, 30 to 40; passing 50 mesh, 20 to 30; passing 30 mesh, 10 to 20; passing 10 mesh, 5 to 15 per cent.

Single-coat Asphalt-Macadam.—(Same report): Type specifications; (*a*) 3-ins. thick on poor foundation for moderate traffic; 1-in. stone, 35; ½-in. stone, 35; graded sand, 18; filler (such as Portland cement), 5 per cent.; bitumen, 7 per cent.; (*b*) 2-ins. thick on sound foundation for heavy traffic; ½-in. stone, 33; graded sand, 45; filler, 10; bitumen, 12 per cent.

Two-coat Asphalt-Macadam.—(Same report): For total thickness 3 ins.; binder course 2¾-ins., wearing course 1-in. Binder course, bitumen 5, sand 15, broken stone all passing 1¼-in. ring and not more than 5 per cent. passing 10 mesh sieve, 65 per cent.; wearing surface, all passing ½-in. mesh sieve; passing 10 mesh and retained on 40 mesh, 10 per cent.; 40–80 mesh, 20; 80–200 10; passing 200 mesh, 12; bitumen soluble in carbon disulphide, 10·5. For 4½-in. total thickness as above, but 3½ and 1½-in. courses; binder course, 7 per cent. bitumen; sand, 25 per cent.; the broken stone, 85 per cent.; wearing surface, all passing ½-in. mesh; 10–40 mesh, 35; 40–80, 55; 80–200, 30; passing 200, 20 per cent.

Concrete Road Crust.—Epsom R.D.C., Class B road, 2,752 tons per day; reinforcement to have ultimate resistance across the road of 12,500 lbs. per foot: slab, 7 ins. of shingle concrete finished with 2 ins. of granite concrete; shingle portion: aggregate, by weight, 54 per cent. passing 1½ to ½-in. square mesh, 24 per cent. passing ⅜ square mesh, 22 per cent. passing ⅜ mesh: sand, all passing ⅜, not more than 5 per cent. passing 100 mesh sieve; cement, rapid-hardening ('ferro-crete'), 370 lbs. to each wetted and mixed cubic yard of concrete; surface layer, 1½ in. dolerite containing sufficient ¼-in. to ½-in. chippings to reduce the voids to 30 per cent. by volume; of this 3 parts; sand 1 to 1½ parts; rapid-hardening cement, 550 lbs. per cubic yard. This cost 9*s.* 8½*d.* per square yard for carriage way 20 ft. wide. Cost, including excavation and surface treatment with bitumen, 9,086*l.* per mile.

Concrete Road Crust.—Southwark; lower course contains 18 per cent. of stone ¾-in. to 2-in. gauge; upper course, 3 of crushed gravel to 1 of cement; the gravel, 8 of ⅜ in. to ½ in., 17 of ½ in. to ¼ in., 75 of ¼ in. to dust, per cent. Such a crust, on roads with 22,000 tons of traffic per week, is treated with silicate of soda, with good results.

Silicated Road Crust.—French practice (Jacques-Thomas): aggregate, hard or semi-hard Jurassic limestone or similar porous limestone; gauge, passing a ring of 1½ in. to 2 in. diam.; coarse sand (the finer kinds, having a tendency to form pasty mortars, are to be avoided). About 40 litres of silicate and ⅓ cub. m. of sand to each cub. m. of broken stone; say, 6¾ gals., ¼ cub. yd., 1 cub. yd. Maximum, of silicate per cub. m., 55 litres, say 9¼ gals. per cub. yd. Proportion of silica to soda in the solution, 3·0 to 3·5, the lower figure for porous materials (see p. 831).

Bitumen, for use in road construction (suggested specification 'Modern Road Construction, Francis Wood). The bitumen should not contain more than 15 per cent. of fixed carbon. The portion insoluble in carbon disulphide at air temperature shall wholly consist of mineral matter and not more than 4 per cent. carbonaceous matter. Not less than 60 per cent. nor more than 75 per cent. shall be soluble in 88° naphtha at air temperature. It shall be soluble in carbon tetrachloride to the extent of not less than 1½ per cent. less or 1½ per cent. more than the solubility in carbon disulphide. It shall not contain more than 2½ per cent. of paraffin scale.

Nature of Pavings used in London.

Based on the Metropolitan Paving Committee's Annual Reports up to and including the 20th Report, 1927. The streets, except in the City of London, are classed as First Class, Second Class, and other streets.

The London area offers a favourable field in the study of street pavements. The climate does not approximate to any of the extremes of the British Isles, the gradients are variable, but seldom very steep, and the market for materials is a good one. The traffic conditions which have to be faced include heavy dock traffic, very busy city traffic, that of residential roads, motor omnibus routes, and the great main roads leading to the country. Lastly, the reports of the Metropolitan Paving Committee provide the materials from which deductions can be made as to the value and importance of different pavements, and including comparisons as to wearing qualities and costs.

Percentage Mileages of Different Pavings, 1925–1926.

For the boroughs of Deptford, Fulham, Hackney, Holborn, Lambeth, Lewisham, Poplar, Saint Marylebone, and Stepney, total mileage 754, the percentage mileages were as follows:

Water-bound Macadam, sprayed and unsprayed, 53·6 (Stepney, nil); *Tar Macadam* and *Bituminous Pavings*, 5·6 (Hackney and Holborn, each less than two miles; Fulham, Poplar, and Stepney, nil, but total mileages not subtracted).

For Hammersmith and Woolwich, both the above pavings, 82·7 per cent.

For all the above boroughs, 908 miles; *Wood Block Paving*, 12·5; *Asphalt*, 10·0; *Granite*, 5·6; *Concrete* (28 miles in Stepney and 0·15 mile in Deptford), 3·1 per cent.

Hammersmith: by area, water-bound macadam, 51·1; granite, 25·1; wood, 17·0; asphalt, 6·0; tar macadam, 0·8.

More than 60 per cent. of the mileage of roads and streets was of water-bound macadam, in Deptford, Lambeth, and Lewisham. In Deptford the mileage of tarred macadam and bituminous pavings exceeded that of wood and asphalt; in Lewisham it approached that of wood, and was about 2½ times that of asphalt and granite; in Saint Marylebone it was exactly equal to that of granite and asphalt, and not much less than that of wood. There was more wood than asphalt in every one of Deptford, Hammersmith, Lewisham, Saint Marylebone, Saint Pancras, and Stepney; more asphalt than wood in Fulham, Hackney, Holborn, Poplar, and Woolwich, in every one. Totals, for the 11 boroughs, Saint Pancras being excluded: Wood, 133 miles; asphalt, 89 miles; for Saint Pancras: Wood, 233,000 sq. yds.; asphalt, 80,000 sq. yds., nearly.

The mileages under wood or asphalt were exceeded by that under granite in Poplar, Stepney, and Saint Pancras; both together being exceeded in Stepney and Saint Pancras.

Creosoted Softwood.—Creosoted softwood, chiefly deal and fir, is largely employed, especially for main thoroughfares, and continues to prove satisfactory. In the earlier work a 6-in. 'foundation' of Portland cement concrete was usually provided, but this thickness is not now found sufficient for heavy traffic. Concrete 8 ins. thick is sometimes put down, but for heavy traffic it is usually from 9 to 12 ins. The thickness of the wood-paving is usually 5 ins., but often 4 ins. The blocks are often grouted with pitch, or dipped in a mixture of tar and pitch when they are being laid, but the most usual recent practice is to run the joints with a mixture of hot pitch and creosote oil. The following sizes of blocks are used: length, width, depth; 9 × 3 × 5, 9 × 3 × 4, 8 × 3 × 5, 8 × 3 × 4.

This is now the principal paving for First Class streets; occasionally used in Second Class and other streets.

Life of Softwood Paving.—Edgware Road, 11 years, to 1905; Cannon Street, 16 years, 1906–22; Ludgate Hill, 17 to 20 years; Queen Victoria Street, 17 years, 1908–25; Edgware Road, 17 years, 1905–22; Fleet Street, 19 years, 1903–22; many streets over 20 years (O. E. Winter); Haverstock Hill, paved 1901, 26 years, so far (O. E. Winter).

Strength Crusts for Softwood Paving.—Softwood paving demands a better strength crust to support it than do some other carpetings, and it repays in a greater degree than those the care and money expended in providing the desired strength and the greatest possible trueness of surface. Floating is, however, not desirable, the smaller roughness of the solid concrete being unimportant if the surface is and remains true. For really heavy traffic, double reinforcement is necessary, since single reinforcement, unless at half-depth, only adds to the strength here and there where the conditions happen to suit the disposition. In London, some of the single reinforcement or plain concrete strength crusts recently provided for softwood paving are not good enough to do justice to the qualities of the wood.

Hardwood.—Hardwood pavings have proved very lasting, but are nearly superseded by softwood or other pavings. *Jarrah* has lasted 10 years in the Euston Road, very heavy traffic; 19 years in the Streatham High Road; 10 to 14 years in heavy traffic thoroughfares in Hampstead; and in other streets 13 to 17 years, and 19 years. *Karri* has lasted up to 21 years. These woods are inferior to softwoods as regards even wearing, and do not so readily take up the armouring of grit which so greatly aids in preventing slipperiness of softwood pavings. In 1915, *sectional Jarrah* blocks, which seem to be better than ordinary blocks of hardwood, were laid in pitch, on a 9-in. concrete 'foundation,' and in some cases re-cut Jarrah blocks were re-laid. Since then these woods have been hardly at all used, but some re-cutting and relaying is still carried out.

Wood-paving is now often laid on a thin layer of asphaltic or bituminous material, between the wood blocks and the concrete, but many road surveyors prefer to lay them directly on the concrete.

Asphalt.—Compressed asphalt on a concrete strength crust or 'foundation' is one of the most important heavy traffic pavings in London. The thickness of concrete required varies as in the case of wood-paving, and is practically the same for similar traffic. The thickness of the asphalt carpet is usually 2 ins. or 1½ ins. Compressed rock asphalt is sometimes used for 'other' streets, being a very sanitary paving.

Asphaltic macadam and asphaltic clinker macadam are used in 'other' streets, and sometimes, especially the latter, in Second Class streets.

Bituminous layers.—Bituminous materials have been employed, in some cases, as carpeting layers only, but in other cases in crusts of sufficient thickness to take a share in distributing the loads. In 1915, only materials of this kind were used for street surface renewals in *Fulham*, usually 2½ to 3½ ins. of 'bituminous macadam' on a 12-in. foundation of hardcore, the surface being treated with liquid bitumen and granite chips or with a 1-in. carpet of asphalt. This construction is very interesting, as it embodies (*a*) a wearing crust which partially distributes the

TABLE XII.—COST OF PAVEMENTS.

Pavement.	Traffic. Tons per Yard Width per Annum.	Life.		Pre-War.						1920.					
				Cost per Square Yard.	Annual Charges.			Ton-Miles per Penny (excluding cleansing).	Cost per Ton-Mile (excluding cleansing).	Cost per Sq. Yd.	Annual Charges.			Ton-Miles per Penny (excluding cleansing).	Cost per Ton-Mile (excluding cleansing).
		Yrs.	Tons per Yard Width.		Int. and S.F. at 3 per Cent.	Maintenance	Cleansing.				Int. and S.F. at 6 per Cent.	Maintenance	Cleansing.		
Surface.				*s. d.*	*d.*	*d.*	*d.*		*d.*	*s. d.*	*s. d.*	*s. d.*	*d.*		*d.*
6-in. sets	524,000	18	9,432,000	10 0	8¾	—	3¼	34·0	0·029	36 0	3 4	—	8	7·4	0·13
4-in. cube sets	150,000	50	7,500,000	7 6	3½	—	3¼	24·4	0·041	31 6	2 0	—	8	3·5	0·28
Hardwood	162,000	17	2,754,000	13 6	12½	—	2½	7·4	0·136	Costs not available			6½	—	—
Softwood	204,000	18	3,672,000	8 6	7½	—	2½	15·5	0·064	46 6	4 4	—	6½	2·2	0·45
4-in. pitch macadam (hard stone)	120,000	20	2,400,000	4 0	3¼	¼	2¼	19·5	0·051	12 6	1 1	0 1	4½	4·9	0·20
4-in. tarred slag macadam	120,000	15	1,800,000	4 0	4	1	2¼	13·6	0·073	8 0	0 10	0 3	4½	5·2	0·19
1-in. Trinidad asphalt on 3-in. asphaltic concrete	120,000	15	1,800,000	7 6	7½	—	2¼	9·1	0·11	18 6	1 11	—	4½	3·0	0·34
4-in. concrete coated with ½-in. pitch and chippings	120,000	20	2,400,000	2 9	2¼	1	2¼	20·9	0·048	8 6	0 9	0 3	4½	5·7	0·18
7-in. water-bound macadam	120,000	1	120,000	3 0	1	9	5½	6·8	0·15	9 0	0 5	2 3	11	2·1	0·47
Do., tar-sprayed	120,000	2	240,000	3 2	1	6	2¼	9·7	0·10	9 4	0 5	1 6	4½	3·0	0·34
Foundation.															
9-in. concrete	524,000	50	26,200,000	4 3	2	—	—	149·0	0·007	13 0	0 9¾	—	—	30·5	0·03
6-in. concrete	150,000 / 204,000	50	7,500,000 / 10,200,000	3 0	1½	—	—	56·8 / 77·3	0·018 / 0·013	9 6	0 7½	—	—	11·8 / 16·0	0·08 / 0·06
10-in. rock pitching	120,000	50	6,000,000	1 3	¾	—	—	90·9	0·011	4 6	0 3½	—	—	19·5	0·05

(*J. A. Brodie, M.I.C.E.*, '*Proc. Inst. C.E.*,' vol. ccxi., 1922.)

load; (*b*) a foundation which is also a strength crust; (*c*) a wide spread on the road bed and low stresses in this crust, these results being obtained by the use of a considerable depth of relatively cheap material; and (*d*) the initial spread of the load by the wearing crust. In *Hampstead*, 'asphaltic macadam' 1½ ins. and 2 ins. thick was laid, and in *St. Marylebone*, 'bituminous pavements' 1½ ins. to 3½ ins., some of these on old macadam crusts. 'Asphaltic graded granite' 3 ins. thick was put down in *St. Pancras*, and 'asphalt macadam,' 4 ins. deep in two layers on existing macadam, in *Woolwich*.

Bituminous crusts and carpets are now largely employed for 'other' streets, destructor clinker being sometimes used as the aggregate.

Tar macadam.—The following were laid in 1915. Tar macadam (granite) 3 ins. thick on old macadam: tar macadam 4½ ins. thick: tarred slag macadam, 4 ins. thick on a foundation of hardcore, and 4½ ins. thick on 'an old foundation.' Since then the use of this form of paving has extended. Work noted in the 1925 report includes: 4-in. 2-coat work on hardcore foundation; seven roads of the 'other' street class in Hammersmith, 4 ins. tar-slag macadam; 3½ ins. tarred limestone macadam on existing macadam; and 4 ins. tar-slag macadam, replacing granite sett paving.

The 1926 report describes work with tar-slag macadam and tarred limestone macadam.

Stone paving.—Considerable areas were paved, in 1915, with small granite setts, the usual depth being 4 ins.; also, Aberdeen granite setts, 4 × 6 ins. on a 12-in. crust of cement and clinker concrete. Re-dressed Aberdeen granite setts 3 ins. by 6 ins. were laid on 6 ins. of concrete; fine dressed 'Norwegian' granite setts were laid in cement and sand grout on 12 ins. of concrete; and setts, 4-in. cubes, laid in 1 in. of ashes and grouted with pitch grout, on a macadam crust.

The 1925 report gives particulars of the use of setts in Deptford; in Tunnel Avenue, Greenwich, traffic 75–100 tons per yard width per hour; in Lambeth, a First Class street, and an 'other' street; in Whitefriars Street; in Poplar; and in Stepney, several streets. The part played by stone setts, now no longer used for main thoroughfares as such, is indicated by the nature of the traffic in the localities mentioned.

The 1926 report refers to stone sett paving in Stepney, St. Pancras, and Greenwich.

The trend of practice, as shown by the 1927, or twentieth, report, may be studied under 'Replacements,' p. 846.

Filler for Concrete Pavements.

A cement-coloured filler for filling cracks and joints in concrete pavements, which does not give the unsightly appearance of the black lines resulting from the use of the bituminous fillers commonly employed, consists of approximately twelve parts rosin, one part crude rubber, with sufficient barium sulphate to give the desired colour. In preparation the rubber is dissolved in petrol, and the rosin is then mixed in with an application of heat, the colouring material being added as required. Any desired consistency can be obtained by varying the proportions. A material with remarkable adhesive properties is produced, and it can be heated so that it will flow into the cracks and joints.

Recent Practice and Costs of Pavings in London.

Foundations.—Recent foundation work includes 11 ins. 6 to 1 concrete with 'fabric' reinforcement; 8 ins. 'Ciment Fondu' 6 to 1 concrete with 'fabric' reinforcement; 9 ins. 6 to 1 concrete, similarly reinforced, several cases; 12 ins. concrete; 12 ins. clinker concrete; 9 ins. clinker concrete; 6 ins. clinker concrete ('other' street); 6 ins. concrete, a notable case, as this (Mile End Road) is a First Class street; 4 ins. reinforced concrete ('other' street); 9 ins. reinforced concrete ('other' street); 6 ins. concrete, a notable case, Commercial Road, East. Both the First Class streets noted as having been provided with 6-in. concrete foundations are sett-paved; but as this paving has no crust strength, the difference in thickness of foundation compared with other streets is remarkable.

Rapid hardening cements ('Ferrocrete' and 'Ciment Fondu') have been used, for the whole foundation or for floating, in many cases. Much foundation work in London is without reinforcement. That usually employed is a single layer with different spacings of lengthwise and transverse rods.

Annual Costs per Square Yard.

In the cases of some of the road crusts or pavings which were replaced or renewed, the annual cost of maintenance of the worn-out or superseded crust or paving is given:

Water-bound Macadam, sprayed or unsprayed; 'other' streets, considerable traffic, 6½*d.*, 3½*d.*

Compressed Rock Asphalt.—First-class streets; very considerable traffic, 1*s.* 10*d.*; considerable traffic, 1*s.*; 'other' streets, 8*d.*

Softwoods.—Creosoted deal, Westminster Bridge Road, 8¼*d.*; yellow deal, Regent Street, laid 1906, 10¼*d.*; softwood, Northumberland Avenue, a very wide street, not heavy traffic, 6*d.*; second-hand, reconditioned blocks, laid 1917, 1*s.* 2¼*d.*

Wood.—Presumably hardwood, Aldersgate Street, laid 1874, 1*s.* 0¼*d.*

Asphaltic Macadam, laid 1917, Vauxhall Bridge, very heavy traffic, 1*s.* 3*d.*

Replacements by Other Pavings: London.

See also 1925 issue, Table XIV., p. 824.

Water-bound Macadam.—Replaced by crusts or carpets on old water-bound crust: 4-in. tar macadam, 2-in. to 4-in. asphaltic or bituminous carpets or pavings, 2½-in. clinker asphalt, 4-in. tar-slag macadam; replaced by 2-in. asphaltic carpet on 9-in. hardcore, by 3½-in. bituminous-grouted macadam on 9-in. P.C. concrete, by 2-in. bituminous carpet on 9-in. P.C. concrete, by stone setts on 9-in. P.C. concrete.

Tar Macadam.—Replaced by 4-in. asphalt macadam, 2-in. asphaltic carpet, by softwood on 9-in. P.C. concrete.

Compressed Rock Asphalt.—Replaced by softwood (Holborn).

Stone Setts.—Replaced by 3-in. bituminous macadam, by 4-in. bituminous pavement, by tar-slag macadam, by softwood blocks on 6-in. P.C. concrete, by mastic asphalt; provided with carpets 2-ins. by 1½-ins. asphaltic.

Hardwood Blocks.—Laid 1909, replaced by softwood 1925; Jarrah, laid 1901, replaced by 5-in. bituminous paving, 1925, laid 1904, replaced by creosoted deal, 1925.

Replacements and Costs: Twentieth Report.

Water-bound Macadam: (1) Replaced by bituminous-bound clinker and bituminous carpet, cost, using old materials, 10*s.* 8½*d.*; (2) by 2½-in. bituminous carpet on the regraded surface, cost, 6*s.* 4*d.*; (3) by 4-in. tar-slag macadam, cost, including strengthening of foundations, 8*s.* 8*d.*; (4) by 3½-in. bituminous-grouted macadam, cost, of preparation, 1*s.* 7*d.*, of the paving, 7*s.* 1*d.* (2 years' free maintenance); (5) by 3-in. asphalt macadam, cost, of preparation, 5*s.* 5½*d.*, of the paving, 10*s.* 6*d.* (5 years' free maintenance); (6) by 4-in. tar-slag macadam, cost, of preparation, 1*s.* 11*d.*, of the paving, 8*s.* 4*d.* (5 years' free maintenance); (7) by bituminous paving, 2¾-in. asphalt concrete, 1¼-in. carpet, cost, of preparation, 2*s.* 11½*d.*, of the paving, 14*s.* 3½*d.* (5 years' free maintenance); (8) by 3-in. bituminous macadam, cost, of preparation, 4*s.*, of the paving, 7*s.* 11*d.* (3 years' free maintenance); (9) by 2-coat asphalt macadam, 5-in., cost, of preparation 4*s.* 10*d.*, of the paving, 12*s.* 6*d.* (5 years' free maintenance); (10) by clinker asphalt, 1½-in. base, 1-in. carpet, hardcore foundation regraded, cost, of preparation 4*s.* 2*d.*, of paving, 7*s.* 4*d.*; (11) by creosoted deal on 8-in., 6 to 1, rapid hardening cement concrete, cost, of foundation, 16*s.* 11*d.*, of the paving, 13*s.* 4*d.*; (12) by Trinidad Lake asphalt macadam, cost, of preparation, 1*s.* 4*d.*, of the paving, 7*s.* 6*d.*; (13) by 3-in. granite concrete; 1 'ferrocrete,' 1 sand, 1 of ⅝-in. granite chippings, 4 of 2-in. granite, surface dressed with silicate of soda, cost, including reshaping the old crust, 11*s.* 3*d.*; a similar case, 17*s.* 6*d.*; (14) by granite setts, 5-in. deep, on 6-in. reinforced concrete, cost, 39*s.*

Tar-slag Macadam, (15) replaced by 8-in. concrete with a granolithic surface, cost, 29*s.* 6*d.*

Tar Macadam, (16) replaced by creosoted deal, laid dry and close, grouted with pitch or bitumen; on 12-in. or 9-in. lightly reinforced concrete foundation, cost, of foundation, 14*s.* 5*d.*, of the paving, 10*s.* 4*d.* (2 years' free maintenance).

Asphaltic Macadam, (17) replaced by softwood; cost of paving, 13*s.* 3*d.*

Jarrah, laid 1912, (18) replaced by creosoted softwood; cost of paving, 15*s.* 1*d.*; (19) by creosoted deal on 12-in. clinker concrete foundation, 1-in. floating, cost, of foundation, 21*s.* 5*d.*, of the paving, 12*s.* 1*d.*; (20) a similar case, cost of paving, 9*s.* 6*d.*

Compressed Rock Asphalt, etc., (21) laid 1911, replaced by softwood, cost of the wood paving, 13*s.* 2*d.* (2 years' free maintenance).

Norwegian Granite Setts, (22) laid 1911, replaced by Aberdeen granite setts, 8 ins. by 5 ins. by 4½ ins., fine dressed, cost of the paving, 42*s.*

Granite Setts, (23) replaced by 2-in. compressed rock asphalt on 9-in. concrete, cost, of foundation, 14*s.* 11*d.*, of the paving, 17*s.* 10*d.* (5 years' free maintenance).

Creosoted Deal, laid 1914, replaced by (24) Swedish granite setts, bitumen-grouted, cost of the paving, 33*s.* 8*d.*

Experimental Rubber Paving.

Various types of rubber paving have recently been put into service, on trial. In *Southwark* (Mr. A. Harrison) two kinds have been put down: (*a*) slabs, 9 ins. by 3 ins. by ¼ in., vulcanised on expanded metal and anchored to concrete: (*b*) composite blocks, 8 ins. by 4 ins. by 4 ins., laid on a concrete foundation, like wood blocks. The second type is regarded as likely to prove successful.

In *Glasgow* and *Edinburgh* (1923) a different method has been adopted (described by Mr. E. J. Edwards). The rubber block, 9 ins. by 4½ ins. by 2 ins., is fixed by means of an embedded steel spike into a concrete base of slightly smaller dimensions. These blocks were laid on a concrete foundation, and were grouted in with pitch or cement. It is thought desirable to lay this paving when the concrete foundation is still green; if not, the blocks should be laid with bitumen and grouted in with pitch and bitumen. The top layer of the blocks laid in Edinburgh and Glasgow contained 30 per cent. of plantation rubber. The present cost (Mr. E. F. Spurrell) of a rubber paving includes about 4*l.* per sq. yd. for the rubber alone.

Matters demanding attention are: the question whether green concrete will set properly under the impervious paving; whether oil spilt on the roadway will seriously harm the rubber; and whether rubber paving can be effectively restored after excavation.

A rubber *footway* laid down in Edinburgh twenty years ago has been found to have lost only a fraction of an inch of its thickness.

London, 1926.—An experiment is being tried in New Bridge Street, Blackfriars, where rubber as a road surface is to be subjected to a very severe test.

Heavy terra-cotta blocks (known as 'Gaisman' blocks), 10½ ins. by 8 ins., are laid as a base to hold a superimposed rubber cap, ⅝ in. in thickness. This is put on by a process which, it is claimed, will withstand the pounding and spreading force of the heaviest traffic. The blocks with these rubber caps are laid on a 12-in. concrete bed, with a cushion of sand ¾ in. thick. They are set in by means of joints, composed of a special bitumen and rubber mixture. During 1927 this paving showed no sign of wear until about November, when flaking off of considerable fragments of the rubber was seen to be taking place here and there, probably due to the sudden 'braking' of vehicles on dry days, and the pressure of grit. It is possible, however, that the blocks which have suffered may have been defective. It is more slippery than the adjacent wood paving, but less slippery, probably, than asphalt. Greasiness in wet weather is partly due to pulverized gritting material brought on to it from adjacent wood paving.

Bradford, 1927.—A small area of experimental paving consisting of wooden blocks, in each of which there is a number of metal caps, each containing a rubber 'egg.' The cups and 'eggs' are replaceable. (Inventor, P. Henry.)

London, Fulham, 1927.—Blocks described as 'Rubberfalte' (S. Cowper), to be tested in a thoroughfare carrying heavy vehicular traffic.

Effects of Motor-Omnibus Traffic and other Heavy Traffic.

Some years before the war reports of the Paving Committee showed that heavy motor traffic had increased the cost of maintenance of macadam roads generally. As regards paved streets and roads, the cost of maintenance had increased in those areas in which the stage of strengthening and improvement had been reached, but had increased only slightly or not at all where this stage had been passed. When the cost of reconstruction had been taken into account on the one hand, and actual increases in the passenger-mileage and ton-mileage on the other, it seemed that the economics of road maintenance in London had not been changed for the worse, though the cost of cutting through the greater thickness of concrete provided a new argument in favour of the scheme for providing subways for the various conduits under the main streets.

Surfaces for Steep Gradients.

Bituminous-bound Destructor Clinker.—Muswell Hill 1 in 10; varied traffic, including London omnibuses.

Broken-stone, Cement Grouted.—Rapid hardening cement; used for gradients of 1 in 15 and 1 in 10.

Tar-Macadam.—Aberdulais-Resolven Road, 1 in 11. In Blackburn (A. T. Grosseman) gradients up to 1 in 6.

Asphaltic-Slag Macadam.—Gradients up to 1 in 12.

Tests of Road Stones.

(*See Report to the Third International Road Congress, T. E. Stanton and R. G. Batson.*)

The equipment of the National Physical Laboratory, Teddington, enables the following test of road stones to be made:—

(1) A dry attrition test (resistance to wear); (2) a wet attrition test; (3) an abrasion test (for hardness); (4) a repeated impact test (toughness); (5) a test of the cementation value; (6) an absorption test.

Attrition test.—The machine is of the 4-cylinder Deval type, as used in France and in the United States. The cylinders are 7½ ins. in diameter and 14 ins. long, set at 30° to the axis of rotation. About fifty pieces of the rock, weighing eleven pounds, are placed in one of the cylinders, and the machine revolved 10,000 times at about 30 revolutions per minute. Only the material which will pass a sieve of $\frac{3}{16}$ mesh is counted in measuring the amount of wear, which is recorded both as a percentage and by the French coefficient $\frac{40}{\text{percentage of wear}}$.

In the wet test 1·1 gallon of water is used with 11 lbs. of stone. The wear is usually greater in the wet than it is in the dry test; but not always.

Repeated impact test.—This test is made with the Page impact machine, which has a hammer weighing 4·4 lbs., delivering the blows through a plunger, the surface of which, in contact with the specimen, is spherical to a radius of 0·4 inch. The test piece is a cylinder, 1 in. by 1 in., ground to the true diameter, and cut to length by a diamond saw. The test consists of a series of blows, beginning with a fall of 0·4 inch, which is increased by 0·4 inch with every successive blow until the test piece is broken. The toughness is measured by the number of blows. Tests can also be made with a constant height of fall.

Abrasion test.—The test piece is prepared in the same way as for the impact test and is of the same size. The machine is of the Dorry type, and consists of a cast steel disc revolving in a horizontal plane. The test piece is held, with its axis vertical and with a load equal to 3·5 lbs. per square inch, against the surface of the disc 26 cms. from the centre. Standard sand of 30 to 40 mesh is fed continuously through funnels at a definite rate, the same in each case. After about 1,000 revolutions of the disc, at the rate of 28 per minute, the test piece is weighed and the loss of weight noted. The test is repeated on the other end of the test piece, and the average loss of weight by the two runs is recorded. The hardness is measured by $(20 - \frac{1}{3}W)$ where W is the loss of weight in grammes per 1,000 revolutions.

Cementation test.—Coarsely crushed rock, weighing 1·1 lb., is ground in a ball mill with 0·02 gallon of water, the balls being steel shots (two) 5·1 ins. in diameter. The material is ground for two and a half hours at the rate of about 2,000 revolutions per hour. The resulting paste is moulded into briquettes, 1 in. diameter and 1 in. long, the maximum pressure being 1,880 lbs. per square inch. After twenty-four hours, the briquette is dried for twenty hours in the air, and for four hours in a hot air bath at 200°F., cooled for twenty minutes in a desiccator, and then tested. It is placed on the anvil of the machine, with its axis vertical, and struck through a plunger by a small hammer with an effective drop of 0·4 in., the rebound being measured by the movement of a lever attached to the hammer, and holding a pencil against a paper-covered revolving drum. This records the number of blows required to destroy the resiliency of the test-piece, after which there is no rebound. The mean of six tests is taken as giving the cementing value of the material.

Crushing strength.—The specimen is a cylinder 1 in. in diameter by 1 in. long, ground out of a rough sample by emery-wheels. The cracking stress and crushing stress are measured.

Specific gravity.—Three samples are taken from each batch of stones, and the average specific gravity recorded as that of the batch.

Absorption of water.—A stone of about 13 lbs. is weighed in air and then in water. It is kept in water for three days and is then weighed in air. If A = weight in air, B = weight in water immediately after immersion, and C = weight in water after immersion for three days, the number of pounds of water absorbed per cubic foot of rock is nearly

$$\frac{C - B}{A - B} \times 62{\cdot}5.$$

Petrological analysis.—The classification of the rock, in the terms of geological nomenclature and as regards its constituents, is made in the Geological Museum, London, S.W.

Samples.—The minimum number of stones sent in the case of a rock to be used as a road stone, if suitable, should be 250, broken to the shapes and sizes usual in road work. For the abrasion and impact tests eight stones should be sent, about 1½ ins. by 1½ ins. by 3 ins. Samples should be sent in strong wooden boxes or in separate compartments of cases. The position of the quarry must be so described that its locality can be identified by the Geological Survey map; or a piece of the map with the position marked on it may be sent.

TESTS OF BITUMINOUS MATERIALS.

Penetration Test.—The material to be tested is usually brought to a definite temperature, which for standard comparisons is 77° F. (25° C.). The penetrometer consists essentially of a weighted needle attached to the 'hand' of a dial by a simple mechanism so that the hand on the dial registers the distance moved by the needle. The point of the needle is brought to the surface of the specimen, the dial reading noted, the needle released for one second or sometimes longer, and then held. The difference between the two readings on the dial measures the penetration. It is desirable to make tests with different weights on the needle and at different temperatures.

Viscosity Tests.—Materials too soft for the needle penetration test may be tested by several methods, including the following: The *Crosby Consistometer* consists of a balanced wheel, grooved at the circumference and provided with a device to measure the arc through which it turns. Wheels of 4 ins. and 8 ins. diameter have been used. At one end of a thread which passes round the circumference of the wheel is a small hook, to which plungers can be attached, and at the other end is suspended a pan for weights. An excess load of 0·3 gramme is required to overcome friction and inertia. The machine measures the distance moved through by a disc of known area under a known load, through a substance contained in a box of fixed dimensions, during five seconds. The plungers are round brass discs with spindles in the centre. The box is 2½ ins. in diameter and 1 in. deep for ordinary materials, 5 ins. deep for very fluid materials. The plunger is immersed, the weight placed in the pan, partly counterbalancing the weight of the plunger and leaving a known downward force which is left to act for 5 seconds, and moves the plunger through the material under test for a distance which can be accurately read on the measuring device. The *float apparatus* of the New York Testing Laboratory measures the time taken before a plug of the substance under test becomes warm enough to flow under given conditions. The plug of the substance is in a brass collar attached to a float or saucer which is floating in water. The temperature of the water is maintained constant, at 90° F., for instance, until the plug is sufficiently soft to allow the water to enter the saucer and sink it. The temperature of the plug at the beginning of the test is fixed by keeping it for 15 minutes in cold water at a constant temperature.

Solubility Test.—Solubility in carbon disulphide. A small quantity is placed in a weighted flask containing 100 c.c. of carbon disulphide, and afterwards decanted through an asbestos mat and the precipitate dried and weighed.

Other Tests.—Appropriate methods are employed for determining the specific gravity, the melting point, and the coefficient of expansion.

ROAD CRUST WORK AND STREET PAVING.

Quarrying.—Ayrshire, quarrying road metal, 3*s.* 2*d.* per ton; quarrying and tarring, 9*s.* 4*d.* per ton. Herefordshire, 13*s.* 3*d.* per ton, including depreciation of plant.

Power Cost Data (E. Dalton).—Quarrying: oil-engine compressor, drills, etc., 100 h.p.; fuel oil nearly 0·4*d.* per brake horse-power-hour; average load factor, 50 per cent.; fuel oil and lubricating oil, 0·75*d.* per ton of rock quarried, the calorific value of the fuel oil being 19,400 B.Th.U., and lubricating oil 3*s.* 6*d.* per gallon.

Stone-breaking Plant.—Output 70 to 80 tons of road metal per day; cost about 2,000*l.*

Road Metal.—Warwickshire, granite and basalt, 23*s.* 8*d.* per ton; West Riding, granite, 17*s.*; Lichfield, gravel crushed at the pit, 7*s.* 10*d.* per cub. yd., or 6*s.* 8*d.* per ton; other cases, 19*s.* to 23*s.* per ton. Truro, roadstone, 4*s.* 10*d.* per ton.

Quantities used in a Year.—680 miles of road, 216,000 tons, including 64,000 tons of tar-macadam; 284 miles of main road, 38,000 tons; 634 miles of road, 132,000 tons, including 32,000 tons of granite coated with tar and bitumen. Per mile, in a year, crust renewals, 269 tons to 360 tons.

About 610 miles; nearly 44,000 tons of granite chippings treated with tar and bitumen in the county hot mixing plants. About 1,400 miles, nearly 944,000 galls. of tar and 259,000 galls. of bitumen used for treating about 6½ million sq. yds. of road surface. 812 miles, 255,000 tons of road materials, 959,000 galls. of tar and other surface dressings; 550 miles, 16,000 tons of tarred slag, 5,400 tons of tarred limestone, 203 tons of tarred granite.

Consolidating Road Metal.—Several counties, about 1*s.* 10*d.* per ton; also 2*s.* to 2*s.* 3*d.*; lowest figure noted, 1*s.* 1½*d.*, 1925. Staffordshire, 1927, carting materials and forming the road crust, 29*s.* 10*d.* per ton, or 3*s.* 9*d.* per sq. yd.; consolidated thickness, 4 ins.

Tar-Macadam Plant.—Durham County Council, output 1,000 tons of tar-macadam and 1,000 tons of all-grade dry slag per week.

Tar-Macadam Crusts.—Various counties: 4-in., about 7*s.* 3*d.*, using old stone, about 6*s.* 2*d.* per sq. yd.; per ton, 36*s.*; Midlothian, 3*s.* 7*d.* per sq. yd. Dorking: analysis of making up roads with tar macadam, including deep scarifying and strengthening of haunches (S. S. Gettings)—Main roads: materials, 73·2 per cent.; manual labour, 9·2 per cent.; team labour, 6·3 per cent.; scarifying and rolling, 10·1 per cent.; tradesmen's bills, 1·2 per cent. 'Assisted' roads: materials, 66·6 per cent.; manual labour, 9·7 per cent.; team labour, 13 per cent.; scarifying and rolling, 8 per cent.; tradesmen's bills, 2·7 per cent. Herefordshire: tarred material, 3-in. coatings, mixed hot with tar, squeegeed with bitumen, 6*s.* per sq. yd., or, if tarred chips are used instead of the bitumen, 5*s.* 6*d.* per sq. yd. London: 3½-in. tarred limestone, 7*s.* 1*d.* Sunderland: tar macadam, 4 ins. thick on 10-in. punning, 8*s.* 9*d.* per sq. yd. Another case, a 4-in. crust, 8*s.* 6*d.*, or with 12 ins. of hardcore base, 14*s.* 6*d.* per sq. yd. Morecombe Ring Road: tar-macadam top course (see 'New Roads'). London (Wandsworth): trial stretch of tar macadam; traffic 24,000 tons per day. Tar-macadam metal, per ton, 36*s.* Watford By-pass road, 17,500 sq. yds., at 7*s.* 6*d.* Newport, Mon.: 200 tons used. Tar-slag, per ton, 22*s.* 6*d.*; dry slag, 12*s.* 6*d.*

Reinforced Tar-Macadam.—A road near Hull (T. W. Chapman): traffic, 4,000 tons per day and upwards; reinforced tar-macadam crust had been practically untouched after three years' service. Leeds: reinforced tar-slag macadam. Warwickshire: experimental, reinforced tarred slag, 6 in. by 6 in. mesh, 6*s.* 3*d.* per sq. yd.

Tar-Macadam.—Recent data; Ossett, laid on 10 ins. of local stone pitching; Sidmouth, most of the local roads are of tar-slag macadam; Swaffham, Urban District: usual practice, re-surfacing with tarred materials with concrete margins for horse traffic. Swindon, tar macadam replacing water-bound crusts.

Tar-slag Macadam.—Recent data; five roads leading to Queensferry Bridge, surfaced with tar-slag macadam; Norfolk, 73 miles of roads converted to tarred slag in one year; Warwickshire, main road reconstruction, 3-in. to 5-in. tarred slag, 2-coat and 3-coat, on slag foundation.

Bristol-Avonmouth road, between Bristol and Shirehampton, nearly all tarmac. Norfolk, 1923, 17½ miles of tar-slag (see 'New Roads' and 'London'). Laying 3-in. of tar-slag macadam on a prepared foundation, about 5*s.* per sq. yd. Strengthening a water-bound crust and surfacing with tar-slag, 5*s.* 4*d.* per sq. yd. London, 2-in. bottom course, 1½-in. second course, ¾-in. to ½-in. topping, 7*s.* 2*d.* per sq. yd.; 4-in., 8*s.* 8*d.* per sq. yd., with 3 years' maintenance; Hampshire: county main roads, 1925-1926, tarred slag used, 15,000 tons.

Asphalt.—Hendon, main roads, 2-in. carpet on reinforced concrete; Northants., main roads, 2-in. carpets; Wrexham, main streets, 2-in. carpets on reinforced concrete. Asphalt carpets laid in 1927 included stretches of roads in Essex, Lincolnshire, Warwickshire, Hertfordshire, and Dumbartonshire, and on the Great North Road.

Synthetic Asphalt Plant.—Outputs of three sizes, tons per hour, 4 to 6, 8 to 10, 12 to 15; corresponding to square yards of carpet 2 ins. thick per ten-hour day, 400 to 600, 800 to 1,000, 1,200 to 1,500.

Asphalt Macadam.—Trinidad asphalt macadam, 2-coat work, 3-in. and 1½-in., 15*s.* 6*d.* per sq. yd.; 4-in. 13*s.*, with two years' maintenance. Warwickshire, 2-coat, 2-in. and 1-in.

Clinker Asphalt.—London, 2½-in., 7*s.* 10*d.*, with five years' maintenance; 6,000 tons, most clinker asphalt, laid in Huddersfield, 1925, 7*s.* 4*d.* per sq. yd. Cheltenham, clinker asphalt for the roads is made at the destructor works; York, 2-in. clinker asphalt on 6-in. reinforced concrete foundation; Sheffield, about 800,000 sq. yds. of streets, clinker asphalt.

Clinker Asphalt Plant.—Huddersfield, 45 tons per eight-hour day.

'Bituminous' Work.—London, 2-in. carpet, stone-filled; bituminous paving, 5-in. 12*s.* 1*d.*, with one year's maintenance; bituminous grouted macadam, 3½-in., 11*s.* 7*d.*, 2 years' maintenance; 2-in. carpet, 7*s.* 11*d.*, with five years' maintenance; 4-in. paving, 11*s.* 8*d.*, with five years' maintenance; 2-in. carpet, aggregate of graded granite, 8*s.* 6*d.* per sq. yd., with five years maintenance. Blackpool, 2-coat surfacing, 9*s.* 6*d.* per sq. yd. 'Bituminous asphalt,' 2-in. 3*s.* 3*d.* to 3*s.* 10*d.*; and 3-in., 5*s.* 7*d.*; 3½-in., 6*s.* 1½*d.* per sq. yd. Hampshire, 2½-in. carpet 7*s.* 8*d.* per sq. yd., 1 ton covering 7·3 sq. yds.

Black-base.—Largely used in the Western States, U.S.A. A generic term for lower courses or strength crusts with stone, slag, or gravel aggregate and 4 to 6 per cent. of bitumen, usually mixed hot. Five states have 2,500 miles of such lower courses.

Water-bound Crusts.—Herefordshire, good limestone crusts for light and medium traffic, tar-sprayed twice, spread with chips, 3*s.* per sq. yd. (not including foundation work). Cornwall, water-bound surfacing, 1*s.* 11*d.* per sq. yd.; Basingstoke, reforming old crust and adjusting camber, 2*s.* 6*d.* per sq. yd. Durban, resurfacing with macadam, 5*s.* 1*d.*

Strength Crusts.—Durban, 9*s.* 10*d.* per sq. yd.; 14-in. of large stone pitching, hand-packed, filled with spalls; on this 2-in. of whinstone, rolled, finished with 3 to 4 ins. of 2-in. whinstone; ready for carpeting after three months.

Sett Paving.—Guildford High Street in the London-Portsmouth main road. Laid November 1867: lasted till 1927, being turned after 48 years' service.

Concrete.—Surrey: reinforced concrete, 8 ins. thick, 5 ins. between the upper and lower reinforcement, bars ½-in. diameter (usually) and spaced 9 ins. both ways in the grille; cost about 10*s.* per sq. yd.

See pp. 837 and 838.

Concrete Foundation Work.—Lytham St. Anne's, housing roads over very bad ground, peat subsoil; excavation 6-ins. below crust proper; 6-ins. of destructor clinker placed to contour; 4-ins. of 2-coat concrete, 1 : 2 : 4, of 1½ to ⅝ Millstone grit and ¼-in. down pit sand; ordinary cement, fabric reinforcement; two treatments with silicate of soda. Bideford, Northern Road deviation, 7-in. local gravel concrete, 2-in. wearing surface of basalt chipping concrete, fabric reinforcement, top and bottom in some places.

Cement Grouting.—Rapid hardening cement; the dry spreading and watering system, on an upper course 2½ ins. to 3 ins. of local gravel, 1*s.* 5½*d.* per sq. yd. Another case, same system, 3-in. crust of hard broken limestone, 2*s.* 4*d.* per sq. yd.

Brick paving (H. Boot, 1924).—Typical case with bricks at 6*l.* per 1,000 and bituminous joints, 8*s.* 9*d.* per sq. yd.; bricks, 5*s.* 9*d.*; jointing, 1*s.*; labour and other charges, 2*s.*; cost at Keighley, 8*s.* per sq. yd.

Brick Paving, experimental. Wolverhampton-Walsall main road, concrete foundation, blue brick on edge. North Midlands. (1) Birmingham, wire-cut blue brick on concrete strength crust, floated ⅜-in. sand-cement; joints grouted 1:1 to 1 mortar; laid Sept. 1922; (2) Stone-Newcastle, Class I. main road, very heavy traffic; 7-in. to 8-in. 6 to 1 concrete strength crust; 9 ins. by 4½ ins. by 3 ins., common blue wire-cut bricks on edge, laid 1922; (3) Wolverhampton-Stourbridge, Class I. main road, two test lengths laid 1923 and 1925; (4) Walsall-Wolverhampton, Class I. main road, 3,000 sq. yds. blue brick grouted with cement, on concrete strength crust; (5) West Bromwich, Class II. road; exceptionally heavy steel-tyred traffic. From a report by J. E. Swindlehurst, M.Inst.C.E., on inspection in the summer of 1926. Relating to (1) little signs of wear under heavy traffic; (2) speaking broadly, surface good after 3½ years; (3) generally in a good state; (5) indications of wear after 3 years.

Cold Emulsion Work. *Oxfordshire* (C. E. Dolphin).—Surfacing main roads with field flints and gravel, the flints from the Chiltern Hills, the gravel from the Thames Valley; flints, 3-in. downwards, hand-picked from fields, cost 5*s.* per cu. yd., laid to depth of 3 in. on the scarified road crust, all shapes together; watered and rolled; bound by grouting with cold emulsion, ¾ gallon per sq. yd., or 1 gallon per 1⅓ sq. yd.; covered with ⅝-in. shingle, 160 sq. yd. per cu. yd.; traffic for a few days, then a sealing coat of emulsion, ¼ gallon per sq. yd.; blinded with fine sand and rolled. Costs, per sq. yd.: flints 8·5*d.*, shingle 0·75*d.*, sand 0·54*d.*, roller and horse hire 2·41*d.*, labour 0·3*d.*, grout 8·25*d.*, sealing coat 2·75*d.*; total, 2*s.* 2·2*d.* A similar but cheaper process is also employed. For roads carrying up to 600 tons per day, a gravel, shingle, sand, grout, sealing coat road costs 1*s.* 11·3*d.* per sq. yd.

Hampshire.—Emulsified bitumen, 2·42*d.* per sq. yd., cost of grouting a limestone road; total average cost, including the sealing, 4*s.* 1¼*d.* per sq. yd.

General Data.

Cheshire (W. Holland, 1924).—30-ft. carriage-way only, per mile: granite paving on concrete, 30,000*l.* (life, 30 years or more). Asphalt on concrete, 20,000*l.* (life of surface, 20 years). Two-coat bituminous surface on existing foundations, 13,000*l.* (life, 20 years). Reinforced concrete, 10,000*l.*; surface limited life, foundations, 30 years or more. Tar macadam, tar-sprayed, 5,280*l.*; life, 10-12 years. Water-bound macadam, 2,200*l.* (life with light traffic, 12 years or more).

Generally (E. S. Sinnott, 1924).—Per sq. yd.: 4½-in. water-bound limestone macadam, 2*s.* 4*d.*; 4½-in. water-bound granite macadam, 3*s.* 9*d.*; 4½-in. tarred slag or stone macadam, 5*s.* 2*d.*; 4½-in. tarred bituminous macadam, 5*s.* 6*d.*; 6 to 9 in. concrete, plain or reinforced, 9*s.* 6*d.* to 12*s.* 6*d.*; 2-in. asphaltic carpet, 6*s.* 6*d.* to 8*s.* 6*d.*; 4½-in. asphaltic macadam, 9*s.* 6*d.*; 4½-in. asphaltic part base and part carpet, 13*s.* to 16*s.* Asphaltic carpet, 2-in., on concrete or reinforced concrete base, 16*s.* to 20*s.* Wood block paving on concrete, 22*s.* 6*d.* to 31*s.*

Top Courses and Carpets.—British report to Fifth International Road Congress: bituminous and asphaltic work; ordinary costs, with five years' maintenance included: 2-coat work, 4-in., 11*s.* 6*d.* to 13*s.*; single-coat, stone and sand aggregates, 3-in., 9*s.* to 10*s.*; 2½-in., 8*s.* to 9*s.* 3*d.*; 2-in., 6*s.* 6*d.* to 7*s.* 6*d.*; clinker, 2-coat, 3-in., 7*s.* 6*d.* to 8*s.* 6*d.*; single coat, 2-in., 6*s.* 3*d.* to 7*s.* 3*d.*; mastic, 2-in., 8*s.* 9*d.* to 10*s.* 6*d.*; compressed rock asphalt carpet, 12*s.* to 15*s.*

Surface Dressing.

Area covered.—The area covered by a gallon of tar is seldom less than 6 or more than 8 sq. yds. The cost varies with the local price of tar, an ordinary rate being 2*d.* to 3*d.* per sq. yd.

Norfolk, 5·6 sq. yd.; bitumen, 4·0 sq. yd. Hampshire, hot bitumen, 7·32 sq. yd.

Surface Tarring.—Evesham and Pebworth rural district, 3·6*d.* per sq. yd. Somerset, county roads, 3·6*d.* Essex, average of costs of dressings, 2·82*d.* Warwickshire, tar-spraying, 2·87*d.*, 7·38 sq. yd. per gal. Staffordshire, 2·92*d.* London: average of 9 boroughs, 2·4*d.*; greatest, 3·37*d.*; least, 1·63*d.* Hammersmith (6·94 sq. yd. per gal.; cost 2·51*d.* per sq. yd. in 1920); 1926, 8·4 sq. yd. per gal., cost 1·87*d.* per sq. yd.; 1927, 1·63*d.* Durban, 6*d.* per sq. yd. Port Adelaide, tar-dressing: roadways, 4*d.*; footpaths, 2½*d.* Hampshire, tar, 1·9*d.*; bitumen, 2¾*d.*

Analyses of Tarring Costs, 1922–1924.

Dorking.—Tar-spraying: manual labour, 17·3 per cent.; team labour, 16·7 per cent.; tar, at 7½*d.* per gallon, 33 per cent.: grit (at about 1 ton per 30 gallons of tar, cost 14*s.* 1*d.* per ton), 25 per cent.; tradesmen's bills, 8 per cent.

Norfolk, urban, 1924 (F. Hall Smith).—Manual labour, 0·43*d.*; tar, at 7*s.* per gallon, 0·82*d.* (covering 7½ square yards); gravel, 0·48*d.* (covering 150 sq. yds. per load); tools and establishment, 10 per cent. Total, 1·85*d.* per sq. yd.

1924 (A. H. Prince).—Per cent.; tar or bitumen, 53; haulage, 25; labour, 12; grit, 8; sundries, 2.

Areas and Mileages, in a year:—

Kent.—1924–1925: the county spent 48,000*l.* on surface treatment, besides contributing 16,000*l.* towards the costs of similar work by urban authorities. *Worcestershire.*—Spent 35,394*l.* on tar painting. *Norfolk.*—5,337,000 sq. yds. treated with tar and 1,180,000 with bitumen, using nearly 944,000 gallons and 259,000 gallons respectively. *Essex*, used 959,000 gallons of tar. *Hampshire*, 392 miles of water-bound main roads are surface dressed.

Emulsified Bitumen.—Applied instead of tarring: Hampshire, 3·28*d.* per sq. yd.; Axbridge rural district, (*a*) first dressing, October, 3·9*d.*, second dressing, in the following May, 3·7*d.*, with chips; (*b*) first dressing, in January, 5·0*d.*, second dressing, with chips in the May following, 5·8*d.*; Bedford, single dressing, 1·86*d.*

Road Machinery.

Concrete Mixers.—From makers' descriptions. Portable concrete mixers, rated as 5 cwt. or 6 cu. ft. capacity, petrol engine, loading skip; output, 25 tons per day or more. Portable mixer, rated as 7 cu. ft., chain drive, interchangeable axles, 3½ h.p. engine. A 5-h.p. mixer, output up to 80 cu. yd. per day. A tilting drum mixer, paraffin engine, 30 to 32 batches of 3½ cu. ft. per hour.

Tar-Macadam Plant.—Drying and mixing plants, 34 to 200 tons per day, range of sizes; others, up to 200 tons per day.

Asphalt-making Plant.—Average on one job, 6½ tons of 2-in. carpet; best day's work, 7½ tons per hour. A 10-ton portable plant, output 1,000 sq. yds. of 2-in. bituminous carpeting in an 8-hour day.

Pneumatic Spade.—A tool on the principle of a pneumatic riveting and chipping machine is the pneumatic spade.

Tar-spreading Machines.—Barnes machine, 1,000 and 700 gal. sizes; brushes made to move to and fro while spreading the tar. Clayton tar-spreading steam wagon, 6-ton, 1,000 gal., 4 to 5 miles per hour speed, interchangeable bodies.

Road Gritting Machine.—Towed by tar-spraying machine; carries 2 to 3 tons of grit; made for various widths, normally 2 to 6 ft.; up to 9 ft. if required.

Street Sweeping Attachment.—About 2½ h.p.; speed, 6 to 8 miles per hour; 6-ft. track; brush 7 ft. long by 20 in. diameter; 70-gal. water tank; two sprinkler nozzles.

Compressed Air Data.—At pressures up to 120 lb. per sq. in.; 100 cu. ft. of air per minute will operate any of the following: 2 rock drills, 2 road chisels, 5 riveting hammers.

Tar-spraying.—Steam vehicles, for whole process, capacities up to 6,000 yards per hour.

Breaking up Concrete.—Machines for breaking up old concrete foundations; 6 to 10 cubic yards per hour on a 12-in. crust.

Road Rollers.

Cardiff R.D.C.—Steam roller, 10-ton, purchased 1897, sold in working order 1924; cost per annum, including overhaul and all additions and repairs, 58*l.* Depreciation, 3·6 per cent. of original cost and cost of scarifiers (1903); maintenance, 8 per cent.; total cost per annum, 11·6 per cent. Steam roller, 12-ton, bought 1905, sold 1924; depreciation 3·05 per cent.; maintenance, 7·87 per cent. Steam roller, 10–12 ton, 772*l.* Motor roller, 773*l.*

Horse Haulage Costs.

Southport.—Refuse collection, cost per house (or other premises) cleared, per annum, 11*s.* 6*d.*

Warwickshire.—Haulage from wharves and railway stations, 6*s.* 5*d.* per ton; 2*s.* 3*d.* per ton-mile.

Smethwick, 1925.—Refuse collection, per ton, 8*s.* 5½*d.*; compared with 8*s.* 10*d.*, by 1-ton motor lorries.

Hampshire.—1·4*d.* per ton-mile.

Camberwell.—4 tons per day, distance 10 miles, cost per ton-mile, 8·7*d.*

Islington.—Using hired horses, collection of refuse, cost per ton, 14*s.* 11*d.*

Newcastle-on-Tyne.—Refuse collection, cost per bin emptied, 2·31*d.* (compared with steam 2·16*d.*, and petrol 2·03*d.*).

Lincolnshire, 1925.—Cart, horse, and driver, 11*s.* per day. Another county, hire of horse and wages of carman, 4*l.* 4*s.* per week.

Durban.—Single-horse cart, 9*s.* 6*d.* per day; 3-mule carts, working under different conditions, 18*s.* per day; up to 1 mile hauls both cost about 1*s.* 4*d.* per ton.

Haulage Costs.

From wharves to jobs, country road work, 5*s.* 10½*d.* per ton. Steam wagons, 9·7*d.* per mile (compared with petrol wagons, 9·3*d.* per mile).

Refuse Collection, 1923.—Working cost 4*s.* 3*d.* per ton when total cost was 7*s.* 10*d.* per ton. A comparison (in the same town): *horsed vehicles*, by day 8*s.* 7*d.*, by night 8*s.* 7½*d.*: *motor vehicles*, by day 7*s.* 11¾*d.*, by night 8*s.* 10½*d.*, all per ton. 1924. Per ton: motor vehicles 12*s.* 4*d.*; horsed vehicles 13*s.* 8*d.* Under some conditions the difference is greater. In a number of cases under different conditions to these horsed vehicles cost less. 1926–1927. Leighton Buzzard, 4*s.* 10½*d.* per load, 3*s.* 8*d.* per ton. Deptford: public cleansing vehicles, all 3–4 ton end-tipping, six comparable vehicles selected, costs ranged from 10*d.* to 1*s.* 8*d.* per ton-mile; mean, 14*d.* nearly. At Coventry, the 'Pagefield' system, cost 10*s.* per ton, has saved 2,000*l.* in one year, working 118 streets per week.

Low-Loading Vehicle.—Two-tonner; hand gear end-tipping; height from roadway, 5 ft. to top of side, about 4 ft. to top of half side (flap down); tips to 45 deg.; 140 cu. ft. capacity, or 5·2 cu. yds.

Sunderland, 1923.—6*s.* per ton; house and shop refuse.

Gosport, 1923.—7*s.* 8*d.* per ton.

Haulage of Road Materials.

Hampshire.

(W. J. Taylor, M.Inst.C.E., County Surveyor: Annual Report.)

(The 'legal loads' were not exceeded.)

Hydraulic Tipping Steam Lorries.—Four of 3½, 3½, 3¾, and 4¾ tons legal loads. Average ton-mileage, 13,740; average cost per ton-mile, 8·93*d.*; highest, 10·34*d.*; lowest, 7·25*d.*

Screw Tipping Steam Lorries.—Four of 3½, 3¾, 3¾, and 3⅞ tons legal loads. Average ton-mileage 14,500; average cost per ton-mile, 7·82*d.*; highest, 9·1*d.*; lowest, 6·6*d.*

Non-Tipping Steam Lorries.—Three of 4, 4, and 4⅜ tons legal loads. Average ton-mileage, 13,307; average cost per ton-mile, 8·91*d.*; highest, 10·9*d.*; lowest, 6·5*d.*

Eleven Steam Lorries.—As above, average ton-mileage, 13,897; average cost per ton-mile, 8·265*d.*

Petrol Lorry, Non-Tipping.—3½-ton, ton-mileage, 20,125; cost per ton-mile, 7·46*d.*

One-ton Petrol Lorries.—Three, average ton-mileage, 8,150; average cost per ton-mile, 8·23*d.*

The costs per day for steam vehicles ranged from 1·31*l.* to 2·17*l.*; average, 1·62*l.* For the 3½-ton petrol vehicle, 2·28*l.*; for the 1-ton trucks, 1·11*l.*

NOTE.—The full table in Mr. Taylor's Report should be consulted, or p. 550 of the July 1926 issue of the *Surveyor*. The figures show in a remarkably clear manner the effects upon costs of the factors:—

(*a*) Ton-mileage and (*b*) empty mileage to full mileage. Considering the range of vehicles and of loads, the degree of conformity with these factors included is notable. No exhaustive study has been made to find the critical figures of basic comparison, but there is a special significance in a portion of the cost, amounting to about 4·5*d.* per ton-mile. Taking this figure and a basic ton-mileage of 14,000, the probable cost in pence per ton-mile for any of these vehicles is indicated by some such formula as:

$$\left(4{\cdot}0 + 4 \times \frac{14{,}000}{\text{ton-mileage}}\right) \times \frac{\text{empty mileage}}{\text{full mileage}}$$

This tentative formula, or qualifier, gives the following results: 9·8 against 10·34 actual; 7·4 against 7·25; 7·03 against 9·1 (relatively few working days); 6·6 against 6·6; 10·5 against 10·9; 7·03 against 6·5; total for steam vehicles, 7·82 against 8·27 actual; petrol vehicle 6·78 against 7·46; 1-ton trucks, 8·16 calculated against 8·23 actual.

Public Service Vehicles: Prices, 1926–1927.

Motor Fire-engines.—1,400*l.*, 1,125*l.*, 1,050*l.*, 725*l.* Motor-cycle fire engine outfit, 300*l.*

Motor Ambulances.—770*l.*, 700*l.* 20–25 h.p., 710*l.* Others, 650*l.*, 255*l.*

Tipping Wagons.—Steam, 3-way, 945*l.* Clayton 6-ton, end-tipping, 885*l.*

Refuse-Collecting Vehicles.—Several types, 580*l.* to 600*l.*; 560*l.*

Gully-Emptying Vehicles.—Steam, 1,050*l.*, several types about 1,000*l.*

Motor Lorries.—425*l.*; 1-ton, 240*l.*; 1-ton Ford, 225*l.*; light motor van, 200*l.* Dennis, 3½-ton, 735*l.*; 2½-ton, 700*l.*; 'Pagefield' refuse-collecting lorry, with 5 containers, 2,046*l.* tipping lorry, 30-cwt., 350*l.*

Steam Waggons.—700*l.*

Street Sweepers.—Rotary sweeper, 578*l.* Sweeper, sprinkler, and collector, 1,000*l.* Sweeper and sprinkler, 850*l.*

Motor Omnibuses and Coaches.—Urban type, 1,250*l.*, 1,144*l.*; single-deck, 6-wheeled, 1,200*l.*; 26-seater, saloon, 1,150*l.*; 20–24 seater, 1,070*l.*; 20–26-seater, 995*l.*; 16-seater, 795*l.*; chassis for 32-seater, 780*l.*; chassis, 14-seater, 375*l.*; 18-seater, 535*l.*; 20-seater, 735*l.*

Tram-cars.—Single decker, 2,455*l.*

Vehicles and Road Plant for 442 Miles of Main Roads, Worcestershire.

(*C. B. Hammond.*)

(*To deal with heavy post-war arrears of work.*)

Fifteen 5-ton steam waggons; two 3-ton petrol waggons; one light works lorry; six motor cycles and side-cars, for divisional surveyors; five trailer waggons for the 5-ton lorries; thirteen steam rollers, 8-ton and 10-ton; two light patching rollers, with trailers; twenty-eight sleeping vans; eighteen water carts; seventeen horse-drawn tar-painting machines; ten hand-drawn tar-painting machines; thirteen horse brooms.

Equipment for Refuse Collection.

Gosport (population 3,400, area 3,998 acres). Vehicles, one Fordson tractor; three covered, 2-wheeled, 2-ton trailers; one 1-ton Ford van, sundry horses—method, horses collect only, tractor plies with trailers to and from the destructor. Cost per ton, 7*s.* 8*d.* Collection twice a week.

New Road Construction: Rates.

(*W. P. Robinson, Surrey.*)

Surface excavation not exceeding 12 ins. deep and run to tip, 8*d.* per sq. yd.; excavation to formation, hauling any distance, shaping, formation and trimming slopes, 2*s.* 8*d.* per cub. yd.; reinforced concrete post and wire fence, 4 ft. 6 ins. high, including straining posts and all fittings, 3*s.* 3½*d.* per lin. yd.; provide, spread and roll clinker, 3 ins. thick, to formation, 10*d.* per sq. yd.; concrete in carriage-way, 8 ins. thick, excluding reinforcement, laid and finished, 7*s.* 9*d.* per sq. yd.; single layer reinforcement, weight 5 lbs. per yd. laid, and including all jointing, laps, etc., 1*s.* 3*d.* per sq. yd.; double layer reinforcement, weight 10 lb. per yd., laid and including joints, laps, etc., 2*s.* 2*d.* per sq. yd.; 10 in. by 6 in. concrete kerb bedded and jointed in cement mortar to carriage-way, 5*d.* per lin. yd.

Tree Planting.

(*R. M. Morton.*)

Rosyth.—Average cost of the tree, 1*s.* 2½*d.*; limes, 1*s.* 7*d.*; chestnuts, 1*s.* 6*d.*; Lombardy poplars, 9*d.* Handling, transport and planting, 3*s.* 3½*d.* per tree; total cost per tree, 4*s.* 6*d.* Relates to 2,721 trees.

Dunfermline.—Total cost per tree, 2*s.* 7*d.* Relates to 210 trees.

Standard Trees for Roads and Hedges.

[Based on information supplied by Lt.-Col. H. V. Lane, Lane's Nurseries, Berkhampstead.]

For Roads.—(i) Planted 60 ft. apart. Height of tree: Common ash, common beech, chestnut, lime, plane, poplar, sycamore, 8 to 12 ft.; oak, 7 to 10 ft.; elm, 6 to 10 ft.; walnut, 6 to 8 ft.; purple beech, 5 to 7 ft.

(ii) Planted 20 ft. apart. Height of tree: Maple and mountain ash, 8 to 10 ft.; acers and thorns, 6 to 7 ft.

For Hedges.—(iii) Planted 1 ft. apart, 3 to 3½ ft. in height: beech, hornbeam, privet. (iv) Planted 7 to the yard; thorn (quick), 2½ ft. high. (v) Planted about 2 ft. apart, 3 to 4 ft. high, holly, yew, box, and cypress.

Costs per Mile of Road.—Basis for independent calculation: per penny per tree, 7*s.* 4*d.* per mile; per shilling per tree, 4*l.* 8*s.* (vi) Single line of trees, stakes at 9*d.* each: at 2*s.* 6*d.* per tree, 14*l.* 6*s.*; at 3*s.* per tree, 16*l.* 10*s.*; at 3*s.* 6*d.* per tree, 18*l.* 14*s.*; at 4*s.* per tree, 20*l.* 18*s.*; at 4*s.* 6*d.* per tree, 23*l.* 2*s.*; at 5*s.* per tree, 25*l.* 6*s.*; at 5*s.* 6*d.* per tree, 27*l.* 10*s.*; at 6*s.* per tree, 29*l.* 14*s.*; at 6*s.* 6*d.* per tree, 31*l.* 18*s.*; at 7*s.* per tree, 34*l.* 2*s.*; at 7*s.* 6*d.* per tree, 36*l.* 6*s.*

(vii) *Hedges*, such as (v) (above), taken as 2 ft. apart; as stakes are not required, other spacings are in proportion: for *single hedge*, at 2*s.* 6*d.* per tree, 330*l.*; at 3*s.*, 396*l.*; at 3*s.* 6*d.*, 462*l.*; at 4*s.*, 528*l.*; at 4*s.* 6*d.*, 594*l.*; at 5*s.*, 660*l.*; at 5*s.* 6*d.*, 726*l.*; at 6*s.*, 792*l.*; at 6*s.* 6*d.*, 858*l.*; at 7*s.*, 924*l.*; at 7*s.* 6*d.*, 990*l.*

(viii) *Hedges*, such as (iii) (above), taken as 1 ft. apart, other spacings in proportion; half the values in (vii).

Quickset Hedge (thorn).—Taken as 7 to the yard: at 5*l.* per 1,000, 61*l.* 12*s.*; at 7*l.* 10*s.* per 1,000, 92*l.* 8*s.*; or, with a per yard and b shillings per 1,000, the cost of *one* hedge is $£\frac{a \times b \times 88}{1000}$.

Watford By-pass Road.—Planted with beech, birch, and sycamore. The choice of beech and sycamore, especially the latter, has been adversely criticised.

Charing, Kent.—North and south by-passes: mountain ash, wych-elm.

WORKING COSTS DATA FOR VEHICLES.

Passenger Vehicles.

(*London County Council Report*, 1924.)

Operating Costs in Pence per Car Mile.

Tramways: Bradford, 18·46; Rotherham, 16·46; Sheffield, 15·46; Birmingham, 14·82; Leeds, 14·57; Wolverhampton, 14·26. London County, 13·85.

Trolley Omnibuses: Bradford, 16·23; Birmingham (4 months), 12·65; Leeds, 11·90.

Petrol Omnibuses: Birmingham, 15·41; London General Omnibus Company, 14·42; Wolverhampton, 13·57; Rotherham, 12·88.

The above figures are operating costs only, and do not include capital charges, which differ considerably comparing town with town, and differs greatly comparing petrol omnibuses with tramways.

The items included are: traffic expenses; general expenses; repairs and maintenance expenses; power expenses. A full analysis is given in *The Surveyor*, May 30, 1924.

See page 859.

Steam Waggons and Lorries.

Steam Waggons.—Per day, 2*l.* 15*s.*; per loaded mile, 5*s.* 7*d.*; per mile, 2*s.* 9*d.*; per ton of load, 5*s.* 1*d.*; per ton-mile, 1*s.* 2*d.* Depreciation, 14 per cent.; wages, 40 per cent.; coal, 15 per cent.; repairs and renewals, 12 per cent.; tyres, 8 per cent.; sundries, 6 per cent.; oil, 5 per cent. Miles travelled in year, loaded, usually 1,500 to 2,000; unloaded, about the same. Working days: four vehicles exceeded 180, three exceeded 120 (out of nine vehicles)—these are 5 to 6-ton vehicles. Average load per journey, about 4½ tons; average distance per journey, three vehicles about 5 miles, three vehicles about 3½ to 4 miles, the other three less.

Liverpool (see 'Electric' and 'Petrol').—Steam waggons, costs: per ton, 5*s.* 5*d.*; per mile, 3*s.* 9*d.*; per ton-mile, 1*s.* 6½*d.*

Camberwell.—Steam waggon, under favourable circumstances, 1922: Running costs, fuel, 28 per cent.; oils, tools, and sundries, 5½ per cent.; licence and insurance, 4 per cent.; repairs and fittings, 5½ per cent.; wages, 53 per cent.; depreciation, 15 per cent.; tyres, 3 per cent.; or, including extra labour for loading, about half these percentages, and extra labour nearly 50 per cent. Total cost, 392*l.*; mileage, 857; cost per mile, 9*s.* 2*d.*; cost per mile without extra labour for loading, 4*s.* 7*d.* Hauling, with trailer, 26 tons per day, distance 10 miles: cost per day, 3*l.* 3*s.*; extra labour for loading, 3*l.* 2*s.*; cost per ton-mile, 5·7*d.*

Berkshire County Council.—Two steam tractors and four steam waggons, jointly: cost per working day, 3*l.* 9*s.*; cost per loaded mile, 7*s.* 5*d.*; per mile travelled, 3*s.* 10*d.*; per ton carried, 5*s.* 3*d.*; per ton-mile, about 17 pence.

Godalming.—Oil-fired steam lorries, heavy oil at 10½*d.* per gallon; six ton-miles per gallon.

Warwickshire.—Per working day, 2*l.* 17*s.* 4*d.*; tons hauled per annum, 5,273; cost per ton delivered on to the road, 2*s.* 6¾*d.*

Nottinghamshire.—For steam waggons: average age, 7 years; average load, 6·5 tons; average mileage, 447; average loaded mileage, 202·5; costs: per day, 3*l.* 7*s.* 3*d.*; per mile, 6*s.* 5½*d.*; per ton-mile, 1*s.* Depreciation at 12½ per cent. has already cleared off the cost of two of these vehicles. About three months after the end of the financial year, 1924–1925, the whole capital sum had been discharged, and the working cost per ton-mile reduced to 10*d.* 1926–1927: steam wagons and trailers; average days worked, 192; tons per journey, 6·56; cost per day, 2*l.* 14*s.* 6*d.*; cost per ton-mile, 10·2*d.*

Durban.—6-ton steam waggons, 1*s.* 4*d.* per ton-mile.

Somerset County Council (W. J. Taylor).—Steam lorries, 5-ton, Foden and Sentinel; costs: per working day, 2*l.* 13*s.* 4*d.*; per mile, 1*s.* 10*d.*; per loaded mile, 3*s.* 8*d.*; per ton, 2*s.* 7*d.*; per ton-mile, 8½*d.* 1925: Foden and Sentinel waggons, per working day, 2*l.* 16*s.*; per loaded mile, 4*s.* 0½*d.*; per mile travelled, 2*s.* 0½*d.*; per ton carried, 2*s.* 8*d.*; per ton-mile, 9½*d.* For those vehicles, percentage costs: wages, 39·9, repairs and renewals, 20·1; depreciation, 14·6; coal, 13·5; oil, 2·7; insurance, licences, and sundries, 3·57.

(*Times Supplement*).

The following tables relate to the running of steam waggons and lorries in different parts of the country. They are actual figures, except in the first set of tables, in which estimated costs are compiled from statistics supplied by a number of users.

In the following figures, relating to the running of 6-ton, 4-ton, and 3-ton Yorkshire steam waggons, the year has been based upon 48 working weeks.

Running costs in pence per mile.	6-ton.	4-ton.	3-ton.
Fuel	2·00	1·75	1·50
Oil	0·45	0·40	0·36
Tyres	1·60	1·35	1·10
Maintenance	2·00	1·50	1·25
Total	6·05	5·00	4·21
Standing charges in pence per week.	**6-ton.**	**4-ton.**	**3-ton.**
Driver's wages	780	780	780
Depreciation	450	387	360
Interest	200	170	155
Rent, rates, and management	150	150	150
Insurance	120	110	100
Tax	150	150	140
Total	1,850	1,747	1,685

Depreciation is taken at 12½ per cent., less tyres, and interest at 5 per cent. To arrive at the daily cost, the total running should be multiplied by the number of miles run, and the result added to the total standing charges divided by the number of days worked weekly. To arrive at the weekly cost, the total running costs should be multiplied by the number of miles run and the figure added to the total standing charges. To get the cost per ton mile, the total working costs should be divided by the total number of miles run loaded multiplied by the weight carried in tons. When a second man is employed 10*s.* a day should be added to the total working costs, and to estimate the full operation charge of a 6-ton waggon and 4-ton trailer 25 per cent. should be added.

A Reading Firm's Record.

The following figures have been supplied by Messrs. H. & G. Simmons, Ltd., of Reading, of demonstration runs made by a 6-7-ton shaft-driven Yorkshire steam waggon :—

Reading to Ludgershall and return. Total distance, 86 miles. Load, 10 tons on waggon and trailer.

Actual travelling time	8 hr. 40 min.
Average speed	9·92 m.p.h.
Fuel used (coal)	6 cwt. 20 lb.
Consumption of coal per mile	8·04 lb.

Reading to London and return. Total distance, 82 miles. Load, 10·1 tons on waggon and trailer.

Actual travelling time	7 hr. 50 min.
Average speed	10·46 m.p.h.
Fuel used (coal)	5 cwt. 78 lb.
Consumption of coal per mile	7·78 lb.

Reading to Portsmouth and return. Total distance, 121 miles. Load, 10 tons 2½ cwt. on waggon and trailer.

Actual travelling time	13 hr. 20 min.
Average speed	9·3 m.p.h.
Fuel used (coal)	11 cwt.
Consumption of coal per mile	9·93 lb.

Somerset County Council.

The following figures for the operation of seventeen steam lorries worked by the Somerset County Council under the County Surveyor, Mr. Edward Stead, are for a year up to April 1923 :—

WORKING COSTS OF 17 STEAM LORRIES.

Details.	Cost. £	s.	d.	Per cent. of Total.
Wages	4,829	13	8	38·43
Coal, etc.	1,521	3	0	12·11
Oil and grease	423	3	3	3·37
Repairs and renewals	2,345	2	7	18·66
Tyres	529	10	8	4·21
Licences	505	0	0	4·02
Insurances	86	4	1	0·69
Miscellaneous	535	13	10	4·26
Depreciation	1,790	14	5	14·25
Totals	12,566	5	6	100·00

Totals for 17 lorries :—

No. of journeys	14,238
No. of miles loaded	57,076
No. of miles unloaded	53,335
No. of tons carried	70,723
No. of ton miles	283,510

Average cost per lorry :—

Per day worked	£3 0*s.* 3½*d.*
Per loaded mile	52·84*d.*
Per mile run	27·31*d.*
Per ton carried	42·64*d.*
Per ton mile	10·64*d.*

Here it must be borne in mind that in county council and municipal work a high ratio of idle to useful running is inevitable in comparison with ordinary commercial haulage.

GAMAGE'S FORD VANS.

The following summary relates to the running costs of the five 1-ton Ford vans belonging to Messrs. Gamage, and is taken for a quarter—April 14–July 7, 1923 :—

TOTAL MILEAGES.

Van.	From.	To.	Miles.
77	July 3, 1922	July 7, 1923	9,615
78	,,	,,	11,243
79	July 31, 1922	,,	9,784
80	October 1, 1922	,,	9,743
81	,,	,,	7,469
			47,854

Overtime and vanguards' wages are included, also overhead charges. Interest on capital is taken at 6 per cent., and depreciation at 15 per cent.

Totals for thirteen weeks April 14–July 7, 1923 :—	£	s.	d.
Wages	186	3	8
Garage expenses	146	15	0
Petrol	102	0	11½
Oil and grease	14	19	6½
Tyres	25	7	0
Sundries	53	17	4½
Interest on capital	13	9	9
Depreciation and insurance	42	19	1
	585	12	1½

Mileage	14,523
Miles per gallon	11·9
Cost per mile	9½*d.*
Petrol (gallons)	1,220

Analysis of Costs.—Steam rollers, Somerset County Council; wages, 32·5, coal, 20·2; oil, 3·0; repairs and renewals, 27·0; depreciation, 15·5; insurance and sundries, 1·6. (See 'Petrol Vehicles.')

Electric Vehicles.

Worcestershire.—County council lorries (all costs except capital charges, depreciation, and insurance), 14·9*d.* per ton-mile.

Willesden.—2½-ton vehicles: capacity, 6 cubic yards; units per mile, 1·223; tons lifted per man-day, 2·29; tons per vehicle per day, 6·28; cost (total) of collection, 11*s.* 2*d.* per ton.

Liverpool (see under 'Steam' and 'Petrol').—Cost per ton, 4*s.* 6*d.*; cost per mile, 5*s.* 9*d.*; cost per ton-mile, 3*s.* 4*d.*

Canterbury.—2½-ton vehicles: cost of electricity, per mile, 7·23*d.*; per ton, 13·7*d.*; cost of electricity, oil, water, grease, and repairs, 20·3*d.* per ton-mile. Total cost per ton-mile, including capital charges and insurance, 2*s.* 9*d.*; per working day, 6*l.* 17*s.*

Wolverhampton.—(A) Vehicles 1½ years old: kilowatt-hours, per mile, 2·22; costs—capital charges, 22 per cent.; battery, 21·6 per cent.; tyres, 2·6 per cent.; insurance, 1·6 per cent.; wages, 30·7 per cent.; repairs and maintenance, 5 per cent.; electrical energy, at 2¼*d.* per unit, 16·5 per cent.; cost per ton-mile, 10·2*d.*; cost per hour in use, 5*s.* 9*d.* (B) Vehicles 3½ years old: kilowatt-hours, per mile, 1·87; costs—capital charges, 21 per cent.; battery, 15·5 per cent.; tyres, 1·8 per cent.; insurance, 0·7 per cent.; wages, 41·6 per cent.; repairs and maintenance, 9·9 per cent.: electrical energy at 2¼*d.* per unit, 9·5 per cent.; cost per ton-mile, 1*s.* 4*d.*; cost per hour in use, 7*s.* 11*d.*

Nottingham.—October 1915 to December 1924: 3-ton electric vehicles; refuse collection. Total costs: current, 4 802*l.*: tyres, 848*l.*; battery upkeep, 453*l.*; maintenance, 3,905*l.*; licences, insurance, etc., 1,678*l.*; depreciation, 13,893*l.*; total upkeep, 25,597*l.*; wages, drivers and mates, 46,341*l.*; grand total, 71,920*l.*; mileage, 322,797; tons, 17,631; cost per ton, 8*s.* 2*d.* Now twenty-eight such in service.

Petrol Vehicles.

Liverpool (see 'Steam' and 'Electric').—Costs: per ton, 6*s.* 7*d.*; per mile 2*s.* 8*d.*; per ton-mile, 1*s.* 7*d.* *Test*, 5½-ton lorry and trailer; tare of lorry, 4 tons 7 cwt.; of trailer, 1 ton 13 cwt.; average speed, 12 miles per hour; petrol, 5·9 miles per gallon; with nearly 11½ tons load, 6 net ton-miles per gallon; with nearly 4½ tons load, 28·5 ton-miles per gallon; average, 46 ton-miles per gallon; oil, 516 miles per gallon. Another place, 3½-ton lorry, 11 miles per gallon of petrol.

Worcestershire.—Ford landaulette, one year, mileage, 6,844; cost per mile, 1*s.* 5½*d.* (this cost includes 'rent,' insurance, 'uniform,' etc.).

Middlesbrough.—Street-watering van: interest and redemption, 18·4 per cent.; tyres, 3·6 per cent.; repairs and renewals, 7·2 per cent.; driver, 22·6 per cent.; oils and grease, 1·4 per cent.; insurance, 1·4 per cent.; petrol (at 2*s.* 2*d.* per gallon), 38·9 per cent.; taxes, 4·3 per cent.; sundries, 2·2 per cent.; cost per day, about 2*l.* 16*s.*

Motor Haulage.—By contract, 13·57*d.* per day; by council's department, 13·40*d.* per day.

Middlesbrough.—Street-sweeping machine: interest and redemption, 10·5 per cent.; tyres, 3·4 per cent.; repairs and renewals, 6·8 per cent.; driver, 17·5 per cent.; oils and grease, 1·8 per cent.; insurance, 1·1 per cent.; petrol (at 2*s.* 2*d.* per gallon), 36·8 per cent.; refills for brooms, 17 per cent.; taxes, 3·3 per cent.; sundries, 1·8 per cent.; costs, about 7*s.* per mile, or 4¾*d.* per 1,000 sq. yds. Street-sweeping machine, 20*s.* per mile.

Street Sweeping.—By motor sweeper, 7*d.* per 1,000 sq. yds.

Refuse and Sweepings Collection.—1*s.* per ton-mile.

Analysis of Costs, 1925.—Petrol rollers, Somerset County Council: wages, 35·7; petrol 21·5; oil, 3·1; repairs and renewals, 11·2; depreciation, 22·7; insurance and sundries, 5·7.

Various Vehicles.

Per Day, 1925.—Steam waggons (Staffordshire County Council), 3*l.* 4*s.* 9*d.*; Nottinghamshire, 2*l.* 14*s.* 9*d.*; Somerset, 2*l.* 16*s.* Steam rollers: nine steam rollers, Warwickshire County Council, working costs only, 29*s.* 6*d.* Nottinghamshire, steam rollers, including the hauling of water, 1*l.* 14*s.* 6*d.* Somerset: steam rollers, working costs, 1*l.* 6*s.* 1*d.*; petrol rollers, 1*l.* 12*s.* 3*d.* Another case, 1*l.* 13*s.* 7*d.* Pembrokeshire, 3*l.* 2*s.*

1925–1926.—Cardiff R.D.C., 1*l.* 18*s.* 6*d.*; West Riding C.C., 1*l.* 11*s.* 4*d.*; petrol rollers, 1*l.* 19*s.* 1*d.*; Somerset C.C., 10-ton steam, 1*l.* 9*s.* 6*d.*; 6-ton petrol, 1*l.* 8*s.* 6*d.*; steam waggons working costs only, 2*l.* 11*s.* 6*d.*; rotary sweepers (motor), 1*l.* 15*s.* 2*d.*; gulley emptiers, 2*l.* 17*s.* 3*d.* (per gulley, 2*s.* 9*d.*; watering van, 1*l.* 19*s.* 9*d.*; steam waggons, 3½ to 4¾ tons lading, hydraulic tipping, 1*l.* 12*s.* 6*d.*; screw tipping, 3½ to 3¾ tons, 1*l.* 14*s.* 4*d.*; non-tipping 4-ton, 1*l.* 10*s.* 5*d.*; petrol 3½-ton vehicle in the same 'fleet,' 2*l.* 5*s.* 7*d.* Torquay: refuse collection, 5*s.* 4*d.* per ton, with current at 2*d.* per unit. See under preceding classified headings.

Per Hour.—One-ton horse carts, 3*s.*; 10-ton steam rollers, 8*s.* 7*d.*; 10-ton motor rollers, 8*s.* 7*d.*; motor gully cleanser, 9*s.* 3*d.*; motor broom, 3*s.* 10*d.*—all including attendants. Electric vehicles, 3¼-ton, 1½ years old, 6*s.*; the same, 3½ years old, 8*s.* 1923: steam roller (Kent), 6*s.* 3*d.* Vehicles of some years' service (Kent): steam tractors, 7*s.* 7*d.*; petrol lorries, 7*s.* 5*d.*; Foden lorries, 6*s.* 6*d.*

Kent: working expenses per hour, 4*s.* 4*d.*; steam tractors, 5*s.* 4*d.*; petrol lorries, 5*s.* 3*d.*; steam lorries, 5*s.* 9*d.*

Per mile.—Lorries, 9·44*d.*; 1-ton Ford trucks, 7¼*d.* (12·2 miles per gallon); rotary motor sweepers, 1*s.* 9*d.*; watering van, 1*s.* 11*d.*; tipping lorry, 4*s.* 2*d.*; the same, hauling road materials only, 3*s.* 2*d.*; steam waggons, 1*s.* 10*d.*

Per ton.—Worcestershire county lorries, 2*s.* 11½*d.*; steam waggons, working costs only, 2*s.* 6½*d.* From wharves and stations to jobs, County Council, 3*s.* 4½*d.*; tipping lorry average, 5*s.* 1*d.*; hauling road materials, 3*s.* 6*d.*

Per ton-mile.—Tipping lorry, 4–5-ton, average, 1*s.* 8*d.*; hauling road materials, 1*s.* 2*d.*; steam lorry, 8½*d.*; steam lorries, capital charges paid off, 10*d.*; steam wagon, hydraulic tipping, 8·9*d.*; screw-tipping, 7·8*d.*; non-tipping, 8·9*d.*; non-tipping petrol lorry, 7·5*d.* (larger mileage). Pembrokeshire county steam waggons (A. H. Thomas), 9·3*d.*

Birmingham (A. Baker).—Operating costs: motor omnibuses, 12 months, 15*s.* 4*d.*; tramcars, 12 months, 14*s.* 8*d.*; trolley omnibuses, 6 months, 12*s.* 6*d.* per mile. See p. 855.

Tramways, Trolley Omnibuses and Motor Omnibuses.

1. *Hard Economic Facts.*—T. Salkield (*The Surveyor*, Feb. 2, 1927) pointed out that though tramways are convenient in respect of peak load, hard economic facts have to be faced: the greater road congestion and noise caused by tram-cars and the greater danger to the public will be the deciding factors.

2. On the recommendation of the tramways committee, Bradford Corporation has decided to equip the Allerton route for trolley-buses, at a cost of nearly 30,000*l.* for overhead equipment and vehicles.

3. Croydon, 1927, George Street and Addison Road tramway route to be done away with.

4. Wolverhampton Corporation, 1926, substituted trolley-buses for tramways on the Wolverhampton-Walsall main road and on the Dudley and Willenhall routes.

5. Kilmarnock.—In May 1926 it was decided to abandon what remained of the tramway system and substitute motor omnibuses.

6. Trolley-buses in operation in Copenhagen, 1926, and on order for Lima.

7. In Darlington, the conversion of electric tramways to trolley-omnibus routes was completed in 1926.

8. The Walsall Tramways Committee, deciding against tramways, compared:

Trolley Omnibuses.—Advantages: better acceleration: use the local electricity; better lighting of vehicles; source of power less liable to market fluctuations. *Disadvantages:* greater capital outlay; vehicles are route-bound; special provision required for turning; guard wires (for G.P.O. main wires) required; failures and blocks stop the whole service; ice forms on the wires in winter.

Motor Omnibuses.—Advantages: smaller capital; saving of dead mileage; available on other routes; easily turned; no overhead equipment. *Disadvantages:* imported fuel of uncertain price; gross operating costs slightly higher. *Present Position, Costs:* on one route, a saving of 686*l.* per annum.

Traffic Statistics.

Paisley–Glasgow Road, 6,796 tons per day; eight roads radiating from Liverpool, over seven million tons (less than one million in 1913); rate for July over nine million tons per annum. London, millions of tons per annum: Hyde Park Corner, estimated, 48; Hammersmith Broadway, 19: The Angel, Islington, 16. Railway statistics suggest that about 34 million tons per annum of traffic has been diverted to the roads. (*Lord Montagu of Beaulieu*, '*The Times*,' 1922.)

Main Route Traffic: Tons per Day.—The three consecutive figures are, in every case, pre-war (1910, 1911, or 1912), 1922, 1925: London-Edinburgh, near Framwellgate Moor, Durham, 636, 3,346, 5,348; London-Dover, near Newington, Kent: 568, 1,943, 4,623; London-Portsmouth, near Pease Marsh, Surrey: 790, 3,809, 6,417; London-Holyhead, near Redbourne, Herts., 508, 2,649, 4,166; Liverpool-Sheffield-Lincoln, near Sankey Bridges, Lancashire, 1,167, 8,250, 11,606. The pre-war figures are averages for the year (presumably), those for 1922 and 1925 being in August (British Report on Bituminous and Asphaltic Roads: Fifth International Road Congress, 1916). A road in Norfolk, 4,752; another, 2,326.

Wolverhampton.—1925-1926, Municipal transport services: tramcars, 30; motor-omnibuses, 27; trolley-buses, 16; passengers carried: trams, 15·24; motor-buses, 5·62; trolley-buses, 4·67 millions per annum.

Scotland.—Traffic census, 1922: tons per day, industrial areas, maximum 5,542: rural areas, maximum 739.

Great Britain.—About 14,000 steam waggons and road locomotives, using a million tons of coal and coke per annum.

London.—About 7,000 motor-omnibuses per day, using the Strand, Oxford St., Piccadilly, Regent St., and Parliament St., taxed at 6*d.* per bus-mile, amounting to 7,000*l.* a mile of these routes (*Strapnell-Smith*).

Paris.—At four cross-roads, 3 p.m. to 7 p.m., during one week: averages per hour; year 1910, 1,240, 2,544, 2,613, and 2,168, respectively; year 1925, in the same order, 2,510, 4,407, 3,677, 3,005.

Average Weight.—Average weight of traffic units: summer, 1922, 1·10 tons; 1925, 1·29 tons; winter, 1925, 1·74 tons; Great Britain.

STREET ACCIDENTS.

Paris.—1925: in the order, total—wounded—fatal accidents; by vehicles: motor-cycles and sidecars, 2,251—836—3; bicycles and tricycles, 8,114—3,145—4; motor-omnibuses, 8,510—1,843—17; tramcars, 8,992—2,283—26; horse-drawn vehicles, 17,328—2,188—16; automobiles, 99,855—18,487—131; totals, 145,050—28,782—197 (Totals in 1922, 86,178—18,689—95).

London.—1921: Metropolitan Police Area, killed, 147; injured, 3,637; estimated, to include the City of London, 150 and 5,778. 1923, including the City, killed, 684; injured, 31,209 (4½ and 5 times 1921, nearly). 1924, killed, 866; injured, 36,005 (nearly 5 times and 6 times 1921). 1925, killed, 853; injured, 40,173 (nearly 5 times and 6½ times 1921). 1926, Metropolitan Police Area, killed, in first 9 months, 710; proportion about 6½ times 1921.

Analysis, 1925.—Killed: Police Area, by omnibuses, 141; by trams, 30; by cabs, 202; by other passenger vehicles, 211; by horses, 2; by trade motor vehicles, 228; by trade horsed vehicles, 48; totals: by motor vehicles, 691; by horsed vehicles, 50; add, by motor cycles, 81; by pedal cycles, 18; killed in the City, 13; grand total, 853.

New York, 1923.—Killed by automobiles, street cars, and motor cycles, 960; Chicago, 589; relative numbers for population of London, as above, 1,284 and 1,568.

Roads and Streets: Comparative Statistics: 1923–1924.

The Comparative Tables, p. 811, relate to the local taxation returns for 1922–1923. The changes as shown by the returns for 1923–1924 do not call for detailed notice, but a few of the more important are noted below.

LONDON.—*Maintenance*, scavenging, and watering of roads and streets: slight increase of average, to 1,495*l.* per mile; increases in 9 cases, decreases in 3. *Loan Debts:* increases, 6, including Wandsworth, to 264,000*l.*; decrease, 1; below 30,000*l.*, all in the list of 1922–1923. Other changes slight. *Public Lighting*, reduced to 238*l.* *Mileage*, 2,221.

COUNTY BOROUGHS.—*Maintenance*, repairs, improvements, scavenging, and watering: England and Wales, 710*l.* *Assessable Value:* small increase to 5·9*l.* per head. *Population:* increases, Liverpool, by 11,000; Cardiff, by 22,000; England and Wales, by 68,000. *Public Lighting*, 146*l.* *Mileage*, 10,765.

NON-COUNTY BOROUGHS.—Non-capital expenditure: *Main Roads* and bridges, increased to 915,621*l.*, and loan charges, increased to 130,567*l.*—total, 1,046,188*l.* *Other Roads* and bridges, increased to 1,287,299*l.*, and loan charges to 348,354*l.*—total, 1,656,653*l.* Total (comparing with 2,676,600*l.*, notes on Table III.), 2,841,000*l.* *Public Lighting:* increased to 528,984*l.* *Loan Debt:* increased to 5,362,200*l.*, highways and lighting. *Rates:* for main roads and bridges, 0·6*d.*; other roads and bridges, 1*s.* 1·3*d.*; scavenging and watering, 4·2*d.*; other highway and bridge services, 0·9*d.*; lighting, 5·4*d.* *Assessable Value* (Poor Rate), 5·4*l.* per head.

URBAN DISTRICTS.—Non-capital expenditure: *Main Roads* and bridges, decreased to 1,447,024*l.*; total, with loan charges, 1,629,838*l.* *Other Roads* and bridges, decreased to 2,430,242*l.*, and loan charges, increased to 392,237*l.*—total, 2,822,479*l.*; scavenging and watering, total, 533,872*l.* Other highway and bridge services, total, decreased to 70,471*l.* *Public Lighting*, 807,778*l.* Net outstanding loan debt, with respect to the above, 5,442,860*l.* *Rates:* main roads, *nil*; other, 1*s.* 1·4*d.*; scavenging and watering, 3·0*d.*; lighting, 4·9*d.* *Assessable Value:* General District Rate, 39,853,815*l.*; per head (Poor Rate), 5·1*l.*

ADMINISTRATIVE COUNTIES.—*Mileages:* Main roads maintained by county councils, in urban districts and boroughs, 1,276; in rural districts, 23,049. All main roads maintained by county councils, 24,325. *All Main Roads*, 29,018. *Average Cost* per mile of roads maintained by county councils: England, 381·7*l.*; Wales, 329·1*l.*; England and Wales, 375·6*l.*; all decreases. *Expenditure:* grand total, 14,248,000*l.* *Government Grants*, 6,073,000*l.* *Costs per Mile:* increases in 15 counties; decreases in 21; other changes small.

RURAL DISTRICTS.—*Population*, 7,845,675. *Rateable Value*, 58,853,000*l.* *Assessable Value* (Poor Rate), 42,230,000*l.*, or 5·4*l.* per head. *District Roads:* Mileage, about 94,600; cost per mile, about 67*l.* *Rates:* District roads, 2*s.* 6·3*d.*; lighting, 0·3*d.*; all services, 3*s.* 8·8*d.*; proportion of highway rate, just over two-thirds.

All Roads: Grand Totals, 1924–1925.

England and Wales: maintenance and scavenging, 40,202,529*l.*; loan charges, 5,578,088*l.*; total, 45,780,617*l.*; fees, tolls, rents, etc., 2,296,262*l.*; Exchequer grants, 12,975,604*l.*; balance falling on rates, 30,509,251*l.*; loans expended during the year, 9,919,862*l.*; outstanding loan debt, 80,025,082*l.*; included in the above, scavenging and watering, about 3,690,000*l.* Public lighting, streets, etc., maintenance, etc., 3,680,855*l.*; loan charges, 21,989*l.*; total, 3,702,844*l.*; fees, rents, etc., 37,269*l.*; Exchequer grants, 1,877*l.*; loans expended, 26,823*l.*; outstanding loan debt, 148,284*l.* Ferries: balance to credit of rates, 11,856*l.*

All expenditure of local authorities, other than out of loans, to nearest thousand: maintenance, etc., 293,407,000*l.*; loan charges, 61,519,000*l.*; total, 354,926,000*l.*; fees, tolls, rents, etc., 125,781,000*l.*; Exchequer grants, 76,068,000*l.*; balance falling on rates, 153,077,000*l.*; loans expended, 70,331,000*l.*; outstanding debt, 864,882,000*l.*

Scotland: maintenance and scavenging, 4,901,471*l.*; loan charges 453,515*l.*; total, 5,354,986*l.*

Report on the Road Fund, 1926–1927.

Finance.—(i) Road Fund receipts and payments: Receipts; issues from the Consolidated Fund (Motor Taxation Receipts), 17,373,190*l.*; Total Receipts, 18,232,948*l.* Payments; net payments under grants, 16,975,232*l.*; transfer to the Exchequer, 7,000,000*l.*; Total net payments, 24,613,320*l.*

(ii) Net amount paid to Exchequer, 21,393,000*l.*; net amount paid by Exchequer to Road Fund, 17,373,190*l.*

(iii) Revenue remitted to the Motor Tax by local authorities, 19,932,706*l.*; licences issued by Post Office, 1,702,500*l.*

Grants.—Maintenance and improvement of Class I. and Class II. roads and bridges, 9,485,166*l.* Maintenance of selected unclassified roads to rural areas, 1,351,214*l.* Unemployment schemes (including trunk road reconstruction, 1,545,507*l.*), 3,924,419*l.* Improvement works in rural areas, 1,294,438*l.* Other improvement schemes: widenings, reconstructions, bridges, etc., 1,555,474*l.* Total grants, 18,050,673*l.*

Distribution of Grants: Classified Roads.

England and Wales: Main Roads, Class I., 5,501,828*l.*; Class II., 718,636*l.* District Roads: urban, Class I., 279,365*l.*; Class II., 197,849*l.*; rural, Class I., 116,101*l.*; Class II., 226,387*l.* Roads in county boroughs, Class I., 856,638*l.*; Class II., 165,990*l.* London Roads, Class I., 366,257*l.*; Class II., 50,997*l.*

Scotland: County Roads, Class I., 619,238*l.*; Class II., 113,454*l.* Burgh Roads: in seven larger burghs, Class I., 74,059*l.*; Class II., 9,118*l.*; in all other burghs, Class I., 135,259*l.*; Class II., 16,455*l.*

Great Britain: Class I., 7,998,745*l.*; Class II., 1,498,886*l.*; both classes, 9,497,631*l.*

Special Grants.

Scotland.—Grants to highway authorities in areas where the highway rates are exceptionally high, 371,078*l.*

Rural Areas.—Towards the cost of re-conditioning important roads, 1,125,000*l.*, including 225,903*l.* in Scotland. Towards ordinary maintenance, on selected unclassified roads, 1,400,000*l.*; including 101,936*l.* in Scotland: these grants amounted to 25 per cent. of the cost of maintenance.

Mileage of Roads.

Increase in mileage of main roads in England and Wales, 1925–1926, 1,100; decrease in mileage of district roads, 950.

Mileages.—Classified roads, 1927–1928, and scheduled roads, 1926–1927; Class I. roads; England and Wales, 19,392; Scotland, 5,720; total, 25,112. Class II., England and Wales, 12,038; Scotland, 3,645; total, 15,683.—Total of both classes, 40,795. Scheduled roads, England and Wales, 35,936; Scotland, 4,997; Great Britain, 40,933: classified and scheduled roads, Great Britain, 81,728, or 45·72 per cent. of all roads. England and Wales: all main roads, 30,702; all district roads, 109,515; county borough roads, 11,235; London roads, 2,209; total, England and Wales, 153,661. Scotland: counties, 24,031; eight burghs 1,045; total, Scotland, 25,076: Grand Total, Great Britain, 178,737.

Number of Road Vehicles.

Approximate numbers of vehicles, based on licences issued, 1925–1926; cars taxed on horse-power, 676,000; cycles, 630,000; invalid vehicles, 800; commercial goods vehicles, 257,000; road locomotives, 2,000; motor ploughs, etc., 16,300; motor tractors, etc., 1,300; motor hackney carriages, 99,000; tram-cars, 14,000; general trade licences, 2,900 limited trade licences, 11,700; exempt licences, 18,000.—Total motor licences, 1,729,000. Horse-drawn vehicles: private, 109,055; hackney, 181,931.—Total horse-drawn, 127,248.

SECTION XVI

ARRANGEMENT AND CONSTRUCTION OF ENGINEERING WORKSHOPS — WORKSHOP PRACTICE

(With Contribution by H. N. Allott, M.Inst.C.E.)

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ARRANGEMENT AND CONSTRUCTION OF ENGINEERING WORKSHOPS—WORKSHOP PRACTICE

ENGINEERING WORKSHOPS.

(Contributed by H. N. Allott, M.Inst.C.E.)

For ordinary engineering purposes the arrangement of shops on one level is most convenient, as this allows of better supervision, better access between the various shops, and better light than is possible where the works are arranged in buildings of more than one storey. Multiple storey buildings are generally only used in cases where the work and the machinery are of a light description and where the cost of land outweighs the increased cost of buildings and the advantages of the single-storey shop.

It is advisable to arrange the position of the office buildings so that the entrance or exit to offices and works, both for persons and goods, may be controlled from one time and enquiry office. For small work where heavy cranes are not required, and where the type of machinery employed is small, the saw-tooth type of roof will be found most convenient; whilst for shops where the machines and the work are of a heavier description, and the spans consequently greater, a ridge roof is the best arrangement.

Figs. 1 and 2 show typical buildings comprising heavy machine and erecting shops, together with light machine and fitting shops.

The heights shown in the buildings are 30 feet for the erecting and heavy machine shops and 15 feet for the light machine and fitting shops. It will be noted that the roofs of all the bays are of the ridge type. The smaller bays of roofing are also of this description, since saw-tooth roofing should not generally speaking be of a greater span than 25 feet.

The widths of the bays depend on the machines employed and the character of the work to be carried out, and where these matters can be arranged to suit a bay of not more than 25 feet in width a roof of the saw-tooth type is undoubtedly the best. If the bays are of a greater width than 25 feet, the increased length of the glazing bars necessitates the use of a centre purlin and also increased strength in the rafter back.

The arrangement shown in figs. 1 and 2 is laid down on the supposition that the flow of work in the small machine bays will be parallel to the line of the larger bays, the machines and cranes where required being arranged in lines in this direction.

The roof principals are arranged at right angles to the length of the shop, so that the shafting, heating, and lighting pipes may be conveniently carried from them, and the span of the roof is accordingly 30 feet. Should, however, the character of the work to be carried out make it convenient to arrange the machines and cranes in the smaller bays at right angles to the length of the shop, the roof principals for the smaller bays will run in the contrary direction, and the span would be reduced to 25 feet, when a saw-tooth roof may be used with advantage. In tropical countries the use of saw-tooth roofing is almost compulsory as the rays of the sun are almost vertical.

Saw-tooth roofing where possible is usually arranged with the glazing facing north so as to prevent the direct glare of the sun through the glass. The principal advantage of the saw-tooth roof is that by its use a more evenly lighted and cooler shop is obtained.

The amount of glazing to be allowed for in a roof of the ridge type should be not less than about 50 per cent. of the area of covering, and in town districts with a smoky atmosphere this may be increased with advantage to 60 per cent. or 70 per cent.

The glass should be equally distributed on both sides of the roof, as by that means a more even illumination is obtained than when all the glass is placed on one side of the roof.

Another advantage of distributing the glazing is that the direct glare of the sun and consequent heating of the shops in summer is minimised.

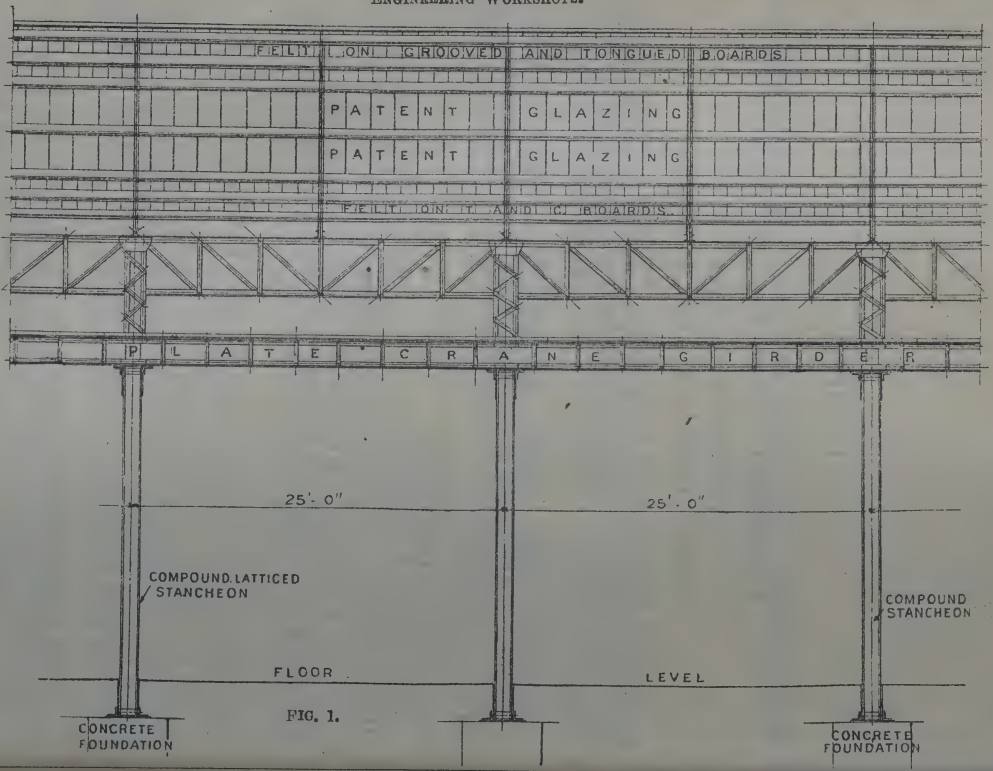

FELLY JOINT GROOVED AND TONGUED BOARDS
PATENT GLAZING
PATENT GLAZING
FELLY JOINT GROOVED AND TONGUED BOARDS
PLATE CRANE GIRDER
25'. 0"
25'. 0"
COMPOUND LATTICED STANCHEON
COMPOUND STANCHEON
FLOOR LEVEL
CONCRETE FOUNDATION
CONCRETE FOUNDATION

FIG. 1.

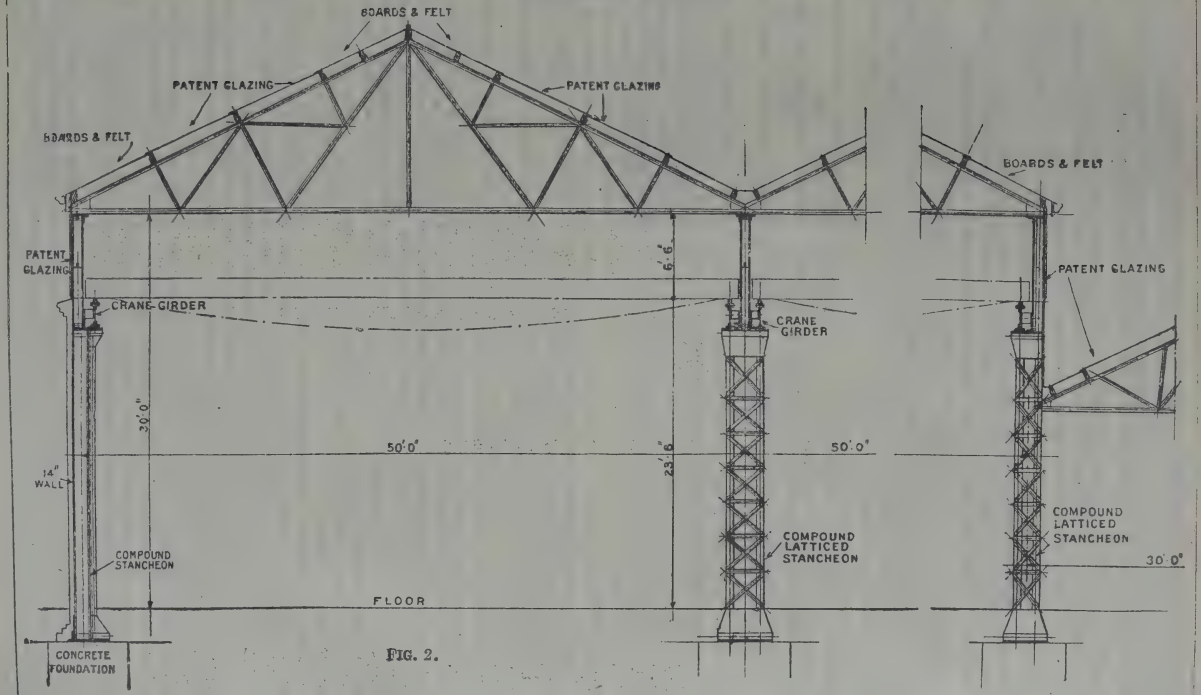

BOARDS & FELT
PATENT GLAZING
PATENT GLAZING
BOARDS & FELT
PATENT GLAZING
CRANE GIRDER
6'6"
30'0"
50'0"
23'6"
50'0"
14" WALL
COMPOUND STANCHEON
CRANE GIRDER
COMPOUND LATTICED STANCHEON
FLOOR
CONCRETE FOUNDATION
BOARDS & FELT
PATENT GLAZING
COMPOUND LATTICED STANCHEON
30'0"

FIG. 2.

The roof covering in this country usually consists either of slates, asphalt felt, or corrugated iron.

For slates or corrugated iron the roof generally is given a rise of not less than quarter of the span, for if made of a flatter slope rain and snow are liable to blow in at the joints.

For felted roofs the roof may be practically flat if the joints are properly made with mastic, and it is only necessary to give a fall of one or two inches to the foot to allow for drainage.

Galvanised corrugated iron is usually only used in this country for buildings required for temporary purposes, and when used should be carefully painted before and after fixing, and afterwards properly maintained, as otherwise its life is only short.

Slating, when used, may be laid on battens nailed to spars, or to boarding nailed to the purlins. When laid on spars the slates should be pointed on the underside with hair mortar. When laid on boarding the boarding should be covered underneath the slates with sarking felt.

An alternative to natural slates is the use of asbestos slates. These are best laid either with the diagonal parallel to the slope of the roof, or in what is termed 'honeycomb' fashion. The point of the slate should be cut off, as it is otherwise liable to be broken by any one walking on the roof. It is necessary in all cases to see that proper lap is given to the slates, and this is especially the case where asbestos slating is used, as owing to its smooth surface the roof is more liable to leakage, where proper attention is not given to this.

An alternative to galvanised corrugated iron sheeting is the use of corrugated sheets of asbestos composition, which can be obtained up to 10 ft. in length and 27½ ins. in width.

Asphalt felt laid on thicknessed, grooved, and tongued boarding is cheaper than slating, and is not damaged like slating by men walking on the roof.

The use of felt of good quality is permitted by the building departments of most local authorities, although one or two treat it as not being sufficiently incombustible.

The felt is laid in mastic and nailed to the boarding, the joints being lapped about 4 ins. One thickness of stout felt will make a satisfactory job, if properly laid and if proper attention is given to maintenance, though the roof is generally covered with an extra thickness of a thinner quality of felt where a thoroughly good job is required. One advantage of the use of felt is that a considerable saving can be effected by forming the gutters in felt, instead of using cast iron gutters; this is especially the case in roofs where large valley gutters are required. A considerable amount of lead required for flashing at various parts of the roof can also be saved.

The only attention required to be given to felted roofs is a coat of varnish at intervals of about five years.

The roof glazing is best carried out with patent glazing, the alternatives to patent glazing being wood or tee steel glazing bars, the glass being puttied in.

The patent glazing is preferable, as with puttied bars the putty becomes defective and the glazing leaky, unless systematic attention and painting is given.

The best systems of patent glazing consist of a steel bar, to which is fixed a lead flashing, which is worked down on to the glass to form a weather-tight joint.

In most cases the glazing bar is sheathed all over in a lead casing, the ends of which are soldered up, thus obviating the necessity of painting. The bars should be galvanised before the sheathing is put on. Except in the case of vertical or steep-pitched glazing, as in the case of a saw-tooth roof, it is not advisable to joggle the glazing bar to form a lap in the glass. If this is done on a flat-pitched roof leakage is liable to occur, owing to capillary attraction between the two panes of glass. Where it is necessary to form a joint in the glazing on a roof of ordinary pitch, it is better to step the glazing bars.

The roof glazing is best carried out with wire wove glass, which holds together and does not drop if a pane is broken.

In a machine shop the number of cubic feet of air space is generally sufficiently large, in comparison with the number of men employed, to render extensive roof ventilation unnecessary, and sufficient ventilation may be provided by opening sashes in the glazing to a saw-tooth roof, or by ventilators at intervals along the ridge in the case of a roof of the ridge type.

The ventilators for a ridge roof to a machine shop are best provided with opening shutters so that the ventilation may be stopped in the winter or in driving rain or snow if required, or if preferred, exhaust ventilators can be used.

In the case of a foundry it is usual to provide ventilators with continuous louvres for the whole length of the shop. These are best made of wood with a rebated fillet screwed on the back to stop rain or snow from driving in as far as possible.

The roof principals are best formed in steel of angles, tees, and other rolled sections. A steel principal offers less obstruction to the light and harbours less dust than a timber principal, and can generally be designed at very little greater cost, if any.

For roofs of moderate span up to, say 50 feet, economical spacing may be taken as from 10 feet to 12 feet, which allows purlins of angle section to be employed. For roofs of larger spans it is frequently more economical to space the roof principals farther apart, and to use purlins of channel, zed, or rolled joist sections.

It is usual to arrange the roof so that the purlins are carried at the panel points of the truss, *i.e.*, at the intersection points of the rafter with the other members. If this is not done the strength of the rafter back must be increased to provide for the bending moment due to the load coming on to it from the purlin, in addition to the compression due to the internal stresses in the framing of the roof principal itself.

A factor of safety of 4, which is equivalent to a tensile stress of about 7 tons per square inch, is commonly used for buildings of a permanent description. In the case of buildings where a long life is not required this figure may be increased to 9 tons per square inch.

The stanchions and girders carrying the roof and gantries are now commonly made of steel of various sections in place of cast iron as in the older shops. A steel stanchion can usually be designed more economically than one of cast iron, is not so liable to damage from blows, and attachments can more easily be arranged for girders to carry shafting, jib cranes, etc.

Round cast-iron columns are sometimes used to carry the roofing of small spans for light machine shops, and light foundries where cranes are not required.

In cases where the crane loads and lengths of the stanchions permit, cheap and convenient forms are provided by the use of rolled steel joists of suitable section, with flat bars or steel channels riveted on to give additional flange area (figs. 3, 4, and 5). The section formed of a rolled steel joist and two channels is a very convenient one, and allows of the easy attachment of brackets, etc., in both directions.

FIG. 3.

FIG. 4.

FIG. 5.

Types of Compound Stanchions to carry Light Cranes or for Multiple Storey Buildings.

Where the shafting is carried from the crane girders, as is sometimes the case, the deflection and stiffness of the girders under load must be inquired into to ensure that the proper running of the shafting is not interfered with.

The economical spacing of the stanchions is determined by the total cost of the stanchions and foundations and the girders carried by them, but this must also in many cases be affected by the spacing of the machinery. In the small machine bays the tools will usually be arranged in long rows parallel to the lines of stanchions and the width of the bay will be a sum of the machine widths and alley ways. The spacing of the stanchions longitudinally will, however, not be affected by the machines, as these will usually be clear of the line of stanchions. For light work, bays arranged with the stanchions placed in squares of 20 feet will usually be suitable and economical in structural cost.

In the case of the large machine bays, the details of the machines will affect the centres of the stanchions longitudinally, as it will be frequently necessary to arrange for these to be placed partly between the stanchions. The width of the bay will be determined by the depth taken by the machines and the space required for assembling work and storing material. The spans and widths of bays shown will be generally convenient for a shop doing ordinary engineering work, but each case requires consideration and should be decided on its merits.

Provision must be made to carry the shafting on the stanchions for the larger bays, where the machines are not independently driven by motors. This is most conveniently arranged for by fixing four longitudinal channels braced together or two rolled steel joists at a convenient height.

The stanchions should be stayed transversely by knee bracing, or by lateral bracing, along the plane of the bottom member of the roof principals. In the case of very high buildings it may be necessary to use both methods.

The roof should also be braced diagonally along the planes of the rafters at the ends of the building, and in the case of very long buildings at intervals in addition.

The foundations for the stanchions and walls are best constructed of cement concrete, mixed six to one. No bedstones are necessary for the stanchions, which can be wedged up to the required level, and grouted with cement and sand in equal proportions. It is advisable to have one or two holes drilled in the stanchion base to vent same, and so allow of the escape of air when grouting. The walls are best constructed of brickwork, in hydraulic lime mortar, or may be framed and constructed of reinforced concrete, about 3 ins. to 4 ins. in thickness.

By the use of special metal lathings, which can be plastered on both sides with cement mortar, it is possible to obtain a weatherproof material with a thickness of 2 ins. If this material is used, a waterproofing medium should be added, in mixing, to the mortar for the outer covering.

This latter method of construction is specially applicable to the filling in to the sides of the main bay, above the roof of the small machine shop, and to the ends of ventilators. It may be also used for a roof covering, where it is necessary that no inflammable material should be used.

Where it is desirable to erect a building with more than one floor, or where galleries are required in a machine shop, these are best constructed with a main framework of steel. The stanchions should be composed of rolled steel joists, or of compound sections, as shown in figs. 9 and

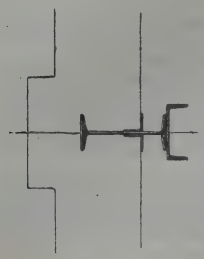


FIG. 6.

FIG. 7.

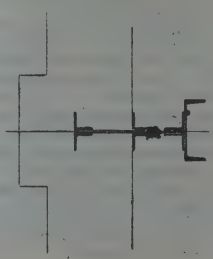


FIG. 8.

Types of Wall Stanchions to carry Cranes.

10, the main floor girders being rolled steel joists or plate girders, as required by the loads coming upon the floor. The depths of the main joists and girders should not be less, if possible, than $\frac{1}{15}$ of the span.

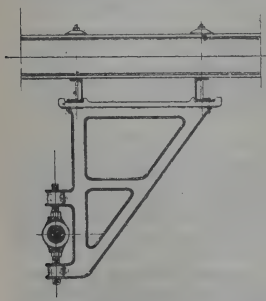


FIG. 9.

Detail Connections for carrying Shafting.

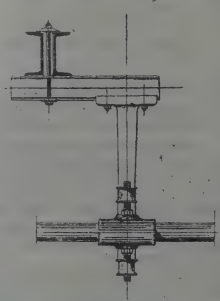


FIG. 10.

The use of a steel frame construction is especially desirable in a building of more than one storey, as the lower floors are dependent for light on the windows, which are placed in the side walls. If steel framing is used, the covering material of brickwork or concrete can be reduced to a minimum, and the window area is correspondingly large.

Floors.

Floors are now generally made of concrete, either with or without a covering of timber.

When the wearing surface is of concrete it should be finished with granite sand and cement, in equal proportions for the thickness of one inch. Concrete is not so suitable as wood for the wearing surface of a floor. It is always impossible to ensure freedom from cracks in concrete over large areas, it is tiring to walk on, is dusty, and liable to damage tools and fragile articles dropped upon it.

If a wood floor is used it is usually laid on a foundation of cement concrete, usually from 4 ins. to 6 ins. in thickness, this being a variable dimension depending on the loads to be put upon the floor, and on the nature of the subsoil.

For floors where the work is of a heavy description the best surface is one of wood blocks 4 ins. deep, which may be formed by sawing off 3-inch deals to lengths. To prevent damp from rising through the concrete the upper surface of the foundation should receive a coat of coal tar pitch about $\frac{1}{4}$ inch thick applied hot, and the blocks should be dipped in the hot coal tar and bedded whilst the pitch is hot, any open joints being afterwards run in with pitch. Where the work is of a lighter character, the most satisfactory wearing surface is grooved and tongued maple planking, nailed either to 4-inch by 3-inch battens laid in the concrete or to planks laid transversely.

The battens should be creosoted, or dipped in '**Jodelite**' or 'Sideroleum,' or some similar wood preservative, and the planking laid in hot tar. It is very important that the whole surface of the floor should be thoroughly tarred before the wood blocks or planking are laid, and that any wood blocks or pegs used for levelling purposes should be removed. Where the loads are very light and the foundation good, tar concrete may be substituted for the cement concrete, the upper surface being tarred as before.

The supported floors of a multi-storey building, or of galleries, are usually constructed of concrete where a fire-resisting floor is required, or of timber in other cases. Where a concrete floor is used it may be constructed of reinforced concrete, or preferably of rolled steel joists and concrete, as the more or less concentrated loads from machines and materials coming on the floor can be more easily arranged for.

In this case the floor can be constructed of small steel joists from 4 ins. to 7 ins. deep, according to the span and load, spaced about 2 feet apart, and finished with a flat ceiling. If the concrete is arched or recessed between the joists, hangers can be easily attached by hook bolts to carry countershafting. Another method where the loads are considerable is to use joists of heavier section, and to form an arched floor of concrete between these.

The upper surface of the floor can be finished with wood planking, as previously described. If the floor is constructed of timber, wood joists bedded on the steel main girders can be used, with wood planking laid on top. It is well, if this form of floor is used, to finish the floor with boards from 1 in. to 1½ in. in thickness, nailed transversely to the planking. Both the planking and the boarding should be thicknessed and laid with grooved and tongued joints.

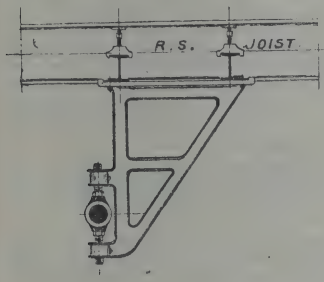
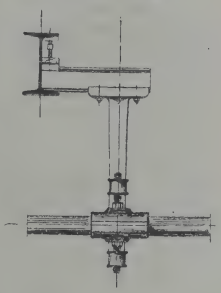


FIG. 11. Detail Connections for carrying Shafting. FIG. 12.



Window sashes are best formed of steel, which if properly painted at intervals is as durable as wood, offers less obstruction to the light, especially in windows of large size, and can be obtained at the same or less cost. The heads to windows may be brick arches, but are preferably formed of concrete, reinforced with small rolled joists or tees.

The position of the sanitary conveniences should be arranged so that undue time is not wasted by a long journey from the shop and back. The minimum accommodation is fixed by the Factory Acts, and the Bye-laws of the local authorities. A regulation of the Factory Acts which is strictly enforced by most local authorities, requires the conveniences to be cut off from the main building by a free air space, and this is undoubtedly desirable from a sanitary point of view.

The foreman of a shop should have a desk and office in that shop. The position should be arranged so as to give him a convenient oversight over the whole of the men employed.

The office may consist of a portion of the shop railed off or of a small wood building glazed all round and raised above the general floor level so as to overlook the shop.

Dry grinding machinery is always to be exhausted by a fan.

Smith work is best done in a separate building. Light smiths' fires are supplied with exhausting fans to clear the smoke.

Wood-working shops may be fitted with exhausters to remove all waste, which is best delivered to the boiler house and destroyed.

As no work can be done cheaply without thorough gauging arrangements, the modern method is to use the limit gauge system, for which purpose every works must have a full set of accurate high-class gauges to be used with special care in testing the working gauges, which may be made of cheaper material, and rejected as wear places them out of the limit of accuracy required.

Finished parts should be inspected as made, and finished machines when ready for shipment.

The tool room is an essential department in a modern workshop. In it are kept all tools and gauges required, and every tool given out for use should have a check in its place in the tool room. Fixtures, belts, and other requisites for different tools should have a place on a shop stand, which may be simply a shelf or two of plate iron, supported by pipe framing. No accumulations must ever be allowed on the floors and in corners. Conical pointed buckets provided for dirty waste cannot be left standing about, but must always be in place in their ring stands.

Provision must be made for the prompt removal of all chips, especially if greasy. Where automatic machinery is employed, oil is pumped over the work by a pump in the machine itself. In some shops oil is supplied in pipes, and returns to the pumps through pipes by way of filters. Machines very freely supplied with oil for the tools should be stood on lead-protected floors to prevent oil soakage. Greasy chips can be purified of oil in a centrifugal machine.

In a large works a tool room in each room or on each floor may be required; but no more than actually needful should be provided. Preferably rooms should be as large and as few as possible. The tool room fully carried out includes much more than mere storing and providing tools; its duty is to lay out systems of doing work, and to collaborate with the drawing office in regard to materials and stores. It is in a sense not merely a part of the works: it is also a part of the managerial department.

The drawing office also should be more than a mere room for drawing. It is, or should be, the very centre of management, for from it should emanate design, orders for materials, and the intellectual work of the whole establishment, so that design may be kept in touch with materials, market prices, etc.

Where tools are belt driven, it is usual to employ a countershaft between line shaft and tool, but if the line shaft runs at 250 r.p.m., as a modern shaft may well do, the countershaft may be omitted; there would then be a fast-and-loose pulley on the machines themselves, and no cone pulleys, their place being taken by the all-gear headstock in the lathe.

Heavy lathes may be driven from built-in motors set across the bed, and driving through chains a worm shaft with a right and left worm driving worm wheels on each side of the face plate wheel, and pinions in the worm shafts driving this wheel.

The introduction of high-speed steel, with its great capacity for removal of metal and its large absorption of power, has completely changed conditions. In the lathe the tendency is to abandon the stepped belt cone and employ a single belt pulley, only driven, it may be, directly off the line shaft, speed variations being obtained by gearing. Motors are still frequently belted to a machine, but the tendency is towards making the motor an integral part of the machine it drives. Small tools are more economically group driven from a shaft and a single motor. Whether tools shall be driven in groups or by a single motor to each tool can only definitely be decided by the actual conditions of the case. Where every machine has its own motor the aggregate power of all the motors will be two or three times that of the current generating dynamo.

The application of electrical methods has tended to advance gas and compressed air and mechanical hammers to displace steam hammers; but for larger work the steam hammer is still imperative, being superior to any other hammer. But for the very largest work of forging, the hydraulic press now does the best work, and steam hammers are not made equal to dealing with the largest work now undertaken.

In place of hooks for lifting, shop cranes are sometimes fitted with electro-magnets for lifting plates or such articles as can be thus easily held. By this means time is economised, for there is no use for slings, and the load can be put down by the lift man without help from labourers to detach, simply by the turn of a switch.

For much work that is too heavy for easy movement, the machine tools are carried to the work. In this system the floor is of heavy cast-iron girder plates grooved like the platen of a planing machine. Work is laid upon this floor, and machine tools are bolted to the floor, and operate on the work. This is rendered possible by a system of electric driving, the motors being part of the machine. Machine tools may be attached to the work, and the designer should take this into consideration in his design, since by slight modifications the work may be made so as to facilitate such fixing of the tools.

FLOOR SPACE FOR MACHINE TOOLS.

Size. Machine.	Greatest No. of Machines per 1,000 sq. ft.
12 ins. to 20 ins. engine lathes, faced same way	20
12 ins. to 20 ins. engine lathes, back to back	24
22 ins. to 24 ins. planers, heads and tails	10
22 ins. to 24 ins. planers, faced same way	9
28 ins. to 30 ins. planers, faced same way	5
14 ins. multi-spindle drills	40
16 ins. to 20 ins. upright drills	36
26 ins. to 30 ins. upright drills	12
Small milling machines	36
Ordinary milling machines and automatic screw machines	20
Hand screw machines and plain and universal grinders	15
Polishing machines	24

The above areas are exclusive of main passage-ways, and if it is decided to run a 6 ft., 8 ft., or 10 ft. passage the entire length of building this area must be added.

Every tool in a workshop should be drawn in outline as regards its leading dimensions, and the drawing pasted on a suitable board together with the overall dimensions of the work it will take, the speeds, feeds, and other information for the drawing office.

The drawing office should be the repository of all information as to stock material; it should really include the stores and purchase department, and work in progress in the shop, and during erection should be visited by the draughtsmen chiefly concerned, so that needless costs and charges in manufacture and erection may be avoided.

Concrete Floors.

To deaden the noise from trucks rumbling over a concrete floor, use a heavy tar paper pasted to the floor by paint. The floor to be protected is first given one coating of grey cement paint. On the following day, when the paint is thoroughly dry, a second coat is applied. At the same time one side of a five-ply tar paper is painted; and when both paper and floor are still wet the paper is carefully laid, wet side down, on the floor and rolled with either a roller or wide-tired truck until all signs of air-pockets beneath the paper disappear. The surface improves with age, and very effectively reduces noise at a low cost.—*Contract Record.*

Oil stains on concrete floors may be removed by using a mixture of 1 lb. of oxalic acid in 3 gallons of water, with enough wheat flour added to make a paste that can be applied with a brush. Allow the application to remain for two days, and then remove it with clean water and a scrubbing brush. A second application may be necessary in stubborn cases.—*Building News.*

To remedy dusty concrete floors, a surface treatment of some kind should be applied to remove the surface skin which does not exceed $\frac{1}{32}$ in., or properly to treat it. One way is to grind the surface by hand or power as a terrazzo floor is polished. Other methods are to apply liquid coatings of various kinds. One of the most satisfactory treatments is with boiled linseed oil thinned with petrol to such a consistency that it will penetrate the pores of the surface. If one coat does not cure the trouble generally two will. A second method is to clean the surface thoroughly and then apply a coat of silicate of soda or water glass, 40 deg. Baumé, diluted one part to six of water, to seal the surface. Then wash off the excess which opens out the pores again and apply a second coat.

See also p. 495.

For making slippery iron floor plates reasonably safe under ordinary shop conditions, mix a small quantity of powdered sal ammoniac thoroughly with a large quantity of fine sand. Sprinkle the mixture over the floor so that all parts are covered, and damp the surface with a watering can and let it lie over a week-end, or even overnight, then sweep the sand up. The rust coating formed by the treatment will be found to last for several weeks, after which the process must be repeated.—*Ironmonger.*

Care of Factory Windows.

A number of tests of the reduction of daylight in factories has been made by the engineers of the Detroit Steel Products Company, Michigan. It was found that with vertical glass the transmission of light through the windows decreased rapidly during the first 20 days after cleaning, from a normal transmission of 80 per cent. for clean glass to 65 per cent. The decrease continued to 34 per cent. at the end of 120 days. Sloping glass collected more dirt. At slopes of 15°, 30°, and 45° the transmission of light decreased from 80 per cent. to 60, 55, and 50 per cent. respectively, in the first 20 days, and to 25, 19, and 16 per cent. at the end of 120 days. Whilst at first sloping windows on a roof admit more light than an equal area on the vertical, this advantage is lost at the end of six months. Owing to wind and rain about one-fourth of the dirt is found on the outer surface and three-fourths on the inner. Factory windows should therefore be washed more often on the inside than on the outside. The autumn, not the spring, is the right time for washing, as during the dark winter months the windows will have been recently cleaned. So far as collection of dirt is concerned there is not much difference between various types of glass, but ribbed and figured glasses are much harder to clean. The roughened side of the glass should be outside, as less dirt collects on that side.

(*W. C. Randall and A. J. Martin*, '*American Ill. Eng. Soc.*,' vol. 22, 1927, pp. 239–253.)

Electric Power Driving.

Where many small machines are placed near together and driven more or less intermittently, one small line shaft and one motor will drive all the little machines, and the motor will be of far less cost and power than the aggregate of motors if applied one to each machine. But for large machines, single motors to each machine are a decided economy.—*C. H. Benjamin.*

The Use of High-Pressure Gas in Works.

A satisfactory arrangement is to have a shop supplied with gas at 200 ins. pressure, to be reduced at the various furnaces, etc., by means of governors or valves, to the predetermined pressure corresponding with the temperature it is desired to maintain in each furnace. Pressures suitable for typical work are as follows:—For melting tin or solder a pressure of 65 ins.; for small furnaces for hardening, etc., the same pressure may be used; for blueing steel, from 65 ins. to 80 ins., the flames playing horizontally under the lime-tray set in a brick frame; for the lead-pot for tempering steel the pressure should be 150 ins.; while for melting metals at from 2000° to 2000° F. it should be 200 ins. Soldering-irons may be heated with gas at 65 ins.; two burners, consuming 6 ft. of gas per hour, and playing direct on to the irons, being sufficient to keep a workman going without delays. For lighting, gas at 65 ins. may be used.

With gas at 2*s.* per 1,000 and coal at 20*s.* per ton there is little to choose between gas and coal firing as regards cost. As regards cleanliness, uniformity, etc., the advantages are, however, in favour of gas, and in many cases with properly-designed furnaces it is greatly superior to coal, not only from the point of view of cost, but from convenience and ease of manipulation. A properly-designed gas-furnace will enable the time of preparation from the cold to be greatly shortened.—*A. W. Onslow.*

WORKSHOP PRACTICE.

Limits and Limit Gauges.

There are four usual 'fits' in practical mechanics, namely—

The *force* fit, which requires a screw, a hydraulic press, or the use of heat on one piece to get the fits together. The *drive* fit, which can be done by a hammer. The *push* fit, which can be pushed together by hand, and may even be revolved slowly, but would heat and seize if run for any time; and the *running* fit, which will run indefinitely if lubricated, and varies with the class of work. Running fits may be divided into several classes, and are classed in three divisions by the Newall Engineering Co.

The provision of a separate external limit gauge for each and every diameter used—and for each variation in the quality of fit required on such diameter—would entail in most cases an expenditure so heavy as to practically prohibit the installation of a full equipment; yet in modern commercial production efficient means of gauging work are imperative, and, to overcome the necessity for the multiplicity of external limit gauges required, an adjustable type was specially designed and introduced by the Newall Engineering Co. These being adjustable, they are not affected by wear as are all solid gauges.

The gauge has two fixed anvils on one jaw and two movable anvils (adjusting screws) on the other jaw, forming two pairs of measuring faces, the front pair being the 'go' and the back pair the 'not go' points; the adjusting screws are securely locked in position by means of cotters and nuts of special design. Each gauge, by the length of travel of its adjusting screws, covers a range of sizes, and can be easily and quickly set up to such diameter and limits within its range as may be wanted.

There are two methods of setting up or adjusting the measuring points. The first is by means of limit reference bars ground to the 'high' and 'low' limits for the different allowances prescribed in standard tables. The other method is with standard reference bars and 'setting dials'; the adjusting screws of the external limit gauges have taper holes in their inner ends, and the dials are provided with taper shanks which fit into these holes. The 'go' and 'not go' points of the gauge are set to a standard reference bar (or other reliable standard) of the nominal size required; the adjusting screws are then locked and the dial and index inserted at zero. The screw carrying the dial is released and can be adjusted to the desired allowance, either above or below 'standard,' by rotating the screw in the plus or minus direction, as shown by the arrows on the index. This screw is then locked, the dial and index transposed, and the process repeated with the other screw. For English sizes the dials are divided to read by 0·00025 in., and for metric sizes by 0·01 mm. One pair will serve for all gauges up to 6 ins., or 150 mm.; gauges over these sizes require a larger pair.

Definitions as given by the British Engineering Standards Association:—*Tolerance*—a difference in dimensions prescribed in order to tolerate unavoidable imperfections of workmanship. *Allowance*—a difference in dimensions prescribed in order to allow of various qualities of fit.

British Standard Limits and Fits for Engineering.*

(No. 164—1924.)

(*Abstract.*)

In 1906, Report No. 27 on British Standard systems for limit gauges was issued. In this Report the shaft was recommended as the constant member, but the recommendation was not generally adopted by the engineering industry. In 1917, therefore, a Committee was appointed to revise the Report, and to consider the whole question of limits for cylindrical work for the engineering industry in general. The present Report is the work of that Committee and is in substitution of Report 27—1906.

The Committee has unanimously decided to reverse the previous decision and to recommend the adoption of the hole as the constant member.

This is generally referred to as the 'hole basis' when speaking of a system of limits, and the principal table of standards will give the tolerances appropriate to holes of different sizes and different grades of workmanship, so that all holes of the same nominal size and same specified grade will be interchangeable.

* By permission of the British Engineering Standards Association.

TABLE 1.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING.

UNILATERAL, BILATERAL, AND OVERSIZE HOLES. (British System—Inches.)

All Dimensions except Nominal Sizes are expressed in thousandths of an inch.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Size Multiplier.	Nominal Sizes.	UNILATERAL HOLES. (In which the Low Limit of the Hole is Nominal Size.)								BILATERAL HOLES. (In which the Nominal Size of the Hole lies between the High and Low Limits.)								OVERSIZE HOLES. (In which the Low Limit of the Hole is larger than the Nominal Size.)						Non-Mating Holes and Shafts.	
		B		U		V		W		K		X		Y		Z		A		G		H		J	
m	Inches.	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
3	0 to 0·29	+0·3	0	+0·6	0	+1·2	0	+ 2·4	0	+0·1	−0·2	+0·3	−0·3	+0·6	−0·6	+1·2	−1·2	+1·2	+0·6	+ 1·8	+1·2	+ 2·4	+ 1·8	+ 3·0	− 3·0
4	0·3 „ 0·59	+0·4	0	+0·8	0	+1·6	0	+ 3·2	0	+0·2	−0·2	+0·4	−0·4	+0·8	−0·8	+1·6	−1·6	+1·6	+0·8	+ 2·4	+1·6	+ 3·2	+ 2·4	+ 4·0	− 4·0
5	0·6 „ 0·99	+0·5	0	+1·0	0	+2·0	0	+ 4·0	0	+0·2	−0·3	+0·5	−0·5	+1·0	−1·0	+2·0	−2·0	+2·0	+1·0	+ 3·0	+2·0	+ 4·0	+ 3·0	+ 5·0	− 5·0
6	1·0 „ 1·49	+0·6	0	+1·2	0	+2·4	0	+ 4·8	0	+0·3	−0·3	+0·6	−0·6	+1·2	−1·2	+2·4	−2·4	+2·4	+1·2	+ 3·6	+2·4	+ 4·8	+ 3·6	+ 6·0	− 6·0
7	1·5 „ 2·09	+0·7	0	+1·4	0	+2·8	0	+ 5·6	0	+0·3	−0·4	+0·7	−0·7	+1·4	−1·4	+2·8	−2·8	+2·8	+1·4	+ 4·2	+2·8	+ 5·6	+ 4·2	+ 7·0	− 7·0
8	2·1 „ 2·79	+0·8	0	+1·6	0	+3·2	0	+ 6·4	0	+0·4	−0·4	+0·8	−0·8	+1·6	−1·6	+3·2	−3·2	+3·2	+1·6	+ 4·8	+3·2	+ 6·4	+ 4·8	+ 8·0	− 8·0
9	2·8 „ 3·59	+0·9	0	+1·8	0	+3·6	0	+ 7·2	0	+0·4	−0·5	+0·9	−0·9	+1·8	−1·8	+3·6	−3·6	+3·6	+1·8	+ 5·4	+3·6	+ 7·2	+ 5·4	+ 9·0	− 9·0
10	3·6 „ 4·49	+1·0	0	+2·0	0	+4·0	0	+ 8·0	0	+0·5	−0·5	+1·0	−1·0	+2·0	−2·0	+4·0	−4·0	+4·0	+2·0	+ 6·0	+4·0	+ 8·0	+ 6·0	+10·0	−10·0
11	4·5 „ 5·49	+1·1	0	+2·2	0	+4·4	0	+ 8·8	0	+0·5	−0·6	+1·1	−1·1	+2·2	−2·2	+4·4	−4·4	+4·4	+2·2	+ 6·6	+4·4	+ 8·8	+ 6·6	+11·0	−11·0
12	5·5 „ 6·59	+1·2	0	+2·4	0	+4·8	0	+ 9·6	0	+0·6	−0·6	+1·2	−1·2	+2·4	−2·4	+4·8	−4·8	+4·8	+2·4	+ 7·2	+4·8	+ 9·6	+ 7·2	+12·0	−12·0
13	6·6 „ 7·79	+1·3	0	+2·6	0	+5·2	0	+10·4	0	+0·6	−0·7	+1·3	−1·3	+2·6	−2·6	+5·2	−5·2	+5·2	+2·6	+ 7·8	+5·2	+10·4	+ 7·8	+13·0	−13·0
14	7·8 „ 9·09	+1·4	0	+2·8	0	+5·6	0	+11·2	0	+0·7	−0·7	+1·4	−1·4	+2·8	−2·8	+5·6	−5·6	+5·6	+2·8	+ 8·4	+5·6	+11·2	+ 8·4	+14·0	−14·0
15	9·1 „ 10·49	+1·5	0	+3·0	0	+6·0	0	+12·0	0	+0·7	−0·8	+1·5	−1·5	+3·0	−3·0	+6·0	−6·0	+6·0	+3·0	+ 9·0	+6·0	+12·0	+ 9·0	+15·0	−15·0
16	10·5 „ 11·99	+1·6	0	+3·2	0	+6·4	0	+12·8	0	+0·8	−0·8	+1·6	−1·6	+3·2	−3·2	+6·4	−6·4	+6·4	+3·2	+ 9·6	+6·4	+12·8	+ 9·6	+16·0	−16·0
17	12·0 „ 13·59	+1·7	0	+3·4	0	+6·8	0	+13·6	0	+0·8	−0·9	+1·7	−1·7	+3·4	−3·4	+6·8	−6·8	+6·8	+3·4	+10·2	+6·8	+13·6	+10·2	+17·0	−17·0
18	13·6 „ 15·29	+1·8	0	+3·6	0	+7·2	0	+14·4	0	+0·9	−0·9	+1·8	−1·8	+3·6	−3·6	+7·2	−7·2	+7·2	+3·6	+10·8	+7·2	+14·4	+10·8	+18·0	−18·0
19	15·3 „ 17·09	+1·9	0	+3·8	0	+7·6	0	+15·2	0	+0·9	−1·0	+1·9	−1·9	+3·8	−3·8	+7·6	−7·6	+7·6	+3·8	+11·4	+7·6	+15·2	+11·4	+19·0	−19·0
20	17·1 „ 18·99	+2·0	0	+4·0	0	+8·0	0	+16·0	0	+1·0	−1·0	+2·0	−2·0	+4·0	−4·0	+8·0	−8·0	+8·0	+4·0	+12·0	+8·0	+16·0	+12·0	+20·0	−20·0
21	19·0 „ 20·99	+2·1	0	+4·2	0	+8·4	0	+16·8	0	+1·0	−1·1	+2·1	−2·1	+4·2	−4·2	+8·4	−8·4	+8·4	+4·2	+12·6	+8·4	+16·8	+12·6	+21·0	−21·0
22	21·0 „ 23·09	+2·2	0	+4·4	0	+8·8	0	+17·6	0	+1·1	−1·1	+2·2	−2·2	+4·4	−4·4	+8·8	−8·8	+8·8	+4·4	+13·2	+8·8	+17·6	+13·2	+22·0	−22·0
23	23·1 „ 25·29	+2·3	0	+4·6	0	+9·2	0	+18·4	0	+1·1	−1·2	+2·3	−2·3	+4·6	−4·6	+9·2	−9·2	+9·2	+4·6	+13·8	+9·2	+18·4	+13·8	+23·0	−23·0
RANGE FACTOR, r		+·1	0	+·2	0	+·4	0	+·8	0	+·05	−·05	+·1	−·1	+·2	−·2	+·4	−·4	+·4	+·2	+·6	+·4	+·8	+·6	+1·0	−1·0

H = High Limit of Tolerance; L = Low Limit of Tolerance; the sign + or − below the symbols H and L indicates whether the limits are positive or negative.

TABLE II.—BRITISH STANDARD LIMITS AND FITS FOR ENGINEERING. STANDARD SHAFTS.
For use with either Unilateral, Bilateral or Oversize Holes. (British System—Inches.)
All Dimensions except Nominal Sizes are expressed in thousandths of an inch.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size Multiplier.	Nominal Sizes.	F		E		D		C		B		K		L		P		M		Q		R		S		T		TT	
m	Inches.	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
3	0 to 0·29	+1·2	+0·9	+0·9	+0·6	+0·6	+0·3	+0·4	+0·1	+0·3	0	+0·1	−0·2	0	−0·3	−0·2	−0·5	−0·3	−0·6	−0·5	−0·9	−0·9	−1·5	−1·5	−2·4	−2·4	−3·6	−3·6	−6·0
4	0·3 „ 0·59	+1·6	+1·2	+1·2	+0·8	+0·8	+0·4	+0·6	+0·2	+0·4	0	+0·2	−0·2	0	−0·4	−0·2	−0·6	−0·4	−0·8	−0·6	−1·2	−1·2	−2·0	−2·0	−3·2	−3·2	−4·8	−4·8	−8·0
5	0·6 „ 0·99	+2·0	+1·5	+1·5	+1·0	+1·0	+0·5	+0·7	+0·2	+0·5	0	+0·2	−0·3	0	−0·5	−0·3	−0·8	−0·5	−1·0	−0·8	−1·5	−1·5	−2·5	−2·5	−4·0	−4·0	−6·0	−6·0	−10·0
6	1·0 „ 1·49	+2·4	+1·8	+1·8	+1·2	+1·2	+0·6	+0·9	+0·3	+0·6	0	+0·3	−0·3	0	−0·6	−0·3	−0·9	−0·6	−1·2	−0·9	−1·8	−1·8	−3·0	−3·0	−4·8	−4·8	−7·2	−7·2	−12·0
7	1·5 „ 2·09	+2·8	+2·1	+2·1	+1·4	+1·4	+0·7	+1·0	+0·3	+0·7	0	+0·3	−0·4	0	−0·7	−0·4	−1·1	−0·7	−1·4	−1·1	−2·1	−2·1	−3·5	−3·5	−5·6	−5·6	−8·4	−8·4	−14·0
8	2·1 „ 2·79	+3·2	+2·4	+2·4	+1·6	+1·6	+0·8	+1·2	+0·4	+0·8	0	+0·4	−0·4	0	−0·8	−0·4	−1·2	−0·8	−1·6	−1·2	−2·4	−2·4	−4·0	−4·0	−6·4	−6·4	−9·6	−9·6	−16·0
9	2·8 „ 3·59	+3·6	+2·7	+2·7	+1·8	+1·8	+0·9	+1·3	+0·4	+0·9	0	+0·4	−0·5	0	−0·9	−0·5	−1·4	−0·9	−1·8	−1·4	−2·7	−2·7	−4·5	−4·5	−7·2	−7·2	−10·8	−10·8	−18·0
10	3·6 „ 4·49	+4·0	+3·0	+3·0	+2·0	+2·0	+1·0	+1·5	+0·5	+1·0	0	+0·5	−0·5	0	−1·0	−0·5	−1·5	−1·0	−2·0	−1·5	−3·0	−3·0	−5·0	−5·0	−8·0	−8·0	−12·0	−12·0	−20·0
11	4·5 „ 5·49	+4·4	+3·3	+3·3	+2·2	+2·2	+1·1	+1·6	+0·5	+1·1	0	+0·5	−0·6	0	−1·1	−0·6	−1·7	−1·1	−2·2	−1·7	−3·3	−3·3	−5·5	−5·5	−8·8	−8·8	−13·2	−13·2	−22·0
12	5·5 „ 6·59	+4·8	+3·6	+3·6	+2·4	+2·4	+1·2	+1·8	+0·6	+1·2	0	+0·6	−0·6	0	−1·2	−0·6	−1·8	−1·2	−2·4	−1·8	−3·6	−3·6	−6·0	−6·0	−9·6	−9·6	−14·4	−14·4	−24·0
13	6·6 „ 7·79	+5·2	+3·9	+3·9	+2·6	+2·6	+1·3	+1·9	+0·6	+1·3	0	+0·6	−0·7	0	−1·3	−0·7	−2·0	−1·3	−2·6	−2·0	−3·9	−3·9	−6·5	−6·5	−10·4	−10·4	−15·6	−15·6	−26·0
14	7·8 „ 9·09	+5·6	+4·2	+4·2	+2·8	+2·8	+1·4	+2·1	+0·7	+1·4	0	+0·7	−0·7	0	−1·4	−0·7	−2·1	−1·4	−2·8	−2·1	−4·2	−4·2	−7·0	−7·0	−11·2	−11·2	−16·8	−16·8	−28·0
15	9·1 „ 10·49	+6·0	+4·5	+4·5	+3·0	+3·0	+1·5	+2·2	+0·7	+1·5	0	+0·7	−0·8	0	−1·5	−0·8	−2·3	−1·5	−3·0	−2·3	−4·5	−4·5	−7·5	−7·5	−12·0	−12·0	−18·0	−18·0	−30·0
16	10·5 „ 11·99	+6·4	+4·8	+4·8	+3·2	+3·2	+1·6	+2·4	+0·8	+1·6	0	+0·8	−0·8	0	−1·6	−0·8	−2·4	−1·6	−3·2	−2·4	−4·8	−4·8	−8·0	−8·0	−12·8	−12·8	−19·2	−19·2	−32·0
17	12·0 „ 13·59	+6·8	+5·1	+5·1	+3·4	+3·4	+1·7	+2·5	+0·8	+1·7	0	+0·8	−0·9	0	−1·7	−0·9	−2·6	−1·7	−3·4	−2·6	−5·1	−5·1	−8·5	−8·5	−13·6	−13·6	−20·4	−20·4	−34·0
18	13·6 „ 15·29	+7·2	+5·4	+5·4	+3·6	+3·6	+1·8	+2·7	+0·9	+1·8	0	+0·9	−0·9	0	−1·8	−0·9	−2·7	−1·8	−3·6	−2·7	−5·4	−5·4	−9·0	−9·0	−14·4	−14·4	−21·6	−21·6	−36·0
19	15·3 „ 17·09	+7·6	+5·7	+5·7	+3·8	+3·8	+1·9	+2·8	+0·9	+1·9	0	+0·9	−1·0	0	−1·9	−1·0	−2·9	−1·9	−3·8	−2·9	−5·7	−5·7	−9·5	−9·5	−15·2	−15·2	−22·8	−22·8	−38·0
20	17·1 „ 18·99	+8·0	+6·0	+6·0	+4·0	+4·0	+2·0	+3·0	+1·0	+2·0	0	+1·0	−1·0	0	−2·0	−1·0	−3·0	−2·0	−4·0	−3·0	−6·0	−6·0	−10·0	−10·0	−16·0	−16·0	−24·0	−24·0	−40·0
21	19·0 „ 20·99	+8·4	+6·3	+6·3	+4·2	+4·2	+2·1	+3·1	+1·0	+2·1	0	+1·0	−1·1	0	−2·1	−1·1	−3·2	−2·1	−4·2	−3·2	−6·3	−6·3	−10·5	−10·5	−16·8	−16·8	−25·2	−25·2	−42·0
22	21·0 „ 23·09	+8·8	+6·6	+6·6	+4·4	+4·4	+2·2	+3·3	+1·1	+2·2	0	+1·1	−1·1	0	−2·2	−1·1	−3·3	−2·2	−4·4	−3·3	−6·6	−6·6	−11·0	−11·0	−17·6	−17·6	−26·4	−26·4	−44·0
23	23·1 „ 25·29	+9·2	+6·9	+6·9	+4·6	+4·6	+2·3	+3·4	+1·1	+2·3	0	+1·1	−1·2	0	−2·3	−1·2	−3·5	−2·3	−4·6	−3·5	−6·9	−6·9	−11·5	−11·5	−18·4	−18·4	−27·6	−27·6	−46·0
RANGE FACTOR, r		+·4	+·3	+·3	+·2	+·2	+·1	+·15	+·05	+·1	0	+·05	−·05	0	−·1	−·05	−·15	−·1	−·2	−·15	−·3	−·3	−·5	−·5	−·8	−·8	−1·2	−1·2	−2·0

H = High Limit of Tolerance; L = Low Limit of Tolerance; The sign + or − below the Symbols H and L indicates whether the limits are positive or negative.

TABLE III.—BRITISH STANDARD LIMITS FOR ENGINEERING.

FITS OF STANDARD SHAFTS IN "U" AND "X" HOLES. (British System—Inches.)

All Dimensions except Nominal Sizes are expressed in thousandths of an inch.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Size Multiplier.	Nominal Sizes.	STANDARD SHAFTS IN UNILATERAL "U" HOLES.														STANDARD SHAFTS IN BILATERAL "X" HOLES.													
m	Inches.	UF	UE	UD	UC	UB	UA	UL	UP	UM	UQ	UR	US	UT	UTT	XF	XE	XD	XC	XB	XA	XL	XP	XM	XQ	XR	XS	XT	XTT
3	0 to 0·29	−1·2 −0·3	−0·9 0	−0·6 +0·3	−0·4 +0·5	−0·3 +0·6	−0·1 +0·8	0 +0·9	+0·2 +1·1	+0·3 +1·2	+0·5 +1·5	+0·9 +2·1	+1·5 +3·0	+2·4 +4·2	+3·6 +6·6	−1·5 −0·6	−1·2 −0·3	−0·9 0	−0·7 +0·2	−0·6 +0·3	−0·4 +0·5	−0·3 +0·6	−0·1 +0·8	0 +0·9	+0·2 +1·2	+0·6 +1·8	+1·2 +2·7	+2·1 +3·9	+3·3 +6·3
4	0·3 „ 0·59	−1·6 −0·4	−1·2 0	−0·8 +0·4	−0·6 +0·6	−0·4 +0·8	−0·2 +1·0	0 +1·2	+0·2 +1·4	+0·4 +1·6	+0·6 +2·0	+1·2 +2·8	+2·0 +4·0	+3·2 +5·6	+4·8 +8·8	−2·0 −0·8	−1·6 −0·4	−1·2 0	−1·0 +0·2	−0·8 +0·4	−0·6 +0·6	−0·4 +0·8	−0·2 +1·0	0 +1·2	+0·2 +1·6	+0·8 +2·4	+1·6 +3·6	+2·8 +5·2	+4·4 +8·4
5	0·6 „ 0·99	−2·0 −0·5	−1·5 0	−1·0 +0·5	−0·7 +0·8	−0·5 +1·0	−0·2 +1·3	0 +1·5	+0·3 +1·8	+0·5 +2·0	+0·8 +2·5	+1·5 +3·5	+2·5 +5·0	+4·0 +7·0	+6·0 +11·0	−2·5 −1·0	−2·0 0	−1·5 +0·3	−1·2 +0·5	−1·0 +0·8	−0·7 +1·0	−0·5 +1·3	−0·2 +1·5	0 +2·0	+0·3 +2·0	+1·0 +3·0	+2·0 +4·5	+3·5 +6·5	+5·5 +10·5
6	1·0 „ 1·49	−2·4 −0·6	−1·8 0	−1·2 +0·6	−0·9 +0·9	−0·6 +1·2	−0·3 +1·5	0 +1·8	+0·3 +2·1	+0·6 +2·4	+0·9 +3·0	+1·8 +4·2	+3·0 +6·0	+4·8 +8·4	+7·2 +13·2	−3·0 −1·2	−2·4 −0·6	−1·8 0	−1·5 +0·3	−1·2 +0·6	−0·9 +0·9	−0·6 +1·2	−0·3 +1·5	0 +1·8	+0·3 +2·4	+1·2 +3·6	+2·4 +5·4	+4·2 +7·8	+6·6 +12·6
7	1·5 „ 2·09	−2·8 −0·7	−2·1 0	−1·4 +0·7	−1·0 +1·1	−0·7 +1·4	−0·3 +1·8	0 +2·1	+0·4 +2·5	+0·7 +2·8	+1·1 +3·5	+2·1 +4·9	+3·5 +7·0	+5·6 +9·8	+8·4 +15·4	−3·5 −1·4	−2·8 −0·7	−2·1 0	−1·7 +0·4	−1·4 +0·7	−1·0 +1·1	−0·7 +1·4	−0·3 +1·8	0 +2·1	+0·4 +2·8	+1·4 +4·2	+2·8 +6·3	+4·9 +9·1	+7·7 +14·7
8	2·1 „ 2·79	−3·2 −0·8	−2·4 0	−1·6 +0·8	−1·2 +1·2	−0·8 +1·6	−0·4 +2·0	0 +2·4	+0·4 +2·8	+0·8 +3·2	+1·2 +4·0	+2·4 +5·6	+4·0 +8·0	+6·4 +11·2	+9·6 +17·6	−4·0 −1·6	−3·2 −0·8	−2·4 0	−2·0 +0·4	−1·6 +0·8	−1·2 +1·2	−0·8 +1·6	−0·4 +2·0	0 +2·4	+0·4 +3·2	+1·6 +4·8	+3·2 +7·2	+5·6 +10·4	+8·8 +16·8
9	2·8 „ 3·59	−3·6 −0·9	−2·7 0	−1·8 +0·9	−1·3 +1·4	−0·9 +1·8	−0·4 +2·3	0 +2·7	+0·5 +3·2	+0·9 +3·6	+1·4 +4·5	+2·7 +6·3	+4·5 +9·0	+7·2 +12·6	+10·8 +19·8	−4·5 −1·8	−3·6 −0·9	−2·7 0	−2·2 +0·5	−1·8 +0·9	−1·3 +1·4	−0·9 +1·8	−0·4 +2·3	0 +2·7	+0·5 +3·6	+1·8 +5·4	+3·6 +8·1	+6·3 +11·7	+9·9 +18·9
10	3·6 „ 4·49	−4·0 −1·0	−3·0 0	−2·0 +1·0	−1·5 +1·5	−1·0 +2·0	−0·5 +2·5	0 +3·0	+0·5 +3·5	+1·0 +4·0	+1·5 +5·0	+3·0 +7·0	+5·0 +10·0	+8·0 +14·0	+12·0 +22·0	−5·0 −2·0	−4·0 −1·0	−3·0 0	−2·5 +0·5	−2·0 +1·0	−1·5 +1·5	−1·0 +2·0	−0·5 +2·5	0 +3·0	+0·5 +4·0	+2·0 +6·0	+4·0 +9·0	+7·0 +13·0	+11·0 +21·0
11	4·5 „ 5·49	−4·4 −1·1	−3·3 0	−2·2 +1·1	−1·6 +1·7	−1·1 +2·2	−0·5 +2·8	0 +3·3	+0·6 +3·9	+1·1 +4·4	+1·7 +5·5	+3·3 +7·7	+5·5 +11·0	+8·8 +15·4	+13·2 +24·2	−5·5 −2·2	−4·4 −1·1	−3·3 0	−2·7 +0·6	−2·2 +1·1	−1·6 +1·7	−1·1 +2·2	−0·5 +2·8	0 +3·3	+0·6 +4·4	+2·2 +6·6	+4·4 +9·9	+7·7 +14·3	+12·1 +23·1
12	5·5 „ 6·59	−4·8 −1·2	−3·6 0	−2·4 +1·2	−1·8 +1·8	−1·2 +2·4	−0·6 +3·0	0 +3·6	+0·6 +4·2	+1·2 +4·8	+1·8 +6·0	+3·6 +8·4	+6·0 +12·0	+9·6 +16·8	+14·4 +26·4	−6·0 −2·4	−4·8 −1·2	−3·6 0	−3·0 +0·6	−2·4 +1·2	−1·8 +1·8	−1·2 +2·4	−0·6 +3·0	0 +3·6	+0·6 +4·8	+2·4 +7·2	+4·8 +10·8	+8·4 +15·6	+13·2 +25·2
13	6·6 „ 7·79	−5·2 −1·3	−3·9 0	−2·6 +1·3	−1·9 +2·0	−1·3 +2·6	−0·6 +3·3	0 +3·9	+0·7 +4·6	+1·3 +5·2	+2·0 +6·5	+3·9 +9·1	+6·5 +13·0	+10·4 +18·2	+15·6 +28·6	−6·5 −2·6	−5·2 −1·3	−3·9 0	−3·2 +0·7	−2·6 +1·3	−1·9 +2·0	−1·3 +2·6	−0·6 +3·3	0 +3·9	+0·7 +5·2	+2·6 +7·8	+5·2 +11·7	+9·1 +16·9	+14·3 +27·3
14	7·8 „ 9·09	−5·6 −1·4	−4·2 0	−2·8 +1·4	−2·1 +2·1	−1·4 +2·8	−0·7 +3·5	0 +4·2	+0·7 +4·9	+1·4 +5·6	+2·1 +7·0	+4·2 +9·8	+7·0 +14·0	+11·2 +19·6	+16·8 +30·8	−7·0 −2·8	−5·6 −1·4	−4·2 0	−3·5 +0·7	−2·8 +1·4	−2·1 +2·1	−1·4 +2·8	−0·7 +3·5	0 +4·2	+0·7 +5·6	+2·8 +8·4	+5·6 +12·6	+9·8 +18·2	+15·4 +29·4
15	9·1 „ 10·49	−6·0 −1·5	−4·5 0	−3·0 +1·5	−2·2 +2·3	−1·5 +3·0	−0·7 +3·8	0 +4·5	+0·8 +5·3	+1·5 +6·0	+2·3 +7·5	+4·5 +10·5	+7·5 +15·0	+12·0 +21·0	+18·0 +33·0	−7·5 −3·0	−6·0 −1·5	−4·5 0	−3·7 +0·8	−3·0 +1·5	−2·2 +2·3	−1·5 +3·0	−0·7 +3·8	0 +4·5	+0·8 +6·0	+3·0 +9·0	+6·0 +13·5	+10·5 +19·5	+16·5 +31·5
16	10·5 „ 11·99	−6·4 −1·6	−4·8 0	−3·2 +1·6	−2·4 +2·4	−1·6 +3·2	−0·8 +4·0	0 +4·8	+0·8 +5·6	+1·6 +6·4	+2·4 +8·0	+4·8 +11·2	+8·0 +16·0	+12·8 +22·4	+19·2 +35·2	−8·0 −3·2	−6·4 −1·6	−4·8 0	−4·0 +0·8	−3·2 +1·6	−2·4 +2·4	−1·6 +3·2	−0·8 +4·0	0 +4·8	+0·8 +6·4	+3·2 +9·6	+6·4 +14·4	+11·2 +20·8	+17·6 +33·6
17	12·0 „ 13·59	−6·8 −1·7	−5·1 0	−3·4 +1·7	−2·5 +2·6	−1·7 +3·4	−0·8 +4·3	0 +5·1	+0·9 +6·0	+1·7 +6·8	+2·6 +8·5	+5·1 +11·9	+8·5 +17·0	+13·6 +23·8	+20·4 +37·4	−8·5 −3·4	−6·8 −1·7	−5·1 0	−4·2 +0·9	−3·4 +1·7	−2·5 +2·6	−1·7 +3·4	−0·8 +4·3	0 +5·1	+0·9 +6·8	+3·4 +10·2	+6·8 +15·3	+11·9 +22·1	+18·7 +35·7
18	13·6 „ 15·29	−7·2 −1·8	−5·4 0	−3·6 +1·8	−2·7 +2·7	−1·8 +3·6	−0·9 +4·5	0 +5·4	+0·9 +6·3	+1·8 +7·2	+2·7 +9·0	+5·4 +12·6	+9·0 +18·0	+14·4 +25·2	+21·6 +39·6	−9·0 −3·6	−7·2 −1·8	−5·4 0	−4·5 +0·9	−3·6 +1·8	−2·7 +2·7	−1·8 +3·6	−0·9 +4·5	0 +5·4	+0·9 +7·2	+3·6 +10·8	+7·2 +16·2	+12·6 +23·4	+19·8 +37·8
19	15·3 „ 17·09	−7·6 −1·9	−5·7 0	−3·8 +1·9	−2·8 +2·9	−1·9 +3·8	−0·9 +4·8	0 +5·7	+1·0 +6·7	+1·9 +7·6	+2·9 +9·5	+5·7 +13·3	+9·5 +19·0	+15·2 +26·6	+22·8 +41·8	−9·5 −3·8	−7·6 −1·9	−5·7 0	−4·7 +1·0	−3·8 +1·9	−2·8 +2·9	−1·9 +3·8	−0·9 +4·8	0 +5·7	+1·0 +7·6	+3·8 +11·4	+7·6 +17·1	+13·3 +24·7	+20·9 +39·9
20	17·1 „ 18·99	−8·0 −2·0	−6·0 0	−4·0 +2·0	−3·0 +3·0	−2·0 +4·0	−1·0 +5·0	0 +6·0	+1·0 +7·0	+2·0 +8·0	+3·0 +10·0	+6·0 +14·0	+10·0 +20·0	+16·0 +28·0	+24·0 +44·0	−10·0 −4·0	−8·0 −2·0	−6·0 0	−5·0 +1·0	−4·0 +2·0	−3·0 +3·0	−2·0 +4·0	−1·0 +5·0	0 +6·0	+1·0 +8·0	+4·0 +12·0	+8·0 +18·0	+14·0 +26·0	+22·0 +42·0
21	19·0 „ 20·99	−8·4 −2·1	−6·3 0	−4·2 +2·1	−3·1 +3·2	−2·1 +4·2	−1·0 +5·3	0 +6·3	+1·1 +7·4	+2·1 +8·4	+3·2 +10·5	+6·3 +14·7	+10·5 +21·0	+16·8 +29·4	+25·2 +46·2	−10·5 −4·2	−8·4 −2·1	−6·3 0	−5·2 +1·1	−4·2 +2·1	−3·1 +3·2	−2·1 +4·2	−1·0 +5·3	0 +6·3	+1·1 +8·4	+4·2 +12·6	+8·4 +18·9	+14·7 +27·3	+23·1 +44·1
22	21·0 „ 23·09	−8·8 −2·2	−6·6 0	−4·4 +2·2	−3·3 +3·3	−2·2 +4·4	−1·1 +5·5	0 +6·6	+1·1 +7·7	+2·2 +8·8	+3·3 +11·0	+6·6 +15·4	+11·0 +22·0	+17·6 +30·8	+26·4 +48·4	−11·0 −4·4	−8·8 −2·2	−6·6 0	−5·5 +1·1	−4·4 +2·2	−3·3 +3·3	−2·2 +4·4	−1·1 +5·5	0 +6·6	+1·1 +8·8	+4·4 +13·2	+8·8 +19·8	+15·4 +28·6	+24·2 +46·2
23	23·1 „ 25·29	−9·2 −2·3	−6·9 0	−4·6 +2·3	−3·4 +3·5	−2·3 +4·6	−1·1 +5·8	0 +6·9	+1·2 +8·1	+2·3 +9·2	+3·5 +11·5	+6·9 +16·1	+11·5 +23·0	+18·4 +32·2	+27·6 +50·6	−11·5 −4·6	−9·2 −2·3	−6·9 0	−5·7 +1·2	−4·6 +2·3	−3·4 +3·5	−2·3 +4·6	−1·1 +5·8	0 +6·9	+1·2 +9·2	+4·6 +13·8	+9·2 +20·7	+16·1 +29·9	+25·3 +48·3

+ = Clearance; − = Interference; the upper figures in each square represent the Minimum, the lower figures the Maximum, Limit of Fit.

Two systems are in common use. In the unilateral system the tolerance is in one direction only from the nominal size and is usually positive: that is to say, every hole in the unilateral system is of the nominal size or larger. In the bilateral system the tolerance extends in both directions (but not always in equal amounts) from the nominal size: that is to say, holes in the bilateral system may be smaller or larger than the nominal size.

The Committee has unanimously agreed to recommend the use of the unilateral system as applied to cylindrical mating surfaces in cases where it does not conflict with predominating present practice.

In deciding on the system of gauging and the amount of the tolerances to be employed, it is important to distinguish between mating surfaces, in which the inter-relation between the surfaces in contact is the guiding feature, and non-mating surfaces in which only one surface has to be considered. The tables in the present report refer primarily to mating surfaces.

2. Table I gives both unilateral and bilateral limits of tolerance for holes. In the unilateral system, the nominal size is the low limit of the hole; in the bilateral system, the nominal size lies between the high and low limits of the hole.

3. Table II gives the recommended limits of tolerance for a standard series of graduated shafts suitable for pairing with either the unilateral or bilateral holes. Table III shows the numerical values of the limits of fit resulting from the assembly of any one of the standard shafts in a particular unilateral hole and a particular bilateral hole. The numerical values of the limits of fit resulting from the assembly of the standard shafts in any of the other holes specified in the tables can be arrived at by simple arithmetical calculation.

4. The effect of transferring any standard shaft from a bilateral hole to a unilateral hole tends either to increase the clearance or decrease the interference—i.e. it makes the fit easier.

6. Table I provides four standard grades of workmanship for holes, in which B (unilateral) and K (bilateral) holes represent the most accurate grade, while U (unilateral) and X (bilateral) holes represent those most commonly employed. Unilateral holes V, W, and bilateral holes Y, Z, have larger tolerances.

7. Table I also provides for the use of three holes A, G, H, each with two positive limits of tolerance. These are called oversize holes. They are common to both the unilateral and bilateral systems, and are included in the table to meet exceptional conditions.

The limit values in the tables are found by multiplying together the 'size multiplier' 'm' and the 'range factor' 'r,' odd half-ten-thousandths being eliminated by subtracting such odd amounts from the products in which they occur, negative products thus becoming more negative.

Example:

To find the limits for a $2\frac{1}{4}$ in. U hole.

The value of 'm' corresponding with $2\frac{1}{4}$ ins. is 8; see Table I.

The value of 'r' for the High Limit of U = 2 (in ten-thousandths of an inch²).

The value of 'r' for the Low Limit of U = 0.

Hence, required limits are + 0·0016 in. and + 0.

Tables with metric values are also given in the Report.

Limit Arms for Micrometers.

A ready means of converting an ordinary micrometer to a limit gauge having a tolerance of from 0·0001 to 0·022 in. with variations of 0·0001 in. is provided by a pair of arms (fig. 13) manufactured by Messrs. Accles & Pollock, Oldbury, Birmingham. The micrometer having first been set to the low limit required, the pair of arms are cramped compass-friction-tight on to the micrometer barrel, the short arm just clearing the figures at the bevelled end. The short arm is now adjusted from its cramp end, so that it strikes the back of the frame at the

low limit. The screws are then tightened. The long arm is similarly adjusted so that it strikes the front of the frame at the high limit. When the change to new limits is greater than one

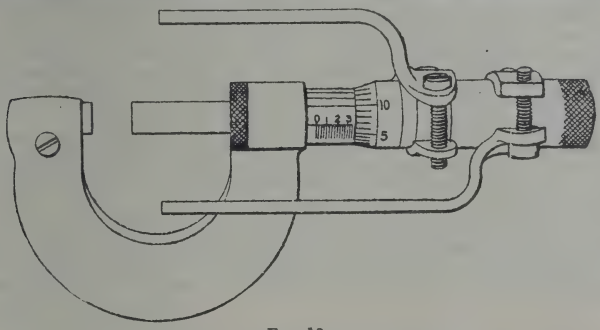


FIG. 13.

revolution of the thimble, the screws are slackened, and both arms brought to the top; the procedure is then as before. The ordinary use of the micrometer is not interfered with.
('*Machinery*.')

INDICATOR FOR WIRE GAUGE.

A simply made indicator to enclose the notch of a wire gauge that is in use, and save time and trouble when making repeated gaugings, or searching amongst stock or scrap, can be made as

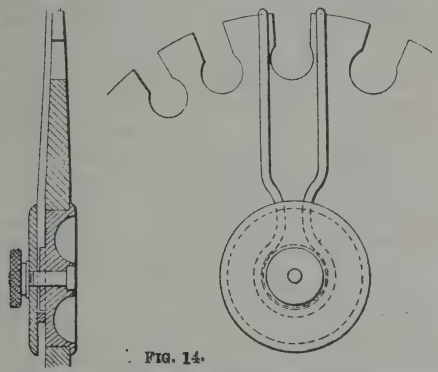


FIG. 14.

shown by fig. 14. The principle is to use springy wire, which may be altered to come just outside the edges of each opening. After holding it at this setting, clamping is done by tightening the knurled nut, which draws the large washer down on the wire and binds it. ('*Machinery*.')

Cost of Unnecessary Accuracy.

Very small limits are often indicated on drawings when it is not only extremely difficult to machine to them, but also when such accuracy is not only unnecessary but causes time and money to be wasted in the drawing office as well as by the man in the shop.

The following examples emphasize the need for sound judgment in deciding when close limits are and are not required.

A firm manufacturing small tools received an inquiry for a metal slitting cutter of the circular disc type. Tolerances were specified to $\pm$ 0·00005 in. The tool manufacturer quoted 20*l*. a piece for these cutters. On the customer replying that the price was excessive, the manufacturer asked him to specify the purpose for which the tools were to be used, and requested that he be

permitted to use his own judgment as to the accuracy required. The result was that perfectly satisfactory cutters were made with tolerances of ± 0·00025 in., which reduced the cost per cutter to 15*s*.

In another case a blue-print was submitted to a manufacturer calling for a screw over 20 ft. long, 3½ ins. in diameter, having four Acme threads to the inch. The tolerance on the pitch diameter and lead per inch was given as ± 0·0001 in. A quotation of over 2,000*l*. was made for the screw. It was estimated that, on account of the size of the screw and the difficulty of handling it, the setting up for making dependable measurements of a pitch diameter and lead error to within the limits required, would have cost about 4*l*. per measurement. In this case there was absolutely no need for accuracy. If there had been a $\frac{1}{10}$-in. tolerance on the diameter of the screw either way it would have made no difference in its application because the nut was to be fitted to the screw by the manufacturer who made the screw, and so long as the two fitted together, there was no question of interchangeability, because only one screw and nut were to be made. Finally, more reasonable tolerances were set on this screw, and it was made for 63*l*. instead of thirty or forty times that amount.

Frequently draughtsmen dimension fillets in decimals, indicating that great accuracy is required. The tool maker generally knows that no accuracy is really wanted, but if he were to follow the drawing exactly he would make the tools with such unnecessary accuracy as to increase their cost several times. If a fillet is marked $\frac{3}{16}$, it is clear that no great accuracy is required, but when it is dimensioned 0·1875 it would appear that an accuracy to the fourth decimal place is wanted.

(*'Machinery,'* August 19, 1926.)

Estimating Cost of Steel Bars.

Locate on axis OA (fig. 15) the position which represents the price in shillings per cwt. at which the particular steel can be bought. From that point travel to the right, horizontally, until the diagonal which represents the diameter of bar required is reached. From that point pass vertically down to axis OB and read off the price per foot for bar of that diameter in the material required.

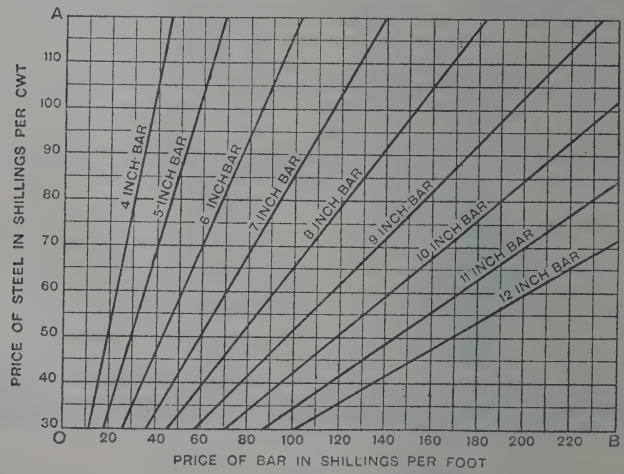


FIG. 15.

The chart covers steels from common mild steel to high grade nickel-chrome steels, and it can be used for determining the value of forgings if the price of plain forgings per cwt. is known.

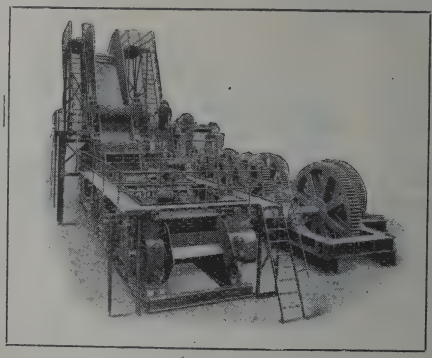
(*Howard Ensaw*; *'Machinery.'*)

SECTION XVII

FLOUR MILLING—COTTON MILLS—OIL MILLS—CANE-SUGAR MILLS AND MACHINERY

CANE & BEET SUGAR

Manufacturing Machinery



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SECTION XVII

FLOUR MILLING — COTTON MILLS — OIL MILLS — CANE-SUGAR MILLS AND MACHINERY.

FLOUR MILLING.

(Contributed by E. R. & F. Turner, Ltd., Engineers, Ipswich.)

Fifty years ago the reducing of wheat to flour was done almost entirely by means of stones; now it is done by chilled iron rolls, except in a few countries where stones are still retained.

Stones are still used in England and elsewhere for making 'stone' flour, whole meal, farmers grist, etc. They are usually from 36 to 48 ins. in diameter, top stone the runner, driven by gearing from a horizontal layshaft; speed about 150 revs. per minute; horse-power required from 8 to 12 b.h.p., but largely dependent on the condition of the grain and the sharpness of the dress in the stones.

ROLLER SYSTEM.

The very white, high-class flour of the present day is obtained by means of a very elaborate system. Every mill of any size is fitted with:—

1. Intake plant. 2. Wheat-cleaning plant. 3. Milling plant.

The intake plant for getting the wheat from trucks or barges into the mill may be either pneumatic (suction) or elevator, and is arranged so that the wheat may be deposited into any one of the storage bins or silos provided for the purpose.

The cleaning plant consists of scourers, aspirators, brush machines, etc., and also includes a plant for washing and drying such wheats as require this treatment.

The milling plant consists of roller mills, purifiers, and dressing machines connected by spouts, elevators, and conveyors. The actual roll contact surface is usually about 100 ins. per sack of 280 lbs. of flour per hour, which is divided up into approximately 40 ins. on the break rolls and 60 on the reductions. The break rolls are fluted from about 12 to 26 per inch, for opening the wheat berry, releasing the kernel and cleaning the bran, which is separated by means of sieves; the reduction rolls are smooth or very finely fluted or scratched, and reduce the kernel into fine flour, which passes into sifting machines and is dressed through fine silk. Sifting machines may be either of the reel type with internal beaters, commonly called 'centrifugals,' or the flat sieve, called 'plansifters,' both types being covered with silk containing from 100 to 150 threads per lineal inch for dressing out the finest flours, or coarser if required.

The semolina and middlings released by the break rolls are passed through purifiers in which strong currents of air pass through them, eliminating fine branny particles and other impurities before they are passed on to the reduction rolls.

Exhaust fans are connected to all machines for drawing away the hot air which is generated by the rolls and other frictional surfaces.

One sack of flour (280 lbs.) is made from 400 lbs. of wheat.

Angles of spouts for wheat should be not less than 25 degrees, and for flour and bran not less than 55 degrees.

Speed of elevators for wheat 300 to 350 feet per minute.
" " flour 180 feet per minute.
" " other mill stock 220 feet per minute.
Speed of spiral conveyors 150 feet per minute.
" band conveyors for wheat 9 feet per second.
" " " light stock 3 feet per second.
" break rolls 900 feet per minute.
" reduction rolls 630 feet per minute.

Power required about 10 to 12 b.h.p. per sack of flour per hour.

See also 'Modern Flour Milling Machinery,' by Lt.-Col. F. W. Turner (Paper read at Summer Meeting of the Institution of Mechanical Engineers, at Ipswich, June 15th, 1926). *Proceedings of the Institution of Mechanical Engineers*, No. 4, 1926, and *Engineering*, July 2nd 1926.

COTTON MILLS.

(*BLACKBURN DISTRICT. YATES & THOM, ENGINEERS.*)

For 90,000 mule spindles and preparation.
Main building, 281 feet by 130 feet; 4 floors; 3 spinning rooms; 1 card room.
74 self-acting mules. Indicated horse-power, 1,380. Boiler-pressure, 160 lbs.
Engines.—Triple-expansion double-tandem condensing; one high-pressure cylinder, one intermediate cylinder, two low-pressure cylinders :—

Diameter of high-pressure cylinder, 21 inches; ratio, 1·0; stroke, 5 feet 6 inches.
Diameter of intermediate-pressure cylinder, 34½ inches; ratio, 2·7; speed, 60 per minute.
Diameter of each low-pressure cylinder, 39 inches; ratio, 6·9; piston speed, 660 feet per minute.

Rope pulley 30 feet diameter, grooved for 32 ropes 1⅝ inch diameter.
Velocity of ropes, 5,654 feet per minute.
Boilers.—Steel. 4 Lancashire type (one being spare); length, 30 feet; diameter, 8 feet. Furnaces, diameter 40 inches; working pressure, 160 lbs.
Economiser.—Green's type, from 278 to 384 pipes.
Mill Shafting.—Card shaft, 185 revolutions; 3⅜ inches to 2½ inches diameter.
9 drawing frames, 9 slubbing frames, 16 intermediate frames, and 44 roving frames of 176 spindles.
Roving shaft, 270 revolutions, 3½ inches to 2½ inches diameter.
Drawing, intermediate, and slubbing shaft, 225 revolutions, 3⅝ inches to 2½ inches diameter; drives also 27 cards.
Spinning-room shafts, 4½ inches to 2¾ inches diameter.

For 71,000 ring spindles and preparation.
Boilers.—Four Lancashire, 30 feet by 8 feet, 160 lbs. per square inch, with Green's economiser of 384 pipes.
Engine.—Horizontal cross compound, 1,700 i.h.p. at 66 r.p.m.
Cylinders, 30 inches and 60 inches diameter by 5 feet stroke.
Jet condenser 50 cubic feet capacity. Two air pumps, each 31 inches diameter by 17-inch stroke at 66 r.p.m.
Flywheel, 24 feet diameter, 57 tons, 43 ropes 1¾ inch diameter.
Rope-speed, 4,970 feet per minute; i.h.p. per rope, 39·5.
Piston speed, 660 feet per minute; air-pump speed, 187 feet per minute.
Cylinder ratio, nominal, 4 to 1; m.e.p., 30 lbs. per square inch.
Machinery.—Includes 15 opening and scutching machines, 132 cards, 18 drawing frames, 11 slubbing frames, 16 winding frames, 22 intermediate frames, 48 roving frames, 164 ring frames of 432 spindles each, 22 beaming machines, 6 warping mills, 100 reels, and 4 bundling presses.

The following are plants completed at Royton, Rochdale, Leigh, and Atherton, by Messrs. Yates & Thom, just before the war :—

ROYTON.

For 117,584 mule spindles, 10's to 24's counts.
Horizontal cross compound engine cylinders, 28 inches and 58 inches diameter 5 feet stroke, 1,600 i.h.p.; 65 revolutions per minute.
Four boilers, 30 feet long, 8 feet 6 inches diameter, 180 lbs. pressure.
Economiser, with 480 pipes.
Fly rope pulley, 24 feet diameter; 40 1⅝-inch ropes.

For 132,000 mule spindles, 10's to 42's counts.
Horizontal cross compound engine cylinders, 28 inches and 58 inches diameter, 5 feet stroke, 1,600 i.h.p. ; 65 revolutions per minute.
Four boilers, 30 feet long, 8 feet 6 inches diameter, 180 lbs. pressure.
Superheaters.
Fly rope pulley, 24 feet diameter ; 40 1⅜-inch ropes.

ROCHDALE.

For 41,000 mule and ring spindles, 2's to 12's counts.
Horizontal cross compound engine cylinders, 19 inches and 40 inches diameter, 4 feet stroke, 600 i.h.p. ; 70 revolutions per minute.
Two boilers, 32 feet long, 8 feet 6 inches diameter, 180 lbs. pressure.
Economiser, with 192 pipes.
Fly rope pulley, 22 feet diameter ; 21 1⅜-inch ropes.

LEIGH.

For 94,560 mule spindles, 40's to 80's counts.
Horizontal cross compound engine cylinders, 23 inches and 50 inches diameter, 5 feet stroke, 1,200 i.h.p. ; 65 revolutions per minute.
Three boilers, 30 feet long, 8 feet 6 inches diameter, 180 lbs. pressure.
Economiser, with 288 pipes.
Fly rope pulley, 24 feet diameter ; 33 1⅜-inch ropes.

For 85,000 mule spindles, 40's to 90's counts.
Horizontal cross compound engine cylinders, 23 inches to 50 inches diameter, 5 feet stroke, 1,200 i.h.p. ; 65 revolutions per minute.
Three boilers, 30 feet long, 9 feet diameter, 180 lbs. pressure.
Economiser, with 288 pipes.
Superheaters.
Fly rope pulley, 24 feet diameter ; 33 1⅜-inch ropes.

ATHERTON.

For 100,000 mule spindles, 60's to 90's counts.
Horizontal cross compound engine cylinders, 28 inches and 56 inches diameter, 5 feet stroke, 1,500 i.h.p. ; 66 revolutions per minute.
Four boilers, 30 feet long, 8 feet diameter ; 165 lbs. pressure.
Economiser, 384 pipes.
Fly rope pulley, 24 feet diameter ; 37 1¼-inch ropes.

(*STOCKPORT DISTRICT. J. & E. WOOD, ENGINEERS, BOLTON.*)

For 53,000 ring spindles and preparation.
Main building, 249 feet by 95 feet ; 5 floors and basement.
140 ring spinning frames of 376 to 396 spindles each, spinning 16's to 40's yarn.
Indicated horse-power, 1,500. Boiler-pressure, 165 lbs.
Engines.—Triple-expansion condensing double-tandem type : 1 high-pressure cylinder, 1 intermediate-pressure cylinder, 2 low-pressure cylinders :—
Diameter of high-pressure cylinder, 23 inches ; ratio, 1·00 ; stroke, 5 feet.
Diameter of intermediate-pressure cylinder, 37 inches ; ratio, 2·60 ; speed, 60 revolutions.
Diameter of low-pressure cylinder, 42 inches ; ratio, 6·66 ; piston speed, 600 feet.
Rope pulley 30 feet diameter, grooved for 52 ropes 1⅜ inch diameter.
Rope velocity, 5,655 feet per minute.
Boilers.—Steel. 4 Lancashire type, 30 feet by 8 feet (one being spare). Pressure, 165 lbs. Furnaces, 39 inches diameter.
Economiser.—Green's type, 448 pipes in 7 groups of 64 pipes each. Feed temperature, 75° F. Delivery to boilers, 320° F.
Chimney.—210 feet high, 8 feet diameter inside at top.
Machinery.—96 cards (flat revolving type), 50-inch cylinder by 45 inches wide ; 4 drawing frames, each 3 heads, 4 deliveries ; 12 drawing frames, each 2 heads, 8 deliveries ; 12 slubbing frames, 104 spindles each ; 20 intermediate frames, 140 spindles each ; 52 roving frames, 180 spindles each ; 140 spinning frames, 376 to 396 spindles each.

(*HEYWOOD DISTRICT.*)

Engines.—The triple expansion condensing engines of the Mutual Spinning Company of Heywood were tested by Mr. J. F. L. Crosland with the following results :—

High-pressure cylinder, 21 inches diameter ; ratio, 1·00 ; stroke, 6 feet.
Intermediate-pressure cylinder, 33 inches diameter ; ratio, 2·50 ; speed, 53 revolutions.
Low-pressure cylinders, 35 inches diameter ; ratio, 5·61 ; piston speed, 636 feet per minute.
Total indicated horse-power, 1,090. Boiler-pressure, 156 lbs.
Cylinder vacuum, 11·2 lbs. ; condenser vacuum, 12·2 lbs. ; injection, 101° ; hot-well, 133° ; steam (2·5 per cent. wet) per horse-power hour, 12·51 lbs. ; dry, 12·2 lbs.
Dry coal per I.H.P. hour, 1·37 lb.

Economiser.—288 pipes ; mechanical stokers.

Boilers.—Two Lancashire boilers, 30 feet by 8 feet ; 66·5 square feet grate surface. Feed to economiser, 130° ; to boilers, 304°. Heating surface : boilers, 2,016 feet ; economiser, 2,880 feet.
Coal : Bituminous slack, 5·6 per cent. ash ; evaporating from and at 212°, 10·36 lbs., of which 16½ per cent. due to feed-heater. Coal per square foot of grate, 24·16 lbs. I.H.P. of engines, shafting and belts on loose pulleys, 242.

EGYPTIAN YARN (FINE).

For spinning fine yarns an indicated horse-power of 1,900 is found to drive 132,000 mule spindles and other preparation machinery at the Irwell Bank Mill, near Bolton.

WEAVING SHED.

(*BLACKBURN DISTRICT. YATES & THOM, ENGINEERS.*)

172 feet 6 inches by 136 feet, to contain 512 looms.

Boiler.—One, 30 feet by 8 feet, 100 lbs. steam pressure.

Economiser.—96 pipes.

Engines.—Compound side-by-side type.
High-pressure cylinder, 16 inches diameter
Low " " 28 " " } Stroke, 4 feet ; revolutions, 55.
Fly rope pulley, 20 feet diameter ; 7 grooves for 1⅝ rope.

The following are plants completed at Great Harwood and Leigh, by Messrs. Yates & Thom just before the war.

GREAT HARWOOD.

Three weaving sheds, each containing between 800 and 1,000 looms, 36 inches to 58 inches wide.
Horizontal cross compound engine cylinders, 17 inches and 34 inches diameter ; 3 feet 6 inches stroke, 450 i.h.p. ; 75 revolutions per minute.
Economiser, 128 pipes.
One boiler, 32 feet long ; 8 feet 6 inches diameter ; 160 lbs. pressure.
Fly rope pulley, 14 feet diameter, for 14 1¾-inch ropes.

LEIGH.

Two weaving sheds, each containing 900 looms, 32 inches to 57 inches wide.
Horizontal cross compound engine cylinders, 16 inches and 32 inches diameter ; 3 feet 6 inches stroke ; 400 i.h.p. ; 80 revolutions per minute.
Boiler, 30 feet long ; 8 feet 6 inches diameter ; 180 lbs. pressure.
Economiser, 96 pipes.
Fly rope pulley, 15 feet ; 11 1¾-inch ropes.

Spinning and Weaving Mill.

Bury.

26,000 mule spindles, 32,000 ring spindles, 10's to 44's counts.
750 looms.
Horizontal cross compound engine cylinders, 33 inches and 66 inches diameter ; 5 feet stroke ; 2,000 i.h.p. ; 65 revolutions per minute.
Five boilers, 30 feet long ; 8 feet diameter ; 175 lbs. pressure.
Economiser, 480 pipes.
Fly rope pulley, 24 feet diameter for 46 $1\frac{3}{4}$-inch ropes.
Superheaters.

Mule Spinning Mill.

(OLDHAM DISTRICT. POLLIT & WIGZELL, ENGINEERS, SOWERBY BRIDGE.)

Mill 5 floors and cellar, 355 feet long, 129 feet wide inside; 107,000 spindles, counts 8's to 40's one-third weft, two-thirds twist; 1,650 indicated horse-power.

Engines.—Cross compound horizontal :—
High-pressure cylinder, 26 inches diameter
Low " " 52 " " } each 5 feet stroke, 75 revolutions per minute.
Flywheel 22 feet diameter, turned for 36 ropes $1\frac{5}{8}$ diameter. Weight of wheel-rim 36 tons.
Coal used for all purposes, 70 tons in summer, 84 tons in winter, per week.

Boilers.—6 Lancashire, 5 working, 1 cleaning ; 30 feet long, 8 feet diameter ; working pressure, 160 lbs. superheated.

Economiser.—Green's, 480 pipes.

Chimney.—7 feet diameter, 180 feet high; main flue 8 feet high, 4 feet wide.

Mill Shafting.—Card-room shafts, 220 revolutions with 18-inch pulleys for drawing, roving and intermediate frames ; 170 revolutions for cards with 16-inch pulleys. Mule-room shafts 300 revolutions with 30-inch pulleys.

In the Yorkshire district it is not unusual to carry on cotton spinning in a shed of one floor as in India.

Ring Spinning Mill.

(POLLIT & WIGZELL, ENGINEERS, SOWERBY BRIDGE.)

One-floor shed, 203 feet wide, 346 feet 6 inches long ; in bays, lengthway, 10 feet 6 inches pitch ; 36,000 spindles, counts 0's to 32's ; average indicated horse-power 995.

Engine.—Tandem horizontal compound :—
High-pressure cylinder, 21 inches diameter
Low " " 42 " " } each 5 feet stroke, 75 revolutions per minute.
Flywheel 20 feet diameter, grooved for 26 ropes $1\frac{5}{8}$ diameter. Weight of rim, 30 tons.
Coal used for all purposes, 40 tons in summer, 58 tons in winter, per week.

Boilers.—3 Lancashire, 30 feet long, 8 feet diameter ; working pressure, 160 lbs., superheated.

Economiser.—Green's, 272 pipes.

Chimney.—5 feet 6 inches diameter, 150 feet high; main flue, 7 feet 6 inches high, 3 feet 3 inches wide.

Mill Shafting.—Card shaft, 175 revolutions with 17-inch pulleys ; drawing, roving, and intermediate frame shafts, 254 revs. with 27-inch pulleys ; spinning shaft, 254 revs. with 42-inch pulleys The last seven bays of the shed are utilised for winding, reeling, and warping.

Boilers.

A Lancashire boiler to work at 160 lbs. pressure for a modern cotton-mill will usually be 30 feet long, 8 feet 6 ins. diameter, shell and end plates of $\frac{13}{16}$-inch steel with double butt strips, which in good work may be of equal breadth and treble riveted ; or the outer strap may be narrower than the inner strap and having only the double riveting. Furnaces and flues $\frac{9}{16}$ inch plate. The whole of the steel to be of 26 to 30 tons tensile strength, and to elongate not less than 20 per cent. in a length of 10 inches. For furnaces, steel with a tensile strength up to 32 tons is sometimes allowed.

Economisers.

THE 'GREEN' ECONOMISER.

(See Section XXX, Part II.)

Main Driving Ropes.

The main driving of cotton-mills is usually by cotton ropes of $1\frac{3}{8}$ inch to $1\frac{3}{4}$ inch diameter, the present tendency being towards the smaller diameter. The following tables are deduced from the weights of pure cotton ropes made by a Lancashire firm :—

Diameter of Rope in inches	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2
Weight per foot in pounds	·18	·25	·33	·40	·50	·60	·72	·84	·98	1·125	1·3
Diameter of smallest Pulley advisable	22″	25″	30″	34″	37″	42″	45″	48′	52″	57″	66″
Total stress in Rope in pounds	110	150	195	246	300	360	430	500	600	675	780
I.H.P. at 5,000 feet velocity	9	12	16	20	25	30	36	42	49	56	64

There is no practical difference in the power of ropes between 3,600 feet and 5,600 feet velocity. In Yorkshire, leather ropes $1\frac{1}{2}$ inch square are used, and will drive 80 i.h.p. per rope.

Cotton Yarn Measurement.

Cotton yarn is measured by the hank of 840 yards of single thread, and is said to be of 40's or 60's counts, when 40 hanks or 60 hanks weigh 1 lb. A lea is one-seventh of a hank or 120 yards. A wrap reel is 54 ins. circumference, so that 80 revolutions wind one lea and the skein thus wound is what is tested for strength. The softness of yarn varies with the number of turns per inch put into it. For equal quality in different counts the turns must vary as the square root of the counts. Thus turns per inch $= c\sqrt{\text{counts}}$.

For Indian and American cotton, $c = 3{\cdot}75$ for mule twist ; $3{\cdot}25$ for mule weft ; $4{\cdot}00$ for ring twist.

For Egyptian cotton the above values of c become $3{\cdot}606$, $3{\cdot}183$, and $3{\cdot}606$ respectively. Thus 50's American ring twist requires full 28 twists per inch.

List of Machinery in a Lancashire Mill, showing Average 30's Twist on Mules or Ring-frames, with approximate production at each process, speeds, etc.

77,000 Mule spindles for 28's to 32's (average 30's) twist spun counts at 31 hanks per spindle calculated to produce 79,566 lbs. of yarn per week of $55\frac{1}{2}$ hours from American cotton, $4\frac{1}{4}$ hanks single roving, or,

52,800 Ring spindles for 28's to 32's (average 30's) twist spun counts, at 45 hanks per spindle, calculated to produce 79,200 lbs. yarn per week of $55\frac{1}{2}$ hours from American cotton, $4\frac{1}{4}$ hanks single roving.

3 Hopper bale breakers, 36 ins. wide.

3 Automatic hopper feeders, 36 ins. wide, with filling apparatus.

3 Single Crighton cylinder parts, with valves and pipes to the exhaust opener, and lap machine.

3 Exhaust openers and lap machine, 48 ins. wide, for 46-in. laps, with lattice feeder, 4 ft. centres, and dust trunks.

7 Single-finisher scutchers and lap machines, 46 ins. wide, for 45-in. laps, feeder for 4 laps. Lap 14 ozs. per yard.

1 Roving waste-opener and feeding-machine.

Details.	Hanks Roving.	Speed.	Prod. Lbs. Each.	Hanks per Week.
108 Single cards, 45″ on wire, 50″ cyl., 106 s.s. flats, $1\frac{3}{8}$″ wide	0·15	Cyl. 170 r.p.m.	774	116
27 Drawing-frames, 2 heads of 4 deliveries = 27 finishing deliveries	0·13	350 r.p.m. of $1\frac{1}{2}$″ front roller	1150	149
9 Slubbing-frames, 96 spindles each 10″ × $5\frac{1}{2}$″ bobbins × 19″ staff	0·675	600 r.p.m. of spindle	94·8	59·2
17 Intermediate-frames, 140 spindles each 10″ × $4\frac{3}{4}$″ bobbins × $26\frac{3}{8}$″ staff	1·60	750 r.p.m. of spindle	34·1	54·5
42 Roving-frames, 180 spindles each 8″ × $3\frac{5}{8}$″ bobbins × $20\frac{1}{2}$″ staff	4·25	1,100 r.p.m. of spindle	10·6	45·1
74 S.A. mules, 1,100 spindles each 54″ stretch	30's, etc.	10,000 r.p.m.	1·03	31
120 Ring-frames, 440 spindles each $2\frac{1}{2}$″ distance, $1\frac{5}{8}$″ rings, $6\frac{1}{2}$″ lift	30's	9,000 r.p.m. of spindle	1·5	45

The above includes for a loss of 1 per cent. at each process, from the card-sliver to the spindle point.

In a modern mill the handling of cotton is reduced to a minimum. The bales of raw cotton are opened and slabs of the fibre flung into the bale-breaker, which delivers either to a mixing-bin or direct to a hopper-feeder, wherein the fibre is automatically regulated to weigh a given weight per yard. Thence it passes forward and is made into laps or rolls. These are removed by hand to the finisher scutcher whence the laps are run by a vertical tramway to the carding engines by hand. The cans of sliver made by the cards, and by the drawing frames and the bobbins, filled at all subsequent operations, must be moved and removed by hand.

The most modern mills are arranged, where possible, with all the card-room or preparation machinery on one floor. It is very usual to extend the ground floor by means of a shed extension along one side of the mill to enable this to be done. Usually the carding-engines are placed under this extension.

For fine counts, 120's to 140's, such as are now much spun in Oldham from Egyptian cotton the card sliver is combed before being drawn, and the modern tendency is to use combs for even coarser yarns. Generally, owing to Indian competition, the tendency in Lancashire is all in the direction of finer counts.

Horse-Power to Drive Cotton Machinery, with Speeds for Pulley.

(Bolton figures.)

	I.H.P.	R.P.M.
Hopper bale breaker	2 to $2\frac{1}{2}$	450 to 500
Porcupine opener	2 to $2\frac{1}{2}$	800
Hopper feeder	$1\frac{1}{2}$	225
Vertical opener, single	4	1,000
„ „ double	8	1,000
Exhaust opener	2	900
Opener with hop machine	12	1,200
Single scutcher	4	1,000 to 1,200
Double „	8	1,000 to 1,200
Carding engine	$\frac{3}{4}$	160 to 180
Sliver-lap machine	$\frac{1}{2}$	200 or 500
Ribbon „	1	262
Single-nip comb	$\frac{5}{8}$	305
Double-nip „	$\frac{3}{4}$	229
12-delivery drawing frame	1	150 to 300
Slubbing frame 90 spindles	2	200 to 300
Intermediate „ 120 „	2	300 to 385
Roving frame 150 „ / Jack „ 200 „	2	310 to 455
Self-acting mules	1 h.p. per 120 to 140 spindles	
Cop winding	1 h.p. „ 300 „	120
Ring frame	1 h.p. „ 90 to 100 „	
„ doubler	1 h.p. „ 55 to 65 „	
Drum winder	1 h.p. „ 100 drums	400 to 600
80-hank reel	$\frac{1}{8}$	250

The power required tends to be more or less according to the speeds of spindles, beaters, etc. For finer counts spindles run at higher speeds, but machinery generally is lighter.

Electrical Driving of Cotton Mills.

The load factor of a cotton mill is probably 90 to 95 per cent. This renders electrical driving of doubtful economy. It cannot be economically done from an outside power station, for this would be doing well if it had a 40 per cent. load factor. A cotton mill with its own generating plant can work more cheaply than by purchased current at a price that would pay an outside power station to charge. Then the transmission line is costly.

A group of mills within a small radius such as may be found in places might perhaps be economically driven from one central power house close to all the mills. But in electrical driving the generator is more costly than the rope rim, and the motors, if on line shafts, are more costly than the driven rope pulleys. The transmission losses and the generator and motor losses appear to be greater than the loss by rope driving, and where each machine has its own motor this and the transmission system seem to cost much more than shafting and pulleys. Where the motor stands on the floor at the end of a spinning or speed frame it compels the cutting out of several spindles, reducing the output capacity several per cent., or by fully as much as it is claimed each spindle will give an increased output as compared with an ordinary mill. But so far this increased output has been only demonstrated as between modern high-speed engines with electrical driving and old slow-speed engines in some out-of-date rope-driven mill. No comparisons are put forward with modern rope-driven mills with modern high-speed engines.

There are two systems of electric driving : (*a*) with the usual line shafts, each shaft with an electric motor taking the place of the usual rope pulley ; (*b*) with motors to each machine. And there may be (*c*) a mixed system on which there are line shafts for certain classes of work and separate motors for other machines. Rapid acceleration is claimed as an advantage of electrical driving. This, of course, demands motors much larger and more powerful than are merely necessary to drive the frame at its normal speed. The same acceleration may be secured with belt driving if the belts are made sufficiently larger than they need to be for the constant normal speed. Shafting does not require very much power to drive it, and where machines such as ring frames are closely spaced under a shaft, as are ring frames, it is difficult to see much benefit from electric driving of these machines, which do not stop until the bobbins are full. But with speed frames which must stop for every broken sliver it may be convenient that each machine should have its own motor. Mules which have an enormous and rapid variation of driving torque are badly suited for separate motors, and appear better driven from a line shaft. Given sufficient belt power any machine can be accelerated as rapidly as desired, and no single machine will be felt by the main engine any more than if accelerated electrically.

The abolition of belts is an advantage of some value in the separate motor system, but so far the experience of electrical driving has not been such as to warrant other than the most careful consideration of each case on its merits, and by an engineer who is a textile man first and an electrical engineer second. The following are estimates of cost of rope and electrical driving which may help the consideration of any particular case. The estimates are based on the driving of a 110,000 spindle mill (Bolton-fine-Counts) :

(Pre-war Prices.)

(*a*) *Rope Driving.*

Capital outlay—	£	*s.*	*d.*
Engine 1,500 i.h.p. and piping in engine-house	4,765	0	0
4 30′ × 8′ × 160 lb. boilers and superheaters	2,400	0	0
All piping in boiler-house (steel and cast iron)	600	0	0
Chimney and boiler seatings	1,000	0	0
Reservoir	1,500	0	0
Engine-house	600	0	0
„ bed	500	0	0
Rope race	500	0	0
Boiler-house	400	0	0
Economiser, dampers, engine, etc.	700	0	0
Lighting generator, 75 k.w., pilot-engine, and generator Switchboard and wiring, etc., 1,200 lights Foundations, etc.	1,450	0	0
Mill gearing, including dynamo driving	2,970	0	0
Cotton driving ropes	450	0	0
15-ton hand-power engine-house crane	300	0	0
Staging and stairs in rope race	300	0	0
	£18,435	0	0

(a) Running Costs.

	£	s.	d.
Coal, 3,850 tons per annum at 12*s.* 6*d.*	2,406	0	0
Wages: engineer, 55*s.*; oiler and greaser, 25*s.*; two stokers, 25*s.*	325	0	0
Oil, waste, stores, etc.	100	0	0
Insurance: engine, £80; boilers and pipes, £33; mill gearing, £60; buildings, £20	193	0	0
Rates, 7*s.* on 5 per cent. of £18,435	323	0	0
Interest and depreciation at 12 per cent. on £18,435	2,212	0	0
	£5,559	0	0

Equal to 0·477 pence per k.w. hour.

(b) Full Electrical Installation at Mill.

Capital outlay—	£	s.	d.
1,000 k.w. Turbo-generator, condensing plant, and piping	6,600	0	0
4 30′ × 8′ × 160 lb. boilers and superheaters	2,600	0	0
Boiler-house piping (steel and cast iron)	600	0	0
Chimney and boiler seatings	1,000	0	0
Reservoir	1,500	0	0
Generator house	400	0	0
,, bed	300	0	0
Motor tower and carrying for motors	250	0	0
Motors, cables, and switchboard	4,000	0	0
Boiler-house	400	0	0
Economiser, dampers, engine, &c.	700	0	0
Pilot engine and generator switchboard, &c.	1,150	0	0
Wiring for 1,200 lights, foundations, &c.			
Mill gearing	1,830	0	0
	£21,330	0	0

(b) Running Costs.

	£	s.	d.
Coal, 4,300 tons per annum at 12*s.* 6*d.*	2,690	0	0
Wages: engineer, 55*s.*; assistant, 25*s.*; 2 stokers, 25*s.*	325	0	0
Oil, waste, and general stores	75	0	0
Insurance: generator set, £110; boilers and pipes, £33; mill gearing, £40; buildings, £15; motors, £60	258	0	0
Rates, 7*s.* on 5 per cent. of £21,330	373	0	0
Interest and depreciation on £21,330 at 12 per cent.	2,560	0	0
	£6,281	0	0

Equal to 0·534 pence per k.w. hour.

To this ought to be added a 75 k.w. combined set for lighting, as it is hardly satisfactory to run lights and power off the same 3-phase generator. The cost would be £560.

(c) Electric Driving, but with Current from a Public Supply Station delivering at 10,000 *Volts.*

Capital outlay—	£	s.	d.
Boiler and piping, pump, &c., for heating	600	0	0
Chimney and boiler seatings	250	0	0
Transformer house	300	0	0
Motor tower and carrying for motors	250	0	0
Motors, cables, and switchboard	4,000	0	0
Transformers (spare set included)	1,000	0	0
Boiler-house	150	0	0
Mill gearing	1,830	0	0
Switchboard and wiring, 1,200 lights	900	0	0
	£9,280	0	0

(c) Running Costs.

	£	s.	d.
Coal for heating, 300 tons at 12*s.* 6*d.*	188	0	0
Wages: engineer, 55*s.*	137	10	0
Oil, waste, general stores	50	0	0
Insurance: motors, £60; transformers, £15; gearing, £40; buildings, £10.	125	0	0
Interest and depreciation on £9,280 at 12 per cent.	1,112	0	0

(*c*) *Running Costs*—continued.

	£	*s.*	*d.*
Current: average load 900 k.w., including lighting, based on uniform charge of 0·5625*d.* per hour	5,906	0	0
	£7,680	10	0

Equal to 0·657 pence per k.w. hour.

From the foregoing it would appear that if current can be bought for about 0·4*d.* per unit the driving by a public supply would cost the same as by ropes.

In the foregoing estimates of running costs, the boiler cleaning charges are omitted, the extra cost of this for (*a*) and (*b*) being about balanced by the omission of the wages of the stoker of the heating boiler in case (*c*). It is at present doubtful if current can be sold at a profit for 0·4*d.* per unit by any power station. The situation is made worse by the necessity for a heating boiler and chimney, &c., for case (*c*).

On the other hand driving electrically disperses with the rope race which divides a mill halfway across into two sections, and it sets free the area of the race for machinery and increases the production within a given total area. But the real success of the system would come where a group of mills could be driven from a joint-power plant in the middle of the group, especially if the warming could be done from the same boilers. There is very little in the claim for steadier driving, this being merely a question of flywheel energy and cyclical regularity equally obtainable with ropes as electrically. No weight must be given to comparisons with old mills driven by old slow engines. Engineers should study the Brown Boveri ring frame, for which electricity does what is otherwise impracticable. In this machine the spindle speed is varied by moving the brushes of the motor so that the tension on the yarn is kept uniform at all stages of the bobbin. This cannot be done except by electrical means.

Machine Sizes in Plan—Pulley Size and Speed.

	Ft.	Ins.		Ft.	Ins.	Inches.					
Opener	11	0	×	6	6	12 × 5	pulley	1,200	revolutions;	shaft, 400	revolutions
Double Scutcher	18	8	×	6	6	9 × 4	,,	1,500	,,	,,	,,
Double Card	15	0	×	6	6	15 × 3	,,	150	,,	150	,,
Single Card	10	0	×	6	6						
Drawing Frame	27	0	×	5	0	14 × 3	,,	250	,,	120	,,
Slubbing Frame	27	4½	×	4	0	12 × 3	,,	410	,,	,,	,,
Intermediate	35	6	×	3	0	11 × 3	,,	460	,,	,,	,,
Roving	35	6	×	3	0	10 × 3	,,	480	,,	,,	,,
Grinder	6	0	×	2	10						

PAPER MILLS.

See 'Modern Paper Mill Plant,' *Proceedings of the Institution of Mechanical Engineers*, No. 3, 1926.

OIL MILLS.

The Manufacture of Vegetable Oils.

There are two methods of extracting oil from vegetable seeds and nuts. These are by means of hydraulic presses and by chemical solvents.

Two types of hydraulic presses are used. The Anglo-American, which has corrugated plates, between which the meal is confined in cloths, the sides being open; and the 'cage' press, the box of which is built up of narrow steel bars held in a vertical position by weldless steel hoops, spaces being left between each bar for the escape of the oil, the solid matter, in the form of a round cake, being retained in the box.

The Anglo-American system is usually employed for seeds which do not contain more than 35 per cent. of oil; as the meal is confined between open plates it is difficult to prevent its escape, and the wrappers are soon destroyed when a large percentage of oil is present. For this reason a 'cage' press should be employed for all materials rich in oil.

The 'cage' press has the further advantage that a cold-drawn oil can be produced, and also double pressing can be resorted to, the second pressing being performed in either a 'cage' press or Anglo-American press.

In the expression of oil from seeds there are three main operations: crushing, heating, and pressing.

The crushing is of great importance; the oil cells must be thoroughly crushed and burst open. Unless this is effectively done it will be impossible to express the maximum amount of oil. The crushing rolls are usually five in number, superimposed, the seed being deflected by scraper plates, so that it is made to pass between the various rolls, and is thus subjected to four crushings, each receiving a heavier pressure than the proceeding one. The heating is done in a mild steel kettle having a steam jacket, a mechanical stirrer, and a steam spray to give the necessary moisture to the meal.

The preliminary treatment of the seed is the same for Anglo-American and 'cage' presses.

For Anglo-American presses the heated meal has to be moulded, compressed, and wrapped in a cloth before it can be placed in the press, the usual number of cakes in each press being sixteen. The cakes leave the press with very oily edges; these have to be trimmed off by a paring machine, the oily edges being returned to the kettle for further treatment.

With 'cage' presses the meal passes directly into the box in measured quantities, a plate dividing each charge. With some seeds flat cloths are also placed between the meal and the plate to prevent cake from adhering to the plate and to assist the flow of the oil. The cakes leave the box in a finished state.

A small self-contained Anglo-American mill with two presses made by the Mirrlees Watson Co., Ltd., has a capacity of 7½ cwts. of seed per hour, and consists of the following parts:—

1 set of crushing rolls, five high, 12 ins. diameter, 18 ins. long.
1 meal-heating kettle, 42 ins. diameter, 27 ins. deep.
1 cake-moulding machine with a steam compressor.
2 hydraulic presses with rams 16 ins. diameter, working pressure 2 tons per sq. in., each press to make sixteen cakes per pressing.
1 cake-paring machine with fine reducing apparatus.
1 set of hydraulic pressure pumps, valves, and pipes.
1 oil collecting and settling tank.
1 rotary oil pump, and elevators to raise the seed to the rolls and meal to the kettle.

The parts are carried on a foundation plate, geared together and driven by a single belt. A smaller mill is also made with one press only. For larger capacities the machines are built separately and driven by belts from a shaft carried upon girders. They are fitted up in sets of four and eight presses, with capacities of 15 cwts. and 30 cwts. of seed per hour. The rolls are 16 ins. diameter, 48 ins. long.

For the eight-press and larger mills hydraulic accumulators are fitted, working at 500 to 600 lbs. and 2 tons per sq. in. The ballast is of sand contained in a mild steel case which is guided by mild steel guides. The sizes generally used are 9 ins. and 3 ins. diameter by 8 ft. stroke for the small plant, and 14 ins. and 4 ins. diameter by 10 ft. stroke for the larger plants.

Small self-contained mills with 'cage' presses are made by the Mirrlees Watson Co., Ltd., with capacities of 1½, 3, and 6 cwts., respectively. The rolls are of the Anglo-American type; the presses work at 2 tons per sq. in. and exert a pressure of over 35 cwts. per sq. inch on the cakes.

The 1½-cwt. mill has rolls 8 ins. diameter, 8 ins. long; kettle 21 ins. diameter, 18 ins. deep; press ram 10½ ins. diameter; box 11 ins. diameter, 54 ins. deep. The 3-cwt. mill has rolls 8 ins. diameter, 12 ins. long; kettle 27 ins. diameter, 20 ins. deep; press ram 13 ins. diameter; box 14 ins. diameter, 60 ins. deep. The 6-cwt. mill has rolls 8 ins. diameter, 18 ins. long; kettle 39 ins. diameter, 21 ins. deep; two presses with rams 13 ins. diameter; boxes 14 ins. diameter, 60 ins. deep.

The mills are complete with hydraulic pumps, valves, and pipes, the machines being geared together and driven by a single belt. The plants are also provided with reducing mills, so that large nuts, copra, etc., can be broken up previous to being passed to the crushing rolls. The cakes from the first pressing can also be broken up when double pressing is resorted to. Larger mills have independently driven machines and presses with boxes up to 19 ins. diameter by 9 ft. deep.

The expressed oil should be passed through a filter press to remove the sediment and produce a bright, clear oil. The filter press is composed of a number of plates with raised pyramid-shaped projections which support the cloth placed over each plate, the plates and cloth being securely clamped together. The oil is forced through the cloth and flows past the projections to the outlets at the bottom, and is collected in a trough fixed to the frames.

The oil passes through a further process of refining to remove the fatty acids and colouring matter, and when required for edible purposes is deodorised to remove the characteristic odour of the oil.

For the solvent process the seed must first be crushed, the meal is then placed in closed vessels, and the solvent, usually benzine, allowed to percolate through it in order to dissolve out the oil content. The mixture of oil and solvent is subjected to distillation—the solvent, being condensed, is used over again, and the oil is heated and steamed to remove the final traces of the solvent.

The meal after the solvent has been drained from it is also heated and steamed to remove all traces of solvent. Large plants are made with a series of vessels so that the solvent can be passed through a number and become heavily impregnated with oil before it is passed to the distiller. The residue from the process is in the form of meal, and should not contain more than about 2 per cent. of oil.

H H

CANE-SUGAR MACHINERY.

For large sugar works, the canes are brought from the field to the factory by rail in trucks which are weighed and unloaded mechanically on to a carrier which continuously conveys them to the

Crushing Mills.

These usually comprise a pair of deeply serrated preparing rollers followed by several sets of three-roller crushing mills in tandem, and steam driven through heavy spur gearing.

The cane in transit through these successive mills is macerated with hot water, enabling ordinarily a juice extraction of over 80 per cent. on the weight of the cane to be obtained. This crushed cane (technically termed megass or bavasse), leaving the final mill with 45 to 50 per cent. of contained moisture, is continuously fed into special boiler furnaces and utilised for steam generation, supplying frequently the entire factory requirements.

MULTIPLE CRUSHING MILLS.

(*The Mirrlees Watson Co. Ltd., Glasgow.*)

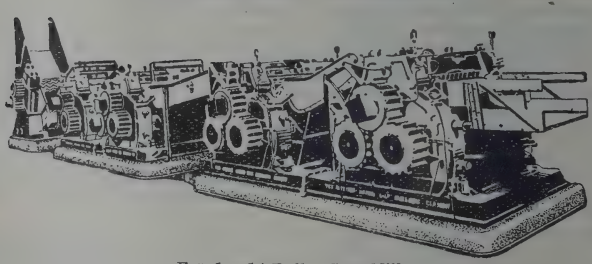

FIG. 1.—14-Roller Cane Mill.

Mill Rollers Dia. and Length.	Tons of Cane Crushed Hourly.		Engine Dia. and Stroke.	
	11-Roller Mills.	14-Roller Mills.	11-Roller.	(2 Engs.) 14-Roller.
Ins. Ins.			Ins. Ins.	Ins. Ins.
24×48	16	18	20×42	18×36
26×54	21	24	22×48	20×42
28×60	27	31	26×48	22×48
30×60	31	36	30×60	28×48
32×72	43	49	32×60	30×60
34×78	53	60	34×60	32×60
36×84	64	72	38×60	34×60

The mill capacity varies according to the class of cane crushed.

Vacuum Evaporators.

The cane juice expressed by the mills is clarified (by liming, heating, subsiding, and filtering) and then concentrated, in vacuo, to about one-fourth its original volume. The apparatus commonly used is a triple or quadruple effect, in which exhaust steam is used as the heating agent for the juice in the first vessel, whose vapour, under a reduced temperature, boils the partly concentrated in the second vessel, which again liberates vapour for boiling the still denser juice, under a still lower temperature in the succeeding vessel, which, in the case of a triple apparatus, is under a high vacuum and consequently low temperature. In a quadruple effect the principle is similar.

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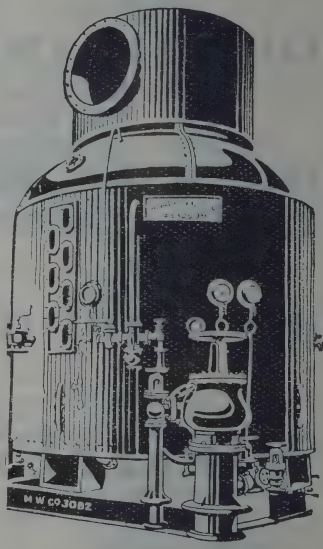

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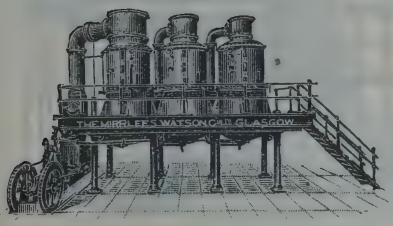
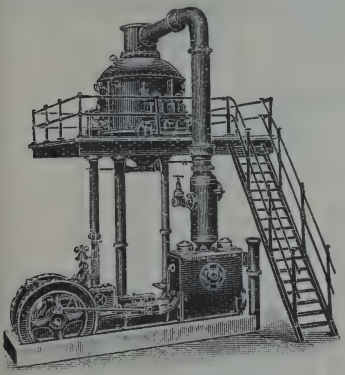


Triple-Effect Evaporator.

Fig. 2.

Diam. of Vessels.	Heating Surface.	Galls. treated per Hour from 9° to 30° Bme.
Ft. In.	Sq. Ft.	
6 0	4,440	2,960
7 0	6,248	4,170
8 0	8,168	5,450
9 0	10,500	7,000
10 0	13,120	8,750
11 0	15,800	10,530
12 0	18,800	12,530
13 0	21,940	14,610
14 0	25,270	16,830
15 0	28,860	19,220

The concentrated syrup is then granulated in vacuum pans.



Vacuum Pan and Air Pump.

Fig. 3.

Vacuum Pan Details.

(The Mirrlees Watson Co. Ltd.)

Diam. of Pan.	Heating Surface.		Strike Capacity Gallons Massecuite.
	Coil Type.	Cal. Type.	
Ft. In.	Sq. Ft.	Sq. Ft.	
8 0	436	582	2,230
9 0	650	867	3,260
10 0	850	1,133	4,210
11 0	1,080	1,440	5,280
12 0	1,450	1,930	8,230
13 0	1,725	2,300	9,850
14 0	2,025	2,700	11,540
15 0	2,360	3,150	13,400

The resulting massecuite is discharged into crystallisers, thence to centrifugal sugar-curing machines, in which the molasses is separated from the crystals, which are thereupon dried and bagged for transport.

Vacuum Evaporators for Trade Liquids.

In the concentration of trade liquors by evaporation, it is generally important that this should be not only economically but also rapidly effected under low temperature, as many liquids exposed to heat deteriorate. Hence the extended adoption of multiple-effect evaporators on the

horizontal tube type of the Mirrlees Watson Co. Ltd., which, having a rapid flow of liquid through their evaporating tubes, meet these requirements with the minimum of deposition on the heating surfaces.

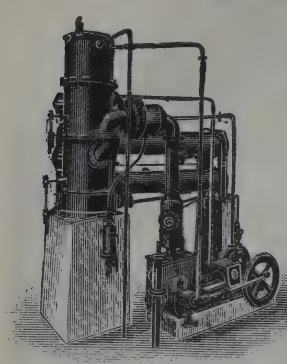


FIG. 4.—Double Effect

For bark and wood extracts, gelatine, glue, glucose, glycerine, and similar liquids of a viscid nature, a wide temperature difference between the vessels is desirable, hence the use of a double effect arrangement (fig. 4); their sizes range from 50 to 1,000 gallons hourly.

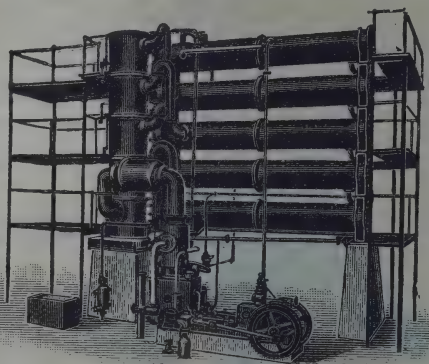


FIG. 5.—Quintuple Effect.

For soda ash recovery in paper mills, caustic soda, caustic potash, meat extract, distillery refuse, and other liquids readily amenable to concentration, triple, quadruple, quintuple (fig. 5), and sextuple (fig. 6) installations are in use; their sizes range from 100 to 3,000 gallons hourly.

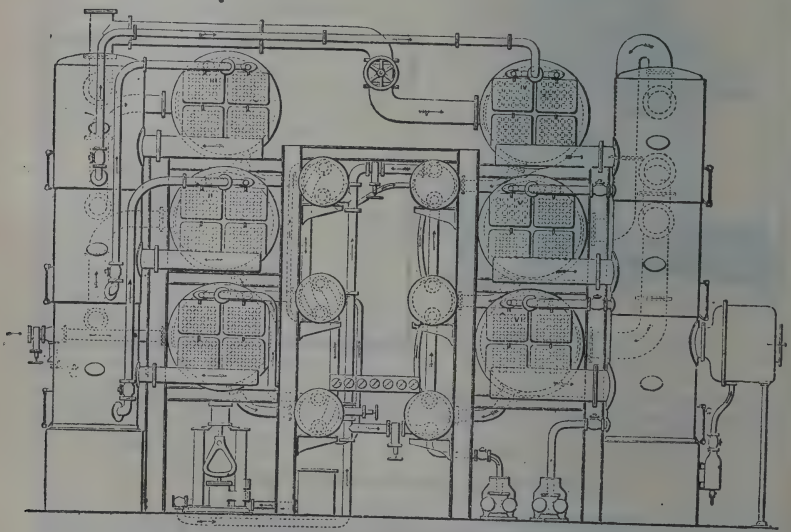


Fig. 6.—Sextuple-Effect Evaporator for Caustic Soda Lye.

Water Distillers.

To meet the demand for large quantities of distilled water at the lowest cost, the Multiple-Effect system of evaporation, extensively used in sugar manufacture, has also been applied largely, by the Mirrlees Watson Co. Ltd., to fresh-water distillers at home and abroad.

The principle on which multiple-effect evaporation is based is that the boiling point, and consequently the vapour temperature of liquids, varies with the surrounding pressure: the lower the pressure, the lower the boiling temperature; this principle is applied by working with diminishing pressures in the successive vessels of the multiple-effect evaporator.

Evaporators on the above principle are extensively used, but considerable experience is required so to proportion the various evaporating and condensing surfaces to secure the highest economy.

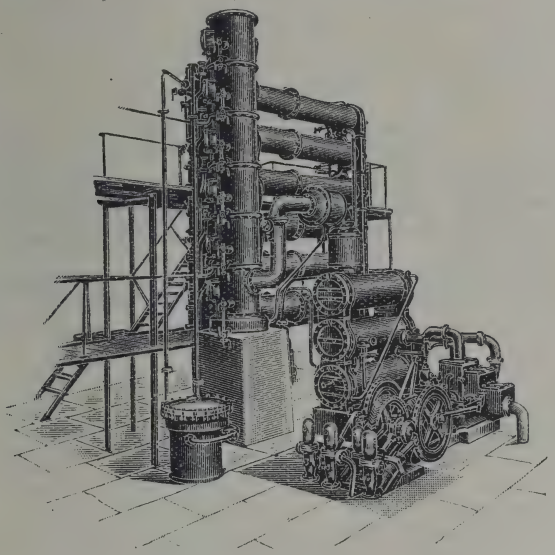


FIG. 7.—Sextuple Distiller.

Fig. 7 shows a sextuple-effect fresh-water distilling plant, which has been brought to a high state of efficiency, producing 44 lbs. of gained water (not including the drip from first vessel, which goes back direct to the boiler) per lb. of coal consumed.

Plants of this design are made to produce from 25 to 350 tons of distilled water per twenty-four hours. This type of distilling plant has been adopted by the British and other Governments.

For countries where earthquakes occur such apparatus is arranged with its evaporating vessels on a horizontal plane in place of the superimposed type illustrated by fig. 7.

(*The Mirrlees Watson Co. Ltd.*)

NOTE ON CONDENSERS.

Great caution should be exercised in guaranteeing the efficiency of condensers which are used for other purposes than the condensation of exhaust steam from steam engines, as for example the exhausting of vacuum pans for sugar manufacture. In such cases it often happens that far more air is present than is the case with ordinary exhaust steam, and consequently the condenser may prove unequal to the task for which it was guaranteed. Those who quote prices or guarantee a particular efficiency in the case of a condenser should make it plain that the 'steam' to be condensed must only contain a certain (specific) quantity of air.

SECTION XVIII

CRANES AND CRANE APPLIANCES — ELECTRIC LIFTS — ELECTRIC WINDING ENGINES — AERIAL ROPEWAYS — CONVEYORS — MAGNETIC SEPARATORS

(With Contributions by John H. Huntley, M.I.E.S., and Professor John Goodman, M.Inst.C.E.)

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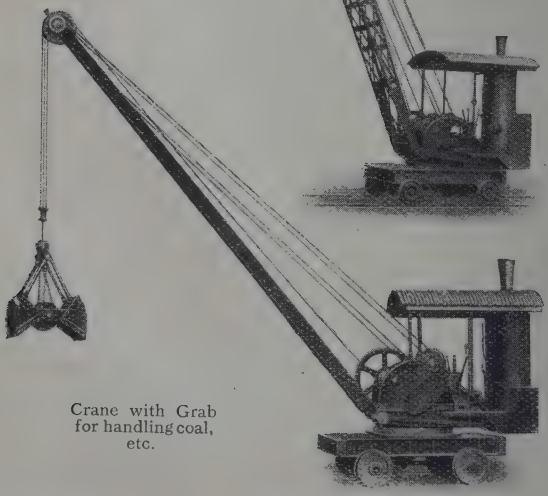

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SECTION XVIII

CRANES AND CRANE APPLIANCES — ELECTRIC LIFTS — ELECTRIC WINDING ENGINES — AERIAL ROPEWAYS — CONVEYORS — MAGNETIC SEPARATORS

CRANES.

(Contributed by John H. Huntley, M.I.E.S.)

General Notes on Cranes.

The selection of a crane for any particular service is governed by several factors, such as load, space available, power at disposal of user, frequency and speed of operation, height of lift, duration of service and cost.

Cranes can be operated by manual, steam, hydraulic, pneumatic, or electric power, or by a combination of these powers.

In power stations, stores, and places where an occasional lift is all that is required, a hand crane is quite suitable, even for loads up to 20 or 30 tons, but for frequent operation, or where the load has to be moved a considerable distance, it is advisable to instal a power-driven crane, even for a load of a few hundredweights, as the saving in time and labour soon pays for the difference in initial cost.

The electric crane has the following points in its favour :—

1. Simplicity of operation.
2. No power consumed whilst crane is standing.
3. Power used varies in proportion to load.
4. Always ready for starting up.

The steam crane has the advantage that it can be used wherever a supply of fuel and water is available, but time is lost in raising steam, and fuel is consumed in keeping up steam between the lifts.

Hydraulic cranes are only economical in operation when constantly working under full load, as the water consumption is the same for light or heavy loads, although by means of double-power rams attempts have been made to overcome this defect. Trouble is caused by frost in exposed situations. Hydraulic cranes are still largely used in shipyards and boiler shops, for handling plates, portable riveters, etc., where a small lift at slow speed is required. The working hydraulic pressure is usually 1,500 lbs. per sq. in., but may be as high as 2 tons per sq. in.

Pneumatic power is applied only to small hoists and pulley blocks, the air pressure being usually about 100 lbs. per sq. in.

Petrol or Paraffin engines have been applied for driving small portable jib cranes, and experience has proved that the nominal horsepower of the engine should be at least 50 % more than the actual brake horsepower required in order to have a sufficient margin for acceleration.

Hand Cranes.

The ordinary height of handle above ground should be 3 ft.; radius of circle described by handle, not more than 18 ins.; 16 ins. is a usual length. Angle of jib, 45°.

Each man working at the handle of a crane will exert a force of 15 to 20 lbs., exclusive of friction.

If W = weight to be lifted by crane in lbs., P = force applied to handle in lbs., D = diameter described by handle in inches, n = number of revolutions of handle to one of barrel, B = diameter of barrel in inches, then

$$B = \frac{D \times P \times n}{W}. \qquad D = \frac{W \times B}{P \times n}. \qquad n = \frac{W \times B}{D \times P} \qquad P = \frac{W \times B}{n \times D} \qquad W = \frac{P \times D \times n}{B}$$

OVERHEAD TRAVELLING CRANES.

For service inside buildings or where the site conditions permit of the construction of a gantry the overhead travelling crane has proved to be the most efficient appliance. For outside work a Goliath crane is often equally serviceable, and has the advantage of a lower first cost than an overhead crane with gantry.

For hand cranes up to 40 ft. span and loads up to 5 tons, a single girder crane can be adopted, but for longer spans or heavier loads it is advisable to use the double girder type to obtain lateral stiffness.

Light cranes are usually operated from the floor level by hanging chains, but for cranes above 10 tons it is advisable to work them from the crane platform. The pull on a hand chain should not exceed 40 lbs. per man, and for crank handles not more than 25 to 30 lbs. per man. The handles should have a radius of 16 ins. to 18 ins. and the centre be at a level of from 2 ft. 6 ins. to 3 ft. above platform level.

Travelling wheels for both crab and crane are usually of cast iron, and should be fitted with ball or roller bearings.

The hoisting gear should be efficient, preferably with machine-cut teeth, pinions of mild steel, wheels of cast iron, and should be fitted with a self-sustaining brake which requires to be released by the operator before the load can be lowered, but which is inoperative in the hoisting direction. This condition can be obtained by an internal ratchet or a screw disc brake.

Worm gear should have a coarse pitch and the sustaining power of the crane should not be dependent upon the inefficiency of the gear.

OVERHEAD ELECTRIC CRANES.

For engineering shops, foundries, steelworks, etc., the overhead electric travelling crane is unequalled for general service.

The motions of hoisting, traversing and travelling are generally arranged, and a separate motor should be fitted for each motion. An auxiliary hoist having a lifting capacity of about one quarter the main hoist is desirable on cranes above 40 tons capacity, and should be operated by an independent motor.

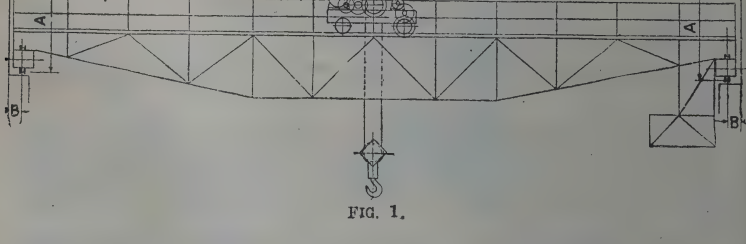


FIG. 1.

The following are particulars of standard 3-motor overhead travelling cranes (fig. 1) 30 ft. lift :—

TABLE OF STANDARD 3-MOTOR OVERHEAD ELECTRIC TRAVELLING CRANES.

Size.	Span.	Head-room. A.	End Space. B.	Wheel Base.	Max. Press. per wheel.	Wt. of Crane.	Speeds in feet per minute.			Falls of Rope.
Tons.	Ft.	Ft. Ins.	Ins.	Ft. Ins.	Tons.	Tons.	Hoist	Traverse	Travel.	
2	30	5 0	7	6 0	2·7	5·8	20	100	300	2
2	40	5 6	7	8 6	3·0	7·3	20	100	300	2
2	50	5 6	7	8 6	3·3	8·5	20	100	300	2
5	40	6 0	8	8 6	5·3	9·8	20	90	300	4
5	50	6 0	8	8 6	5·8	11·5	20	90	300	4
5	60	6 0	8	9 6	6·1	13·0	20	90	300	4
10	40	6 6	8½	10 0	8·4	12·0	15	80	300	4
10	50	6 9	8½	10 0	9·1	14·5	15	80	300	4
10	60	6 9	8½	10 0	9·7	16·5	15	80	300	4

TABLE OF STANDARD 3-MOTOR OVERHEAD ELECTRIC TRAVELLING CRANES—*contd.*

Size.	Span.	Head-room. A.	End Space. B.	Wheel Base.	Max. Press. per wheel.	Wt. of Crane.	Speeds in feet per minute.			Falls of Rope.
							Hoist.	Traverse.	Travel.	
Tons.	Ft.	Ft. Ins.	Ins.	Ft. Ins.	Tons.	Tons.				
15	40	7 0	9	10 0	11·3	13·8	13	80	275	6
15	50	7 0	9	10 0	12·0	16·2	13	80	275	6
15	60	7 0	9	10 0	12·5	18·0	13	80	275	6
20	40	7 3	9½	10 6	14·5	16·5	10	80	275	8
20	50	7 3	9½	10 6	15·2	19·0	10	80	275	8
20	60	7 3	9½	10 6	15·8	21·0	10	80	275	8
25	40	7 6	10	11 6	17·5	19·0	10	80	250	8
25	50	7 6	10	11 6	18·5	22·0	10	80	250	8
25	60	7 9	10	11 6	19·2	24·2	10	80	250	8
30	40	8 0	10½	12 0	20·3	22·0	10	75	250	8
30	50	8 0	10½	12 0	21·5	25·0	10	75	250	8
30	60	8 3	10½	12 0	22·5	28·0	10	75	250	8
40	40	9 0	11	13 0	26·5	26·0	10	70	250	8
40	50	9 0	11	13 0	27·8	30·0	10	70	250	8
40	60	9 3	11	13 0	29·5	34·5	10	70	250	8
50	40	10 0	11	13 0	32·0	31·0	10	70	230	8
50	50	10 0	11	13 0	34·0	35·0	10	70	230	8
50	60	10 3	11	13 0	35·5	39·5	10	70	230	8
60	40	10 3	12	13 6	38·5	35·0	8	70	230	10
60	50	10 3	12	13 6	40·5	40·0	8	70	230	10
60	60	10 6	12	13 6	42·5	45·0	8	70	230	10

The above table is for cranes on four travelling wheels.

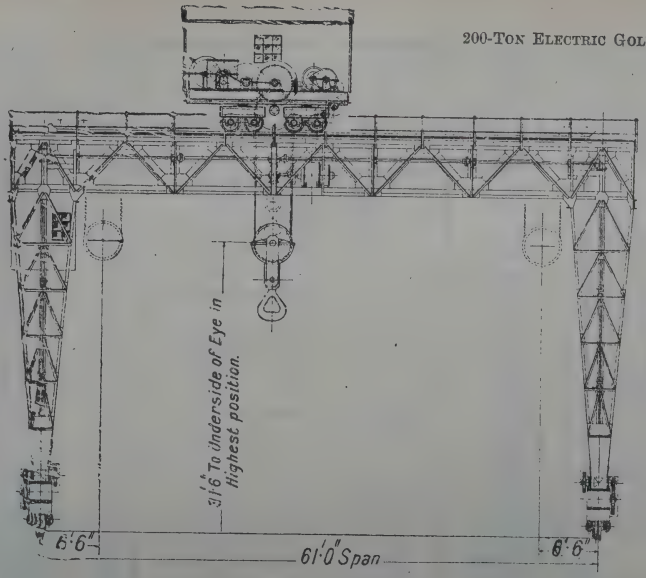
For 70-ton cranes and upwards the usual practice is to mount the crane on eight travelling wheels, and the wheel loads in the following table are based on this. The column headed 'Centres of Wheel Bogies' indicates the distance between the centre of each pair of wheels in each end carriage, and the following column gives the distance between the two wheels of each pair:—

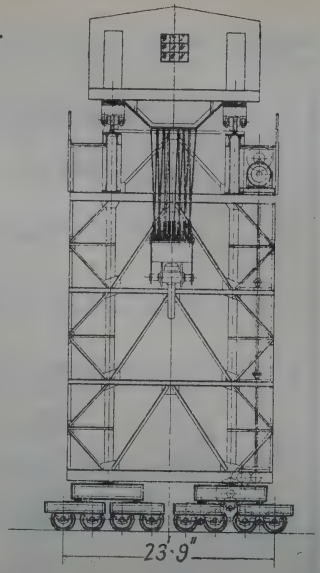
Size.	Span.	Head-room A.	End Space B.	Crs. of Wheel Bogies.	Bogie Wheel Centres.	Max. Press. per Wheel.	Wt. of Crane.	Speeds in F.P.M.			Falls of Rope.
								Hoist	Trav-erse.	Travel	
Ton	Ft	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Tons.	Tons.	Ft.	Ft.	Ft.	
70	50	10 9	1 1	10 6	5 0	22·82	46	7	60	200	10
70	60	10 9	1 1	10 6	5 0	23·90	50½	7	60	180	10
70	70	11 0	1 1	10 6	5 0	24·87	56	7	60	180	10
80	50	11 0	1 2	11 0	5 0	25·40	51	6	60	180	12
80	60	11 0	1 2	11 0	5 0	26·75	56	6	60	150	12
80	70	11 3	1 2	11 0	5 0	28·00	62	6	60	150	12
100	50	11 3	1 3	11 6	5 3	32·12	62	5	60	150	12
100	60	11 3	1 3	11 6	5 3	32·62	68	5	60	150	12
100	70	11 6	1 3	11 6	5 3	35·00	75	5	60	150	12

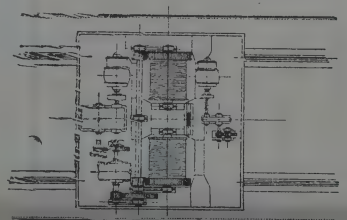
NOTE.—The headroom figures allow for about 3 ins. clearance and the end space for about 1½ in. clearance.

For short-span cranes of small size, a pair of 'H' beams make an economical set of girders, but the span should not exceed sixty times the width of the flange of one girder. For cranes up to 60 ft. span the most economical construction is the trapezoidal single web girder, with lattice auxiliary connected to the main girder by horizontal and diagonal bracing. This makes a very stiff construction, is easy to manufacture, and all surfaces are accessible for painting. The platform and travelling gear can be well supported by bearers between the main and auxiliary girders. For long spans and for outside service it is desirable to make the girder of the lattice

200-TON ELECTRIC GOLIATH CRANE.







SPEEDS AND MOTORS.

Hoisting	200	tons at	3	ft. per min. Motor 65 B.H.P.
„	75	„	8	„ „ Change gear.
Traverse	200	„	30	„ „ Motor 25 B.H.P.
Travel	200	„	50	„ „ „ 65 B.H.P.

FIG. 2.

type to reduce weight and wind surface. The depth of the girder is usually made one-twelfth the span. The maximum bending moment due to the crab, assuming each wheel equally loaded, is given by the formula :—

$$\frac{W}{2S}\left(S-\frac{B}{2}\right)^2 \text{ ft. tons,}$$

where,

W = load per wheel in tons ; S = span in feet ; B = wheel base of crab in feet.

To this must be added the bending moment due to the deadweight of the girder and travelling gear. The modulus of the girder section should be such as to give a stress of between 5 and 6 tons per sq. in. The stresses in lattice girders are best determined by graphic methods.

The end carriages can be constructed of channels, and built up of plates and angles, when larger sections are required. They should be connected to the girders by large gusset plates, and fitted bolts to prevent cross winding. The wheel base should preferably be one-fifth to one-sixth of the span.

Rail wheels should be of cast steel, or of cast iron centres with steel tyres shrunk on. The width of the rolling surface of the rail is an important point, and for heavy loads a rounded surface should be avoided. The safe load on a wheel may be arrived at by the following empirical formula :—

For cast steel wheels, safe load in pounds = $800 \times W \times D$,

„ steel tyred „ „ „ „ = $1{,}200 \times W \times D$,

where,

W = width of rail face in inches ; D = dia. of wheel in inches.

Rails for heavy cranes are now rolled with a working face of 6 ins. and weight of 265 lbs. per yard.

To calculate the power required to travel a crane, a tractive force of from 60 to 70 lbs. per ton is usually taken, and for outside service the effect of wind pressure must be considered.

To prevent cross winding the cross shaft should be stiff enough to avoid undue torsional deflection when the driving wheels are unequally loaded due to the crab being at one end of the span. A foot brake should be fitted to the cross shaft on cage control cranes and a solenoid brake fitted to the motor shaft on all cranes working in the open.

The crab frame should be built up of steel sections well stiffened to form a rigid support for the motors and gearing. The traversing wheels should be of cast steel or have steel tyres, the latter only being necessary on crabs of the largest size.

It is unnecessary to fit a brake to the traversing motion unless the speed exceeds 100 ft. per minute, when a solenoid brake can be fitted.

The load is preferably lifted on wire ropes winding on to a cast iron drum rotated by gearing, the number of falls of rope depending upon the load. For cranes up to 3 tons capacity, the load may be lifted on two falls winding one fall on to the barrel. Where four or more falls of rope are used, two falls should wind on to the barrel, which should have right and left-hand spiral grooves and thus keep the load central between the girders.

The efficiency of the gearing varies from about 75 per cent. on small cranes to 65 per cent. on large cranes. A convenient rule to determine the horse-power of the motor is

$$\text{H.P.} = \frac{\text{foot-tons per minute}}{10}$$

The speeds of working given in the table, p. 902, are suitable for general engineering shop work, but for steelworks very much higher speeds are used, and as continuous night and day service is the general practice in these works the design of the crane should be specially considered and made very robust.

All cranes are preferably fitted with two brakes, one of which should be an automatic solenoid brake; the type of the other brake will depend entirely on the service for which the crane is used.

Fig. 3 shows a small crab made by Messrs. Babcock & Wilcox. The framework consists of mild steel plates or channels connected by stretchers which support the motors and the

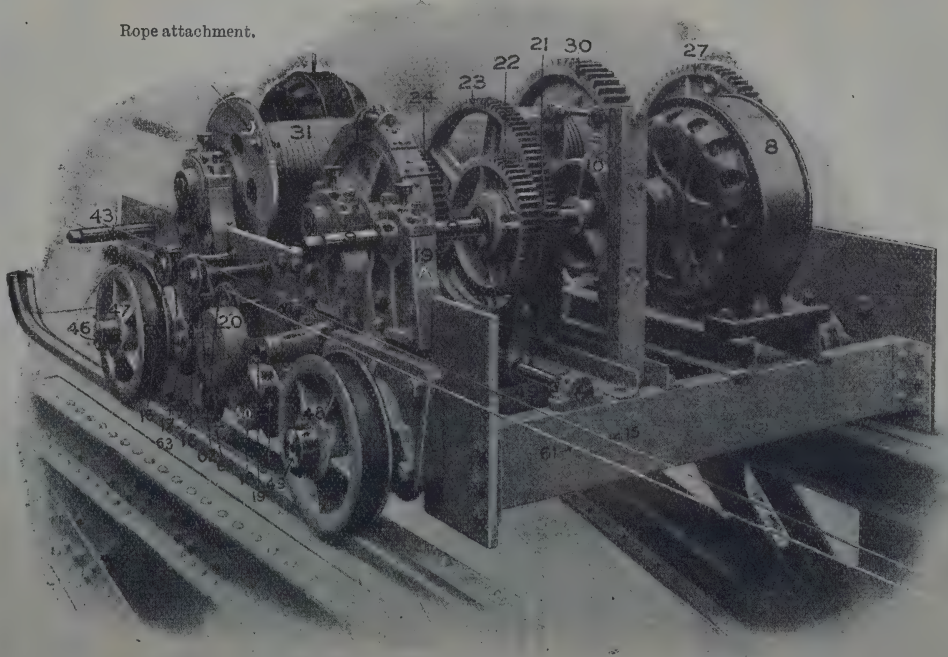


FIG. 3.—View of left-hand side of Babcock & Wilcox Crab, from hoisting motor end.

return sheaves of the hoisting ropes. The hoisting motor (8) is fitted with an extension shaft (9) on which is fixed the automatic magnetic brake (10). Two blocks press against the face of the brake pulley by means of a counterweight (50), when the crane is standing. When current is switched on, the weight is lifted by the action of the solenoid, and is automatically reapplied when current is cut off. There is also a mechanical brake (12), operated from the cage by a foot pedal attached to a lever. This lever is connected to the flexible wire (15) stretching from end to end of the cross-girders and passing over two fixed pulleys (16) and under a movable pulley (17) coupled to a counterweight (20) which serves to keep the brake strap clear of the brake-wheel. By operating the pedal the brake strap can be tightened round the brake-wheel.

The hoisting motor extension shaft (9) carries two sliding pinions, one for slow and heavy hoists (21), and the other for quick and light hoists (22), and these may be put into gear by means of a lever operated by hand from the driver's cage when the crab is opposite to it. These pinions gear with spur wheels (23) and (24) on the first motion shaft which carries the mechanical brake (12). At the farther end of this shaft, a pinion gears into the spur wheel (27) on the second motion shaft. On this latter shaft, another pinion gears with the main spur wheel (30) which is bolted to the hoisting barrel (31). The two ends of the hoisting rope are secured to the ends of this barrel, which is grooved right and left-handed, so that the rope on each side is wound uniformly towards the centre and a truly vertical movement given to the lifting hook. An overwinding gear is fitted consisting of a screw spindle and travelling nut which, when the hoisting hook has reached its highest position, strikes a lever connected to an emergency cut-out in series with the hoisting controller and motor. This action opens the switch, cuts the current off the motor and applies the magnetic brake, thus stopping any further winding. With D.C. motors the hoisting controller is fitted with rheostatic brake steps to control the load when lowering. With A.C. motors hand gear is used to release the magnetic brake mechanically. This gear consists of a lever attached to a flexible wire (61), stretching from one end to the other of the cross-girder, passing over two fixed pulleys (62) and under a movable pulley (63), fitted with the counterweight (50). By operating the lever, the movable pulley and weight may be raised, thereby freeing the brake to any desired extent.

On the spindle of the traversing motor (40) a pinion is fitted which gears with a spur wheel keyed on to the first motion traversing shaft (43). By means of another pinion and spur wheel this shaft is connected to the driving axle (46) to which are keyed two of the wheels (47) on which the crab runs. The remaining two wheels (48) are keyed to the trailing axle (49) which runs freely in its bearings.

For handling hot ingots in rolling mills, special cranes with semi-automatic tongs are used, and have been made to fulfil such varied functions as stripping the ingot from the mould, charging and withdrawing the ingot from the soaking pit, and lifting and replacing the soaking pit cover.

For handling molten metal, special cranes known as 'ladle cranes' have been designed, and are made up to 150 tons capacity, but cranes of 80 to 100 tons are more generally used. These cranes are fitted with two crabs, the main crab running on top of the girders and the auxiliary crab between the girders and on the lower flanges. The main crab has two barrels arranged so that the hoisting ropes pass outside the girders to sheaves attached to a lifting beam from which the ladle is suspended. The auxiliary crab has usually a lifting capacity of about 20 per cent. of the main crab and serves for general lifts and for tipping the ladle if required.

For handling forgings under hydraulic presses, special cranes have been developed with relieving gear to prevent overloads due to the action of the press in pulling down a forging which is suspended not quite level with the anvil. These cranes are made up to 200 tons capacity, and can be fitted with detachable gear for rotating the forgings.

For stores, warehouses, and machine shops an overhead travelling crane with underhung jib has many advantages owing to the increased area covered by the jib.

For outside service the Goliath crane fulfils the same function as an overhead traveller, and eliminates the gantry. Fig. 2 (p. 904) shows a crane of this type designed for lifting loads up to 200 tons.

The speeds of working and sizes of motors are:—

Hoisting, slow gear	200 tons,	3 ft. per min.	Motor 65 h.p.
,, fast ,,	75 ,,	8 ft. ,,	
Traversing	200 ,,	30 ft. ,,	,, 25 ,,
Travelling	200 ,,	50 ft. ,,	,, 65 ,,

The load is lifted on sixteen parts wire rope, winding one part on to each of two barrels rotated by the 65 h.p. motor through four reductions of gearing. Change-speed gear is provided for handling loads up to 75 tons at a quicker speed. An automatic solenoid and automatic mechanical brake are fitted, the latter working entirely enclosed in an oil box. The crab is mounted on four two-wheeled bogies and traversed by the 25 h.p. motor driving four rail wheels through four reductions of gearing. The crane travels on a twin rail track, there being eight centre-flanged steel-tyred wheels under each leg. Four wheels on each side of the crane are driven. The girders are of the lattice type with auxiliary girders and bracing to give lateral stiffness. All motions are operated from an enclosed cabin situated in an elevated position, the hoisting and travelling controllers are of the contactor type and the traversing of the drum type.

Overhead Runways.

Overhead runway systems, consisting of a track formed from a single rolled-steel joist which may be curved to suit local conditions, and have switches or turntables, are frequently installed in warehouses, steelworks, gas works, and other situations where an overhead crane is unsuitable or too expensive. Hand-pulley blocks and trolleys are used on the runways for occasional service and light loads, but for speed and loads up to five tons an electric trolley hoist should be installed. These may be either floor or cage controlled, and have usually separate motors for hoisting and travelling. The lifting speed may be as much as 100 ft. per minute, and the travelling speed from 200 to 800 ft. per minute, according to the duty required.

Grabs can be fitted to lift coal, ore, or similar material.

Derrick Cranes.

The Scotch derrick crane, largely used by contractors, has many advantages on account of its portability, simplicity of erection and long outreach. As commercially manufactured in stock patterns, these cranes have not usually a very large factor of safety, and if the full load is to be constantly handled it is advisable to specify a crane for about 25 per cent. greater load. Cranes of this type are specially made in large sizes for dock-side service in fitting out vessels under construction, but are giving way in favour of the more efficient cantilever crane.

Locomotive Cranes.

For general service on railway sidings around works and shipyards the locomotive steam crane is unequalled. These cranes are made in standard sizes up to 10 tons capacity and lift the load free on track with the jib in any position.

The following table gives particulars of standard steam cranes :—

Standard Locomotive Steam Cranes, 4 ft. 8½ in. Gauge.

Size.	Radius.	Size of Engines. (Cylinders.)	Size of Boiler.	Steam Press.	Speeds.			Weight.
					Hoist, f.p.m.	Slew, r.p.m.	Travel, f.p.m.	
Tons.	Ft.	Ins. Ins.	Ft. Ins. Ft. Ins.	Lbs.				Tons.
3	16	7 by 10	7 9 by 3 6	100	80	2½	350	14½
5	16	8 by 10	8 3 by 4 0	100	80	2½	350	22½
7	16	8 by 12	8 3 by 4 0	100	50	2	300	32½
10	16	9 by 12	9 0 by 4 0	100	40	2	250	45
15	16	9 by 12	9 0 by 4 0	100	40	1½	200	54

For cranes of longer radius or greater lifting capacity than the above, blocking girders and rail clips are fitted to give the necessary stability, or the cranes may be made heavier.

Cranes that are to travel round sharp curves should have sliding axle gears or differential gears and the conditions pointed out to the crane makers at the time of ordering.

The travelling gear should be of steel, also the slewing ring and pinion.

The slewing spur-ring forms the roller path and should rest on a machined seating on the truck, the pressure of the slewing rollers being sufficient to hold it in position for normal working, but in the event of sudden loads it will slide sufficiently to absorb the shock and prevent damage to the gearing.

The engines are usually of the double cylinder non-condensing type, cranks at right angles and cut off at about three-quarter stroke. The boiler is of the vertical cross-tube type for a working pressure of 80 to 100 lbs. per sq. in. and should be lagged. Two means of feed should be fitted, and the incoming water should enter above the firebox and not impinge directly on the heated plates.

The mountings should preferably be flanged, and secured by studs to pads riveted to the shell of the boiler, rather than screwed directly to the shell. The safety valve should be separate and not a combined mounting with the stop valve.

A list of standard boiler mountings would consist of :

1 steam-pressure gauge with syphon ;
1 water gauge with plate glass protection ;
1 spring loaded safety valve ;
1 steam stop valve ;
1 injector with steam cock and feed check valve ;
2 test cocks ;
1 steam jet cock and pipe to funnel ;
1 blow-off cock.

The feed pump may be either a steam donkey pump or be driven direct from the engine crosshead.

Runabout Cranes.

For service in situations where overhead cranes or rail tracks are not available, a handy type of crane, known as the Runabout Crane, has been recently developed. It is operated by electric motors, taking current from storage batteries or a petrol-driven dynamo. The truck or chassis carries the source of power, the operating motors, and gearing. It is mounted on a fixed two-wheel axle, and at the rear on a two-wheel articulated castor which adapts itself to any unevenness of the ground and is used as the medium for steering and slewing. The jib is of the bascule type, pivoted at the apex of an A frame carried on the chassis. It is held and adjusted by a wire rope purchase acting on the back arm operated through derricking gear to vary the height and radius. The load is lifted on wire rope and held by an automatic solenoid brake. The cranes are made in sizes up to 2 tons at 6 ft. outreach and 25 cwts. at 10 ft. 6 ins. outreach, in front of the truck.

Steam Breakdown Cranes

for use on the permanent way, have been made up to 100 tons lifting capacity, but in Great Britain the usual size is from 10 to 35 tons. The truck of these cranes is provided with the usual permanent-way fittings and the axles are spring borne. The maximum load per axle with the crane in running order should not exceed 18 tons When the crane is 'in train' the travelling gear should be disconnected and the superstructure locked to prevent it turning. Owing to the limited space due to the crane having to clear the loading gauge, a comparatively small size boiler must be fitted, and this should be of the multitubular type as the ordinary cross-tube boiler would not generate enough steam.

Wharf Cranes.

For dockside service in loading and unloading ships, the high gantry type of jib crane is principally used. The usual sizes are from 1½ tons to 5 tons and the radius from 40 to 60 ft. The gantry is made wide and high enough to admit of the passage of rolling stock underneath and to keep the jib clear of the sides of large vessels. A separate motor should be fitted for each motion.

Typical speeds of working, in feet per minute, are as follows :—

Description.	Size.		
	1½ tons.	3 tons.	5 tons.
Hoisting	200	150	120
Slewing	500	400	300
Travelling	100	100	80
Derricking	150	120	100

For high derricking speeds some form of compensating gear is essential to reduce the power consumption due to raising the load and jib each time the radius is reduced. With the ideal compensating gear the path of the load is kept horizontal as the jib is raised or lowered, and with the jib balanced the power required is only that necessary to overcome friction.

For rapid handling of coal, ore, or similar loose materials, the transporter grab crane is unequalled. The load is carried by a trolley which travels on a horizontal track, supported in a suitable manner by the crane structure, which latter may take the form of a tower with cantilevers on each side or a bridge, if it is desired, to convey the load over a considerable distance.

If working at the dockside the outer cantilever may be made to hinge up to clear the masts and funnels of ships when coming alongside.

The operating machinery can be fixed on the structure and the trolley carry only guide sheaves for the hoisting ropes and be hauled along by other ropes winding on to a separate winch, or the hoisting and transporting gear can be carried by the trolley. The latter system is usually adopted when the gross load exceeds 5 tons, as with the fixed machinery system the wear of the ropes becomes excessive in the larger sizes and off-sets the initial saving due to the lighter design of structure.

The advantage of this type of crane over the jib crane is that the load is conveyed in a direct line from point to point instead of through the arc of a circle. The transporting speed can be at the rate of 800 to 1,000 ft. per minute, whilst the maximum safe slewing speed is not more than 400 to 500 ft. per minute. With a 3-ton grab the transporter crane will usually handle 150 tons per hour against 100 to 120 tons on a jib crane.

For handling coal, ore, and similar materials, much time and labour is saved by using grabs; these may be on the single or double-chain principle.

The single-chain grab may be fitted to any crane lifting on a single fall of rope, but grabs of the double-chain type require an extra drum to coil up the opening or closing rope. This should preferably be driven through a friction drive, although for short lifts a spring drum is quite suitable.

With the larger sizes two independent motor-driven winches, one for each rope, are sometimes used. The opening and closing of the grab is then performed by movement of the motor controller handles. For satisfactory operation automatic contactor controllers should be used with relays to prevent excessive overloading of the hoisting motor in the event of the driver being late in starting the holding rope winch when coming away from the material with a full grab.

Grabbing work is very severe on cranes, and the nominal size of the crane should be 50 per cent. in excess of the combined weight of grab and contents. The empty grab may be balanced by sliding counter weights to reduce the power consumption.

Double rope grabs have a tendency to spin and twist the ropes round each other. This may be overcome by fitting a large sheave at the grab head, and leading the opening and closing rope back to the jib head or winch, the grab being thus suspended on three ropes spread apart by the sheaves, which keeps it perfectly steady. On heavy grabs two hoisting ropes are used either on the single or double chain principle.

Automatic self-dumping single-rope grabs, which open when the weight of the grab is relieved from the hoisting rope, require only a single-drum winch for operation and give a higher duty than the single-rope grab with fixed discharge gear.

CAPACITY AND WEIGHTS OF GRABS.

For Coal.			For Iron Ore.		
Capacity.	Weight of Grab.	Approx. Weight of Coal.	Capacity.	Weight of Grab.	Approx. Weight of Ore.
Cub. ft.	Cwts.	Cwts.	Cub. ft.	Cwts.	Cwts.
45	30	15	21	38	20
56	36	20	31	49	30
63	42	25	42	60	40
82	48	30	65	90	60
112	68	40	150	220	200
180	112	70	—	—	—

SHIPBUILDING CRANES.

For service over shipbuilding berths, high gantries with overhead travellers and mono-rail cranes, gantries with cantilever cranes, steel derricks and tower cranes, are used, and experience favours the latter type.

Tower cranes may be either of the fixed or travelling type, practice in Great Britain being inclined to the fixed type, as they require less clearance between the berths, and use is made of valuable space which would otherwise have to be kept clear for the track of a travelling crane.

The crane structure consists of a horizontal cantilever supporting the track for the load trolley, and is carried on the top of a braced steel mast which is free to revolve inside a fixed or travelling tower. The cantilever is balanced by a tail carrying the machinery, which gives the crane a hammer-headed appearance.

The motions of hoisting, slewing, racking, and travelling are fitted, operated by independent motors. The cranes are made with a lifting height up to 120 ft., and a radius up to 140 ft. The usual capacity is 5 tons at 100 ft. radius and 10 tons at 50 ft. Travelling cranes of this type have been made to lift 30 tons at 100 ft. radius, 15 tons at 140 ft. radius, and with a height of lift of 120 ft., but these are exceptional sizes.

These cranes, if desired to lift varying loads at different radii, should be fitted with an automatic anti-overload device which will prevent a load above the safe limit for its radius being lifted, and will also prevent the trolley traversing beyond the safe radius for that particular load.

For fitting out, cranes of the wharf type with derricking jibs are used, and range in size from 10 to 40 tons, with radii up to 80 ft., according to requirements. Two speeds of hoisting are generally arranged, so that light loads may be lifted at a speed of 50 to 80 ft. per minute. A typical crane of this type lifts 30 tons at 55 ft., 20 tons at 72 ft., 10 tons at 80 ft. radius, and is mounted on a gantry to clear rolling stock, the centres of the gantry track being 22 ft.

Cranes of this type are installed for dry dock service, and it is occasionally necessary that they should work from both sides of the dock. This may be arranged by connecting the two sides of the dock by a track at the end and introducing turntables, or better by making the track sweep round on a curve and carrying the rail wheels on special swivelling bogies and inserting an epicyclic gear between the sections of the travelling motion cross shaft which connects the driving rail wheels on each side of the crane.

A large fitting-out crane is shown by fig. 4. This crane is designed to lift a load of 25 tons at 84 ft. radius, 5 tons at 112 ft. radius, and has a total range of lift above track level of 137 ft. The centres of the track rails are 40 ft.

The load of 25 tons is lifted at a speed of 20 ft. per minute, and 5 tons at 100 ft. per minute.

Floating cranes are occasionally used for fitting out and repair service, and have the advantage of being transferable from dock to dock, but with them it is not easy to deposit a heavy load with

precision, as the crane follows the movement of the water and its equilibrium is disturbed with every fluctuation of loading. These cranes are usually steam operated, but in recent years several large cranes have been electrically driven. This appears an unnecessary and expensive refinement, offering little advantage to compare with the additional cost of installing generators unless other use can be made of the power.

The pontoons are usually rectangular, flat-bottomed vessels, but if self-propelled it is advisable to give them a ship shape. The angle of heel under full load conditions and a 5 lb. wind should be not more than 5°. Travelling ballast is sometimes fitted to limit the heel under various loading conditions. A crane of this type, constructed by Sir Wm. Arrol & Co. Ltd., Glasgow, for the Brazilian Government, is designed to lift 30 tons at 10 metres outreach from the side of the vessel and is steam operated, the motions of hoisting, derricking, and slewing being fitted.

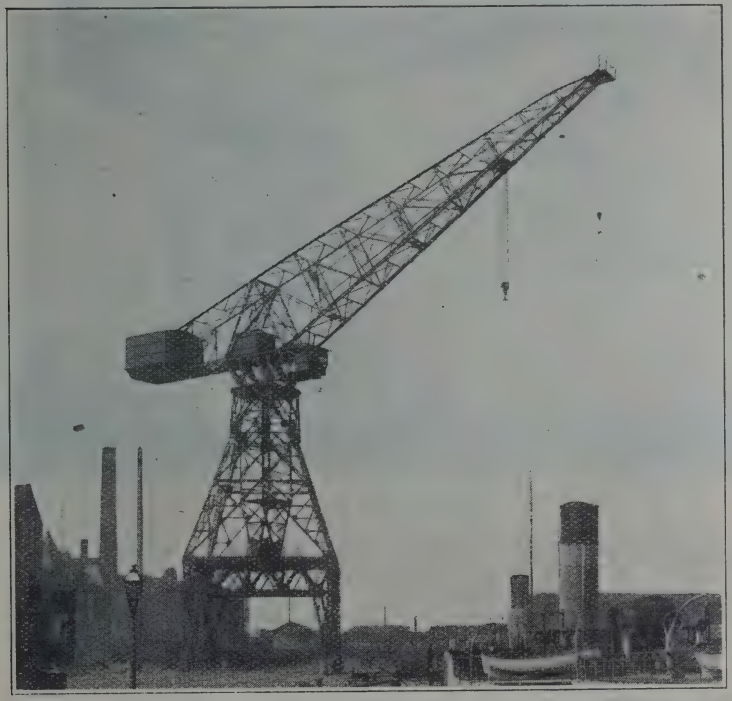


FIG. 4.—25-Ton Wharf Crane.

The pontoon, built by Messrs. Ritchie, Graham & Milne, of Glasgow, is of the self-propelled type, 150 ft. long by 50 ft. beam by 8 ft. deep, and is fitted with two sets of compound surface condensing engines having cylinders 13 ins. and 26 ins. by 18 ins. stroke, to give a speed of seven knots.

The outline of the largest floating crane so far constructed is shown in fig. 6, p. 913. This crane is designed to lift 350 tons at a radius of 100 ft., 300 tons at 121 ft., and 50 tons at about 160 ft. The range of lift with full load is 140 ft., and with 50-ton load 200 ft.

The crane, which was made by Messrs. Cowans, Sheldon & Co., Ld., of Carlisle, for service in Japan, is operated by steam, there being nine sets of double-cylinder condensing engines, each motion being independently operated without the use of clutches. Control of the load for lowering is obtained by hydraulic brakes which enable very precise movements to be obtained.

The pontoon is 270 ft. long by 92 ft. wide, with draught of 10 ft., and is self-propelled by twin screw compound engines supplied with steam at 150 lbs. pressure from two single-ended boilers.

The boilers are of the water-tube type and supply steam to the crane engines, auxiliary machinery and electric light set.

The Giant cantilever crane is adapted for loads from 75 to 250 tons and enables large portions of machinery, gun turrets, etc., to be lifted on board as a complete unit. A typical crane of this

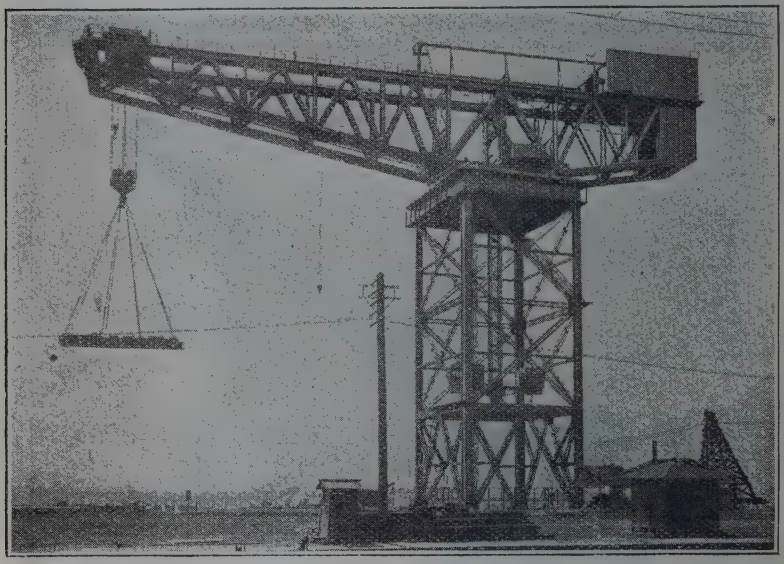


FIG. 5.—250-Ton Giant Crane.

type, manufactured by Sir Wm. Arrol & Co. Ltd., Glasgow, is shown in fig. 5. The leading dimensions are :—

Max. radius for 250 tons	105 ft.
,, ,, ,, 120 ,,	130 ft.
,, ,, ,, 80 ,,	160 ft.
Height to top of tower	140 ft.
Base of tower	50 ft. square.

The main hoisting machinery consists of independent hoists each of 125 tons capacity, which can be worked together when required. The auxiliary hoist is of 40 tons capacity and the jigger hoist of 10 tons, this latter having a separate track and trolley on the underside of one of the cantilever girders. The crane was satisfactorily tested with a load of 360 tons.

CAPSTANS.

For hauling trucks in goods stations or on the dock side a capstan designed to exert a pull of 1 ton at a speed of 150 to 200 ft. per minute is sufficient. The free bollard type with the rope attached to the bollard is more economical in use than the fixed bollard type which depends upon the friction of the coils of rope round the bollard for hauling power.

The warping of ships into position in the docks is done by capstans of from 10 to 20 tons pull. A constant torque at varying speeds is the desideratum for this duty, and the characteristics of the Austin constant-current motor make it eminently suitable for this work.

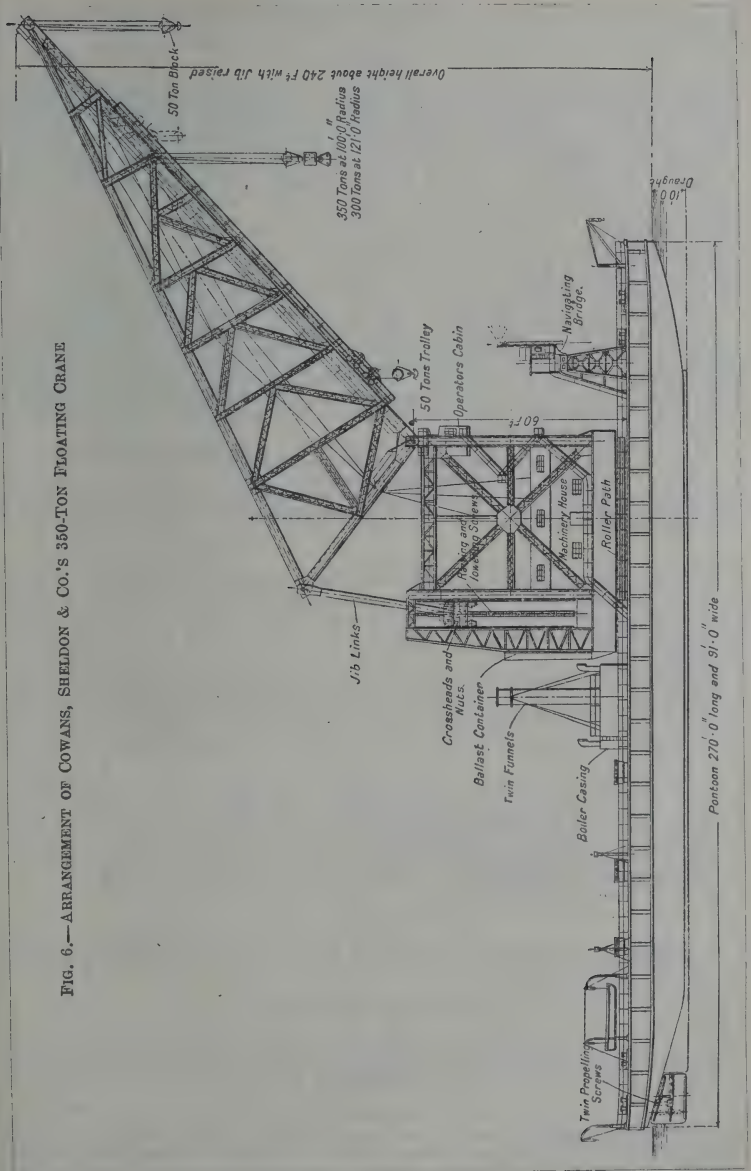


FIG. 6.—ARRANGEMENT OF COWANS, SHELDON & CO.'S 350-TON FLOATING CRANE

General Data.

Structures.

Crane structures should be made of open-hearth mild steel, 28 to 32 tons tensile strength, extension not less than 20 per cent. in eight inches. In determining the section of members, allowance should be made for the vibration due to the movement of the load and machinery, for the movement of the structure in the case of a travelling crane, and deflection should be considered where bearings for shafts are carried on structural members. The stresses should be such as to give a factor of 5 to 6 on the ultimate strength of the material. The ratio of length to radius of gyration should carefully be considered in struts, and charts plotted from Claxton Fidler's or Tetmeyer's formula form a reliable basis on which to determine the stresses. For wind bracings the factor of safety need not be more than three, as this is an exceptional loading infrequently applied.

Wind pressure on cranes in exposed positions in Great Britain may be taken as a maximum of 40 lbs. per sq. ft. It is inadvisable to work a crane in a wind pressure above 5 lbs. per sq. ft., and when designing the structure it is therefore unnecessary to allow for a higher pressure under full load conditions. The maximum wind pressure must of course be considered separately.

The revolving superstructure of jib or cantilever cranes may be carried on a ring of live rollers, or on a set of four or eight large diameter rollers designed as travelling wheels, but with conical treads and unflanged. The live rollers may be of either forged or cast steel and should run between two steel guard rings connected to the centre pin casting by radial rods. A gunmetal washer should be fitted between each roller and the outer guard ring, to take the outward thrust of the rollers. For unhardened rollers the pressure in lbs. should not exceed 400 by length in inches by diameter in inches. The roller-paths should be of steel, machined conical on the face to form a full bearing for the rollers.

On jib cranes up to about 5 tons capacity the roller-path frequently consists of a flat-bottom rail bent to a circle, and the superstructure is then mounted on four rollers 15 ins. to 18 ins. diameter. This is a cheap and serviceable construction.

A friction clutch should be incorporated in the slewing gear adjusted to slip and prevent damage in the event of excessive shock due to too sudden application of the brake or the fouling of jib with some stationary object.

Gearing.

On all high-class crane work the gearing should be machine cut. For hand and low-power cranes cast-iron wheels and steel pinions are satisfactory, but for all high-speed cranes the gearing should be of steel, with the possible exception of motor pinions, which, to ensure silent running, may be of rawhide, fabroil, or phosphor bronze.

For heavy loads and high speeds, machine-cut double helical gearing is very satisfactory efficient, and silent.

The strength of spur gearing can be determined by the Lewis formula (page 1011).

Gearing with stub teeth and 29° involute is advised for crane work, as the strength is greater than standard 14½° involute, by 30 per cent. with a rack, to 50 per cent. with a 12T pinion. The addendum is 0·27 of the circular pitch and the dedendum 0·32. With diametral pitch the outside diameter of the wheel is determined by adding 1·75 to the number of teeth and dividing by the pitch.

Worm wheels should consist of a phosphor bronze rim fixed on a cast-iron or steel centre, and have machine-cut teeth. The worm should be of high tensile forged steel and need not be hardened unless facilities exist for grinding the threads. In determining the size of worm gearing the heating effect must be considered as well as the strength.

For the highest efficiency a special globoidal gear, known as Enveloping Worm Gear, developed by Bostock & Bramley of Leeds, is recommended. This gear has a greater bearing surface than any other form and occupies less space than ordinary worm gear for the same power.

(See also 'Worm Gearing,' p. 1025.)

Shafts.

In designing shafts the resultant loads should be determined and the effect of combined bending and twisting moments considered. The equivalent twisting moment due to combined bending and twisting is equal to

$$BM + \sqrt{(BM)^2 + (TM)^2},$$

where,

BM = bending moment; TM = twisting moment.

Stresses should be low on account of the frequent reversal and impulsive loads common with crane work. Where keys are fitted, the shafts should be increased in diameter.

Bearings.

For cheap hand cranes the bearings are usually of cast-iron and not bushed. All power-driven cranes should have gunmetal bushed bearings. The bearing brackets should be fitted with caps, and the bushes be in halves. Studs for securing the caps are not desirable. Tee-

headed bolts should be used, and these should fit in a slot accessible from the outside of the pedestal, so that the bolts can be withdrawn after the cap is removed and without disturbing the steps. The pressure per sq. in. for shafts running at medium speeds should not exceed 600 lbs. For slow-moving pulleys and axles the pressure may be as high as 1,000 lbs. per sq. in. Fast-running shafts, such as motor spindles, should have ring lubrication. Axles are frequently fitted with float lubrication, which consists of a cylinder of cork floating in an oil-well formed in the inverted cap of the bearing and by contact with the axle supplying the necessary lubricant. Screw-down and spring-feed lubricators with grease are very satisfactory.

To reduce frictional losses, ball or roller bearings are sometimes fitted, and the makers should be consulted regarding the size of these. Ball bearings are very serviceable for worm thrust bearings, footstep bearings, and for under the hook.

Ropes.

Ropes for crane work should be of extra special flexible quality, 6/37 stranding if above $1\frac{3}{4}$ in. circumference, below this size 6/24 or 6/19 stranding. For ordinary work a hemp cord is suitable, but where exposed to heat a soft iron core is desirable. The diameter of the barrel and pulleys round which the rope passes should be between six to seven times the circumference of the rope. For high speeds it is advisable to use even larger pulleys than given by this rule. Sharp and reverse bends should be avoided, although with single ropes which may twist in winding the effect of a reverse bend is problematical. When lifting on a single fall, a so-called 'non-twisting' rope should be used. Ropes made from very high tensile steel wire are stiff and tend to 'bird-cage' or open out. The rope, particulars of which are given on page 927, is recommended for cranes. Ropes should be lubricated and examined in service for broken wires and corrosion. The barrels and pulleys should be machine-grooved to form a smooth and even surface for the rope to bed on. Hoisting ropes should have a factor of safety of at least seven, and even higher with small size ropes.

British Standard Specification for Round Strand Steel Wire Ropes for Cranes.*

(No. 302—1927.) (*Abstract.*)

(*This Specification is intended to provide for round strand ropes of Ordinary Lay having wires approximately uniform in diameter and of* 4×37, 6×19, 6×24, 6×37, *and* 6×61 *constructions, for the Lifting and Derricking, Ropes of Cranes and Coal Hoists, Transporters, and other similar lifting appliances.*)

3. The wire used in the manufacture of ropes to this specification shall be made from steel billets made by the acid open-hearth process and containing not more than 0·04 per cent. of sulphur and 0·04 per cent. of phosphorus.

The wire shall be of one of the following qualities as specified by the purchaser:

Grade A.—Special acid or 'Swedish' quality.
B.—Acid quality.

4. The wire used in the manufacture of ropes to this specification shall conform to one of the following descriptions, as specified by the purchaser:

Tensile Breaking Strength in Tons per sq. in.	Trade Description.
80– 90	Best Patent Steel.
90–100	Special Improved Patent Steel.
100–110	Best Plough Steel.
110–120	Special Improved Plough Steel.
115–125	Extra Special Improved Plough Steel.

14. The fibre used for the central or main core of the rope shall be new, and free, long fibre, good quality hemp, manila or jute.

(See also page 309.)

Hooks.

Fig. 7 gives proportions of hooks in terms of the diameter at the bottom of the thread. The size for any load can be arrived at by fixing the size of the shank to carry the load in tension. The area at the bottom of the thread must be taken. Hooks should be forged from mild steel.

Crane hooks depending from large travelling cranes in machine shops ought to be painted white, so as to be easily seen. With this improvement in visibility workmen will be less likely to run against a hook or to be struck by one which is moving.

Foundry ladle hooks fail from time to time without any previous indication of weakening, so that in many foundries it is usual to change them after a definite period of service. A German firm has brought out an improved hook made of a number of laminæ with an air space between.

* By permission of The British Engineering Standards Association.

This hook is said to be absolutely safe, for if a lamina should break, the remaining ones will be strong enough to hold the ladle. It is also necessary to replace only the broken strip. To ensure

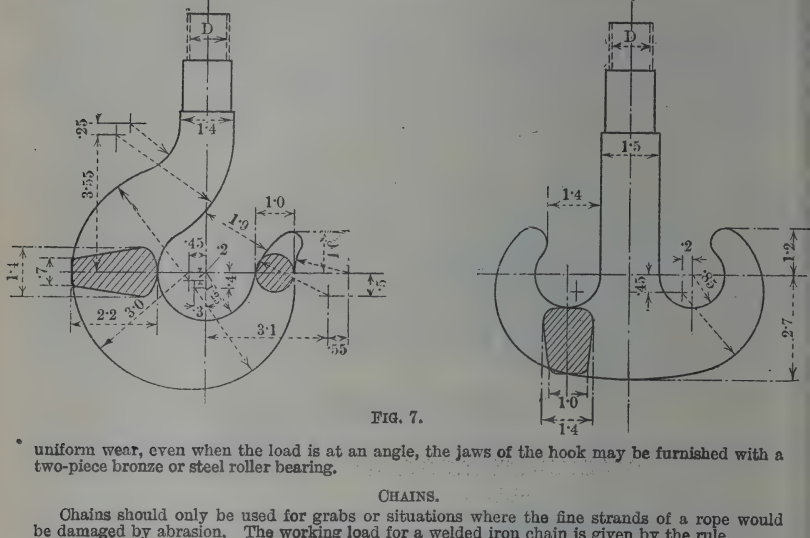


FIG. 7.

uniform wear, even when the load is at an angle, the jaws of the hook may be furnished with a two-piece bronze or steel roller bearing.

CHAINS.

Chains should only be used for grabs or situations where the fine strands of a rope would be damaged by abrasion. The working load for a welded iron chain is given by the rule.

$$W = \frac{(\text{dia. of iron in } \tfrac{1}{8} \text{ in.})^2}{9}.$$

Weldless steel chains are about 13 per cent. stronger, and make good slings on account of their lower weight. Steel plate driving chains are sometimes used for drives instead of gearing, and give good results if properly designed. The burden chain for large ingot rotating gears is best constructed of one inner and two outer links connected by steel studs.

(See also page 303.)

DESIGN OF LIFTING TACKLE.

Fig. 8 shows a faulty design of eye-bolt, likely to break without warning; and fig. 9 one which would stand rough usage, permit a pull at bad angles, and give notice before it broke, and at the same time possesses a useful strength (over 200 per cent.) beyond that of fig. 8.

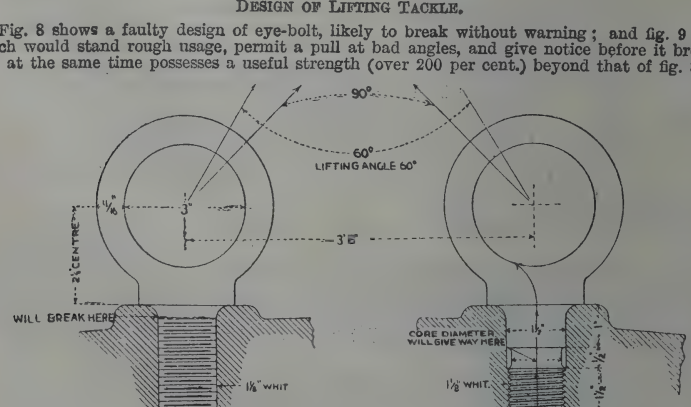


FIG. 8. FIG. 9.

These eye-bolts—hand-forged, of both types—have been tested to complete destruction at various 'punishing' angles, by Messrs. Kirkaldy, and the verdict has been from 50 per cent. to 250 per cent. in favour of the fig. 9 pattern.

The arrows depict the form and direction of the strains, and such were precisely followed in the tests by Messrs. Kirkaldy.

The increased strength, as a result of decreased material, refers to the reduced part A, for this reduction is an effective factor which contributes to the need that the strain of the load should be distributed over as large a volume of the composition of the bolt as is possible.

(*J. W. Towlson, 'The Electrical Review.'*)

BRAKES.

One of the most important features on a crane is the brake, and this should have a large factor of safety. The brakes in common use are electric, automatic solenoid, centrifugal, automatic mechanical, and manual brakes. Hydraulic and pneumatic brakes are used for heavy loads, or where extremely fine control is desired.

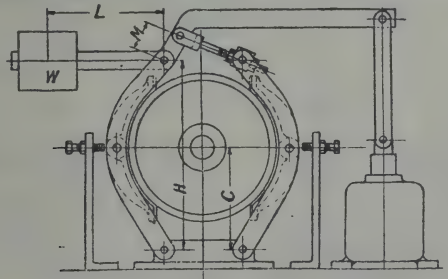


FIG. 10.

A typical arrangement of a solenoid brake is shown in fig. 10. The brake is applied by the weight and released by a solenoid magnet connected in the motor circuit so that it is excited immediately current is switched on to the motor.

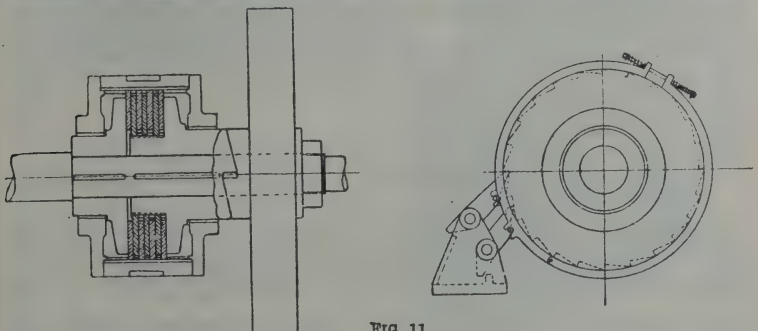


FIG. 11.

If F is the turning force on the rim and μ the coefficient of friction between the brake shoes and sheave, then the weight required to apply the brake equals

$$\frac{C \times M \times F}{H \times L \times 2\mu}$$

where C, M, H, and L refer to the dimensions shown in fig. 10.

The weight of the solenoid plunger and levers must be taken into account, and about 10 per cent. is usually added for friction in joints.

The centrifugal brake is designed to control speed, and does not serve to sustain the load at rest. In one form it consists of a series of weighted slippers which are pressed by centrifugal action on the inner rim of a fixed annulus, and thus have a retarding effect. The brake shoes should be slightly lubricated and ample radiating surface allowed to dissipate the heat generated.

The automatic mechanical brake, known also as the 'Weston washer brake,' depends for its action upon the friction between a set of fixed and rotating discs. The pressure on the discs is obtained by a screw and nut, or two helical surfaces which set up an axial thrust along the brake shaft. Fig. 11 shows one type of this brake in which the friction discs, alternately of bronze and steel, are enclosed in a cast-iron box, with ratchet teeth on the outside. One set of discs is connected by feathers to the box, and the other set to the thrust plate. The driving wheel has a helical face formed on the boss which engages with a corresponding face on the thrust plate. When hoisting, the discs are pressed up tight and the whole brake revolves, but when lowering, the pawls engage with the ratchet box, and hold it stationary. The pressure on the discs is relieved by the reversal of the motor, and the load is free to descend. As it tends to accelerate and gain on the motor, the discs are pressed together again and the friction between the surfaces of the fixed and revolving discs forms the braking effect. Ample lubrication and radiating surface are essential for the successful operation of this brake.

The pitch of the helical faces is determined by the following formula:

$$T = \frac{PL}{R \times \mu \times N} \quad \text{and} \quad \frac{PL}{Tr} - f = \tan A;$$

therefore,

$$\text{lead of helix} = \tan A \times 2\pi r;$$

where,

R = average radius of disc;	μ = coefficient of friction = ·07;
PL = torque on driving wheel;	r = mean radius of helical faces;
A = angle of helix;	T = thrust or pressure on discs;
N = number of rubbing surfaces;	f = coefficient of friction of helical faces.

The brake should be proportioned so that an angle of helix of about 10° will give the requisite pressure. The brake should run at a speed not exceeding 150 revs. per minute, and the pressure on the discs should not be more than 200 lbs. per sq. in. and on the helical faces 500 lbs. per sq. in.

Manual brakes are usually of the band or post type. Band brakes should have a bar fitted round the outside of the strap with adjusting screws to ensure that when the brake is released the strap will come away evenly from the sheave.

Band brakes are generally only suitable for a torque in one direction, i.e. away from the fixed end of the strap.

To find the pull to be applied to the loose end of the strap, the following formula may be used:

$$P = \frac{F}{e^{\mu\theta} - 1},$$

where,

P = pull;	μ = coefficient of friction;
F = turning force on rim of brake sheave;	θ = angle of sheave embraced by strap in radians.
e = base of Napierian logs.	

Brake sheaves are usually made of cast iron, but steel should be used for severe duty. The brake shoes or strap may be lined with wood, leather, or one of the asbestos fabrics such as 'Chekko' or Ferodo lining; wood and leather are inclined to char and glaze and the coefficient of friction is reduced. Bonded asbestos (page 948) is not subject to these objections and maintains a constant coefficient of friction, which in practice may be taken as 0·3.

Electric cranes may be controlled by dynamic or rheostatic braking if direct current is used. Dynamic braking with potentiometer control is to be preferred to plain rheostatic braking, as practically automatic speed control is obtained in the lowering direction irrespective of the weight of the load. Heavy rushes of current and mechanical shock can be produced on the motor by either system of electric braking, and some form of current limit control should be provided.

Speeds up to 2½ times full load hoisting speed can now be obtained without difficulty in lowering the light hook under potentiometer control.

A shunt solenoid should be used with this system of braking, as the current may fall too low to excite a series coil sufficiently to hold off the brake.

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A508

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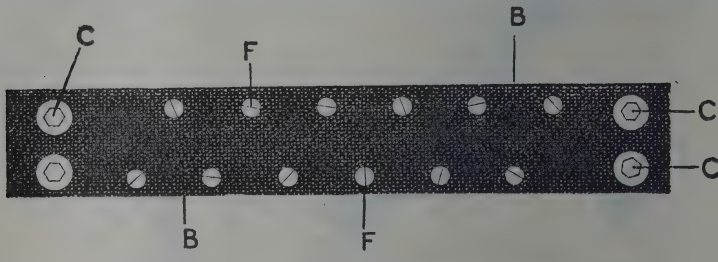
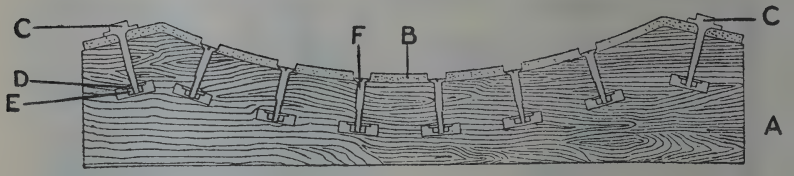
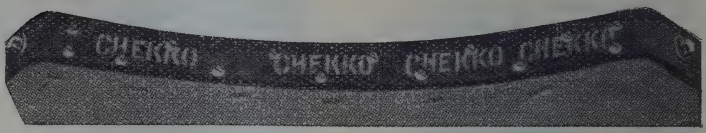






Method for fixing CHEKKO LINING to Post Blocks.

A—Wooden Blocks. B—Chekko Lining. C—Cresswell's Special End Bolts. D—Steel Washer. E—Steel Nut. F—Countersunk Brass Metal Screws.

Drill holes in lining with a sharp drill ground to the correct angle to suit bolts. Counter sink $\frac{3}{4}$ of the depth of the lining.

The distance between any two bolts should *not* exceed $3\frac{1}{2}$ in.

Before bending Chekko Lining heat it well under steam pipe.

F. 919

Messrs. Laurence Scott have recently developed what is termed floating brake control for speed regulation, with the object of avoiding the disadvantages of dynamic braking. The brake consists of fixed and rotating discs mounted co-axial with the motor spindle. The discs are pressed together by springs and released by an electric magnet, excited when current is switched on to the motor. By arranging the starting resistance so as to divert current from the brake coils the magnetic flux is weakened to such a degree that the pressure of the springs begins partially to apply the brake and the speed is regulated according to the amount of current diverted from the series winding of the brake coils. The value of the resistance in circuit is adjusted through the medium of the controller used for starting the motor. This system has been used on a number of cranes with success.

To control the lowering of heavy loads at slow speeds, a hydraulic brake is the most efficient. In principle this consists of either a reciprocating or rotary pump with closed circuit and throttle valve.

The pump is in the train of gearing between the motor and the rope drum, and by means of a free wheel drive is inoperative in the hoisting direction. On lowering, the solenoid or other brake is released, and the descending load drives the gearing and pump. The speed is controlled by the throttle valve, and very fine regulation at constant speed can be obtained. The system is especially suitable for placing guns, turbines, and engines on board ship.

For gun tempering, armour treatment, and processes where immersion in a cooling bath is necessary, it is essential that the load should be rapidly lowered at speeds varying from 60 ft. to 150 ft. per min.

The lifting speed is about one-tenth of these speeds, and the usual practice is to disconnect the rope drum from the gearing and motor when lowering.

A coil clutch is used for the purpose, and a powerful brake must be fitted to control the lowering speed and sustain the load. Manual brakes have proved satisfactory for this purpose, particularly in conjunction with a centrifugal brake for speed control. On cranes of over 100 tons capacity elaborate electro-hydraulic systems have been used with great success, but they are very costly.

Electrical Equipment.

Cranes may be worked by either direct or alternating current, but the former is to be preferred for the following reasons:

1. Series-wound motors may be used with high starting torque and speed variation in proportion to load.

2. Very fine control can be obtained and dynamic braking used.

3. Lower first cost and less wiring.

Alternating-current motors usually require less attention than direct-current motors, but the starting torque is limited and the running speed is practically the same under light and full load conditions. The starting torque for alternating-current motors should be not less than two-and-a-half times the full load torque, and in fixing the horse-power it is advisable to make it about 10 per cent. higher than for direct-current motors for the same duty.

With reference to paragraph 1, it should be noted that whilst with ordinary series motors the speed increases with a reduction in the load the variation is not very great between full and approximately half load, and as in many cases light loads are more frequently lifted, mechanical change gear is used to increase the speed and take advantage of the full power of the motor. This can, however, be eliminated by means of a special two-speed motor, designed to develop its full horse-power at two definite speeds besides having the usual series characteristic. The alteration in speed is obtained by diverting part of the field current, and with the Scott Bentley discriminator control this can be done automatically, thus relieving the operator from the trouble of changing gear and ensuring the correct speed for the weight of the load. The efficiency of the crane is increased without any added complications.

Two-speed squirrel-cage motors are now also manufactured, the change of speed being obtained by altering the number of poles.

The horsepower is in proportion to the speed, and the principal object of this design is to reduce the initial current peak by starting up at a slow speed and switching over to the higher when the gear is in motion.

Squirrel-cage motors are not in general suitable for crane work, but a number of cranes have been successfully equipped with special squirrel-cage motors having high resistance rotors and giving about twice full-load starting torque. There is rather a high rush of current at starting, but this is only momentary and does not appear objectionable. Care must be taken to select switchgear of ample size to break the peak current if small adjustments of the load are desired, and consideration should be given to the effect of the starting current on all parts of the circuit. The use of these motors greatly simplifies the wiring, and starting resistances are not required.

All motors should preferably be of the totally enclosed type. For ordinary engineering shop service crane motors rated to develop their full power for a period of half-an-hour with a temperature rise of 90° F. are quite suitable. For steel works and other situations where the duty

is severe, the rating should be for one hour. It is desirable to have the yoke and bearings made in halves so that easy access may be had to the interior of the motor.

A special design of direct-current motor known as the Mill type is largely used on steelworks cranes. It has a steel carcase made to hinge open along the centre line to permit of easy removal of the armature. The armature is of small diameter to reduce inertia stresses on reversal, and the insulation and winding are such as to permit of stalling the motor without injury. It was originally developed for service in rolling mills, hence the name.

Controllers.

For ordinary crane service and motors up to about 60 h.p. the drum controller gives very good service. There should be ample room inside the controller for connections, all parts accessible, finger tips and drum contacts easily renewable, insulation of mica or micanite, and a definite step should be felt as the barrel is moved round to each contact. Magnetic blow-out should be fitted on direct-current controllers.

For frequent operation and large currents a solenoid operated or contactor controller should be fitted. The contactor switches handle the main current to the motor and are controlled by a small drum, or master controller, which deals only with the shunt current required to excite the contactor coils. A development of this system is the Holme Portable Remote Control, in which the master controller can be carried about by the operator and connection is made to the contactor panel by a multicore flexible cable.

Creeping control for foundry or riveting work is obtained by inserting resistance in paralle with the motor armature circuit, thus magnifying the strength of the field and enabling full-load torque to be obtained at a very slow speed.

Cam operated controllers have outwardly the appearance of drum controllers but the fingers consist of a series of simple contractors actuated by a number of cams mounted on a vertical spidle rotated by the controller handle. They are used where the current is considered rather heavy for an ordinary drum controller and yet not sufficiently heavy to justify an automatic controller.

On alternating current circuits speed regulation is obtained by resistance in the rotor circuit, but the same range of speeds cannot be obtained as with direct current, particularly on light loads.

When creeping speeds are required with alternating current the most practical method is to load up the motor with a manual brake, and then use the controller and resistance to adjust the speed.

Up to about five h.p. resistances are usually made of wire-wound porcelain bobbins, and above this power consist either of stamped steel grids or a drawn continuous strip bent into grid form. The grids should be well stiffened to eliminate vibration and sherardised to prevent rusting. Cast-iron grids should be avoided, as they give trouble due to breakage.

Resistances are usually rated to be in circuit two or five minutes out of every fifteen minutes, with a temperature rise not exceeding 350° to 400° F. For creeping control ten minutes or even continuous rating is desirable.

Switchboards.

Many cranes are fitted with a main switch and fuses for the protection of each motor circuit, but it is desirable that these should be replaced by a main automatic circuit breaker and relay switches for each branch circuit. The relay switches do away entirely with fuses and obviate the loss of valuable time at critical moments due to replacing them. Each switchboard should have a pilot lamp and socket for portable lamp connection. It is advisable, although not essential, to fit an ammeter and a voltmeter.

Limit Switches.

Limit switches to prevent overwinding or overtravelling should be of the shunt type, and connected in the no-volt coil circuit of the main breaker on the switch-board, so that in the event of the switch coming into operation the main circuit is opened at the breaker.

Special contacts can be fitted on the controller to short-circuit the limit switch on bringing the controller on to the first notch in the reverse direction. The breaker can then be reset and the motor reversed. The limit switch should be of the totally enclosed self-resetting type.

Solenoids.

Solenoids for brake operation are preferably of the series type on direct-current circuits, but where rheostatic or dynamic braking is used they must be of the shunt type, in which case a discharge resistance should be fitted to take up the induced current on breaking circuit. For alternating circuits solenoids are preferably connected in all phases. The rating of a solenoid should be the same as the motor with which it is in circuit. The coils should be enclosed as a protection against damage, dirt, and damp.

The Lewis brake solenoid made by *Messrs. Ransomes & Rapier, Ltd.*, has two plungers, one sliding inside the other. The inner one is connected to the brake lever and is free to move independently of the outer plunger or armature. When the magnet is excited the two plungers are automatically and mechanically coupled and act as one in releasing the brake, but when the current is switched off they are disconnected and the inner plunger is free to follow the movement of the brake lever independently of the stroke of the magnet. As the brake surfaces wear the inner plunger is partially withdrawn from the outer, but owing to the automatic clutching arrangement, the full stroke of the magnet is always effective and releases the brake freely, obviating the rubbing and wear which take place with the ordinary brake if the shoes are not occasionally adjusted.

WIRING.

For crane work the current density may be in excess of ordinary practice for shop motors owing to the intermittent service, and the I.E.E. have drawn up a set of rules for this duty.

Cables, unless lead-covered and armoured, should be enclosed in metal conduits. Current is supplied to travelling cranes from bare conductors stretched along the track by means of slipper or trolley collectors. The bare conductors may be of copper wire, or, as is now common practice in steel works .steel tee or angle bars ground on the sliding face.

For jib cranes the conductors may be carried overhead or in a conduit. An alternative system is to run the cables in a closed conduit with junction boxes at intervals from which connection can be made by plug and flexible cable. A drum should be fitted on the crane to coil up the slack cable.

The drum may be hand operated if the crane is infrequently moved or if the length of travel as small, not exceeding 50 ft., and the cable light; a spring can be used to automatically revolve the drum as the cable becomes slack and prevent loose coils lying on the ground. Where space will permit, it is better to have a weight-operated overhauling gear to exert a torque on the drum, and lengths of heavy cable up to 150 ft. long can be handled in this manner. Cable drums geared to the travelling motion are inadvisable owing to wheel slip on the rails, which may cause a considerable tension on the cable, with resulting damage.

Electro-Lifting Magnets.

Electro-lifting magnets are largely used in connection with cranes for handling all classes of iron and steel materials, and their application shows a considerable saving in time and cost compared with manual labour or even ordinary crane service with slings.

For lifting pig iron, small and heavy scrap, and large solid masses, a single circular magnet is adopted, and for lifting long and wide plates two or more of these magnets are used spaced along a beam which can be slung from the crane hook.

For rails and long bars or tubes a series of two or three rectangular or oval magnets on a beam are better, as greater lifting capacity is obtained with less dead weight.

The circular type of magnet consists of an outer casing or yoke of high permeability steel with a central boss which forms the inner pole of the magnet, the walls of the casing forming the outer pole. The annular space between the poles serves to contain a coil of high conductivity insulated copper wire or strip, secured in place and protected by a non-magnetic manganese steel bumping plate, the latter being held in position by the inner and outer pole shoes which are bolted to the casing and form the contact face of the magnet. In the 'Phœnix' magnet there are two annular recesses each with a coil; this construction increases the area of the central pole and adds to the lifting power of the magnet.

The outer casing is provided with lugs for attaching the sling chains, and a terminal box is fitted for making connection between the magnet coil and the supply cable.

Circular magnets are not suitable for stacking material in any systematic form, as the tendency with such magnets is to lift the material two or three deep only, where the centre pole gives contact, and a smaller quantity over the remaining surface of the magnet; consequently the quantity of material lifted is uncertain, and it is impossible to keep the stacks or banks in systematic heaps.

The Phœnix Patent Bi-Polar Magnet (fig. 12) has been specially designed for stacking systematically such material as rails, billets, ingots, bars, joists, etc. With this magnet the attractive force is distributed evenly across the pole faces, so that the magnet lifts and deposits the material in single layers without disturbing the underlying material. Further, it will lift single pieces out of a layer without disturbing the surrounding pieces. This systematic stacking is essential in works where large quantities of material are stored, and the use of the magnet must obviously effect great economies in time and labour.

The Phœnix bi-polar magnets can be used in several ways. The single magnet is used for lifting sections of comparatively short length—say up to 12 to 15 ft. To obtain greater lifting capacity with the same material than is given by a single magnet, two, three, or more magnets can be bolted together (see fig. 12, which shows three such magnets). When lifting material in long lengths, such as rails, a pair of single magnets are set at suitable centres and suspended from a lifting beam.

FIG. 12.

As regards the *lifting of hot material*, circular magnets are unsuitable, because they offer such large heating surfaces, and the windings are so close to the heat that there is bound to be overheating. The Phœnix bi-polar magnet offers the minimum surface to the heat, and when constructed for lifting hot material the pole pieces are extended about 8 ins. at the bottom to lift the coils farther away from the heat; the pole faces are then at a distance of 12 ins. from the coils.

The following typical cases are given to show the advantages accruing from the use of magnets:

1. 62-in. diameter circular Phœnix magnet, fitted on a 12-ton electric overhead crane, commanding a scrap storage ground. Weight of magnet about 65 cwts. Current consumption about 50 amperes at 220 volts.

2. A truck load of steel turnings unloaded in seven minutes, work which formerly took four men five hours.

3. Four large furnace boxes, each measuring 6 ft. by 2 ft. 7 ins. by 1 ft. 6 ins. deep, placed side by side on a rail lorry, filled in four lifts averaging 17½ cwts. each.

4. Four furnace boxes of the same size filled with 2½ tons of tube scrap in three lifts.

5. 52-in. diameter circular Phœnix magnet, handling steel turnings from stock heaps into railway trucks. Approximate weight of magnet 50 cwts. Approximate current consumption 40 amperes at 220 volts. The magnet made twelve lifts in seventeen minutes and handled in this time 95½ cwts.—an average of, say, 8 cwts. per lift. Steel turnings are difficult to handle, particularly if rusted together or with long turnings interlaced.

A 52-in. Phœnix magnet has also unloaded from trucks 600 tons of pig iron in 6¾ hours with the crane driver solely controlling the operations, no other labour being employed.

6. A pair of oval-shaped Phœnix magnets for handling combs of pigs. Without the magnets the time occupied to lift a bed of 22 combs was four hours; with one set of magnets the work is done in sixteen minutes.

With the magnets in use, only two or three ground men are employed, whereas hitherto 30 or 40 were required.

Steel may be handled by magnets up to a temperature of about 700° C.

The following table gives the approximate weights and lifting capacities with ingot and pig-iron for various sizes of circular lifting magnets :—

Diameter of Lifting Magnet.	Weight of Magnet.	Safe Load of Solid Steel Ingot.	Approximate Load of Pig Iron per Lift.	Current Consumption.
24 in.	5½ cwt.	5 tons	—	1·75 k.w.
36 ,,	16 ,,	7 ,,	9 cwt.	3·5 ,,
42 ,,	25 ,,	10 ,,	14 ,,	5 ,,
54 ,,	39 ,,	18 ,,	23 ,,	7·5 ,,
66 ,,	60 ,,	30 ,,	40 ,,	12 ,,

Mobile Finger Magnet.

For lifting rails and bars of similar section, Messrs. Allen West & Co., Ltd., have developed a rectangular magnet (fig. 13) along the face of which are four rows of short steel pieces free

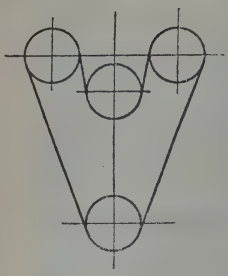
Fig. 13.

to move and adjust themselves to the contour of the bar to be lifted. Owing to these steel pieces forming a better path for the magnetic lines of force, the lifting capacity of the magnet is increased when dealing with irregular sections.

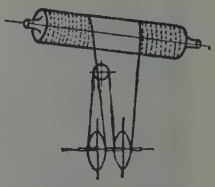
Vacuum Cup Lifting.

A German firm is using a system of vacuum cups, in place of slings, for handling non-magnetic plates with an overhead crane. A vacuum of 0·1 to 0·5 atmosphere is employed and is provided by a 5-h.p. rotary pump.

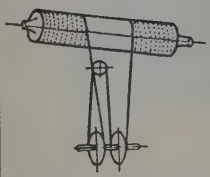
VARIOUS ARRANGEMENTS IN LIFTING APPLIANCES.



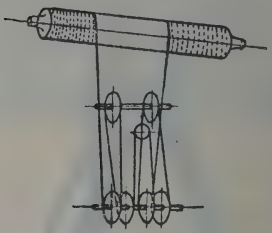
1.—One Bend.



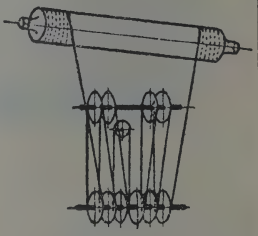
2.—Three Bends



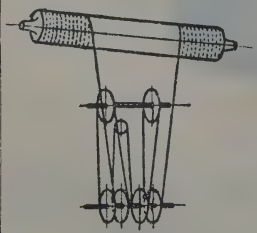
3.—Three Bends, One Reverse.



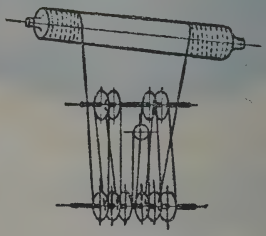
4.—Seven Bends.



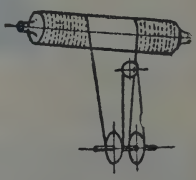
5.—Eleven Bends.



6.—Seven Bends, One Reverse.



7.—Eleven Bends, One Reverse.



8.—Three Bends, Large Bottom Pulleys.

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WHITECROSS WIRE ROPES

F. 925

Durability of Wire Ropes.

The two most important conditions appertaining to the manufacture and use of steel wire ropes that affect their durability are:

(a) Quality of material and size of wire.

(b) Diameter of pulleys and arrangement of ropes.

(a) Wire used for lifting ropes is of steel whose ultimate tensile strength varies from 80 to 130 tons per square inch. Ropes of material having a higher tensile strength are of smaller diameter for a given load and factor of safety, but since they are stiffer, larger drums are necessary to obtain the same durability.

The stress in a wire due to bending round a pulley is proportional to:

$$\frac{\text{(Modulus of elasticity)} \times \text{(Diameter of wire)}}{\text{(Diameter of pulley)}}$$

hence large wires are more quickly fatigued than small ones. On the other hand, small wires are more quickly worn through.

For a given ratio of pulley to rope diameter, given rope diameter and load, the life of the rope, if limited by abrasion and not by fatigue, increases as the square of the diameter of the wires of which it is made.

(b) For a given diameter of rope (d), diameter of wire (a) and load (P), the life of the rope depends on the square of the ratio of pulley to rope diameter (m) for large values of the latter.

The above statements have also been deduced from theoretical considerations by Prof. J. T. Nicolson, D.Sc., and may be represented by the formula given by him.

$$\text{Life of rope} = C\frac{m\,(m+1)\,d^2a^2}{P}$$

where the symbols m, d and a have the meanings given above, and C is a constant.

The practice of passing wire ropes on a crab as shown by fig. 14 entailing successively a 90° bend, a 180° reverse bend, and a 90° bend, is a bad one and deteriorates the strand wires:

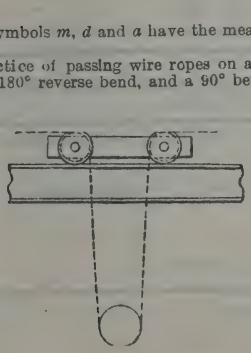

Fig. 14.

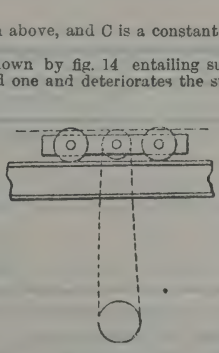

Fig. 15.

a better method is shown by fig. 15, the rope being taken over one upper pulley, down to the block, and up over the second pulley, the bend being always in the same direction, the reverse bend being thus abolished; this arrangement will increase the life of a rope as much as 50 per cent.

The effect of different arrangements of pulleys is shown by Nos. 1 to 7, page 924, and the accompanying tables, case No. 1 being taken as the standard.

COMPARISON OF ANTICIPATED LENGTH OF LIFE OF ROPES ARRANGED AS SHOWN IN NOS. 1 TO 7, PAGE 907.

No.	Number of Bends.	Relative Life of Rope.
1	1	300
2	3	100
3	3*	75
4	7	43
5	11	27
6	7*	37½
7	11*	25

REQUIRED INCREASE IN DIAMETERS OF ROPE DRUMS (MEASURED IN TERMS OF CIRCUMFERENCE OF ROPE) TO GIVE EQUAL DURABILITY.

No.	Increase of Diameter called for by No. 2.
3	1 circumference of rope
4	2⅓ circumferences of rope
5	4 „ „
6	3 „ „
7	4 „ „

RATIO OF DIAMETER OF PULLEYS AND DRUMS TO CIRCUMFERENCE OF ROPE TO GIVE EQUAL DURABILITY.

No.	Ratio of Pulley and Drum Diameter to Rope Circumference.
1	4 to 1
2	7 to 1 (standard)
3	8 to 1
4	9·5 to 1
5	11 to 1
6	10 to 1
7	11 to 1

RELATIVE ROPE CIRCUMFERENCE ALLOWING FOR SMALLER ROPES DUE TO INCREASED NUMBER OF FALLS.

No.	Number of Falls.	Relative Rope Circumference.
1	2	140
2	4	100 (standard)
3	4	100
4	8	70
5	12	57
6	8	70
7	12	57

† Points to remember in connection with wire ropes :

1. In general, use the lowest grade of steel.
2. In general, use the middle flexibility.
3. Use Lang's lay, if possible.
4. Ratio of pulley to rope diameter should not be less than 26 ; 30 is better.
5. If possible, employ a ratio of pulley to rope diameter of 40, and then keep to the lowest instead of the middle flexibility.
6. In the case of peculiar double turns, use pulleys as large as possible.
7. Avoid unnecessary reverse bends.
8. Keep the ropes well oiled.

* Including one reverse bend which is twice as effective in wearing out the rope.

† Mr. George Hughes, M.I.Mech.E., in Proc. Inst. Mech. Engrs., 1912.

Extra Special Flexible Steel Wire Crane Ropes.

TABLE OF SIX-STRANDED ROPES (37 WIRES PER STRAND).

Circumference.		Diameter.		Approx Weight per Fathom. Lbs.	Best Patent 80/90 Tons per square inch. Breaking Stress.		Special Improved Patent 90/100 Tons per square inch. Breaking Stress.		Best Plough 100/110 Tons per square inch. Breaking Stress.		Special Improved Plough 110/120 Tons per square inch. Breaking Stress.		Extra Special Improved Plough 120 Tons per square inch. Breaking Stress.	
Ins.	Mm.	Ins.	Mm.		Aggregate Tons.	Actual Tons.	Aggregate Tons.	Actual Tons.	Aggregate Tons.	Actual Tons.	Aggregate Tons.	Actual Tons.	Aggregate Tons.	Actual Tons.
1	25	5/16	8	1·08	3·1	2·6	3·5	2·9	3·9	3·2	4·3	3·5	4·4	3·6
1 1/8	29	3/8	9	1·26	4·2	3·4	4·6	3·8	5·1	4·2	5·6	4·6	5·9	4·9
1 1/4	32		10	1·50	4·7	3·9	5·2	4·3	5·8	4·8	6·4	5·3	6·5	5·4
1 3/8	35	7/16	11	1·80	5·7	4·7	6·4	5·3	7·1	5·8	7·8	6·4	8·1	6·7
1 1/2	38		12	2·16	7·0	5·8	7·8	6·4	8·6	7·1	9·4	7·7	9·8	8·1
1 5/8	41	1/2	13	2·58	8·3	6·8	9·3	7·7	10·2	8·4	11·2	9·2	11·7	9·6
1 3/4	44	9/16	14	3·00	9·7	8·0	10·9	9·0	12·0	9·9	13·2	10·9	13·7	11·3
2	51	5/8	16	3·96	13·0	10·7	14·5	11·9	16·0	13·2	17·5	14·4	18·3	15·1
2 1/8	54	11/16	17	4·44	14·7	12·1	16·5	13·6	18·2	15·0	20·0	16·5	20·8	17·1
2 1/4	57		18	5·04	16·7	13·8	18·6	15·3	20·6	17·0	22·5	18·6	23·5	19·4
2 3/8	60	3/4	19	5·52	17·6	14·5	19·7	16·2	21·8	18·0	23·9	19·7	24·9	20·5
2 1/2	63	13/16	20	6·12	19·7	16·2	22·0	18·1	24·4	20·1	26·7	22·0	27·8	22·9
2 3/4	70	7/8	22	7·38	24·2	19·9	27·1	22·3	29·9	24·7	32·8	27·0	34·2	28·2
3	76	15/16	24	8·70	29·2	24·1	32·6	26·9	36·1	29·8	39·5	32·6	41·2	34·0
3 1/8	79	1	25	9·54	31·8	26·2	35·6	29·4	39·3	32·4	43·1	35·5	44·9	37·0
3 1/4	83		26	10·32	33·2	27·4	37·1	30·6	41·0	33·8	44·9	37·0	46·9	38·7
3 3/8	86	1 1/16	27	11·10	36·0	29·7	40·3	33·2	44·5	36·7	48·8	40·2	50·9	42·0
3 1/2	89	1 1/8	28	11·88	39·0	32·2	43·6	36·0	48·1	39·7	52·7	43·5	55·0	45·4
3 3/4	95		30	13·80	45·2	37·3	50·5	41·7	55·8	46·0	61·2	50·5	63·8	52·6
3 7/8	98	1 1/4	31	14·52	48·5	40·0	54·2	44·7	59·9	49·4	65·6	54·1	68·5	56·5
4	102		32	15·78	51·9	42·8	58·0	47·8	64·1	52·9	70·2	57·9	73·3	60·5
4 1/4	108		34	17·70	59·0	48·7	66·0	54·4	72·9	60·1	79·9	65·9	83·4	68·8
4 3/8	111	1 3/8	35	18·66	60·9	50·2	68·1	56·2	75·2	62·0	82·4	68·0	86·0	70·9
4 1/2	114		36	19·98	64·7	53·4	72·3	59·6	79·9	65·9	87·6	72·3	91·4	75·4
4 3/4	121	1 1/2	38	22·14	72·7	60·0	81·2	67·0	89·8	74·1	98·3	81·1	102·6	84·6
5	127		40	24·54	81·1	66·9	90·6	74·7	100·2	82·6	109·7	90·5	114·5	94·4
5 1/4	130	1 5/8	41	26·04	85·5	70·5	95·5	78·8	105·6	87·1	115·7	95·4	120·7	99·6
5 1/2	133		42	27·18	90·0	74·2	100·6	83·0	111·1	91·6	121·7	100·4	127·0	104·8
5 3/4	140	1 3/4	44	29·58	96·9	79·9	108·3	89·3	119·8	98·8	131·2	108·2	136·9	112·9
5 3/4	146		46	32·28	106·6	87·9	119·2	98·3	131·7	108·6	144·3	119·0	150·5	124·2
6	152	1 7/8	48	35·40	116·8	96·3	130·5	107·6	144·3	119·0	158·0	130·3	164·9	136·0
6 1/4	159	2	50	37·92	124·7	102·9	139·4	115·0	154·0	127·0	168·7	139·2	176·0	145·2
6 1/2	165		52	40·92	135·7	111·9	151·6	125·1	167·6	138·3	183·5	151·4	191·5	158·0

LIFTS.

Notes on Lifts.

The usual height of a car from the floor to the top of the cross-head is 10 ft., and allowing the over-travel space or head room of 3 ft., this indicates that the minimum height to the underside of the floor of the engine or gear room from the top landing is 13 ft. The thickness of the floor depends upon the weight to be carried, but will not be less than 6 ins. When the engine is in the basement, 4 ft. is probably sufficient, but 6 ft. is desirable for the guide sheaves at the top of the shaft. Eight feet clear height should be regarded as the minimum for the engine room, whether it be situated in the basement or at the top of the shaft, and 9 ft. 6 ins. is desirable for the larger machines. Wherever possible a steel joist and lifting tackle should be installed in the engine-room to facilitate repairs when two or more lifts are provided.

The weight on the engine-room floor when the engine is located at the top of the shaft is, for a speed of 50 ft. per minute, approximately as follows, exclusive of the controller and cables :—

Car Capacity. *Passengers.*	Dead Load. *Tons.*
6	2·6
9	3·4
12	4·6
15	5·5
18	6·5

An allowance of 2 sq. ft. per passenger and 4 sq. ft. for the attendant (to enable him to handle the controller, car gate, and landing doors rapidly) is the usual basis for figuring car capacity ; for instance, a car having a floor area of 6 ft. by 5 ft. = 30 sq. ft. would have a passenger capacity of 30 less 4 = 26, which divided by 2 gives 13 passengers.

Similarly, the weight of the average individual has been ascertained to be 140 to 150 lbs., and, therefore, the assumed load is figured at 75 lbs. per sq. ft. of floor area.

Convenient car sizes are as follows :—

Depth.	Width.	Area.	Passengers.	Attendant.	Total.	Live Load.
ft. in.	ft.	sq. ft.				lbs.
6 0	7	42	19	1	20	3,150
5 0	6	30	13	1	14	2,250
4 4	6	26	11	1	12	1,950
4 0	5	20	8	1	9	1,500
3 0	4	12	4	1	5	900

In modern office buildings up to ten floors a very useful size for the car is 5 ft. wide by 4 ft. 4 ins. deep (*i.e.* 21·5 ft. super., carrying eight to nine passengers). Large departmental stores of the Oxford Street, Regent Street, and Kensington type generally require a larger car, and in this case the size is frequently 8 ft. wide by 6 ft. deep, giving a floor area of 48 sq. ft., and designed for a maximum load of 3,600 lbs. With these exceptions a 6 ft. by 6 ft. car is generally regarded as the largest standard car, rated for sixteen passengers and a gross load of 2,700 lbs.

Details of Tee Guide Rails.

Lbs. per foot run.	Width of Base (ins.).	Height of Web (ins.).	Width of Web (ins.).	Remarks.
6¼	2¾	$1\frac{5}{16}$	$\frac{21}{32}$	Counterweight
14	4½	$3\frac{7}{16}$	$\frac{25}{32}$	Car
21	$5\frac{7}{16}$	$3\frac{17}{32}$	$\frac{7}{8}$	
39·4	6	$5\frac{3}{16}$	1	

Guide rails, which are either cold-rolled or planed steel, are usually supplied in 14 ft. to 16 ft. lengths. Alignment is secured by groove-and-tongue joints and a splice plate bolted at the

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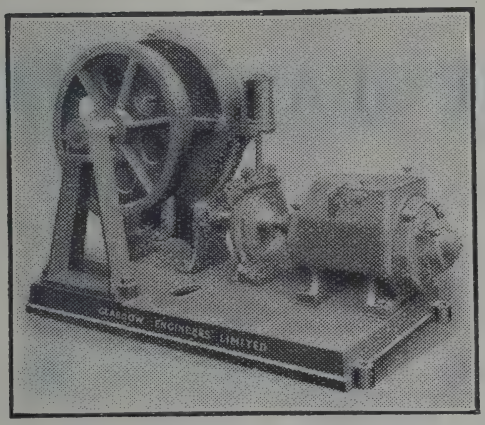

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back. Splice plates for car guides are frequently specified to be not less than 12 ins. long, four ⅝-in. bolts being required for each end of the guide. For counterweight guides, which are not called upon to stand heavy strains from the safety gear, 9-in. plates and ½-in. bolts are accepted. In cases where the supports on wall fixings are at a greater distance apart than 12 ft., angle iron or channel iron stiffeners are used, which run about 9 to 10 lb. per foot.

Guide grips should have a minimum clearance of ⅛ in. to avoid the risk of their being brought into action accidentally.

Usually the empty car is overbalanced to the extent of 40 per cent. of the maximum passenger capacity of the car, which has been shown to be the average load if the equipment is well designed. Careful balancing not only has a marked effect on the consumption of electrical energy, but also on the speed of an empty descending car and proper upward stopping distance.

As a very rough guide, the following figures are given for speeds :—

Travel of Car.	Load Speed.
30 to 40 ft. . . .	150 to 200 ft. per min.
45 to 70 ft. . . .	180 to 250 ft. per min.
75 to 100 ft. . . .	222 to 300 ft. per min.
100 ft. and over . .	300 to 400 ft. per min.

Due allowance must, of course, be made for car size, distance of average non-stop run, etc. In New York City, 500 ft. per min. is the legal limit of speed for local elevators and 700 ft. per min. for expresses, *i.e.* when there is a clear non-stop run of 80 ft.

Over-travel spaces at both the top and the bottom of the shaft are essential, as the brake is subject to wear and cannot be relied upon for accurate floor levelling, especially with high-speed traction machines.

The depth of the pit or sump—*i.e.* the over-travel at the bottom of the shaft—should be 3 ft. 6 ins., measured from the lowest landing. For higher speeds the space must be increased to 4 ft. 6 ins., and for traction-drive express lifts 7 ft. 6 ins. may be required. As an additional precaution against jar or shock, should the brake slip, spring or oil buffers are used under the car and also under the counterweight. The cost of a spring-loaded set, of a simple character, is small, and the installation is strongly recommended.

A clear space of 3 ft. is usually the minimum required between the top of the crosshead of the car and the underside of the shaft ceiling when the car is at its top landing. For speeds above 350 ft. per minute, 5 ft. is regarded as the minimum space.

All footings for columns and for foundations adjoining lift shafts should be carried below the pit in order to ensure that all sides of the pit are true and plumb with the finished sides of the shaft. Similarly, off-sets on the inner sides of the shaft walls should be avoided wherever possible, since the working forces of both the car and counter-balance weight guide rails must be truly vertical, and any inaccuracy in the builders' work will involve considerable additional expenditure for erection of the lifts.

A clear space of not less than 3 ft. should be provided between the bottom of the shaft and the lowest point of the underside of the car floor when the car is standing at its lowest landing, and between the top of the cross-head of the car and the underside of the ceiling of the shaft when the car is at the top landing. For express lifts these over-travel spaces must be increased up to a maximum of 7 ft. for the highest speeds, and even for slow-speed alternating-current lifts 4 ft. is desirable.

Collapsible gates are not desirable for brick shafts on account of the added fire risk, due to flue effect, and also because of draughts. The type of door should be that best adapted to the particular type of car to be installed, and the width of the opening should be such that ingress and egress will be as free as possible—usually 66 per cent. of the width of the car, in order to provide standing space for the attendant. Adequate allowance should be made for floor projections into the shaft, which vary with the type of door adopted, viz. combination slide and swing single slide ; double doors sliding in the same direction ; double doors sliding in opposite directions ; double swing doors, etc. Wired glass panels should be provided in all landing doors to avoid accidents when opened quickly. The standard height of landing doors is 7 ft., and the minimum width should be 2 ft. 6 ins.

(*'The Builder,' Jan. 6, April 7, 21, 1922—Abstracts.*)

ELECTRIC LIFTS.

Typical Specification for Electric Lift.

The following are the main particulars of the lift :—

Extreme travel . . 38 ft. 9 ins. Speed . . . . 120 ft. per min.
Maximum load to be carried, 10 cwt. Inside dimensions of cage, 3 ft. 6 ins. × 3 ft. × 7 ft. high.

Position for Motor, etc.—The motor, etc., to be placed in the basement in the position shown in the plan.

If fixed overhead, the driving sheave or drum should be designed, if possible, to span correctly from the centre of cage to centre of weight, so as to save the use of diverting sheaves.

The overhead sheaves are to be supported on suitable rolled steel joists, to be supplied and put in position by the contractor.

Cage.—The cage walls are to be made of well-seasoned pine, with a substantial iron or steel framework, and adjustable guides at the top and bottom to work on the runners. No seat will be required. A Bostwick or other approved sliding gate to be provided at the cage entrance.

The construction of the cage may be either (*a*) framed with grooved and tongued panels, the woodwork forming the panels being put in diagonally, and the whole bolted to the iron framework of the cage ; or (*b*) of grooved and tongued planks on the flat bolted to the iron framework of the cage with an additional strengthening iron ; or (*c*) of an approved type. If method (*a*) is adopted, the framing must not be of less than $1\frac{1}{2}$ in. stuff, and the panels not less than $\frac{3}{4}$ in. ; if (*b*) the planks must be uniformly 1 in. thick. The floor of the cage must be of maple, 2 ins. thick. All the above dimensions are finished sizes.

An opening to be provided in the top to allow for the lighting of the cage by daylight. This opening is to be covered over and under with iron wire trellis of 1 in. mesh, of not less than No. 13 S.W.G. The wirework to be galvanised after it is made up.

The interior of the cage, with the exception of the floor, to be varnished with three coats of good oak varnish.

The cage to be fitted with an electric light fitting of the bulkhead or other approved type, with genuine enamel reflector. A bayonet collar lamp-holder, lamp, cut-out and tumbler switch for this fitting, and a length of flexible cable for making connection to a ceiling rose fixed about half-way down the lift-well, to be provided and fixed by the contractor.

Electric Bell.—Suitable bell pushes are to be provided and fixed on each landing, and connected to an electric bell, to be provided and fixed in and about midway up the lift-well, and to an indicator for each floor, to be provided and fixed in the lift cage. A battery for working the bell is to be provided.

The whole of the bell work, including the necessary wiring, is to be done in the most approved manner.

Gates for Cage and Openings in Lift Well.—Collapsible gates, with spring-catch lock of the Bostwick, B. and S., or other approved pattern, are to be provided and fixed to the lift-well openings on each floor, to the lift cage and motor enclosure. Six gates in all will be required. The locks and gates (except in the case where push buttons are required to be fitted) to be so constructed that they cannot be opened except by use of the authorised key.

The gates, which are to be carefully finished black, are required to open the width of the cage opening, and to reach to the top of the cage opening.

Lift-Well Enclosure and Wirework Guards.—A wirework guard is to be fixed to the gate uprights, and continued round the lift-well above and below the hand-rail from the basement to the second floor at a height of 7 ft. from the stair treads. Suitable supports for the attachment of the wire guard are to be provided, and care is to be taken to prevent the guard or its supports from interfering with the free use of the stairs hand-rail. The guard is to be over and under iron trellis of 1 in. mesh, not less than No. 13 S.W.G., and is to be finished black, and stiffened where necessary by angle iron or tubing.

A wirework screen with suitable channel iron supporting frame, at least 7 ft. high, with Bostwick gate, to be provided in the basement for the protection of the motor and gear.

*Carrying Capacity and Speed.**—The cage to carry a maximum load of 10 cwt., and to travel at a speed of 120 ft. per minute when fully loaded. The maximum variation of speed ascending or descending at any other load must not exceed 10 per cent.

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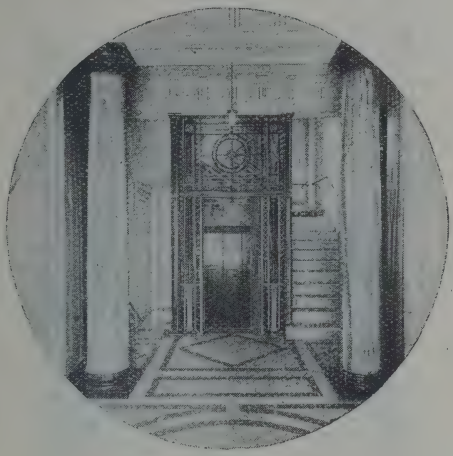
* In the case of passenger lift with car switch operation, the speed is now from 200 to 300 feet per minute.

For Passengers



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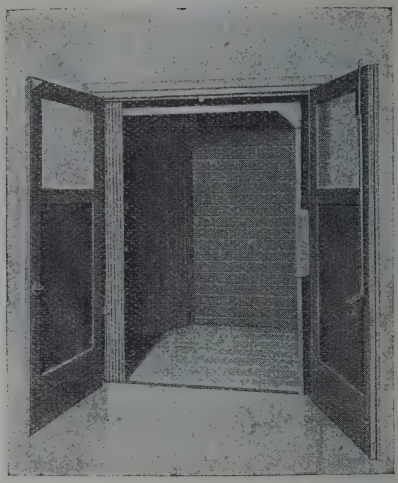
For Goods



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Safety Devices.—The most improved system of safety devices is required. A full description of all safety devices to be employed is to accompany tender. They must include the following :—(*a*) The locking of the cage on the guides or guide backings if one or more of the suspending ropes break or slacken ; (*b*) automatic stopping of the motor when the cage is brought to rest from any cause, unless the V wheel drive is used ; (*c*) automatic stopping of the cage before it reaches the top or bottom of the lift well.

Painting.—The whole of the materials fixed and supplied by the contractor, with the exception of the electric light and bell fittings, cables and resistances, bright metal work, folding gates, and the inside of the cage, which is to be varnished, is to be painted with three coats of oil paint, the finishing coat to be of a colour to be selected. The wood work, including all portions of the cage which are not visible, is to be knotted and primed before being painted.

Lubrication and Contact Cleaning.—The whole of the plant is required to work automatically and to require no attention beyond occasional lubrication, and occasional cleaning of the contacts.

Factor of Safety.—The factor of safety for the suspending ropes is to be not less than ten, and for all other parts a factor of safety of at least five is to be provided.

Precautions against Fire.—The contractor is required to make such arrangements as will prevent an outbreak of fire should the armature or any other part of the apparatus fuse or become excessively hot.

Quality of Material.—The material and workmanship to be of the best possible description throughout.

Tests.—Immediately the lift has been erected, the contractor will be required to make the following tests to the satisfaction of the inspecting officer :—

1. The cage to be loaded until the weight on the ropes is twice the combined weight of the cage and specified maximum load. The gear and suspending ropes must bear this weight for 30 minutes without showing any sign of weakness, temporary set, or permanent elongation of the rope strands.
2. Tests to determine if the specified speed is complied with.
3. Tests to determine if the various safety devices comply with the conditions of the contract. These are to include : (*a*) Starting the cage up and down and letting it run to the end of its journey without attention ; (*b*) slackening one or more as required of the suspending ropes.
4. Tests to determine the suitability of the switching gear.

The contractor is required to provide a man to start the lift and to attend to it for one week from the time when it is accepted as running satisfactorily.

Leading makers such as *Smith, Major & Stevens, Ltd.*, and *Waygood-Otis, Ltd.*, use the following speeds on their lift motors, for continuous current :—

Up to 3 h.p. . . .	1,000 revs.	Up to 7½–10 h.p. . .	650–750 revs.
„ 5 „ . . .	930 „	„ 15 „ . .	500–700 „

For single phase, 50 periods, 6 pole machines usually.
For 2 and 3 phase, 50 periods, 6 pole up to 10 h.p., and 8 pole above.

ELECTRIC WINDING.

The Ward Leonard System.

(English Electric Co., Ltd.)

This system (fig. 16) is based on the fact that the speed of a separately excited D.C. motor is directly proportional to the voltage applied to the armature. If, therefore, the D.C. motor, 1, is used to drive the drum D, it can be made to run at any desired speed and in either direction of rotation, by varying the voltage and direction of the current impressed on the armature. This D.C. power is obtained from a separate generator, 2, known as the variable voltage generator, and driven at constant speed by a motor, 3, connected to the supply mains. The variable voltage generator and its driving motor are coupled together and mounted on a common bedplate, which also carries, on the same shaft as the other two machines, a small D.C. generator. This generator supplies the excitation current to the variable voltage generator and the winding motor, the triple combination being known as the converter set.

A regulator, 5, is used to vary the field of the V.V. generator and, consequently, its voltage between 0 and a ± maximum, and in this way the speed of the winding motor to which this voltage is applied can also be varied between zero and ± maximum.

The principal feature of the control is that the speed and direction of rotation of the winding motor are determined solely by the regulator or, in other words, by the position of the driver's control lever. For all practical purposes this holds true whatever the load in the cage may be, and whether the load is being raised or lowered. When in a running position—by moving the control lever towards the 'off' position—a strong electrical braking effect is obtained, as the motor then acts as a generator and returns energy through the converter set to the line. The same electrical braking effect can be obtained when lowering loads, and the low speeds required for inspection tests can be readily obtained by a slight movement of the lever from the 'off' position.

It should be noted that the controller only deals with the field of the V.V. generator (about 2 to 3 per cent. of the output), consequently, it is very small as compared with an A.C. controller, and can be readily operated even on the largest winders without the use of auxiliary gear.

As any given position of the control lever corresponds to one speed only, and one direction of rotation, it is possible to provide simple safety appliances of absolute reliability.

In Fig. 16A is shown diagrammatically the system used by the *English Electric Co.* for the automatic control of the acceleration and retardation.

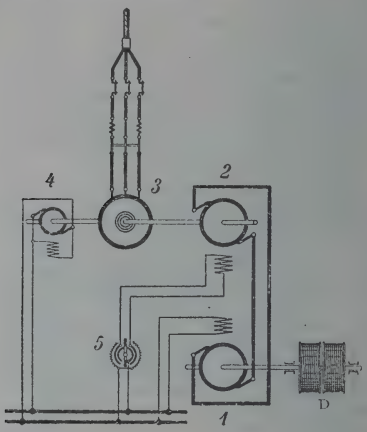

FIG. 16.

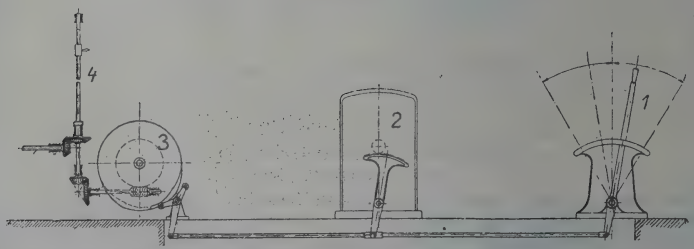

FIG. 16A.—Diagram of Depth Indicator with Safety Device as used by the English Electric Co., Ltd.
(1) Operating Lever. (2) Controller. (3) Control Cam. (4) Depth Indicator.

The spindle of the depth indicator drives two cam wheels, one for each cage, through gearing proportioned so that the wheels make nearly one complete revolution. Each wheel has two cams, one for acceleration and one for deceleration. When starting, the control lever can only be moved from its mid position at a rate determined by the shape of the cams, which shape is designed to give the predetermined rate of acceleration. This rate cannot be exceeded. When retardation should begin, if the driver has not already started to bring back his lever, the deceleration cam gradually forces the lever back to the 'off' position. Acceleration, retardation and speed of wind are thus within the driver's control, provided he does not attempt to exceed the limits for which the cams are designed.

In the event of an overspeed, electric braking automatically takes place. The winding motor will act as a generator and supply power to the V.V. generator, which will then act as a motor driving the set above synchronous speed, causing the induction motor to act as an asynchronous generator and pay back power to the line. Should the speed of the set exceed a predetermined maximum, a centrifugal switch driven from the shaft of the set will open the circuit of the brake magnet and apply the emergency brake.

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AERIAL ROPEWAYS.

Aerial Ropeways may be divided into two fundamental types:—The SINGLE ROPE or MONOCABLE, and the DOUBLE ROPE or BI-CABLE. In the first, a single endless rope is used both to support and move the loads. In the second, there are one or more supporting ropes and an endless hauling rope. Adapted to these types are the 'Fixed or Non-detachable Clip System,' on the Single Rope Type, and the 'Jig-back' or 'To-and-fro System,' which is applicable to either type.

There is considerable divergence of opinion upon the merits and demerits of the two systems, which is due largely to the fact that a number of plants have been installed without giving due consideration to which type is most applicable to the nature of ground to be traversed, and the duty to be performed.

THE SINGLE ROPE OR MONOCABLE SYSTEM.

Ropes.

By experience, it has been found the most suitable form of rope on an average length line is a 6·7 Lang's lay, with a specially hard hemp core. On short lines when the rope is subject to a great number of bends per hour around the terminal sheaves, compound lays are sometimes used. Wire cored ropes are also occasionally employed, owing to the fact that they tend to stretch less than those with hemp cores, but they have been found by experience not to have such a long life.

On a well-constructed line, depreciation on rope is covered by ·125 pence to ·3 pence per ton mile carried, on the basis of a line not less than 1,000 yards long, and a capacity of over 25 tons per hour; as the length and capacity increases, the depreciation per ton mile carried decreases. The fact that on a single rope system the entire length of the rope is constantly passing under observation at the terminals renders it very safe against failure, and it can be worked until a comparatively low factor of safety is reached. The diameter and breaking strain of ropes can be obtained from the formula given on page 938, under 'Diameter of Hauling Ropes.' No rule can be given, however, for finding initial tension, as this is dependent upon driving power required and spans to be negotiated, etc., apart from capacity of line and so forth.

Loads.

When possible, individual loads should be kept to about 1 per cent. of the hourly capacity of a line, for the purpose of distributing the weight on spans. Heavy individual loads tend to increase prime costs.

Carriers and Clips.

Among the best known are Roe's Patent Toggle and Saddle Clips.

The former, fig. 17, is capable of sustaining a load at an angle of over 45°, and in theory is the most efficient of all clips actuated by the load, as the whole of the tare weight also is used

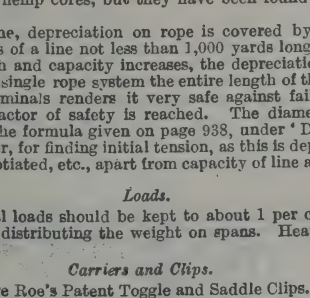

FIG. 17.

for gripping. In practice, however, the saddle clip, fig. 18, is found preferable and is usually adopted. The gripping in this type is performed by two cast chilled saddles, the sides of which are inclined, one side having a feather projection which engages into the lay of the rope, this projection being so formed that it disengages itself without damaging the strands when the carrier enters a station. The ruling grade on which this type of clip can be safely worked is 1 in 2¼. The tare weight of clip, carrier, and bucket is usually about one-third of the net load.

Fig. 19 shows the 'Roe Balance Beam.' The arrangement is used for distributing the pressure equally on a series of sheaves; these are arranged in groups of 2, 4, and 8. The introduction of a number of balanced sheaves in series greatly facilitates the working of long spans, and reduces wear and tear of rope where heavy pressure on any trestle has to be sustained.

A fair speed for the rope is 400 ft. per minute, though under certain conditions it can be run up to 550 ft. per minute, when no automatic return or dumping is required. The factor that rules the speed is the velocity at which the loads can be brought up to for engaging

with the rope, bearing in mind that the load and rope velocity should synchronise at the point of attachment.

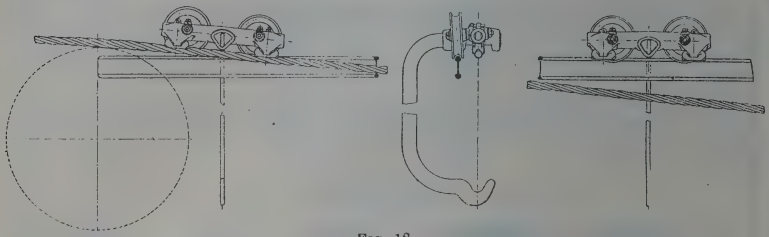

FIG. 18.

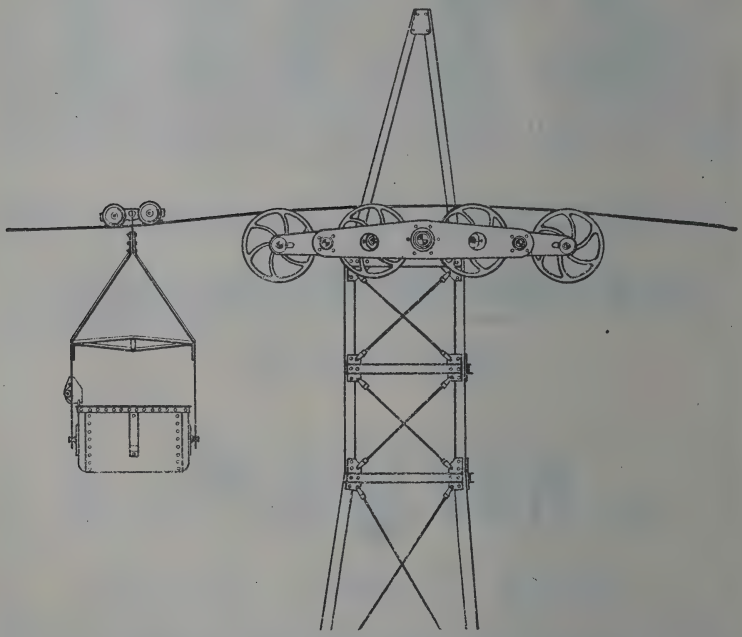

FIG. 19.

Power.

Any available power can be used as long as it is steady. Trouble, however, may be caused by using intermittent power, as this gives rise to oscillation of the rope in long spans. On automatic lines, the surplus power is preferably absorbed by means of a fan or turbine. When possible, the power should be placed at the upper end of a line, and the tension at the lower terminal. In long lines that have to be sectionalised, the driving or brake station, as the case may be, is sometimes placed between two sections, and the tension arrangements at the ends

Tension.

To ensure a constant and even tension, it is essential that the counterweights should be always free and floating, and owing to the amount of stretch in hemp cored ropes, taking-up gear must also be allowed for. Fig. 20 shows an arrangement which combines a multiplying and taking-up device. The two sheaves at A are attached to the tension trolley, the winch and differential drum being mounted on an independent frame placed over the tension

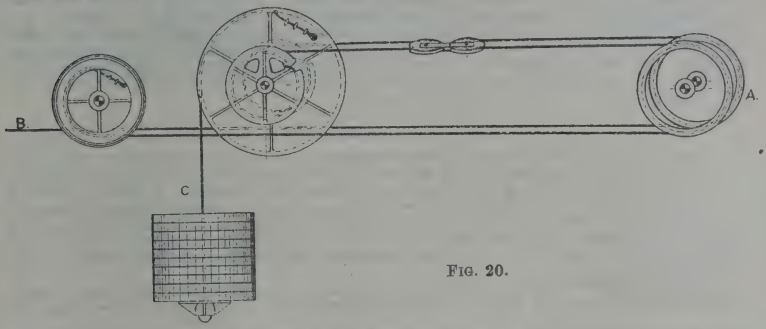

FIG. 20.

pit; one end of the rope B is anchored, the other being made fast to the tension winch drum. By this arrangement the resultant pull at A is four times the dead weight applied at C, and the weights can always be kept in suspension without the necessity of a deep pit, by taking in the slack with the winch.

Spans.

The distance between standards is dependent on the configuration of the ground, but over undulating country the average distance is approximately 330 ft. for lines of up to an hourly capacity of 60 tons. On a ropeway over the Andes, having a total length of 46 miles, several spans are being worked of 2,800 ft., though the longest recorded span on the single rope system is 3,600 ft.

DOUBLE ROPE OR BI-CABLE SYSTEM.*

Carrying Ropes.

Carrying ropes may be divided into two main classes, 'spiral,' fig. 21, and 'locked coil,' fig. 22. The main advantage of the spiral type is its cheapness, and in lines transporting a small tonnage

FIG. 21.

FIG. 22.

per hour it will generally answer its purpose. Ropes of this type should consist of 19 wires in ropes up to 1 in. diameter and of 37 wires in ropes up to 1½ in. diameter. With this latter the individual wires have a diameter of about ·205 in., which is about the limit to ensure perfect homogeneity of the material. Above 1½ in. diameter, locked coil ropes should invariably be used.

Locked coil ropes, fig. 22, are of two types, the special locked, *a*, and the full locked, *b* and *c*. The former consists of a spiral core surrounded by a layer of round wires kept apart by wires

* Abstract, by permission, from 'The Engineer,' July 23, 1915.

drawn to a special section. This rope is sold at a medium price between plain spiral rope and full locked coil. The surface of the special locked rope is not perfectly smooth, small interstices occurring between the wires. The full locked coil, on the other hand, presents a perfectly cylindrical surface to the passage of the cars. The second type of full locked construction—shown at *c*—is particularly useful for very heavy carriers, as, owing to the rope having an inner layer of tapered section wires, the crushing and distorting effect of the load when passing over the saddles on which the rope is supported is minimised. In addition to the great advantage of offering a smooth surface to the wheels of the cars (with the result that the wires may be of a lower breaking stress than with spiral ropes), the locked coil ropes possess the great advantage that, should by any chance one of the individual wires break, it is held in place by the neighbouring wires, and does not spring from the texture of the rope, as is the case with the spiral construction. This springing of the wires is often the cause of accidents, as the cars run against the outstanding wire, and are thrown off the line.

Fixture of Ropes.

The ropes are anchored at one end of their length, and some form of tensioning device applied at the other end. This generally takes the form of a hanging weight, which may generally be from one-quarter to one-fifth of the total breaking strength of the rope. A factor of safety of 4·5 is a good medium. It has been proved that for spiral ropes a breaking stress of 95 tons per square inch, and for the locked coil ropes 65 tons per square inch, give the best results. When calculating the tension weight required, the fact must be taken into account, that should the weight be situated on a lower level than the anchorage, the weight of the rope itself acts as a tensioning factor.

For fixing the ends of the rope a satisfactory arrangement is to employ the ring wedge coupling. In this anchorage—shown in section in fig. 23—the single wires are kept apart by small nail-like

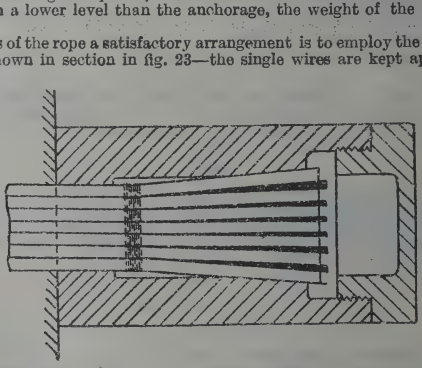

FIG. 23.

wedges, and the layers by means of ring wedges made in halves. These wedges are driven in and then a cap is screwed home, firmly locking them in place and entirely preventing any chance of the wires pulling out.

The same form of coupling, only made tapered at both ends, fig. 24, may be used for joining the various lengths of rope along the line.

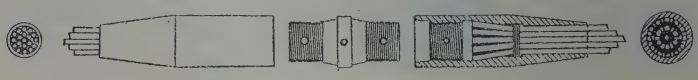

FIG. 24.

The distance apart of the tensioning weights varies according to the carrying capacity of the line, weight of carriers, number of long spans occurring, etc. A good rule is not to exceed a length of 1½ mile between anchorage and tensioning device, although on level lines, with a small capacity, distances up to 2 miles may be taken.

Another method of tensioning is by means of buffer springs at either end of the rope, but this system is only applicable to short lines with light loads.

Diameter of Carrying Ropes.

It has been proved by experience that most trouble is caused by breaking due to bending near the saddles, and for this reason in order to obtain the diameter of the carrying rope

required, many firms employ formulæ based on stresses due to bending. A formula often used is:—

$$\text{Weight per metre of ropes} = \frac{0{\cdot}85}{100}\left\{(\text{weight of carrier}) + \left((\text{distance between carriers in metres}) \times (\text{weight of traction rope per metre})\right)\right\}$$

This is for spiral construction ropes. With locked coil ropes the factor 0·85 becomes 1·05. This works well for small lines up to about 50 tons capacity hourly. For each additional 5 tons, 0·05 should be added to the factor 0·85. The following table shows the various diameters of a special locked rope for various loads and traction ropes:—

(Two-Wheeled Carriages.)

Dia. of Hauling Rope.	Weight of Loads in Cwts.									
	3	4	5	6	8	10	16	20	24	28
In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Ins.
$\frac{1}{2}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{3}{16}$	—	—	—	—
$\frac{9}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{3}{8}$	$1\frac{1}{4}$	—	—	—	—
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{2}$	$1\frac{1}{2}$	—	—	—
$\frac{11}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{9}{16}$	—	—	—
$\frac{3}{4}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{9}{16}$	$1\frac{13}{16}$	$1\frac{13}{16}$	—
$\frac{13}{16}$	—	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{9}{16}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2
$\frac{7}{8}$	—	—	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2

Design of Ropeway.

To lay out the profile for a ropeway, when the line is laid out on paper, the curve of the rope may be obtained and set out from the formula—

$$\text{Dip} = L^2W/8T,$$

where,

L = span; W = weight per unit length; 8 = constant; T = tension,

and then the supporting trestles placed accordingly. It sometimes happens, however, in practice that when the rope is fully tensioned it 'floats' or rises up from the supporting tower, owing perhaps to a minute error in the drawn profile. To avoid this, some Continental makers employ a so-called factor of safety for the dip—that is, the denominator 8T is multiplied by a constant—the formula giving, as a result, a dip smaller than the actual. It will be obvious that if the curve with the dip so obtained is set out and the trestles drawn up to it, they will be slightly higher than need actually be the case, thus avoiding any possibility of 'floating' when the line is erected. This factor of safety may be 1·5 for spiral ropes and 1·1 for locked coil ropes.

There has been of late years an increasing tendency to employ saddles (upon which the rope is supported at the trestles) which are pivoted at the centre, and can consequently adapt themselves to the varying gradients of the rope, and there is little doubt that this type when properly designed, and well greased to allow of play in the rope, gives full satisfaction. In designing the shoes a good medium value for the pressure of the rope is 250 lbs. pressure per square inch of projected area of the rope. This is for locked coil ropes; for spiral ropes a little less should be taken.

It sometimes happens that at a trestle, on either side of which are long free spans, there is a heavy downward reaction of the hauling rope, which, when the carrier passes over the saddle, produces a heavier pressure on the rope than that for which it was calculated. In this case the rope is protected by means of a steel plate cap over which the carrier runs, thereby removing the pressure from the rope. There is a difference of opinion as to when these caps should be employed, but it may safely be said that their use is to be recommended where the hauling rope reaction exceeds 450 lbs.

Hauling Ropes.

The *traction* or *hauling rope*, by means of which the carriers are propelled, is invariably a stranded rope with a hemp core, the flexibility depending on the size of the individual wires in the strands and the breaking stress of the material. This rope is endless and in constant motion. In the general case it passes round a driving sheave at one end of the line and round a surging or tension sheave at the other end. In some cases this plan may be varied, as, for instance, when the carriers are required to pass automatically round a large sheave at one end station. In this case no manual attention is required at this station and the driving and tensioning sheaves are combined in the station at the opposite end of the line. Whenever possible

the driving should take place at the upper and the tensioning at the lower end of the line. In this way the accumulative tension in the rope due to its own weight is utilised as a tensioning agent, whereas, were the tensioning to take place at the upper end, an additional amount of weight would be required to counterbalance the weight of the rope. The amount of the tensioning weight should be such as to give sufficient grip round the driving sheave to ensure perfect driving when the full load is on the line.

Diameter of Hauling Ropes.

The diameter of the hauling rope depends upon the highest tension occurring in it.

$$\text{Tension of rope in lbs.} = \left\{\text{Initial tension} + \left(\frac{W}{S} \times H\right) + (w \times H)\right\} + \left\{(W \times \mu_1 \times N) + (L \times \mu_2 \times w) + (R \times 2)\right\},$$

where,

W = weight of full carrier; S = spacing of carriers in feet; H = difference in level between stations in feet; w = weight per foot of traction rope; μ_1 = coefficient of friction of cars; μ_2 = coefficient of friction of traction rope; L = length of line in feet; N = number of carriers on one side of line; R = number of supporting rollers on one side of line.

This tension if multiplied by the factor of safety—6 to 8—and divided by the breaking stress, gives the area of the rope necessary. This is for the general case with the drive at the upper terminal and the loads ascending. When the loads are descending, the plus sign in the centre of the formula becomes minus. To obtain the tension when the ropeway is just put into work the second half of the formula should be doubled.

The usual breaking stresses of traction ropes are from 80 to 115 tons per square inch. The surge of the hauling rope tension sheave depends upon the distance apart of the carriers, whether long spans occur in the line, etc. As an average, 6 ft. play may be allowed for to commence with, and then an additional 12 ft. for each mile of length. In some cases in long lines it is necessary to split up the line into sections to avoid excessive tensions occurring.

Driving Power.

$$\text{Power in ft. lbs.} = \left\{\left(W_1 \times W_2 \times \mu_1 \times \frac{N}{2} \times V\right) + (w \times 2L \times \mu_2 \times V) + (2R \times V) + (F)\right\} + \text{or} - \text{theoretical power},$$

where,

W_1 = weight of full carrier; W_2 = weight of empty carrier; μ_1 = coefficient of friction for cars; N = total number of cars on line; V = velocity in feet per minute of cars; w = weight per foot of traction rope; L = length of line in feet; μ_2 = coefficient of friction for traction rope; R = number of supporting pulleys; F = power required for station friction.

The first four factors give the power necessary to overcome friction, and the theoretical power required or developed depends upon whether the loads are ascending or descending. The factor for station friction varies greatly for different lines, and is solely a matter of experience, although 0·02 of the total weight of the moving parts on the stations multiplied by the speed may be taken as a good mean.

Carriers.

There are two kinds of carriers in general use, those employing screw grips and those with lever grips. These may again be divided into sections, the overtype and the undertype grips. In the former, the hauling rope is attached to the carrier or running head at a point above, and in the latter at a point below the carrying rope.

The main advantage of the overtype grip is that the length of the stations is shorter than with the undertype grip, as the hauling rope may be led in and out of the jaws without interfering with the shunt rails. In the case of lever grips the overtype is generally the cheaper, and on lines containing no steep gradients can often be employed with advantage. Further, it may be more easily adapted for taking curves in both directions than the undertype. The overtype grip has, however, several great disadvantages. Chief amongst these is the fact that when ascending steep gradients the traction rope reaction falls outside the wheel base, tending to tip the whole running head, a tendency which may not be counterbalanced by the weight of the carrier, with the consequence that the whole apparatus leaves the line. Again, owing to the fact that the centre line of the hauling rope must fall outside the centre line of the carrying rope to avoid any entangling, there is a decided tendency for the carrier to tip sideways as soon as a heavy hauling rope reaction occurs, a tendency which is very detrimental to the perfect working of the line when it is required to discharge the contents of the carrier automatically whilst the carriage is on the open track. These defects may be remedied by having the hauling rope directly below the carrying rope, *i.e.*, using an undertype grip. Practically the only defect

of this type is that the stations are generally longer than with the overtype grip, thus involving extra structural work. Even this may be overcome by employing an undertype grip in which the jaws open downwards instead of upwards, as is usual.

The speed at which the carriers should be run depends upon whether it is necessary for them to be hauled automatically round curve or return sheaves by the traction rope. The following figures represent good practice :—

Straight lines	400–450 ft. p.m.
Curves up to about 45° change of direction	Undertype up to 400 ft. p.m. Overtype „ 300 ft. p.m.
With automatic haul-round—	
Sheave, 20 ft. dia.	Undertype, 350 ft. p.m. Overtype, 300 ft. p.m.
Sheave, 16 ft. dia.	Undertype, 300 ft. p.m. Overtype, 250 ft. p.m.
Sheave, 12 ft. dia.	Undertype, 200 ft. p.m. Overtype, 150 ft. p.m.

The running wheels should be of high quality cast steel, the diameter depending on the load and type of rope, larger diameter wheels being employed with spiral ropes than with locked coil. The runner pins should be self-oiling. The following table gives some diameters of wheels for varying loads, carriers with two wheels being employed :—

Weight of load and carrier, cwts.	Diameter of wheel, ins.
14	8
30	10
40	12

Screw Grips.

There are two distinct main classes of screw grip, in the first of which the grip is operated by a lever and strikers in the stations. In the second the grip is operated by the weight of the carrier and load. The best example of the former is shown in fig. 25. There are two jaws—(*a*) the movable and (*b*) the fixed. The movable jaw is actuated by a shaft carrying two screws, one a rapid thread and the other a fine thread. This shaft is turned by the lever C. The action of the grip is as follows :—On the lever C being turned over, the rapid thread operates and the movable jaw quickly approaches the fixed jaw until the rope is just gripped. The fine thread now comes into action and applies the necessary force to grip the rope firmly. To unlock the

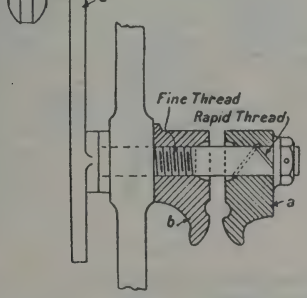

FIG. 25.

grip the reverse action takes place. The lever C is actuated at the stations by strikers constructed of angle irons.

In the other form of screw grip, in which the pressure is obtained from the weight of the carrier and load, the action is the same, the necessary turning moment being applied to the screw by hanging the carrier at the end of the lever arm. The grip is opened to allow of the rope entering or leaving, by means of rails, generally formed of angle irons, which depress small pulleys fixed at the end of the lever arm opposite to that on which the carrier is hung, thus raising the latter and thereby opening the jaws. It has been found in practice that the position of this lever arm should not be less than 35° to 40° to the vertical, to allow of easy depression of the rollers.

Lever Grips.

One of the best known Continental types is that shown in fig. 26. In this grip the pressure is applied by the weight of the carrier and load acting through a simple system of levers to give a multiplied pressure on the jaws. The grip is released by lifting the load, which is accomplished by means of small rollers running on to rails in the stations. Another type of grip—the

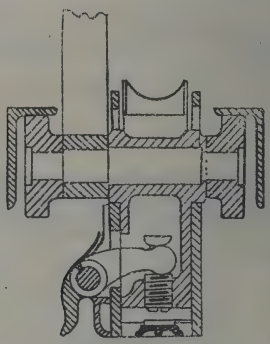

FIG. 26.

inclined plane type—is illustrated in fig. 27. The carrier and load are attached to a hanger having at its upper end a curved slot. This slot engages with a circular pin attached to the movable jaw. The downward pull of the hanger draws in this pin and with it the movable jaw, thus closing it upon the rope. When the pin is in the upper part of the slot the grip is absolutely locked, as no amount of upward pull of the rope can force the jaws apart. The grip is released

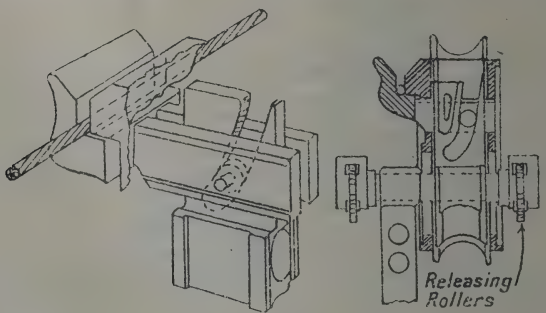

FIG. 27

in the stations in the same manner as the type shown in fig. 26. In practice this form of grip has been found extremely simple and efficient.

In the matter of taking curves automatically in both directions, the advantage lies with the lever type of grip. In cost the latter generally has a great advantage. A ropeway, with lever grips, carrying two-ton loads on an incline of 86 per cent., is being used for carrying timber in South-West Africa.

Costs.[*]

The following tables of prime and working costs for ropeways represent the standard amounts for plants possessing no peculiar complications.

[*] The figures given are those current some time prior to the war.

Prime Cost of Plant with Structures in Steel.

Capacity in Tons per Hour.	Length of Line in Miles.			
	½	1	2	5
	£	£	£	£
5	1,900	2,000	3,300	6,900
10	2,100	2,300	3,650	7,400
20	2,350	2,600	3,900	8,000
40	2,500	2,870	5,000	10,500
60	2,850	3,200	5,700	11,900
80	3,100	3,500	6,300	13,100

The above prices are reckoned on the basis of employing spiral construction ropes up to 20 tons capacity and locked coil ropes for 40 to 80 tons capacity, and represent the total cost of the plant erected. For lengths above 5 miles a proportional cost may be taken.

Working Costs per Day.

Length in Miles.	Capacity per Day in Tons.					
	50	100	200	400	800	1,000
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
½	17 6	21 0	25 0	32 0	42 4	48 0
1	19 5	24 0	28 10	37 7	52 0	58 5
2	26 6	31 6	36 4	49 7	68 10	76 10
5	45 7	51 0	61 0	83 3	126 0	156 10

The above costs are inclusive of depreciation, but exclusive of the cost of driving, this being so different in each case, depending on difference of height between stations, etc., that it is impossible to standardise, and it must therefore be reckoned as an extra to the above for each separate plant.

Fixed Clip Single Rope System.

This type of ropeway is only applicable for light capacities, and is used largely on plantations and for the transport of valuable ores, where comparatively small quantities are handled.

The carrier head, fig. 28, is permanently attached to the rope by means of a spring steel strap, and is designed in such a way that it can pass freely over trestle sheaves, under depression wheels and round the terminals, without being detached from the rope. As both rope and carriers are in constant motion, loading has to be done by hand, or by means of a travelling hopper, which is usually hung from overhead rails at the terminal. The terminals are extremely simple and

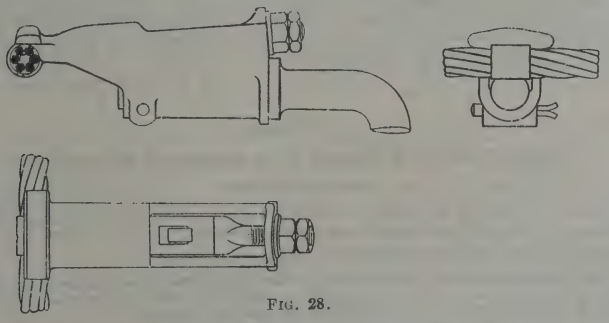

Fig. 28.

compact, as all shunt rails are done away with. The tension terminal is usually mounted on a trolley or on skids, the whole being movable by means of tension gear, to allow for stretch of rope, etc. Angles can be worked with the fixed clip system, but they should be preferably avoided, as they tend to produce excessive rope and gear wear at such places.

This type of line is run at a slow speed, namely, about 200 ft. per minute, and the only

advantages it can claim are its simplicity, adaptability to steep grades, and its low prime cost when light capacities and moderate lengths have to be dealt with.

Jig-Back or To-and-Fro.

This type of ropeway is useful for short distances, and is operated with a pair of carriers that travel in reverse directions and are loaded or brought to rest alternatively at the opposite stations, but which do not pass round the terminals; it is, therefore, intermittent in its action, and the direction of travel is reversed after each journey. Where loads are to be carried which are heavy individually in relation to the capacity, and where the distance is short, the 'To-and-Fro System' is particularly applicable. A high carrier and rope velocity may be adopted during the run, especially where a clear span occurs between terminals, and where there are no intermediate trestles. These installations may be on the 'Monocable' or 'Bi-cable' principle, and in either case the moving rope is clamped to the carriers, and is not usually disconnected from them at the terminals.

It should be mentioned that, up to the present, the 'To-and-Fro' ropeway is the only system that is used for regular passenger traffic, as the carriers lend themselves to the adoption of a safety grip used in conjunction with an auxiliary standing rope, but with such appliances these installations are very costly and present mechanical difficulties on lines of any length.

The following table, giving a rough idea of the capabilities of the various systems mentioned, shows the maximum lengths, capacities, and loads carried on various lines at present working or in course of construction:

System.	Present Maximum Lengths.	Present Maximum Hourly Capacity.	Present Maximum Individual Load.
	Yards.	Tons.	Tons.
Monocable	80,196	200	1½
Bi-cable	38,800	250	2
Fixed Clip	2,330	8	4 cwts.
To-and-Fro	1,850	Passengers' weight unknown.	17 tons.

Limitations of Types of Aerial Ropeways.

The *jig-back* type is the cheapest for short distances and a capacity of 8 to 12 tons per hour. Where the distance is considerable the loss of time in making the double journey between each load is too great, and where individual loads are heavy and the speed high too much time and energy is lost in starting and stopping.

The *monocable* type is suitable for a capacity up to 80 or 100 tons per hour where the grade of the rope is not steeper than 1 in 2¼ or 1 in 2½. Where the rope grade would be steeper than this the boxhead clips would be liable to slip on the rope, and a bi-cable would have to be considered.

The *bi-cable* type is required for steep grades and large hourly capacity. It is evident from general principles that if the number and weight of the individual loads carried by a rope be gradually increased the tension and weight of the rope will have to be increased also, and at last a point will be reached when it is cheaper to fix the heavy main rope and use it for carrying purposes only and to provide an extra and lighter rope for hauling the loads. This point marks the natural transition from monocable to bi-cable.

(*A. J. Knight, B.Sc., M.I.Struct.E.*)

CONVEYORS.

(Contributed by Professor John Goodman, M.Inst.C.E.)

Belt Conveyors.

The horse-power required to drive belt conveyors varies so much with the design and spacing of the idlers, and the local conditions, that no accurate rules applicable to all cases can be given.

The following formula may be found useful for the average case:

W = total weight of material delivered per minute; W_1 = total weight of belt; S = speed of belt in feet per minute; H.P. = horse-power; W_2 = maximum weight of material on belt at any one time; H = total height to which material is elevated by conveyor.

$$\text{H.P.} = \frac{(0{\cdot}15\ W_1 + 0{\cdot}07\ W_2)\ S + H\ W}{33000}.$$

An allowance of from 4 per cent. to 6 per cent. should be made for each tripper, and all other unusual elements taken into consideration. (*E. J. Haddick.*)

A belt 30 ins. wide, made up of eight plies of cotton duck faced and fitted with rubber, is known to have elevated 2,000,000 tons of coal at a South African Colony, while working at a speed of 460 ft. per min. The best performance was 3,000 tons in ten hours; no guide rollers were used.

The life of a 48-in. belt should be not less than 1,000,000 tons of coal carried. The ultimate tensile strength of a 6-ply belt, 24 ins. wide, will be about 25 tons; such a belt would work well on a conveyor when stressed to 2 tons by the tension load and drive. A rubber and fabric belt 30 ins. wide by 2,000 ft. in length, working on a conveyor nearly 1,000 ft. long, at a speed of 350 ft. per min., and loading coal at the rate of 200 tons per hour, will stand a drive of 60 h.p. when using tandem pulleys, without unduly stressing the belt. A belt 60 ins. wide, capable of carrying 3,000 tons of iron ore per hour, is quite a practical proposition.

The quality of rubber used on the working face of a belt should be capable of stretching three times its length, 3 to 5 ins., before breaking, and the belt will give the best results if in a flexible condition with the rubber rendered not too hard by over-vulcanisation. The adhesion of the rubber face to the canvas should require a force of not less than 20 lbs. applied for one minute to separate 1 sq. in. The 'frictioning' between the layers of canvas should require a force of not less than 16 lbs. for the same purpose. The best speed for belt conveyors is from 300 ft. per min. for smaller sizes, up to 500 ft. for the larger. The speed should not be less than 300 ft., because the trajectory of the load, after leaving the belt at lesser speeds, falls too rapidly towards the vertical to ensure the whole of the stream being discharged clear of the head pulley. On the other hand, with speeds exceeding 500 ft. per min., it is difficult to deliver the load to the belt without serious abrasion.

The angle of an inclined belt should flatten gradually into the horizontal from 5 to 15 ft. (according to width) before reaching the feed from the hopper.

All inclined conveyors should be driven through worm-gearing to overcome any tendency of the belt to run back when stopped in an overloaded condition.

(*H. J. Smith*, '*The Mechanical Loading of Ships*,' *The Inst. Mech. Eng.*, *No.* 1, 1921.)

Steel Belt Conveyors.

(*Steel Belt Conveyors Ltd.*)

Conveyors employing a flexible steel band in lieu of the textile fabric or rubber belt are in use in Scandinavia, on the Continent generally, in Great Britain and Colonies, and U.S.A., for handling a wide variety of materials, and have proved particularly successful in the stone, ore, cement, brick, confectionery, and sugar trades.

The band itself consists of finest quality cold-rolled, hardened and tempered Swedish charcoal steel of the "Sandvik" brand, is of very dense texture, highly resistant to rust and corrosion, extremely durable, and has a tensile strength of about 80 tons per sq. in., equal to about 3 tons per inch of width of belt. It is rolled at present in widths up to 24 ins., one-piece lengths up to 300–350 ft., and thicknesses up to 1 mm. (about 0·04 in.), the longitudinal edges being rounded and smooth. It is joined by means of simple lap riveted or butt strap riveted joints which can be made in less than an hour. Small conveyors can have brazed or welded joints. The flexibility of the material is such that a coil of 300 ft. of 16 in. belt can be sent out packed in a case 2 ft. square by 1 ft. 6 ins. deep; it weighs approximately 2 lbs. per foot run.

Consequent upon its transverse stiffness and ability to be loaded over its full width without the edges yielding downwards, steel belt has a high carrying capacity, and in addition for many materials it can be troughed by means of skirting boards (the belt forming the bottom of a rectangular trough) which increases the capacity three to four times. Thus, an open 16 ins. belt at 200 ft. per minute could handle about 35 tons of coal per hour, and if troughed from 100 to 120. Under similar conditions an open belt could handle 100 tons of broken granite per hour on the basis of 150 lbs. per cubic ft.

The usual end-drums and intermediate supports at suitable intervals for the top and bottom strands are used. The supports usually consist of simple Roller Idler Sets, but for light duty conveyors the strands can slide on timber runners that have a smooth and graphited face.

The belt does not stretch, and the only variation that has to be provided for is due to expansion and contraction; the tension devices are therefore of the simplest, and for a conveyor not exceeding 120 ft. in length working at normal temperature the sag in the bottom strand is sufficient to provide for all give and take required. Other than that a simple tension frame is employed, operated by either balance weight and rope, balance weight and levers, or springs.

Material up to a temperature of 200° F. may be conveyed without unduly affecting the belt.

Notes on Belt Conveyors.

For conveying materials continuously over long distances in a horizontal or inclined direction band conveyors are usually employed.

Single conveyors are made up to 48 ins. in width and over 1,000 ft. in length. They can be employed for handling almost any class of material excepting those which are hot or sticky.

Solid woven cotton belts are lowest in first cost, but they are not suitable for continuous or heavy duties, because sharp substances soon cut the fabric, and, moreover, they are not waterproof and are very sensitive to climatic changes, which cause them to stretch and contract abnormally.

Belts treated with bituminous solutions are partially waterproof and resist wear much better, but have the disadvantage of becoming hard, and, moreover, they will not accommodate themselves to the troughing idlers.

Balata belts, when manufactured with the true vegetable gum, are satisfactory for work in the open, as they resist damp better than any other type. The best quality belts are durable and easily conform to the troughing idlers.

Vulcanised rubber belts of best quality, although high in first cost, are the best and ultimately the cheapest for conveying hard, heavy, or sharp materials. The cotton duck, which forms the basis, provides great tensile strength, whilst the rubber cover is the best-known material for resisting wear and abrasion. The cover on the carrying side should be at least $\frac{1}{16}$ in. thick.

Woven wire belts of various types are used for special purposes, as, for example, colliery picking belts, where it is desired to extract dust during conveyance.

The following table, taken from the *Engineering Magazine*, March 1909, shows the comparative values of different belts and materials to resist abrasion. Sample strips were submitted to equal sand-blast, and the volume of material worn away was measured.

Rubber belt	1·0	Woven cotton belt (high grade)	6·5
Rolled steel bar	1·5	Stitched duck („ „)	8·0
Cast iron	3·5	Woven cotton belt (low grade)	9·0 to 15·0
Balata belt	5·0		

The life which may be expected from a best quality rubber belt when handling coal is given by the following expression:

$$N = 3W_b^3L$$

where,

N = the number of tons which a rubber belt may be expected to convey before it is worn out;
L = length of conveyor centres in feet;
W_b = width of belt in inches.

When estimating the life of belts made of other materials, the result obtained by the above expression must be divided by the corresponding figure in the table.

Belt Joints.—For short conveyors, endless belts may be used, but owing to difficulty of fixing they are not recommended for long conveyors. The best fastener for heavy duty is made of thin steel plates in the form of a hinge, with pins of hard copper, and used in combination with leather safes for the ends of the belt. The fasteners are secured by copper rivets.

For short and medium conveyors a satisfactory joint can be made with 'Alligator' fasteners.

Intermediate Idlers usually consist of C.I. pulleys, 5 ins. or 6 ins. diameter, mounted on hollow shafts fixed in C.I. brackets and provided with grease lubricators.

Table I. gives the thickness of belt and pitch of idlers recommended.

Table I.

Width of Band.	Effective Cross-section of Material carried in Sq. Ft.		Largest Pieces Belt will carry.	Ply.	Pitch of Idlers.	
Inches.	Flat.	Troughed.	Inches.		Ft. Ins.	Ft. Ins.
12	0·04	0·09	$2\frac{1}{2}$ cubes	3 to 4	5 6 to	6 0
16	0·07	0·15	$3\frac{1}{2}$ „	4 „ 5	5 0 „	6 0
18	0·09	0·19	4 „	4 „ 5	4 6 „	5 6
20	0·12	0·22	5 „	4 „ 6	4 6 „	5 6
24	0·16	0·34	$6\frac{1}{2}$ „	5 „ 7	4 6 „	5 6
30	0·27	0·55	10 „	6 „ 8	4 0 „	5 0

Terminal drums should have a crowned face 3 ins. wider than the belt, and the diameter should be not less than 5 times the number of plies in the belt.

The driven terminal should be mounted on a carriage controlled by weights to automatically take up any belt stretch.

The usual speeds of conveyors when handling coal, ore, broken stone, etc., are from 250 to 350 ft. per minute.

Belts are usually carried on troughing idlers for the above-mentioned materials.

Speed for handling grain, 400 ft. to 600 ft. per minute. Grain containing chaff should run at the lower speed.

Grain bands usually run on flat idlers.

The capacity in cubic feet per minute may be taken from Table I. by multiplying the effective cross-section of material carried by the speed of the belt in feet per minute.

The pitch of the idlers for the return belt should be from 9 ft. to 12 ft., according to the weight of the belt.

The power required depends on workmanship, diameter of idlers, and other factors.

If fully loaded and the conditions are good, the following expression gives the horse-power required for band conveyors:

$$\text{H.P.} = \frac{(0{\cdot}15B + 0{\cdot}07M)S + HW}{33{,}000};$$

where,

B = weight of belt in pounds; M = weight of material on belt at any time in pounds; S = speed in feet per minute; H = height elevated in feet; W = weight of material delivered per minute in pounds.

Drag Bar or Scraper Conveyors.

These take the form of a wide chain travelling in a fixed trough, the material being dragged along by the chain bars. Considerable horse-power is required to drive this type, on account of the

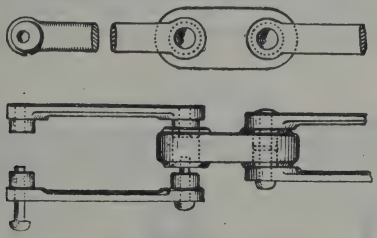

Fig. 29.

friction of the material and chain in the trough. Even with this fault the type is largely used where simplicity and few working parts are of premier importance. Examples are the 'Blackett' Conveyor, used at the coal face in collieries. The 'Bennis' Conveyor, much used in boiler stoking plants, and the 'Jenkins' 'DB' Patent Conveyor, which is principally used in gasworks for conveying hot or cold coke. It is also used for handling ashes, gravel, etc.

The conditions met with in handling coke are probably more severe than with any other material. First, because the coke reaches the trough at a temperature up to 1,700° F.; and, secondly, the coke is of a hard cutting nature, and contains a quantity of fine particles which work into the joints. Lubricants cannot be used, and finally the conveyor is in use night and day all the year round. Yet these chains frequently have a life of from three to four years, and convey up to 130,000 tons of material.

The 'DB' Conveyor consists of a special double chain connected together with cross-bars integral with special links at intervals of 2 ft. 1½ ins., and in widths from 12 ins. to 36 ins. or more. The detail of the chain is shown in fig. 29, and as used with a trough for hot coke, fig. 30.

It will be noticed that special short links are used alternately with long narrow links. Only the short links bear on the trough. The usual speed of such a conveyor is from 40 to 50 ft. per minute.

A trough 2 ft. 6 ins. wide, 7 ins. deep, will convey 20 tons of coke per hour and consume about 1 h.p. per 33 ft. of horizontal length.

The conveyor will work satisfactorily on inclines up to 33°, and with special cross-bars up to 7°.

The longest single conveyor installed is 350 ft. long, on the horizontal, with the addition of 60 ft. inclined at 30°.

The power required to drive this conveyor fully loaded is 14 b.h.p.

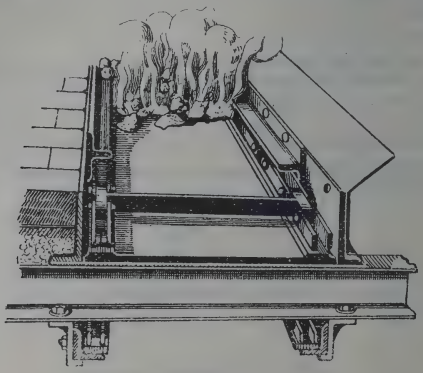

FIG. 30.

Scraper Conveyors are mostly used for handling coal when it is desired to discharge at short intervals and when dealing with quantities of from 20 to 40 tons per hour up to a maximum length of about 200 ft. For lengths beyond this it is better to use a Pushplate Conveyor, on account of the power required to drive being so much less.

The longest 'DB' Scraper Conveyor installed is 231 ft. long, dealing with 40 tons per hour, and requires 16 h.p. when fully loaded.

PUSHPLATE CONVEYORS.

These are in general use for conveying and delivering coal into storage hoppers. Conveyors of this type are superior to any other when it is desired to deliver coal at many intermediate points. For this purpose, outlets, with slide doors, are arranged in the trough where

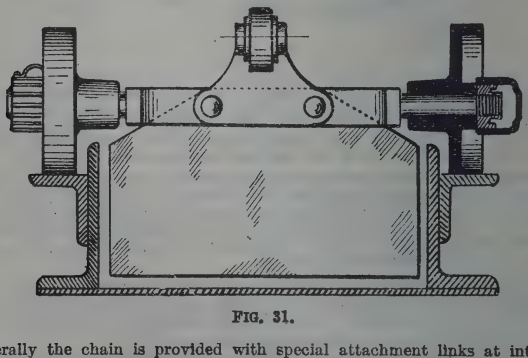

FIG. 31.

desired. Generally the chain is provided with special attachment links at intervals, which carry M.S. plates and axles fitted with C.I. rollers, and grease lubricators. The plates are kept clear of the trough so as to avoid any noise when working.

The usual speed is 100 to 120 ft. per minute, and as there is only the sliding friction between the coal and the trough the power taken is not excessive.

A typical Pushplate Conveyor is shown in section by fig. 31. For dealing with 25 tons of coal per hour the trough would be 15 ins. wide and 6 ins. deep. A single chain would be fitted with pushplates 17 ins. apart. The rollers would be grease lubricated, 6 ins. diameter and 4 ft. 3 ins. apart. A conveyor of this type, 250 ft. long, running at 120 ft. per minute, requires 5 b.h.p. to run empty, and 7 b.h.p. to run fully loaded.

TABLE II.—PUSHPLATE CONVEYOR FOR COAL.

Size and Capacity in Tons per Hour.			
Width of Trough.	Pitch of Pushplates.	Depth of Trough.	Tons of Coal per Hour.
Inches.	Feet.	Inches.	
12	1·5	6	20
15	1·5	6	28
18	1·5	6	35
24	1·5	6	45

The following gives the horse-power of scraper and pushplate conveyors:

$$\text{H.P.} = \frac{KS(M + G)}{33{,}000},$$

where,

K = constant, say 0·37 for scraper and 0·13 for pushplate conveyor with rollers; S = speed in feet per minute; M = weight of material on conveyor at any one time in pounds; G = weight of moving parts of chain in pounds.

The friction of the driving gear must be added to the above.

GRAVITY BUCKET CONVEYORS.

This type of conveyor is unique in the sense that one unit can transport vertically, horizontally, and at any intermediate angle, and for this reason they are much used in power-stations for elevating and storing coal in overhead bunkers.

The principle employed is a series of buckets mounted on steel spindles, which are connected to two endless chains at regular intervals, the ends of the spindles are provided with C.I. grease-lubricated rollers for the purpose of travelling on horizontal rails or between inclined guides.

The buckets are suspended above their centre of gravity in such a manner that they always remain in an upright position until they are tilted by cams or levers provided for the purpose.

The corner guides for changing the direction of the chain should preferably consist of two sprocket wheels large enough in diameter to allow the buckets to swing clear of the shaft; one wheel should be keyed in place, and the other allowed to turn freely on the shaft between collars, so as to rectify any trouble that may arise should one chain stretch more than the other.

As the buckets are mounted on the chains with a space of an inch or more between, it is necessary to provide a special 'feeding device' for filling the buckets. Several types are in use, but probably the most popular is in the form of a drum having a circumference equal to at least five pitches of buckets. Outlets are arranged corresponding with the pitch, with blank plate between.

The drum is rotated by direct gear with the chain, and the material is fed through the centre. The blank plates prevent the material spilling between the buckets.

It is sometimes necessary to feed buckets at several points; in this case the filler is provided with travelling wheels to run on separate rails, and is rotated by a large sprocket wheel which engages with one of the bucket chains.

TABLE III.—SIZE AND CAPACITY OF G.B. BUCKET CONVEYORS FOR COAL.

Tons per Hour.	Pitch of Buckets.	Buckets.			Speed.
		Length.	Width.	Depth.	
	Inches.	Inches.	Inches.	Inches.	
30	21	22	16	9	45 ft. per minute
40	27	24	16	10	" "
50	27	24	20	11	" "
60	27	24	22	11	" "
100	27	26	30	12	" "

The following gives the horse-power required for gravity bucket conveyors:

$$H.P. = \frac{CH}{884} + \frac{S(W_m + W_c)}{180}$$

where,

C = capacity in tons per hour; H = height to be lifted in feet; S = speed in feet per minute; W_m = total weight of moving parts of conveyor in tons; W_c = total weight of coal in conveyor in tons.

Add for friction of gearing and motive power. (*John Goodman.*)

See also *Proceedings of the Inst. Mech. Engrs.*, No. 2, 1921.

PNEUMATIC CONVEYORS.

See "The Nuvako Pneumatic Conveying System"; *Engineering*, Dec. 9, 1927.

Brake Linings.

FERODO APPLIED TO BRAKES.

(*Ferodo, Ltd., Chapel-en-le-Frith.*)

Present-day high speeds and heavy loads require powerful and reliable brakes, these being especially necessary for modern lifting machinery. The friction coefficients of wood, leather, and metal (the materials generally used) are comparatively low, the values usually falling with heat and general working conditions; with the Ferodo lining on brakes (block, band, or disc type) the coefficient of friction increases as the temperature increases, the action is smooth, reliable and powerful, and reduces the wear and tear on the drums and gears. Ferodo fabric is readily fixed to a steel band, metal, or wood blocks.

For description of, and tests with, this material, see page 995.

CHEKKO BRAKE AND CLUTCH LININGS.

(*Cresswell's Asbestos Co., Ltd., Wellington Mills, Bradford.*)

These linings are made from 100 per cent. pure long asbestos fibre woven into brass wire in one solid piece; they are made in sheet from 2 in. to 12 in. wide, and in thickness varying from $\frac{3}{8}$ in. to $\frac{3}{4}$ in. The sheeting when cut to the required size is fastened to wood foundation blocks by means of counter-sunk brass screws, which screw into metal nuts, the latter lying in slots cut in the wood. In the case of a steel band being lined with the material, the screws pass through the band and screw into nuts on the outside of the band, or aluminium rivets may be used for the purpose. See also p. 995.

NOTES ON FABRIC LININGS.

A most important point to observe in regard to the use of fabric linings is that the blocks to be lined are first worn down so that they will make a true arc of contact, also that the fabric lining after being fitted is clear of the brake path at every point of its surface when not in action. In band-type brakes the same observations are essential, and an arrangement should be fitted whereby the top half of the band is kept well clear of the brake path by suitably arranged and powerful springs when idle.

Brake paths which are out of truth or have undue lateral play should be corrected, and the paths should be as smooth as possible. Given these conditions, experience proves that fabric linings are cheaper in the end as regards mere cost than materials which may cost little in themselves and are only costly in labour and renewal. In addition to the saving effected, there is improved efficiency, greater power, much sweeter action when engaging and disengaging, and greater durability.

In all brake paths the abutting edges should be tapered back a good 2 ins. to eliminate all possibility of any edge rising above the circumference of the path.

The manufacturers generally send out carefully printed instructions regarding fixing and applying, also as regards the correct material to use, and a little care and thought are all that are required to eliminate the possibility of failure.

Magnetic Separators.

(*The Rapid Magnetting Machine Co., Ltd., Birmingham.*)

Magnetic separators are made for removing iron as an impurity, recovering for its value, and preventing damage to crushing and other machinery.

One of the latest applications of magnetic separation, fig. 32, is for the recovery of iron (largely in the form of empty tins, used for canned food) from house refuse, *before passing to the destructor*.

The Rapid Magnetting Machine Co., Ltd., Birmingham, have taken out a patent for use in conjunction with the revolving screen used for removal of the dust as a preliminary operation.

FIG. 32.

The invention primarily consists of a very powerful electro-magnet, partly surrounding the 'delivery-off' end of the screen. As the iron reaches the magnetic field the metal is drawn to the inside surface of the screen and carried up to the vertical centre, where it is automatically released without the aid of mechanical cut-outs, falling into a shoot which diverts it to the side of the apparatus.

A common use of a magnetic separator is for the separation of iron from non-ferrous metals.

SECTION XIX

POWER TRANSMISSION

(Revised and amplified by Professor Dempster Smith, M.B.E., M.Sc.Tech., M.I.Mech.E.)

PART I

BELTING—ROPE DRIVING—CLUTCHES (pp. 953–995)

PART II

CHAIN GEARING (pp. 997–1004)

PART III

TOOTH GEARING—WORM GEARING—VARIABLE-SPEED GEAR—LINK MOTION (pp. 1005–1035)

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F. 953

SECTION XIX

(Revised and amplified by Professor Dempster Smith, M.B.E., M.Sc.Tech. M.I.Mech.E.)

PART I

BELTING—ROPE DRIVING—CLUTCHES.

BELTING.

Power Transmitted by Belting.

The following formula gives the power transmitted by any belt :—

$$H = \frac{(T - t)v}{33{,}000},$$

where,

H = actual horse-power transmitted ; T = tension in lbs. on the pulling side of the belt; t = tension in lbs. on the slack side of the belt ; v = speed of belt in feet per minute.

When a belt is doing its full work, T will be the greatest safe working tension that the belt will stand ; this is about 90 lbs. per inch of width for singles (more accurately 60 lbs. to 120 lbs., according to the thickness of the leather), and about 150 lbs. for doubles (135 lbs. for light and 160 lbs. for heavy doubles). In order that the belt shall do as much as possible, t must bear such a ratio to T that the belt just does not slip over the pulleys. In practice t varies from $\frac{1}{3}$ to $\frac{2}{3}$ of T, depending on the character of the surfaces of the belt and pulley, and on the fraction of the circumference of the pulley embraced by the belt ; $\frac{1}{2}$ of T will be a safe average value for t; so that $T - t$ will be on the average 45 lbs. for singles and 75 lbs. for doubles for every inch of width; hence the following rule for finding the power that any given belt should transmit :—

Multiply the width of the belt in inches by 45 if single, by 75 if double ; multiply this again by the speed in feet per minute, and divide by 33,000 ; the quotient will be the number of actual horse-power the belt will transmit.

EXAMPLE 1.—Required the horse-power which a 5-in. single belt, running at 1,000 feet per minute, will transmit.

$$5 \times 45 \times 1{,}000 \div 33{,}000 = 7 \text{ horse-power (nearly).}$$

EXAMPLE 2.—What power can be transmitted by a 12-in. double, running at 1,500 feet per minute ?

$$12 \times 75 \times 1{,}500 \div 33{,}000 = 41 \text{ horse-power (nearly).}$$

EXAMPLE 3.—An example of the reverse kind : What width must a belt be to transmit 20 horse-power, the belt running at a speed of 2,500 feet per minute ?

$$(20 \times 33{,}000) \div (2{,}500 \times 45) = 6 \text{ ins. nearly, if single.}$$
$$(20 \times 33{,}000) \div (2{,}500 \times 75) = 3\tfrac{1}{2} \text{ ins., about, if double}$$

The values given in the table are more accurately calculated, and hence do not exactly agree with the above examples.

The size of the pulleys or the number of square inches of contact between belt and pulleys has no effect on the power transmitted ; that is to say, the same belt will have just as much grip, other things being equal, on 1-foot pulleys as on 4-foot pulleys. The fraction of the circumference of the pulley embraced by the belt, however, has an important effect on the friction between the two ; that is to say, if the belt is in contact with the pulley for more than half the circumference of the latter it will get a better grip, and will therefore transmit more power than if in contact for less than half the circumference ; hence the desirability, where possible, of making the pulling half of the belt the lower one, so that the slack upper side may sag down and lap further round the pulley.

The following table gives the number of horse-power which belts of various sizes should transmit. Allowance has been made for the loss of power at high speeds, due to the centrifugal force of the belt. This loss is negligible at low speeds, but increases with the velocity, amounting

to about 10 per cent. at a speed of 3,000 feet per minute, and about 30 per cent. at 5,000 feet per minute; no advantage is gained by running a belt faster than 4,000 or 5,000 feet per minute.

Under very good conditions of working, belting will transmit up to 1¼ times the amounts given in the following table without being overstrained. (*Richardson.*)

TABLE SHOWING HORSE-POWER TRANSMITTED BY LEATHER BELTS UNDER AVERAGE WORKING CONDITIONS.

Speed of Belt. Ft. per Min.	Width of 'Single Thickness' Belts (ins.).									
	1	2	3	4	5	6	7	8	9	10
500	0·67	1·4	2·2	3	3·7	4·5	5·2	5·9	6·7	7·4
600	0·81	1·7	2·6	3·6	4·5	5·4	6·3	7·2	8·1	9
700	0·93	2	3	4·1	5·2	6·2	7·3	8·3	9·2	10·4
800	1·1	2·2	3·5	4·7	5·9	7·1	8·3	9·4	11·6	11·8
900	1·2	2·5	3·9	5·4	6·7	8	9·4	10·7	12	13·4
1,000	1·3	2·8	4·3	5·8	7·3	8·8	10·2	11·7	13·1	14·6
1,500	2·0	4·1	6·3	9·5	10·8	13	15	17·3	19·4	21·6
2,000	2·6	5·5	6·7	11·4	14·3	17·1	20	22·8	25·7	28·6
2,500	3·2	6·8	10·4	14·2	17·7	21·2	25	28·4	32	35·4
3,000	3·8	8	12·3	16·8	21	25	29·5	33·5	38	42
3,500	4·3	9·2	14	19·2	24	29	34	38·5	43	48
4,000	4·8	10·4	16	21·8	27·2	32·5	38	43·5	49	54·2
4,500	5·4	11·4	17·5	24	30	36	42	48	54	60
5,000	6·0	12·5	19·3	26·5	33	40	46	53	60	66

Light 'double thickness' belts will transmit 30 per cent. more power than that given in the above table.

For ordinary 'double thickness' belts the values given in the table may be increased 50 per cent., whilst for extra heavy 'double thickness' belts the values given in the table may be increased 70 per cent.

For intermediate speeds, and widths of belt, the h.p. transmitted is proportional to the speed or width of belt.

DICK'S ORIGINAL BALATA BELTING.

Table showing the horse-power which each inch of width of Dick belting, from 3-ply to 10 ply, will transmit at the speeds given.

Speed of Belt per minute.	3 Ply	4 Ply.	5 Ply.	6 Ply.	7 Ply.	8 Ply.	9 Ply.	10 Ply.
Ft.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.
500	0·60	0·90	1·21	1·51	1·81	2·12	2·42	2·71
750	0·90	1·36	1·81	2·27	2·72	3·18	3·63	4·08
1,000	1·21	1·81	2·42	3·03	3·63	4·24	4·84	5·44
1,250	1·51	2·27	3·03	3·79	4·55	5·30	6·06	6·82
1,500	1·81	2·72	3·63	4·55	5·45	6·36	7·27	8·17
1,750	2·12	3·18	4·24	5·30	6·36	7·42	8·48	9·54
2,000	2·42	3·63	4·85	6·06	7·27	8·48	9·70	10·90
2,250	2·72	4·09	5·45	6·82	8·18	9·54	10·90	12·27
2,500	3·03	4·54	6·06	7·58	9·10	10·60	12·12	13·64
2,750	3·33	4·99	6·66	8·34	10·00	11·66	13·32	14·99
3,000	3·63	5·44	7·26	9·10	10·90	12·72	14·52	16·34
3,250	3·93	5·90	7·87	9·85	11·81	13·78	15·74	17·71
3,500	4·24	6·36	8·48	10·60	12·72	14·84	17·96	19·08
3,750	4·54	6·81	9·09	11·36	13·63	15·90	18·18	20·44
4,000	4·84	7·27	9·70	12·12	14·54	16·96	19·40	21·81
4,250	5·15	7·72	10·30	12·88	15·45	18·02	20·60	23·17
4,500	5·45	8·18	10·90	13·64	16·36	19·08	21·80	24·54
4,750	5·75	8·63	11·51	14·40	17·28	20·14	23·02	25·91
5,000	6·06	9·08	12·12	15·16	18·20	21·20	24·24	27·28

N.B.—These calculations, which are based on the most conservative lines, are given for ordinary loads over pulleys of proper diameters; anything abnormal in a drive should be taken into account in specifying the belt required.

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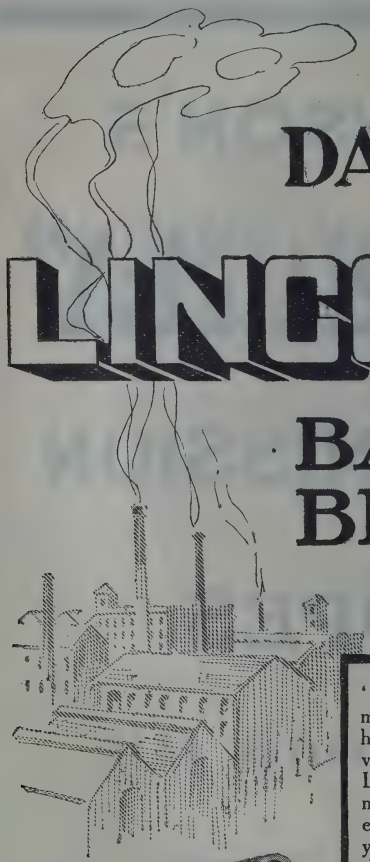

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F. 955

The following table is the 'Dick Equivalent' of the best quality of leather belt :—

Dick belt 3-ply equals 14 ozs. single leather.
" 4 " " 18 ozs. "
" 5 " " 26–28 ozs. double leather (up to 12 ins. wide).
" 6 " " 30–32 ozs. double leather (over 12 ins. wide).

(*R. & J. Dick, Ltd.*)

German Practice.

In Germany it is usual to allow a higher effective tension per inch of belt width with increase in the diameter of pulley and speed. The table given below is compiled by Herr O. Otto Gehrckens and represents his practice for the past few years :—

Safe Effective Tension per Inch of Width (*Gehrckens*).

Diam. of Pulley.	Velocity Feet per Min.											
	600		1,000		2,000		3,000		4,000		5,000	
Ft. Ins.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
0 4	11	—	13·5	—	16·5	—	16·5	—	19·0	—	19·0	—
0 8	16·5	—	22	—	27·5	—	30·0	—	33	—	36·0	—
1 8	27·5	44	38·5	49·5	44	55	49·5	60·5	55	66	60·5	71·5
3 3	33	55	46·5	66	55	77	60·5	88	66	93·5	71·5	99
6 6	38·5	66	55	82·5	66	110	71·5	121	77	132	82·5	137·5

A. Single thickness belts. B. Double thickness belts.

Reddaway Belting.

Table showing Horse-power Transmitted by the 'Camel Hair' Belting
(By permission of the Sole Manufacturers, *F. Reddaway & Co. Ltd., Manchester.*)

Vel. of Belt. Ft. per Min.	Width of Belt in Inches.												
	1	2	3	4	5	6	7	8	9	10	12	14	16
500	1·0	2·0	3·1	4·2	5·3	6·2	7·3	8·2	9·3	10·3	12·5	14·5	16·5
600	1·2	2·5	3·7	5·0	6·2	7·4	8·7	9·9	11·3	12·4	14·9	17·4	19·7
700	1·4	2·9	4·3	5·8	7·2	8·7	10·3	11·6	13·1	14·5	17·4	20·3	23·2
800	1·6	3·3	4·9	6·6	8·2	9·9	11·5	13·2	14·8	16·5	19·8	23·1	26·4
900	1·8	3·7	5·6	7·4	9·3	11·1	13·0	14·8	16·7	18·6	22·3	26·0	29·7
1,000	2·0	4·1	6·2	8·3	10·6	12·4	14·5	16·5	18·6	20·7	25·0	29·0	33·0
1,100	2·3	4·6	6·8	9·1	11·4	13·7	16·0	18·2	20·5	22·8	27·4	32·0	36·5
1,200	2·5	5·0	7·4	9·9	12·4	14·9	17·4	19·8	22·4	24·8	29·8	34·7	39·7
1,300	2·7	5·4	8·1	10·7	13·4	16·1	18·8	21·5	24·2	26·9	32·3	37·7	43·1
1,400	2·9	5·8	8·7	11·6	14·5	17·4	20·3	23·2	26·1	29·0	34·8	40·7	46·4
1,500	3·1	6·2	9·3	12·4	15·5	18·7	21·7	24·8	28·0	31·1	37·3	43·5	50·0
1,600	3·3	6·6	9·9	13·2	16·5	19·8	23 2	26·5	29·8	33·1	39·8	46·4	53·0
1,700	3·5	7·0	10·5	14·1	17·6	21·1	24·6	28·1	31·7	35·2	42·3	49·3	56·3
1,800	3·7	7·4	11·2	14·9	18·7	22·4	26·1	29·8	33·6	37·3	44·7	52·2	59·7
1,900	3·9	7·9	11·8	15·7	19·7	23·6	27·6	31·5	35 5	39·4	47·3	55·2	63·0
2,000	4·1	8·3	12·4	16·5	20·7	25·0	29·0	33·1	37·3	41·4	49·6	58·0	66·2
2,100	4·3	8·7	13·0	17·4	21·7	26·1	30·5	34·8	39·2	43·5	52·2	60·8	69·6
2,200	4·5	9·2	13·6	18·2	22·8	27·4	32·0	36·4	41·0	45·6	54·8	64·0	73·0
2,300	4·7	9·6	14·2	19·0	23·8	28·6	33·3	38·1	42·9	47·6	57·2	66·7	76·2
2,400	5·0	10·0	14·8	19·8	24·8	29·8	34·8	39·6	44·8	49·7	59·6	69·4	79·4
2,500	5·2	10·4	15·5	20·6	25·8	31·0	36·1	41·3	46·5	51·7	62·0	72·4	82·7
2,600	5·4	10·8	16·2	21·4	26·8	32·2	37·6	43·0	48·4	53·8	64·6	75·4	86·2
2,700	5·6	11·2	16·8	22·4	28·0	33·5	39·1	44·7	50·2	55·9	67·0	78·2	89·5
2,800	5·8	11·6	17·4	23·2	29·0	34·8	40·6	46·4	52·2	58·0	69·6	81·4	92·8
2,900	6·0	12·0	18·0	24·0	30·0	36·0	42·0	48·0	54·0	60·0	72·0	84·0	96·0
3,000	6·2	12·4	18·6	24·8	31·0	37·4	43·4	49·6	56·0	62·1	74·6	87·0	100·0

REDDAWAY BELTING.

TABLE SHOWING HORSE-POWER TRANSMITTED BY THE 'CAMEL HAIR' BELTING *(continued)*

(By permission of the Sole Manufacturers, *F. Reddaway & Co. Ltd., Manchester.*)

Vel. of Belt. Ft. per Min.	Width of Belt in Inches.												
	1	2	3	4	5	6	7	8	9	10	12	14	16
3,100	6·4	12 8	19·3	25·7	32·1	38·5	45·0	51·3	57·8	64·2	77 0	90·0	102·0
3,200	6·6	13·2	19·8	26·4	33·0	39·6	46·4	53·0	59·6	66·2	79·6	92·8	106·0
3,300	6·8	13·6	20·5	27·3	34·1	41·0	47·8	54·7	61·5	68·3	82·0	95·6	109·0
3,400	7·0	14·0	21·0	28·2	35·2	42·2	49·2	56·2	63·4	70·4	84·6	98·6	112·0
3,500	7·2	14·4	21·7	29·0	36·2	43·5	50·8	58·0	65·2	72·5	87·0	101·0	116·0
3,600	7·4	14·8	22·4	29·8	37·4	44·8	52·2	59·6	67·2	74·5	89·4	104·0	120·0
3,700	7·7	15·3	23·0	30·6	38·3	46·0	53·6	61 2	69·0	76·6	92·0	107·0	123·0
3,800	7 9	15·8	23·6	31·4	39·4	47·2	55·2	63·0	71·0	78·7	94·6	110·0	126·0
3,900	8·1	16·1	24·2	32·2	40·3	48·3	56·4	64·5	72·5	80·7	96·8	113·0	129·0
4,000	8·3	16·6	24·8	33·0	42·0	50·0	58·0	66·2	74·6	82·9	99·2	116·0	132·0
4,100	8·5	17·0	25·5	34·0	42·5	51·0	59 5	68·0	76·5	85·0	102·0	119·0	136·0
4,200	8 7	17·4	26·1	34·8	43·5	52·2	61·0	69·5	78·2	87·0	104·0	122·0	139·0
4,300	8·9	17·8	26·7	35·6	44·5	53·4	62·3	71·2	80·0	89·0	107·0	125·0	142·0
4,400	9·1	18·4	27·2	36·4	45·6	54·8	64·0	72·8	82·0	91·0	109·0	128·0	146·0
4,500	9·3	18·6	28·0	37·3	46·6	56 0	65·2	74·5	84·0	93·2	112·0	130·0	150·0

NOTE.—This table may be thoroughly relied upon for all ordinary conditions of working The results of tests made by Chas. Hopkinson, M.Inst.C.E., M.Inst.M.E., B.Sc., show that the 'Camel' Brand belt working under favourable conditions will safely transmit double the horse-power given in the above table.

'GRIPOLY' BELTING.

(*Lewis and Tylor, Ltd., Gripoly Mills, Cardiff, and* 9 *St. Thomas's Street, London, S.E.* 1.)

'Gripoly' is a solid woven belt, fig. 1, *i.e.* it is not composed of plies, but is woven into a homogeneous unit of thickness at one operation in special looms made by the proprietors.

FIG. 1.

Recently further improvements in belt-weaving machinery have made possible the production of this belting in homogeneous units as regards length—that is to say, it is woven endless, *i.e.* not

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jointed in an invisible manner, but actually woven without end or seam throughout; this results in the attainment of an ideal of equality of strength, flexibility, and driving power which is very desirable on certain types of drive, particularly in connection with electrical machinery, and which obviates any fastener trouble.

The warp of the belting is composed of yarns of 'Camel hair,' well known for its qualities of strength and endurance, and also for its elasticity, the material thus being specially suitable for the transmission of tensional stresses. These qualities are essential for heavy work, especially in adverse atmospheric conditions such as obtain in the tropics and elsewhere, under which circumstances price becomes a consideration which is secondary to efficient service.

'Gripoly' is not a cheap belt, owing to the high cost of its material, which is guaranteed and maintained by regular tests at a definite high standard of strength and purity.

The first cost of a belt is automatically reduced if care is exercised in the selection and maintenance of the right belt for each duty. It is probably true that the lives of more belts are shortened through being too strong than through being too weak. The selection of the right type of 'fastener' for a given duty is also important.

As the 'lay out' of a system of belting is important, Messrs. Lewis and Tylor, Ltd., have a special department undertaking the complete lay out of power transmission schemes by means of belting, etc., and are prepared to quote inclusive prices for designing, supplying, and setting to work all the necessary gear.

Belting repays continual care after it has been properly installed. Under most circumstances it tends in time to dry up and lose its flexibility, resiliency, and frictional grip; these can be maintained by use of suitable dressings adapted to the make-up of the particular belt in use. It may be taken that 'cleanliness and castor oil,' is a safe general prescription in the absence of further information on the subject.

Cross Section of Belts.

The following table shows what area of cross section of leather belt is needed to give various horse-powers, with various arcs of contact on cast-iron pulleys, at a belt speed of 3,000 feet per minute, the fastenings being single leather lacings. From it, having decided on the thickness, the width may be determined, or *vice versa*, by simple division:

Arc Contact.	Horse-powers.									
	5	10	15	20	25	30	35	40	45	50
Deg.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.	Sq. in.
30	0·90	1·79	2·68	3·58	4·48	5·37	6·27	7·16	8·06	8·95
45	0·63	1·26	1·88	2·51	3·14	3·77	4·40	5·02	5·65	6·28
60	0·49	0·99	1·48	1·98	2·97	2·96	3·46	3·95	4·45	4·94
75	0·41	0·83	1·24	1·64	2·07	2·49	2·90	3·28	3·73	4·14
90	0·36	0·73	1·09	1·45	1·82	2·17	2·55	2·91	3·26	3·64
105	0·33	0·65	0·98	1·31	1·63	1·96	2·29	2·61	2·94	3·27
120	0·30	0·60	0·90	1·20	1·50	1·80	2·10	2·40	2·70	2·99
135	0·28	0·56	0·83	1·11	1·39	1·67	1·94	2·22	2·50	2·78
150	0·26	0·52	0·78	1·04	1·30	1·56	1·82	2·09	2·35	2·61
165	0·25	0·50	0·75	0·99	1·44	1·49	1·74	1·99	2·24	2·49
180	0·24	0·47	0·71	0·95	1·20	1·42	1·62	1·90	2·13	2·37
195	0·23	0·46	0·68	0·91	1·14	1·37	1·60	1·83	2·05	2·28
210	0·22	0·44	0·66	0·88	1·10	1·32	1·54	1·76	1·98	2·20
240	0·21	0·42	0·62	0·84	1·05	1·25	1·46	1·68	1·87	2·09
270	0·20	0·40	0·60	0·80	0·99	1·20	1·49	1·60	1·80	1·99
300	0·19	0·39	0·58	0·77	0·97	1·16	1·35	1·54	1·74	1·93

Belt Tension.

To find out whether the force carried by a belt is more than should be properly put upon it, or upon its fastening, we must know how much the arc of contact is, and what the tension on both the tight and the slack folds. The greatest tension upon it is that in the tight fold or side; and this is equal to that on the slack side plus the pull which the belt gives to the pulley or which the pulley gives to it. The greater the arc of contact, the greater the ratio between the tight and the slack side, and the less the tension will be upon the belt and its fastening to transmit a given power at a steady speed. Thus, if we have a pull of 10,000 lbs. necessary to carry a certain horse-power, when the arc of contact of the belt on the pulley is 90°, that means

that the ratio between the tension on the tight side and that on the slack side is 1·874; in other words, for every pound upon the slack side there will be 1·874 lbs. on the tight side; and if the difference between the tensions on the slack and the tight sides be 1,000 lbs., it will be necessary to have 1,000 ÷ 0·874 = 1,144 lbs. tension on the slack fold, and 2,144 on the tight one. (These figures apply to leather belts in good condition upon cast-iron pulleys, also in good condition.) The following table shows the ratio between the tension and transmitted pull for various arcs of contact from 30° to 300°:—

TABLE OF GREATEST TENSION ON BELTS.

Degrees of Arc . .	30	45	60	75	90	105	120	135
Ratio between tension and transmitted pull .	5·29	3·71	2·92	2·45	2·14	1·93	1·77	1·64
Degrees of Arc . .	150	165	180	195	210	240	270	300
Ratio between tension and transmitted pull .	1·54	1·47	1·40	1·35	1·30	1·23	1·18	1·14

EXAMPLE.—If it takes a pull of 300 lbs. to carry a given horse-power when the arc of contact is 195°, then the tension upon the tight side will be 1·35 × 300 lbs., or 405 lbs. Expressing results in horse-power instead of pounds pull, suppose that it is necessary to carry 175 horse-power with a belt running 2,000 feet per minute, and having 210° arc of contact; then the pull on the pulley will be 33,000 × 175 ÷ 2,000 = 2,887 lbs.; and the greatest tension upon the belt will be 2,887 × 1·3 = 3,753 lbs.

For double leather main belts,

$$\text{H.P.} = \frac{80\ W\ V}{33{,}000}$$

where

W = breadth in inches; V = velocity in feet per minute.

General Rules for Belts.

(1.)

A good all-round rule, and one easily remembered for belt calculations, is that 1 ft. per minute of belt speed per inch of width of belt is safely equal to the transmission of 1 watt of electrical energy. If we therefore multiply the belt speed in feet per minute by the width in inches, the result will be the total energy in watts; and if we divide the result by 1,000, the energy is obtained in kilo-watts, which energy the band may be relied upon to transmit without any undue tension being brought upon any part of the belt or excessive friction in any part of the machinery. These data, however, only apply to single leather belting or to woven belting of a similar thickness. If a light double band be employed, then 25 per cent. more energy may be calculated upon; or for heavy double leather belting as much as 60 per cent. more may be added. The great advantage for this method of calculation is that it fixes a constant for working tensions, so that the working tension becomes directly proportional to the width in inches, this constant being 44·24 lbs. pull per inch width of belt. If we wish, therefore, to know the difference in pounds pull on the tight and on the slack side of any belt, all that is necessary is to divide the total output of the machine in watts by the velocity of the belt in feet per minute, and multiply the result by 44·24, and the product will be the extra pull in pounds on the tight over the slack side. (*R. Berry.*)

(2.)

One horse-power will be transmitted by a single thickness belt 1 inch wide running at the rate of 1,000 feet per minute.

A belt $\frac{2}{10}$ths of a square inch section will transmit 1 horse-power at the foregoing rate.

Tension on belt by either of these rules will be 33 lbs. per inch of width and 165 lbs. per square inch of section.

With belts in good working order the frictional hold on the pulleys is about 58 per cent. of the pressure of the belt on the surface of the pulley as a maximum, and about 42 per cent. under ordinary atmospheric conditions.

It is safe to reckon that a double belt will do half as much work again as a single one.

Belting made of Helvetia leather is much stronger and will bear a heavier load than that made from ordinary tanned leather.

F. REDDAWAY & CO., LTD.

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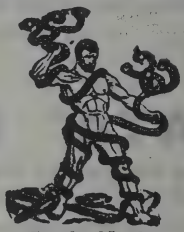

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Speciality:

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Bursting Pressure 2½in. diameter, 650 lbs. per sq. inch.

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BUSH HOUSE, ALDWYCH, LONDON, W.C. 2.

A double belt is more serviceable upon pulleys of large than upon those of small diameter, and should not be used upon pulleys whose diameters are less than about 3 times the width of the belt, unless the belt width exceeds about 4 ins.

Rubber belts will transmit from 25 to 40 per cent. more power per given arc of contact than leather belts. They should not be used in situations where they will be subject to a temperature of over about 90° F.

The average weight of a good four-ply rubber belt 7 ins. wide is 16 ozs. per linear foot. The best rubber belting is made with 32 ozs. duck, and then weighs 20 ozs. per linear foot.

It is a common error among mechanics and owners of factories to make the face of their pulleys narrow, in order to economise on the first cost of belting; but this false economy seldom decreases the cost of the machinery, and only saves a trifle in the first cost of belting. The small amount saved is soon lost by the stopping of machinery caused by the slipping of belts, strain on the shafting, increased friction (requiring additional driving power), and rapid destruction of the belts themselves. Were pulleys made of a proper size and width and face, and belts of proper width run with the *grain* side of leather to the pulley, a considerable saving of coal might be effected annually, and an immense amount of trouble avoided.

Leather belts with grain side to pulley can drive 34 per cent. more than flesh side.

(3.)

To find the diameter of driving pulley.—Multiply the diameter of the driven by the number of revolutions it should make, and divide the product by the number of revolutions of the driver.

To find the diameter of driven.—Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven.

To find the number of revolutions of the driven.—Multiply the diameter of the driver by its number of revolutions, and divide by the diameter of the driven.

To find the horse-power of a pulley.—Multiply the circumference of the pulley (feet) by the revolutions per minute, and the product thus obtained by the width of the belt, and divide the result by 600. The quotient will be the horse-power.

Length of Belts.

(1.)

(*Not crossed.*)

RULE.—Add the diameter of the two pulleys together, divide the result by 2, and multiply the quotient by $3\frac{1}{7}$; then add this product to twice the distance between the centres of the shafts; the result is approximately the length required.

(*Crossed.*)

RULE.—Mark off by lines the pulleys, set at their proper distance apart (either full size or to scale), and measure the length of the side of the belt, supposing the belt to envelop one-half the circumference only of each pulley, and add to this one-half the circumference of each pulley. If there is a great difference between the relative diameters of the pulleys, and the distance apart of the shafts is unusually small, the length of the straight sides of the belt should be measured, and the arcs of contact around the pulleys stepped around by compasses, the set of the latter being not more than about one-tenth the circumference of the pulley.

In the case of both running horizontally, the upper half of the belt should be the driving side.

(2.)

(*Auguste Esnouf, A.C.G.I.*)

Let X = distance between centres of pulleys; D and d = respective diameters * of pulleys; C and c = respective circumferences; P = a parameter equal to D − d for open, and to D + d for crossed belts, exclusive of lap for jointing; L = length of belt, then

$$L = \tfrac{1}{2}(C + c) + 4X - \sqrt{4X^2 - P^2},$$

with an approximation such that the relative error is less than 1 in 1,000 for values of the ratio $\frac{X}{P}$ greater than or equal to 1·5; the relative error is about $\frac{1}{2}$ per cent. when $\frac{X}{P} = 1$.

For exact results, $L = \frac{1}{2}(C + c) + KX$, for both open and crossed belts; and $L = mX$ for crossed belts, where K and m are coefficients, tabulated herewith for the various values of the ratio $\frac{X}{P}$.

---

* Strictly speaking, D and d should be the theoretical diameters—that is to say, actual diameters plus thickness of belt.

$\frac{X}{P}$	K.	m.	$\frac{X}{P}$	K.	m.	$\frac{X}{P}$	K.	m.	$\frac{X}{P}$	K.	m.
0·700	2·537	4·781	0·81	2·394	4·333	1·02	2·246	3·786	1·7	2·082	3·006
0·705	2·528	4·756	0·82	2·384	4·299	1·03	2·241	3·766	1·8	2·078	2·951
0·710	2·520	4·732	0·83	2·374	4·266	1·04	2·237	3·747	1·9	2·070	2·897
0·715	2·512	4·709	0·84	2·365	4·235	1·05	2·232	3·728	2·0	2·063	2·848
0·720	2·505	4·687	0 85	2·357	4·205	1·06	2·228	3·710	2·2	2·051	2·765
0·725	2·498	4·665	0·86	2·349	4·175	1·07	2·224	3·692	2·4	2·043	2·697
0·730	2·491	4·643	0·87	2·341	4·146	1·08	2·219	3·674	2·6	2·037	2·641
0·735	2·484	4·621	0 88	2·333	4·118	1·09	2·215	3·656	2·8	2·032	2·593
0·740	2·477	4·600	0·89	2·325	4·090	1·10	2·211	3·639	3·0	2·028	2·552
0·745	2·470	4·578	0·90	2·318	4·063	1·12	2·203	3·605	3·5	2·021	2·470
0·750	2·463	4·557	0·91	2·311	4·037	1·14	2·196	3·574	4·0	2·016	2·408
0·755	2·457	4·537	0·92	2·304	4·011	1·16	2·189	3·543	4·5	2·012	2·361
0·760	2·451	4·518	0·93	2·297	3·986	1·18	2·182	3·513	5·0	2·010	2·324
0·765	2·445	4·498	0·94	2·290	3·961	1·20	2·176	3·485	5·5	2·008	2·293
0·770	2·439	4·479	0·95	2·284	3·937	1·25	2·162	3·419	6·0	2·007	2·269
0·775	2·433	4·460	0·96	2·278	3·914	1·30	2·150	3·358	6·5	2·006	2·248
0·780	2·427	4·441	0·97	2·272	3·891	1·35	2·138	3·302	7·0	2·005	2·229
0·785	2·421	4·422	0·98	2·266	3·869	1·40	2·128	3·250	8·0	2·004	2·200
0·790	2·416	4·404	0·99	2·261	3·848	1·45	2·119	3·202	9·0	2·003	2·178
0·795	2·410	4·386	1·00	2·256	3·827	1·50	2·112	3·159	10·0	2·002	2·159
0·800	2·405	4·368	1·01	2·251	3·806	1·60	2·099	3·081			

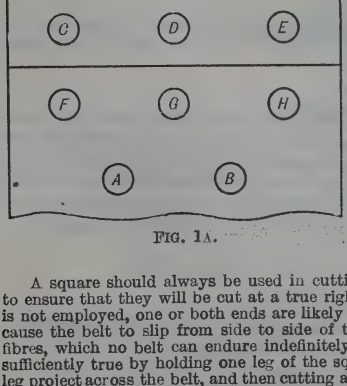

FIG. 1A.

Jointing Belts.

LACED BUTT JOINT.

For belts about 3 ins. wide and over, the holes C, D, E, and F, G, H, should be about 1 in. apart and $\frac{3}{8}$ in. from the line of joint; A, B, and I, J should be about $\frac{1}{2}$ in. behind C, D, E, and F, G, H, respectively.

The sizes of the holes should be as follows:

Width of belt up to 4 ins. Size of punched hole, $\frac{1}{4}$ in.
" " from 4 to 8 ins. " " $\frac{5}{16}$ in.
" " " 8 ins. upwards " " $\frac{3}{8}$ in.

WIDTH OF LACES.

Width of belt 24 ins. and over. Width of lace, $\frac{1}{2}$ in.
" " 6 to 24 ins. " " $\frac{3}{8}$ in.
" " 2 to 4 ins. " " $\frac{5}{16}$ in.
" " 2 ins. and less " " $\frac{1}{4}$ in.

A square should always be used in cutting the ends of a belt preparatory to joining them, to ensure that they will be cut at a true right angle to the centre line of the belt. If a square is not employed, one or both ends are likely to be cut uneven or irregular, and these conditions cause the belt to slip from side to side of the pulley and impose irregular strains on the belt fibres, which no belt can endure indefinitely. Belts of widths up to about 18 ins. can be cut sufficiently true by holding one leg of the square against one side of the belt, having the other leg project across the belt, and then cutting along the edge of the latter with a sharp knife held perpendicular to the belt. The knife blade should be made wet occasionally to make it cut easily.

The ends of wide belts are difficult to cut square on account of slight variations in their widths and because the sides may not be exactly parallel; satisfactory results may be assured by the following method: At any point on the belt near where it is to be cut, measure across and find the centre, then at a point 2 or 3 ft. back from these dimensions, locate the centre again, and between these two points draw a clean sharp line. Next, by holding one leg of a square against the centre line just made, trim off one-half of the end of the belt by cutting along the other leg. By laying the square on the other side of the centre line, the other half of the belt can be cut. The square should be held firmly in position while cutting the belt, and if two small nails are driven in the belt on the centre line, they will help to keep the square from slipping.

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PATENTED ALL OVER THE WORLD.

Efficiency in Power Transmission
a Vital Factor
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Before the War the merits of the HENDRY BELT were recognised by foremost users at home and abroad, including the British Admiralty, War Office, India Office, Ordnance Works, Shipyards, Electric Power Plants, Mining Companies, Engineers, and scores of others. . . .

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Millions of the Allies' steel messages of "Friendship" to the Boche Lines owed their spinning flight to HENDRY BELTS in Shell and Gun Factory. . . . Whilst our dauntless Bird-men winged their way by wondrous Engines shaped in tools of precision driven by Hendry. . . . . .

With Peace Driving Efficiency becomes a matter of urgent National moment, its Study, the patriotic and practical duty of every power user. . . A knowledge of the HENDRY BELT, its unique patented construction and remarkable efficiency, is therefore an essential to the heads of all progressive plants. . . . . .

P.T.O.

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F. 960

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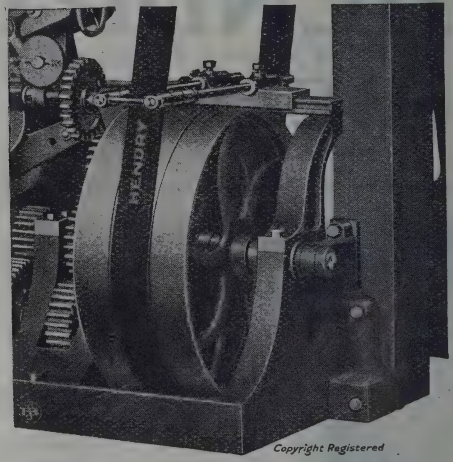

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For Planing Machine, Lathe and all Heavy Machine Tool Driving the HENDRY new patent Flexible construction gives a peculiar Elasticity and Spring not found in any other Belting, which acts as a cushion against heavy and irregular stresses, and reduces stretching and wear to a minimum. . . . . The largest concerns at home and abroad have conclusively proved that HENDRY belting permits of higher speeds, heavier cuts, steadier running and an all-round increase of output. . .

STANDARD SIZES OF HENDRY BELTING.

The Hendry Belt is made to meet every requirement, in Seven standard Weights from ¼in. to 1in. thick and from 1in. wide to 48in. and upwards. . . Whatever your Driving Problems, Hendry's expert advice and assistance is freely at your service. . . Write for the Book of the Hendry Belt, post free.

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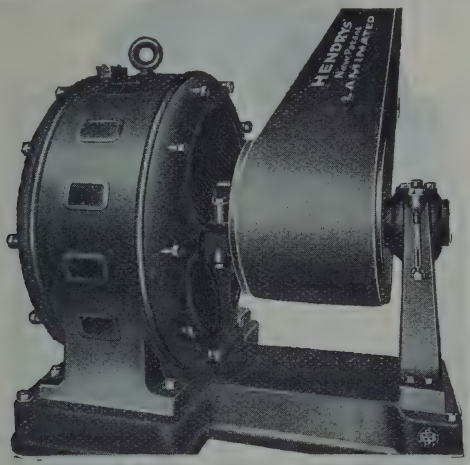
The Hendry Patent Construction,—the Secret of Hendry Efficiency



HENDRY
FROM A SINGLE STRAND
BELTING

One of the leading Electrical Engineers of the day describes the HENDRY Patent Laminated Leather BELTING as forming a true Endless Belt, which is adaptable to universal service. . . . . .

The Hendry ENDLESS SPLICE forms a joint identical in Texture, Thickness, Flexibility and Driving Grip with the belt itself. . . . A HENDRY BELT runs without jar, vibration, or slip under the heaviest load and at the highest speed. . . . . The new Patent Hendry Belt effects a marked saving in the consumption of Electrical Power per H.P. transmitted. . .

THE HENDRY SIMPLE HORSE-POWER DATA

As every Drive is in a measure a law unto itself, it is difficult to furnish a detailed table of Horse Powers which is universally applicable. The following simple data will, however, enable the working out of any particular condition, and will ensure satisfactory driving with a fairly average life to the belt. . . . . .
The calculations are based on the transmission of 1 H.P. per lin. of width at the various speeds for each number of thickness of belt, working over pulleys 18in. diameter.

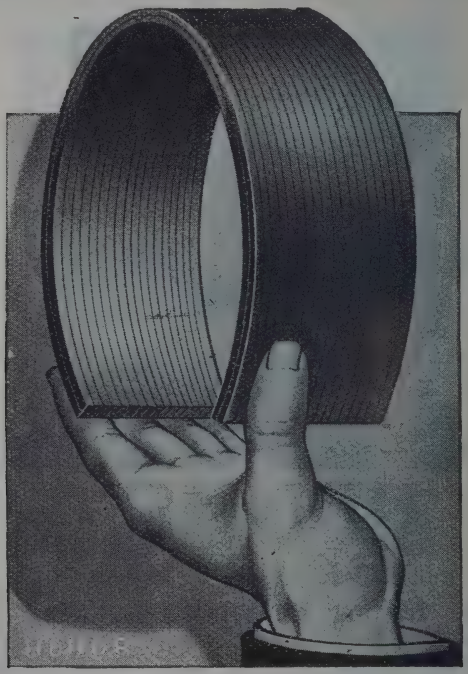
With Driving Side on BOTTOM:

No. 1. size, velocity	**700 F.P.M.**		**No. 3. size, velocity**	**500 F.P.M.**
No. 2. " "	**575 F.P.M.**		**No. 4. " "**	**450 F.P.M.**

Pulleys under **18in.** *in dia. deduct* **4½%** *for each inch under.*

With Driving Side on TOP deduct 20%

The Hendry new Patent Flexible Construction,—a notable Advance



FLEXIBILITY (*Drawn from Life*)
ILLUSTRATING HENDRY NO. 5 ($\frac{3}{4}$ in.) BELT.

The HENDRY BELT is protected by recent Patents throughout the world. . . . . .

The latest HENDRY patented improvements effect such an extraordinary increase in the Flexibility, Driving Grip and Life of the HENDRY Laminated Belting as to enable us to guarantee efficient Driving over Pulleys. *One-Half* to *Two-Thirds* smaller than is practical with any other type of flat belting.

The new Patent Flexible construction is now adopted for all sizes of HENDRY Belting.

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F. 961

Joining Thin Belts.

Place two ends of belt together, with edges fair one with the other, and make with an awl a row of holes, at *a*, through both ends. Then take about half a yard of strong twine, and draw half the length through the first hole; then pass each end of the twine through the second hole, one to the right and the other to the left, and draw both tight at the same time

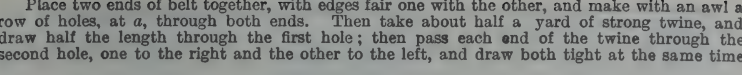

Fig. 2.

and so on until the last hole is reached, when one end only of the twine is passed through. The two ends of the twine are then knotted together, and the excess cut off.

Lap Joints.

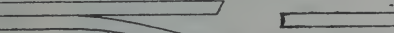

Fig. 3.

Cut down overlap to a plain bevel, cement surfaces together, and insert small taper wooden pegs, such as are used for boot and shoe manufacture. This is the strongest form of joint that can be made.

Length of Lap.

Width of single belt, in inches .	1 to 4½	5	6 to 8	9	10 to 14	15 to 24
Length of lap, in inches . . .	4½	5	6	6½	7	8

All double belts should have a 6-inch lap at least.

Cement for Belt Joints.

Equal parts of good glue and American isinglass; place the material in a glue pot and add sufficient water to cover the whole. Let the mixture soak ten hours, then bring the whole to a boiling heat, and add pure tannin until the whole appears like the white of an egg. Apply warm. Buff the grain of the leather where it is to be cemented, keep the joint surfaces pressed firmly together, let the joint dry for a few hours, and the belt will be ready for use.

(*Railway and Locomotive Engineer.*)

To Find Length in Feet of Belt in a Roll.

From outside diameter (D) deduct inside diameter (*d*), multiply by number of turns (*n*) and by 0·262.

Example.—D = 12 ins., *d* = 4 ins., *n* = 16 ins. Length = (12 − 4) × 16 × 0·262 = 33·5 ft.

Belt Dressings.

'Gripwell' Belting Syrup (*Turner Brothers Asbestos Co. Ltd., Rochdale*) is particularly suited for fast and loose drives or shock drives, to prevent slip; the dressing is applied hot, so as to penetrate the belt freely.

Oiling and Greasing Leather Belts.

When the belt is pliable, and only dry and husky, apply blood-warm tallow, and dry in by heat of fire or sun. The addition of resin to the tallow for belts used in wet places is advantageous. Belts which have become hard and dry should have an application of neatsfoot or cod-liver oil mixed with a *small* quantity of resin.

Suggestions to Belt Users.

In order to obtain a given amount of power, it is better to use a narrow belt running at a high speed than a wide belt running at a low speed.

If possible, use a belt speed of about 3,000 feet per minute for smaller powers, and about 4,000 feet per minute for high powers. Thrashing machine belts run at about 2,200 feet per minute, and this is the usual speed for agricultural machines.

Use a pulley that is wide enough, so that a small amount of irregularity in the belt does not make it run off. Allow at least $\frac{1}{2}$ in. on machine pulleys and 1 in. or more on countershaft and lineshaft pulleys. Use crowned pulleys wherever possible.

If possible, use a horizontal belt with large centre distances and with the pulling side at the bottom. In a horizontal drive, the slack side of the belt at the top of the drive increases the belt contact.

When using a vertical belt, do not have more centre distance than is absolutely necessary, because the weight of the belt reduces the efficiency of the drive.

Avoid crossed belts on short centre distances. Avoid the crossing of wide belts. If it is necessary to cross belts, see to it that the rubbing of the belt surfaces does not have a tendency to open up the laps.

Keep belts flexible and as clean as possible. Do not use belt dressing containing mineral oils or resins.

Hints on Belt Driving.*

(John Tullis & Son, Ltd., St. Ann's Works, Glasgow.)

Pulleys having a high convexity prevent the belt from grasping its work. One-sixteenth of an inch is sufficient convexity for pulleys 6 ins. wide and under; $\frac{3}{32}$ of an inch is enough for pulleys over 12 ins. wide.

By compounding two single or double belts the gain in horse-power is close on 100 per cent.

By compounding three single or double belts the gain in horse-power will be close on 200 per cent.

Double belts should never be run on pulleys of small diameter. Compound single belts give much better results as regards power, longer life, and less cost.

Compound belts save the cost of wide pulleys as well as the room of wide pulley space.

Every inch in width of good double leather belting, travelling at 500 ft. per minute, while working on pulleys 24 ins. diameter, will transmit one horse-power, provided the arc of contact is 180 degrees.

Every inch in width of good single leather belting, travelling at 800 ft. per minute, while working on pulleys 24 ins. diameter, will transmit one horse-power, provided the arc of contact is 180 degrees.

A comfortable working strain for a single belt is about 50 lbs. for every inch of breadth, and for a double belt 80 lbs.

A belt running with the soft flesh side next the pulley will wear longest, because it is working according to the natural growth of the hide.

When driving on pulleys of 4 ins. diameter and under, the belt ought to be barely $\frac{1}{8}$ in. thick. On pulleys $4\frac{1}{4}$ ins. to 8 ins. diameter the belt should be about $\frac{5}{64}$ in. thick. On pulleys $8\frac{1}{4}$ ins. to 12 ins. diameter the belt should be about $\frac{3}{16}$ in. thick. On pulleys $12\frac{1}{4}$ ins. to 18 ins. diameter the belt ought to be barely $\frac{1}{4}$ in. thick. On any diameter above 18 ins. heavy leather can be used with profit.

If the slack side of a main driving belt runs in wave form it is certain that the engine is getting more steam on one side of the piston than on the other. This unsteadiness is transmitted to all the working belts in the factory.

A badly balanced pulley, running at a high speed, will impart an unsteady motion to the belt running on it. The machine so driven makes bad work.

When a belt gets saturated with waste oil, an application of ground chalk will soon absorb the oil and make the belt workable.

Where possible, all belts should be run with the driving or tight side under the pulleys. The sag of the upper or slack side helps the belt to hug the pulley to the extent of 20 per cent. gain in driving power, as compared with a belt running with the tight side uppermost.

Belts running over pulleys of small diameter at high speeds ought to be as thin and as wide as possible. Orange-tan leather of uniform thickness answers remarkably well.

HIGH-SPEED BELTS.—A belt made from selected orange-tan leather, not too thick, softened, and made flexible, is the toughest and best leather belt for this class of drive. This belt will transmit great power when running at a belt speed of six to nine thousand feet per minute. The

* Abstract from 'Guide to Belt Driving.'

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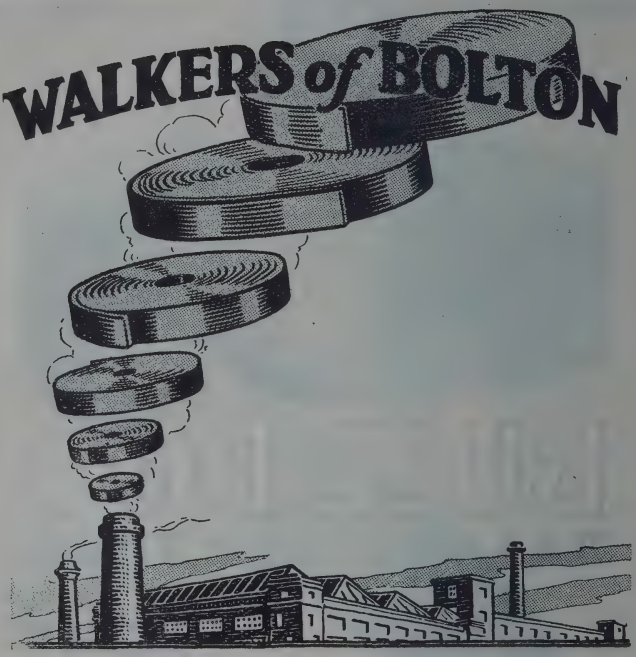

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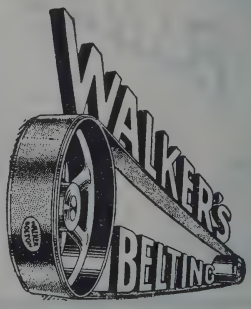

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pulleys used for such drives must be strong and equally balanced, carefully turned to template, having a convexity no higher than one-sixteenth of an inch. Such pulleys must be hung perfectly true to each other upon the driving and driven shafts.

Thin belts, as wide as possible, give by far the best results working vertically. A thick vertical belt will not hug the pulleys.

In the use of vertical pulleys and guide pulleys, these pulleys ought to be twice the width of the belt, having no flange.

For machinery requiring the continuous shifting of the belt, single orange-tan leather is too thin, but double is highly recommended.

Leather link belting cut from the butt and made concave to suit the convexity of the pulleys will transmit from 25 to 30 per cent. more power than a flat belt.

Orange-tan leather rope, 1 in. square, running at 1,000 ft. per minute, on pulleys not less than 4 ft. in diameter. will transmit 10 horse-power.

In lacing hair belts the laces should run in parallel lines, each row laced separately, and no stitches placed across between the rows.

A circular saw belt ought not to be narrower than one-fourth of the diameter of the saw. The spindle pulley should be as great in diameter as the width of the belt.

The following show tensile breaking stresses of leather belting :—

British Oak-tanned	4500–5000 lbs. per sq. in.
British Orange-tanned	6000–6500 ,, ,,

According to *J. E. Rhoades and Sons*, the strongest part of belt leather is about one-third the way through from the flesh or rough side ; it is therefore desirable to run the grain or smooth side on the pulley so that the strongest part of the belt may be subject to the least wear. The flesh side is not as liable to crack as the grain side when the belt is old, hence it is better to crimp the grain than to stretch it. Experiments at Cornell University (U.S.A.) have established the fact that under reasonable shop tension the flesh side will transmit but 35 per cent. to 80 per cent. as much power as the grain side, with an average of 50 per cent. to 60 per cent., depending on the belt, the tension, etc.

A report issued by the Leather Belting Exchange Foundation, at Cornell University, on experiments to determine the relative power-transmitting capacity of belts on vertical, angular, and horizontal drives, gave the following conclusions :—

1. A vertical belt transmitted about 12 per cent. less power under average conditions than a horizontal belt, at 7 ft. 6 ins. centre distance. The percentage difference varies somewhat with the centre distance.

2. A given increase in tension increases the capacity of a vertical belt more than it does that of a horizontal belt, and *vice versa*. Therefore a vertical belt is more sensitive to tension, and ought to be retightened a little oftener to maintain an equally uniform transmitting capacity.

3. At the higher tensions, vertical, angle, and horizontal drives perform more nearly alike, while at low tensions they are widely different in transmitting capacity.

4. The power-transmitting capacities of four drives with the tight side below fall in the following order: First, horizontal belt ; second, 45° belt ; third, 67½° belt ; and fourth, vertical belt. There is practically no difference between the horizontal and 45° drives, or drives in between these two, except at low tension, when the horizontal is better.

5. Comparing the effect of using the tight side above and below with 45° and 67½° belts, it was found that when the tight side was below, leather belts gave about 12 per cent. more power on the 45° drive and about 6 per cent. more power on the 67½° drive, under average operating conditions.

Opinion differs somewhat as to which side of the belt should be run next to the pulley face —the grain or the flesh side,—but the balance appears to be in favour of the grain side. In the case of a good belt the grain side should transmit nearly twice the power conveyed by the flesh side. One disadvantage of using the flesh side next to the pulley is that whenever slip begins, the strength of the belt gets ground away by the quicker-running pulley acting like a grindstone. By running the grain side next to the pulley face, the essential sinews and muscles on the flesh side are preserved, while the less important and harder grain side takes the wear and tear caused by belt slip. (*Liverpool Journal of Commerce.*)

Belt Pulleys.

These should be at least an inch wider than the belt, and the rim should be convex to keep the belt in the centre ; about $\frac{1}{16}$ in. to $\frac{3}{32}$ in. of convexity is usually allowed in pulleys up to 12 ins. wide and over. The ratio of the diameters of two pulleys which work together should not exceed 6 to 1. The distance apart should, if possible, be such that the arc of contact on the smaller pulley is not less than 165°. If the arc of contact is less the width of the belt should be increased (see page 957). The diameter of pulleys is seldom less than 50 times the thickness

of the belt in the case of ordinary belts, or 30 times the thickness of link belts; that is, if any reasonable amount of power is being transmitted.

The slip in the case of a wood pulley with a single-ply oak-tanned leather belt is less than with one of cast-iron, if the belt tension is low.

A Simple Method of Crowning a Flat Pulley.

A belt-driven generator in a plant was originally fitted with a flat-faced pulley, and the belt would frequently run over to one side when an increase of load was thrown on the generator.

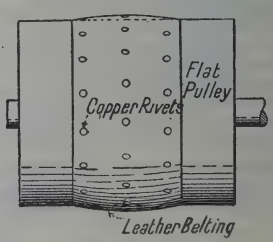

Fig. 4.

To overcome this, a crown was made on the pulley with leather lagging as shown by fig. 4. A piece of single-ply leather belting, 8 ins. wide, was procured and shaved down thin on the edges, and punched for three rows of ½-in. rivets. The leather was then fitted around the centre of the pulley, and the rivet holes were marked and drilled in the rim. The pulley was then warmed with a gasoline torch and a coat of belt cement applied and the leather pressed on smoothly, care being taken to draw it straight and to fit the ends together evenly. The rivets were then put in and headed up and the cement allowed to set twenty-four hours. This machine has run over four years since the job was done, and the driving belt has run perfectly under all conditions. (*Power.*)

Leather covers to pulleys are said to be conducive to excessive wear.

Belt Driving with Quarter or Right Angle Twist.

(1)

Fig. 5 shows the arrangement of pulleys for this purpose. In this case the centre of the bottom pulley should be in a dead line with the left-hand circumference of the top pulley, and the left-hand circumference of the bottom pulley should be in a dead line with the centre of the

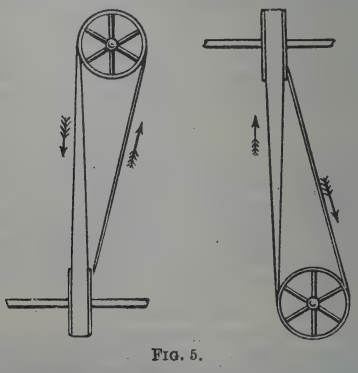

Fig. 5.

top. This is the correct position, but in actual practice the position of both pulleys has to be sometimes slightly altered to suit the running of the belt; this is a very simple matter, as it only means moving the pulley along the shaft one way or the other until it is seen that the belt

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is in contact with the face of the pulley. No 'guide' pulleys are necessary. The pulleys should preferably be slightly crowned, *i.e.* a little larger in diameter at the middle than at the edges.

In practice, the centre plane of the lower pulley should be to the left of the edge of the upper pulley by an amount equal to half of the belt thickness.

With thick belts this point is sometimes of importance. No shifting of pulleys should usually be required if the drive is correctly set out.

With horizontal drives at long centres and pulleys with small crowning, a little adjustment is sometimes called for to compensate for dropping of belt due to its weight or perhaps due to the difficulty of getting a true horizontal line when 'setting out.' *(Geo. T. Pardoe.)*

(2)

The position for the machine pulley, with respect to the pulley on the shaft, depends on the relative direction of rotation of the pulleys. In any event the machine pulley must be in such a position with respect to the overhead pulley that when a plumb line is hung over the falling side of the overhead pulley at the middle of its face, the line must touch the rising side of the machine pulley at the middle of its face.

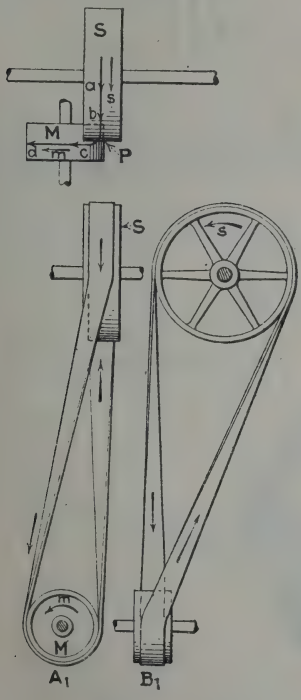


FIG. 5A.

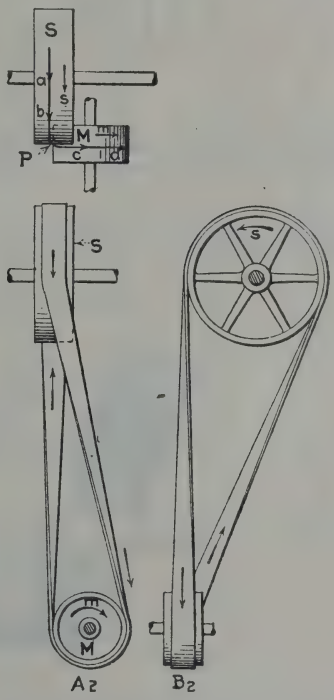


FIG. 5B.

If S, fig. 5A, is the overhead pulley whose direction of rotation is indicated by the arrow *s*, and it is desired to drive the machine pulley M in the direction indicated by the arrow *m*, then the middle of the face of the rising side of pulley M must be vertically under the middle of the face of the falling side of pulley S, that is, a plumb line hung over S at P, fig. 5A or fig. 5B, should touch the rising side of pulley M at the middle of its face. It should be noted that where *s* and

m indicate the directions of rotation, whether in fig. 5A or fig. 5B, the belt must pass over the top of the overhead pulley and thence to the far side of the machine pulley as indicated, in each plan, by the arrows *abcd*.

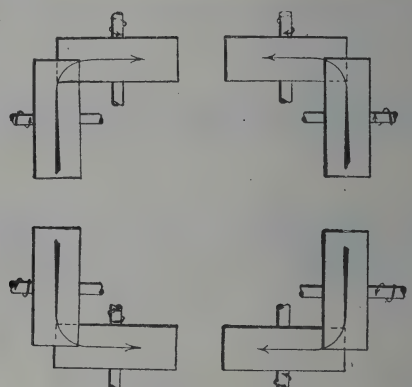


FIG. 6.

Mr. E. Bunzel points out that in laying out the drive, all that has to be seen to is that when looking down on the top of the two pulleys, the arrow of direction of the upper pulley follows the arrow of direction of the lower pulley. Fig. 6 shows the application of this rule for all four cases. (*Power.*)

Link belts are not generally used for this kind of drive, but flat belts are made with a special curve to suit the drive in question; the curve of the belt varies according to the diameter of the pulleys, one to each other, and also to the length of the centres.

Putting on Heavy Belts.

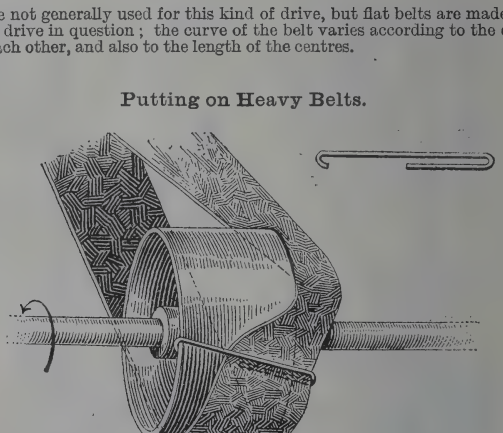


FIG. 7.

Fig. 7 shows a simple device for putting on heavy belts when it is necessary to shut down in order to do so, and where a rope is usually employed for the purpose.

Take a piece of $\frac{1}{4}$- or $\frac{5}{16}$-in. round iron and bend it, as shown in the small sketch. Hook the short end over the edge of the rim of the pulley and the long end under the belt as indicated. Start the engine slowly, and when the belt is on it is not necessary to stop, because the short end of the hook will straighten out and disengage itself. It is a good plan to use a rod of as light weight as will answer the purpose, since it will straighten out and free itself with less stress on the belt; the iron hook then falls to the floor. (*Power.*)

Link or Chain Belts.

HORSE-POWER TRANSMITTED BY LINK OR CHAIN BELTS PER INCH OF WIDTH.

Velocity of Belt in Feet per Minute.	Ins. $\frac{3}{8}$	Ins. $\frac{1}{2}$	Ins. $\frac{5}{8}$	Ins. $\frac{3}{4}$	Ins. $\frac{7}{8}$	Ins. 1
100	0·13	0·15	0·17	0·20	0·24	0·27
200	0·25	0·29	0·35	0·40	0·47	0·55
300	0·38	0·44	0·52	0·60	0·71	0·82
400	0·51	0·58	0·69	0·80	0·95	1·09
500	0·64	0·73	0·86	1·00	1·18	1·36
600	0·76	0·87	1·04	1·20	1·42	1·64
700	0·89	1·02	1·21	1·40	1·65	1·91
800	0·92	1·16	1·38	1·60	1·89	2·18
900	1·05	1·31	1·55	1·80	2·13	2·45
1,000	1·27	1·45	1·73	2·00	2·36	2·73
1,100	1·40	1·60	1·90	2·20	2·60	3·00
1,200	1·53	1·75	2·07	2·40	2·84	3·27
1,300	1·65	1·89	2·25	2·60	3·07	3·55
1,400	1·78	2·04	2·42	2·80	3·31	3·82
1,500	1·91	2·18	2·59	3·00	3·55	4·09
1,600	2·04	2·33	2·76	3·20	3·78	4·36
1,700	2·16	2·47	2·94	3·40	4·02	4·64
1,800	2·29	2·62	3·11	3·60	4·25	4·91
1,900	2·42	2·76	3·28	3·80	4·49	5·18
2,000	2·55	2·91	3·45	4·00	4·73	5·45
2,100	2·67	3·05	3·63	4·20	4·96	5·73
2,200	2·80	3·20	3·80	4·40	5·20	6·00
2,300	2·93	3·35	3·97	4·60	5·44	6·27
2,400	3·05	3·49	4·15	4·80	5·67	6·55
2,500	3·18	3·64	4·32	5·00	5·91	5·82
2,600	3·24	3·78	4·49	5·20	6·15	7·09
2,700	3·28	3·85	4·66	5·40	6·38	7·36
2,800	3·31	3·86	4·73	5·60	6·62	7·64
2,900	3·32	3·87	4·78	5·80	6·85	7·91
3,000	3·31	3·86	4·75	5·97	7·09	8·18
3,100	3·30	3·85	4·73	5·96	7·33	8·45
3,200	3·28	3·82	4·71	5·94	7·37	8·73
3,300	3·24	3·77	4·70	5·92	7·35	8·88
3,400	3·19	3·71	4·64	5·87	7·32	8·86
3,500	3·13	3·61	4·50	5·78	7·26	8·80
3,600	3·05	3·50	4·37	5·67	7·16	8·73
3,700	2·96	3·39	4·26	5·55	7·01	8·58
3,800	2·84	3·28	4·15	5·41	6·87	8·41
3,900	2·72	3·13	4·02	5·20	6·70	8·27
4,000	2·58	2·95	3·84	5·01	6·48	8·04
4,200	2·27	2·55	3·37	4·52	5·98	7·51
4,500	1·64	1·77	2·45	3·68	5·05	6·55
5,000	0·42	0·15	0·61	1·55	2·78	4·32

(*A. G. Brown.*)

Coefficients of Friction.

Dry new leather	·155 (average)
Old greased belts on well-polished pulleys	·200 to ·220
,, ,, on pulleys not well-polished	·300 to ·330
Moist new leather	·120
Ropes, cords, twine, and sewing thread	·070 to ·075

Steel Belting.

Steel belts have been recently introduced for the purpose of transmitting power, and are in somewhat extensive use on the Continent. These belts are from $\frac{3}{10}$ to $\frac{9}{10}$ mm. thick, and from 22 mm. to 200 mm. wide, as required. The steel for such belts is of a very high temper and is manufactured specially for this purpose. The difficulty of jointing the belt is one of the great objections. At present the joint is generally made by the makers, and is usually effected

by soldering the ends to a keep plate on both sides of the band, and made doubly secure by screws. The length of the belt is obtained by stretching a special tape to a predetermined tension across the pulley, and both ends of the tape are cut at the overlap.

These steel bands run quite well on the bare pulley, but there is a tendency to polish the same, and it is therefore desirable to cover the pulley with a very thin cork covering, which is glued on to canvas which in turn is cemented to the pulley. With this arrangement there appears to be little or no slip whatever. This is proved in practice by the fact that the cork covering does not wear away.

With such a belt, 32 mm. wide by 0·3 mm. thick, and cork-faced pulley, Prof. Kammerer, of the Charlottenburg University, transmitted 26·3 h.p. at a speed of 15·7 metres per second. Both pulleys were 1,250 mm. diameter, and the slip was equal to 0·91 per cent.

ROPE DRIVING.

For the majority of conditions the three-strand rope made from pure cotton is the most popular. From figures in the last official census of production it appears that at least 90 per cent. of the driving ropes made in this country are of this type.

MATERIAL.

As a material for driving ropes hemp has been superseded by cotton; even though a good cotton rope costs roughly three times the price of a Manila rope its greater suitability has resulted in the almost complete disuse of Manila in the British Isles.

In the U.S.A. at the present time there are only one or two rolling-mills which employ Manila ropes, the remainder having gone over to the use of cotton, mainly of the three-strand variety.

CONSTRUCTION.

The objections raised to four and seven-strand ropes, as compared with three-strand, is that they must be subjected to unequal rates of stressing. They have a central core which bears a direct load whilst the surrounding strands only receive an oblique component. The fracture of the central core, which sometimes happens, is the result of this unequal stressing, and when this does occur the equilibrium of the rope may be seriously disturbed; it results in a 'corkscrewed' rope which is, however, a serious defect, for if it does not actually produce immediate failure it will reduce the effective life of a rope by about 50 per cent. It is also sometimes argued four and seven strand ropes are more difficult and take longer to splice than three-strand ropes.

The interstranded type of cotton driving rope manufactured by the original patentees—William Kenyon & Sons, Ltd.—is an attempt to get away from the old method of walk construction and to eliminate all the defects inherent to this method of manufacture.

Pulleys.

Rope driving pulleys are usually made of cast iron. The metal should be of a good blend, which leaves a hard, bright finished surface after machining.

GROOVES.

The grooves now generally adopted are the straight-sided type shown in fig. 8.

The best angle to employ between the faces varies with conditions. The standard for general conditions is 40° for ropes 1 in. in diameter and larger; and 30° for smaller ropes. Sharper angles are employed in special instances; curved sided and flanged grooves have been generally discarded.

The grooves of a driving pulley should be polished, and the pulley as a whole should be accurately balanced. Pulley grooves are generally cored in the casting, but are sometimes milled from the solid for small diameters.

The old practice of leaving rope grooves rough 'to help the grip' is fortunately discredited. Groove surfaces left unpolished in the machine shop have to be finished at the cost of the rope, which becomes worn.

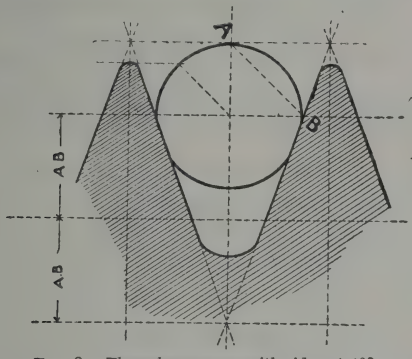


FIG. 8.—Flangeless groove with sides at 40°.

The method of setting out Hart's improved rope groove is shown by figs. 9 and 10. One great advantage of this groove is that it is made so deep as to prevent the rope ever reaching the bottom, a very important point.

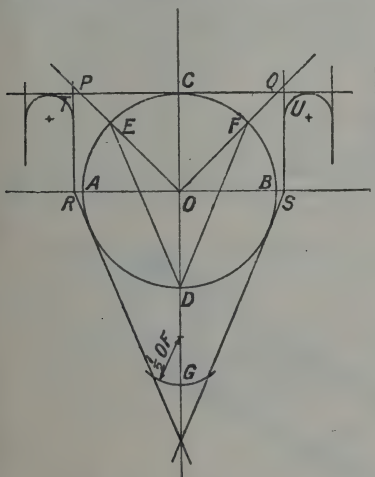


FIG. 9.

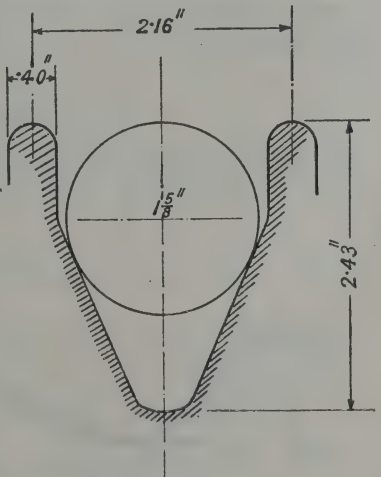


FIG. 10.

Section of Groove for Cotton Driving Ropes. (*Hart.*)

Table of Measurements in Inches.

Diameter of Rope	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2
Pitch of Grooves .	·69	·84	1·02	1·18	1·35	1·51	1·675	1·82	2	2·16	2·35	2·51	2·72
Depth of Groove .	·75	·93	1·125	1·31	1·5	1·68	1.875	2·06	2·25	2·43	2·625	2·81	3
Thickness of Mid-feather . .	·125	·156	·187	·21	·25	·281	·31	·343	·375	·40	·43	·46	·5

CONSTRUCTION FOR A 45° ROPE GROOVE.

With centre O and radius OA, draw a circle equal in diameter to the rope required.

Draw horizontal and vertical diameters AOB and COD.

With A, B, and C as centres, and radius OA, draw arcs to intersect at P and Q.

Join P and Q to centre O, cutting circle at E and F.

Join DE and DF, and parallel to these two lines draw tangents to the circle cutting AB produced at R and S.

Through R and S draw RT and SU parallel to COD, cutting PCQ, produced in T and U.

Make DG = DO and draw arc through G with radius = $\frac{1}{2}$ OA.

Thickness of mid-feathers = $\frac{1}{2}$ OA.

Round off all corners of the groove TRGSU.

SPEED OF PULLEYS.

The limiting peripheral speed for solid c.i. pulleys is 6,000 f.p.m., and 5,3000 f.p.m. for split pulleys. Built-up pulleys with wrot arms, steel spokes, and c.i. hubs have been employed up to 8,750 f.p.m. Experiments in U.S.A. with wooden pulleys have gone up to a peripheral speed of nearly 29,000 f.p.m. without failure.

Porosity of rim at root of arms, cracked bosses, and transverse cracks at smallest sections of the arms in c.i. pulleys are the great dangers which have to be avoided by careful design and regional cooling-off in foundry.

Systems of Rope Driving.

There are two systems of rope driving—the 'multiple rope' system and the 'continuous rope' system. These are sometimes, and without real justification, called the 'English' and 'American' systems respectively. The former is the most commonly used because, consisting

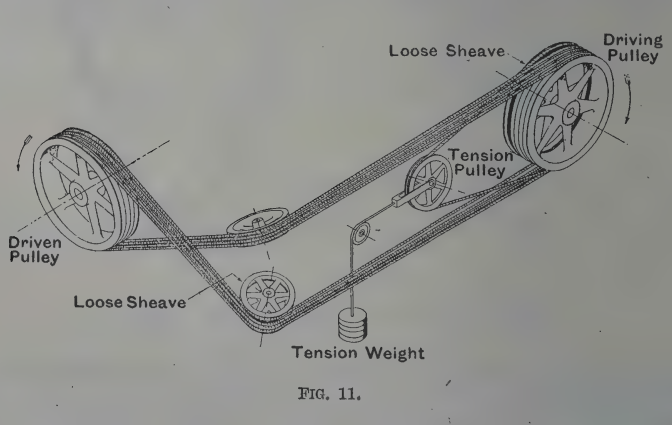


FIG. 11.

of a number of independent endless ropes running side by side it has a great margin of reliability, which constitutes the unique advantage of rope driving. A crossed right-angle drive on the continuous system is shown diagrammatically by fig. 11.

By a reduction in margin of reliability the continuous drive can be usefully employed in some situations where a multiple drive would be expensive, inefficient, or inconvenient. Such cases are :

(1) Very short centre distances with large loads.
(2) Vertical drives.
(3) Limited widths with large loads.
(4) A few special angular drives.

A rope drive can be successfully arranged, by the aid of guide pulleys if necessary, for any possible relative position of the driving and driven shafts. This is the second great advantage of rope driving.

Design of Rope Drives.

The most important item in the design of a rope drive is to determine the correct ratio between pulley and rope diameters. The smallest pulley on the drive, *whether driving pulley or idler*, is the one to which this ratio applies. The old ' 30 times ' rule is obsolete, because the dimensional and speed limits have been widely extended during the past twenty years. Many rope drives are now running with highly satisfactory results, with a ratio of less than 10 in 1 between smallest pulley diameter and rope diameter.

Experimental work is still being carried out by the leading rope drive firms. The following is a table of rope pulley diameters extracted from a chart published by *Messrs. William Kenyon & Sons, Ltd.* This table is applicable to general heavy power conditions.

	Minimum advisable Pulley Diameters in Inches.										
Rope Sizes :	¾ In.	⅞ In.	1 In.	1⅛ In.	1¼ In.	1⅜ In.	1½ In.	1⅝ In.	1¾ In.	1⅞ In.	2 Ins.
Rope Speeds :	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins
1,000	10	12½	15	18½	20	24	28	31	35	40	45
1,500	11½	14	16½	20	22	26	29	33	38	42	47
2,000	12½	15	18	21½	24	28	31	35½	41	44½	50
2,500	13½	16½	19½	23	26	30	34	38½	44	48	53½
3,000	15	18	21	25	28½	32½	37	41½	47	51½	57
3,500	16½	19½	23	27	31	35	40	44	50	55	61
4,000	18½	21	25	29	33½	38	43	47½	53½	59	65
4,500	—	23	27	31	36	41	45½	51	57	63	69
5,000	—	25	29	33½	38½	44	49½	54½	60½	67	74
5,500	—	27½	31	35½	41	47	52	58	65	71½	79
6,000	—	30	33	38	44	50	55½	62½	69½	76	84
6,500	—	—	35	40½	47	54	59	67	74	82	90
7,000	—	—	37	43	50	58	63	71½	79	88	96

For high-speed light drives, such as from electric motors running at speeds above 700 r.p.m., it is best to consult a leading firm, as the fullest possibilities are not yet recognised or even definitely tabulated.

Wherever circumstances permit a margin above the lowest possible ratio of pulley to rope diameter should be allowed, as this will result in a direct increase of rope life. In special instances it is permissible to go below the minimum ratio if a shorter rope life is economically justified.

Ropes ½ in. diameter have given over four years' life running on 6 in. and smaller pulleys at speeds of up to 5,000 f.p.m.

Transmissible Power of Ropes.

The power transmissible by a cotton rope depends upon—

(*a*) Groove angle ;
(*b*) Coefficient of friction between rope and metal ;
(*c*) Running back tension on drive ;
(*d*) Ratio of pulley diameter to rope diameter ;
(*e*) Ratio between pulley diameters.

Obviously some of these factors are functions of several other terms, and any generalisation or table of figures must be handled with caution.

The following table of powers, however, has been found to answer well in general practice.

TABLE OF POWERS FOR COTTON ROPES.

(Messrs. Wm. Kenyon & Sons, Ltd., Dukinfield, near Manchester.)

Velocity in Ft. per Min.	Diameter of Ropes.										
	¾″	⅞″	1″	1⅛″	1¼″	1⅜″	1½″	1⅝″	1¾″	1⅞″	2″
2,000	3·6	5·0	6·5	8·2	10·1	12·2	14·9	17·2	20	22·9	26·1
2,200	3·9	5·5	7·1	9·0	11·1	13·4	16·3	18·9	22	25·3	28·7
2,400	4·3	6·0	7·8	9·9	12·1	14·7	17·8	20·7	24	27·6	31·3
2,600	4·6	6·5	8·4	10·7	13·1	15·9	19·2	22·4	26	29·9	33·9
2,800	5·0	7·0	9·1	11·5	14·1	17·1	20·8	24·1	28	32·2	36·5
3,000	5·4	7·5	9·7	12·3	15·1	18·3	22·3	25·8	30	34·5	39·1
3,200	5·7	8·0	10·4	13·2	16·2	19·6	23·8	27·6	32	36·8	41·8
3,400	6·1	8·5	11·0	14·0	17·2	20·8	25·3	29·3	34	39·1	44·4
3,600	6·4	9·0	11·7	14·8	18·2	22·0	26·7	31·0	36	41·4	47·0
3,800	6·8	9·5	12·3	15·6	19·2	23·2	28·2	32·7	38	43·7	49·6
4,000	7·2	10·0	13·0	16·4	20·2	24·5	29·7	34·5	40	46·0	52·2
4,200	7·5	10·5	13·6	17·3	21·2	25·7	31·2	36·2	42	48·3	54·8
4,400	7·9	11·0	14·3	18·1	22·2	26·9	32·7	37·9	44	50·6	57·4
4,600	8·2	11·5	14·9	18·9	23·2	28·1	34·2	39·6	46	52·9	60·0
4,800	8·6	12·0	15·6	19·8	24·2	29·4	35·7	41·4	48	55·2	62·7
5,000	9·0	12·5	16·2	20·6	25·3	30·6	37·1	43·1	50	57·5	65·3
5,200	9·3	13·0	16·9	21·4	26·3	31·8	38·6	44·8	52	59·8	67·9
5,400	9·7	13·5	17·5	22·2	27·3	33·0	40·1	46·5	54	62·1	70·5
5,600	10·0	14·0	18·2	23·1	28·3	34·3	41·6	48·3	56	64·4	73·1
5,800	10·4	14·5	18·8	23·9	29·3	35·5	43·1	50·0	58	66·7	75·7
6,000	10·8	15·0	19·5	24·7	30·3	36·7	44·6	51·7	60	69·0	78·3
6,200	11·1	15·5	20·1	25·5	31·3	37·9	46·1	53·4	62	71·3	80·9
6,400	11·5	16·0	20·8	26·4	32·4	39·2	47·6	55·2	64	73·6	83·6
6,600	11·8	16·5	21·4	27·2	33·4	40·4	49·0	56·9	66	75·9	86·2
6,800	12·2	17·0	22·1	28·0	34·4	41·6	50·5	58·5	68	78·2	88·8
7,000	12·6	17·5	22·7	28·8	35·4	42·8	52·0	60·3	70	80·5	91·4

At a rough generalisation these figures may be accepted under the following conditions:

(1) Pulley grooves not exceeding 45° in angle and straight sided.
(2) Minimum centre distance approximately equal to twice the mean pulley diameter.
(3) Inclination to horizontal not exceeding 30°.

For worn or wide angle grooves, additional ropes are necessary.

The permissible ratio of tight side to slack side tension for different groove angles are given below:

Groove Angle.	Groove Coefficient of Friction. μ_g.	Maximum Advisable Value of $\frac{T_1}{T_2}$.
30°	0·36	3·1
35°	0·298	2·5
40°	0·27	2·3
45°	0·24	2·125

Taking the coefficient of friction of lubricated cotton rope on polished cast iron as 0·0926, any value can be determined from the expressions:

$$\frac{T_1}{T_2} = e^{\alpha \mu_g} \quad \ldots \quad (1)$$

where μ_g = groove coefficient;

α = arc of contact of ropes on smallest pulley, in radians;

e = base of Naperian logs.

And

$$\mu_g = \mu \operatorname{cosec} \frac{\theta}{2} \quad \ldots \quad (2)$$

where

μ = real coefficient of friction for flat surfaces.

θ = groove angle in degrees.

Centre distance is not limited except where the slack side of a drive is uppermost. Then the drive should be no longer than will permit a maximum sag of 10 per cent. before the two sides of the drive rub.

Rolling-mill drives have been installed with the pulley rims almost touching. If there is no limit to width, the multiple system may be used. If width is limited, the continuous system with a suitable tension weight will generally overcome the difficulty.

Rope Driving Speed.

At one time an arbitrary critical speed was fixed for rope driving at 4,800 f.p.m. This was determined by fixing a maximum permissible tension for each rope and subtracting the centrifugal

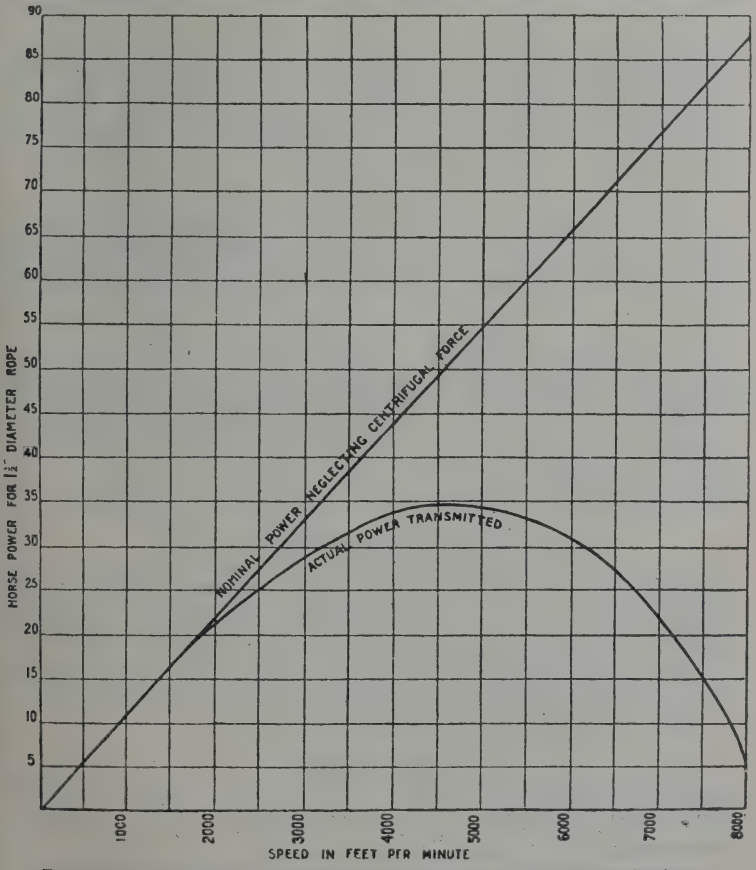


FIG. 12.—Diagram showing the effect of Centrifugal Force at different speeds of rope.

tension from this, the remainder being assumed to be the determining factor in power capacity. The result of these assumptions was a curve of horse-power capacity reading a maximum at 4,800 f.p.m. and then falling back to zero at about 8,300 f.p.m. as shown in fig. 12.

The total direct tension on a driving rope is, however, of small importance. The resistance to slip in the grooves is what determines maximum capacity, since a rope will slip along before the tension approaches the ultimate strength of the rope.

Furthermore, bending stresses are more important than direct stresses from the point of view of wear.

In practice the maximum direct stress in a driving rope at 4,500 f.p.m. does not exceed $\frac{1}{10}$th of its ultimate strength, and may, therefore, be increased appreciably without detriment, *provided the slipping point is not reached.*

Increase of speed actually raises the slipping point, because, if T_c is centrifugal tension; then the total running tension on the tight and slack sides respectively become $T_1 + T_c$ and $T_2 + T_c$, and it is obvious that

$$\frac{T_1}{T_2} > \frac{T_1 + T_c}{T_2 + T_c}$$

That is to say, for constant values of $e^{\alpha\mu}$ and T_2, as T_c increases, T_1 may be increased also. The power transmitted is a direct function of $(T_1 - T_2)$ so that power capacity actually increases with speed instead of decreasing. Allowance has to be made for bending stresses and increased rate of wear, however, so that the curve of capacity is actually below the straight line shown on fig. 15, but it continues to have a positive inclination up to a speed of 10,000 f.p.m. This explains why 2 in. diameter cotton ropes are actually transmitting 125–150 h.p. each at 8,750 f.p.m. on a Belgian rolling mill drive, with satisfactory results, when, according to the old theory, they ought not to be capable of transmitting power satisfactory at all.

STEADINESS.

The use of cotton driving ropes for rolling mills in order to cushion heavy 'peak' loads is quite old; only recently, however, is the importance of resilience being appreciated in other directions. A book on 'The Driving of Spinning Frames,' published by Messrs. Wm. Kenyon & Sons, Ltd., gives a selection of tachograph records showing very strikingly how an irregular torque on a lineshaft can be damped out or considerably improved by the intervention of a rope drive.

Efficiency of Rope Driving.

Accurate and detailed data in respect of large drives is very scanty. Tests carried out by Prof. Bonte at Charlottenburg before 1914 on a drive of 200 h.p. capacity showed that rope efficiency increased with both speed and with loading. There is no simple law, however, and low loading it appears probable that efficiency will fall off beyond a speed of approximately 4,600 f.p.m.

For average rates of loading efficiencies of from 96 per cent. at 1,500 f.p.m. to 98·7 per cent. at 5,000 f.p.m. were obtained. This seems to indicate that the friction losses on ropes running under ordinary industrial conditions need not exceed 3 per cent.

Small drives usually have slightly lower efficiencies on account of the lower ratio of pulley to rope diameters, but at very high speeds efficiencies of 99 per cent. have been obtained.

Drives with Irregular Impulses or Loads.

When either the load or impulse is irregular, there are two main effects which must be provided against. The first is, if the ropes are fully loaded, or nearly so, for the general conditions of the drive, the irregular load or impulse has the effect of causing the ropes to slip, although under a load equal to the average load the drives might run perfectly well. In driving from single cylinder gas-engines (old type) as much as 50 per cent. extra ropes were sometimes found necessary. For a modern gas-engine 10 per cent. extra ropes are advisable.

The second is, that with either irregular impulses or loads, the ropes have a tendency to lash about, which, if not controlled, tends to excessive wear. The best thing to do is to regulate by flywheel effect and thus get rid of this action altogether. This, however, is not always possible. In that case the provision of a rope guard is advisable.

Rope Guards.

A design of the rope guard which has been used with great success is shown in fig. 13, and the method of installation in fig. 14.

To construct this, first determine the pitch, P, of the pulley grooves; let D = rope diameter, then thickness of blade $= P - \left(D + \frac{D}{8}\right)$.

The blades should be made of a good hard wood of even grain, without knots, with rounded edges, as shown on enlarged section. The ends are shaped to fit slots in cross-bars of frame where they are held in place by stretchers secured with coach-screws, thus facilitating replacement in case of breakage.

ROPE GUARD.

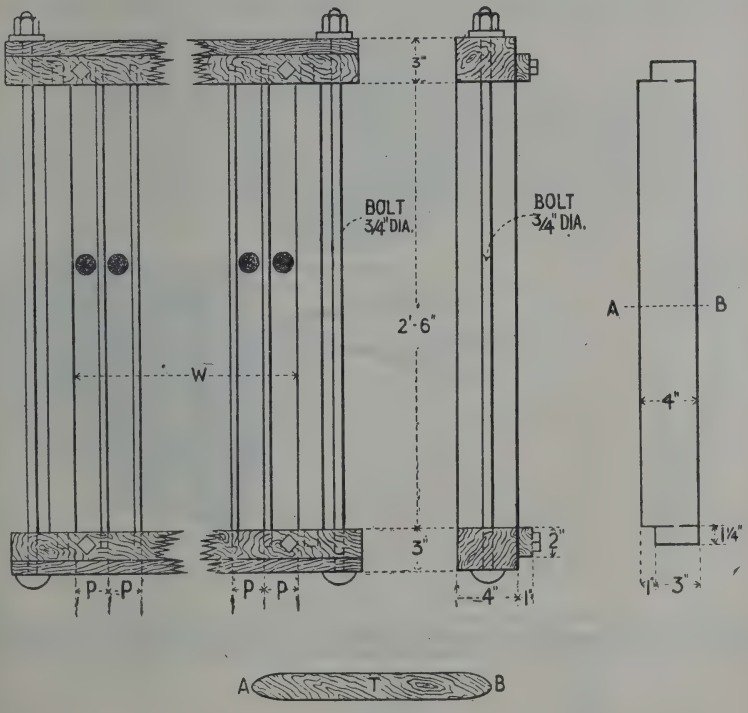


FIG. 13.

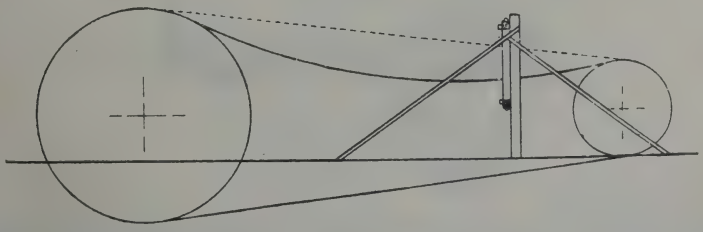


FIG. 14.

The method of applying this rope guard depends upon the relative positions of the two pulleys and direction of rotation. In oblique driving it is often attached to the roof or sides of a building, stayed by iron rods and tilted to meet the driving angle. These thin wooden blades are quite sufficient to stop the largest ropes from lashing; the action of lashing being accumulative, the blades steady each small impulse as it arises.

Long keyways are advantageous in fixing up angular drives, as they enable the pulley to be moved to the most desirable position in the circumstances.

Adaptability of Rope Drives.

In the case of a vertical half-cross drive, such as that shown in fig. 15, it is only necessary for success to ensure that the relations of the pulleys are such as to allow the slack to fall in a direct line, while the tight is deflected in the manner shown in the figure.

A right-angle drive is shown in fig. 16.

It will be seen that in this case the rope runs over four guide pulleys, so arranged in pairs of unequal size that the larger diameter leads to the smaller one, and *vice versa*. These guides run freely on studs, which may be moved along the slotted sides of a rectangular bracket, thus serving as rope tighteners if required.

FIG. 15.

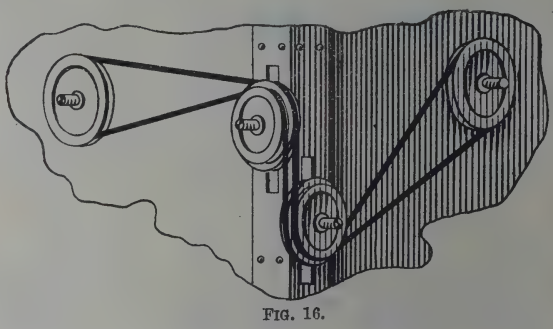


FIG. 16.

FAST AND LOOSE PULLEY.

Fig. 17 shows this combination in its most approved form. The working groove is set out at an angle of 30° on the lines previously described. A shallow intermediate groove provides for a gradual start and knock off, corresponding to the slip of a belt. The loose groove on the

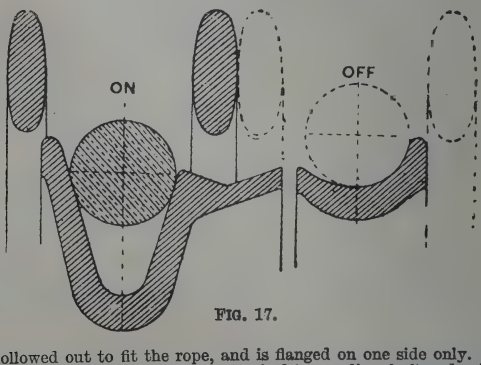
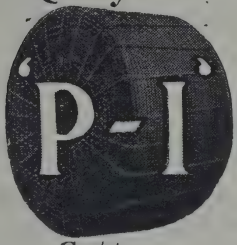


FIG. 17.

right is simply hollowed out to fit the rope, and is flanged on one side only. The rope shifter usually takes the curve of the pulleys, and is attached to a radius shaft and actuated by a small lever. A slight force on the slack side suffices to pass the ropes in or out of gear, and there is very little friction.

Kenyon's



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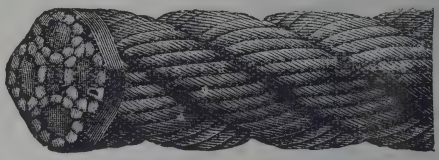

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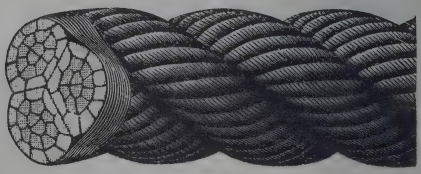

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Notes on Rope Driving.

The following *Hints to users of ropes* are taken from Mr. Thomas Hart's book on 'Rope Driving':—

Take care that ropes do not get wet; water does them much harm.

Take care that ropes do not rub on anything in their flight, either when running at full speed or when starting and stopping the engine.

Take care that ropes do not slip; if they slip they are probably overloaded, or are too small for the grooves.

All ropes should be lubricated with a good anti-fraying and lubricating composition. Blackead mixtures should not be used.

Instructions for Splicing Lambeth Cotton Driving Ropes (Four Strand).

(*Thomas Hart, Ltd., Blackburn.*)

Storing, Stretching, etc.

If it is necessary to store the ropes before fixing, they should be kept in a dry room, not on an earthen floor. When ready for fixing uncoil the ropes left-handed—the opposite to the way the hands of a clock move. Then stretch out with a pair of hand blocks, but do not allow the rope to revolve during this operation, or the 'turn' or 'twist' will be taken out of it. Everything depends upon the strength of shafting, etc., as to how tight the rope should be stretched, but under ordinary circumstances it is usual to have about four men pulling on a pair of hand blocks. Pass a string around the drive to get the exact running length of rope, and by tying two bands around the rope, mark off the exact running length whilst it is on the stretch, allowing ten feet (five feet each end) for the splice. For ropes 2 ins. diameter allow 12 feet of splice.

Splicing.

Unlay the five feet each end that has been allowed for splice, that is, as far back as the bands which mark the running length of rope; it is advisable to tie a string around the end of each of the loose strands to prevent the twist from coming out. The strands are now interlaced together, one from the right-hand side being next to one from the left-hand side, and so on, as shown in fig. 18. These strands should be pulled tight so that the bands butt together, and

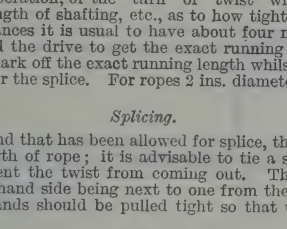


FIG. 18.

the loose strands on one side tied temporarily around the rope to keep the two ends of the rope in the position they now are.

Cut one of the bands, say the one on the right, and unlay strand No. 1A, at the same time laying in its place its fellow strand No. 1 from the opposite side of the rope. Do this for about four feet, and tie the two strands temporarily until all are ready for tucking in. The next strand to this, as will be seen in fig. 18, is numbered 2, but do not touch this now; take the next strand but one, numbered 3A, and unlay it, laying in its place strand No. 3, but only for about 1 ft. 6 ins.; tie these temporarily. It is very important in splicing four-strand ropes that two strands next to each other should not be laid up in the same direction.

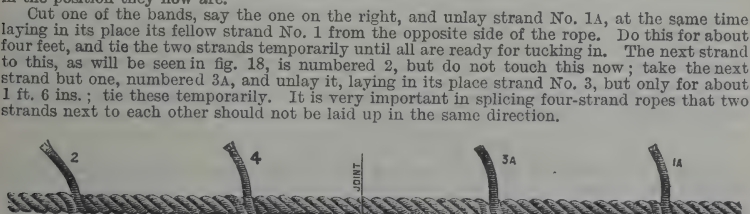


FIG. 19.

Next cut the other band, and proceed in the same manner with strands No. 2 and No. 4, but of course in the opposite direction. Care should be taken to keep the 'turn' or 'twist' in the strands, and they should be laid well and evenly down in their places. The splice should now be as fig. 19.

Begin now at joint No. 1 and 1A; untie the temporary fastening and shorten the strands to equal lengths of about 1 ft. 6 ins. An examination of the strands will show that the outside layer is composed of ten threads; for reference we will call these the friction bands; the internal portion of the strand we will call the tension strand. Take No. 1A and remove from it the ten friction bands and divide them into two lots of five, but do not cut them off. Now take strand No. 1 and unlay it two turns or laps, and whilst it is there remove from it the ten friction bands, divide them into two lots of five, but do not cut off. Now lay in again the tension strand only of No. 1 turn, and reduce it by leaving out about one-quarter, lay up the remaining three-quarters one turn, thus bringing it up to tension strand of No. 1A; tie the two with an overhand knot. At this knot the rope should be about its original diameter, and the joint should appear as shown in fig. 20.

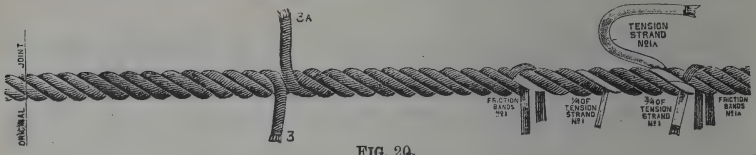


FIG. 20.

Take tension strand 1A and with the splicing pin work it under and over tension strand No. 1, as shown at fig. 21, passing it under and over spirally about five times; it will then have reached friction bands No. 1.

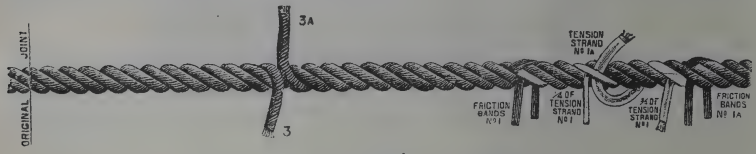


FIG. 21.

Now reduce it by cutting out a portion, and pass the remainder between the two lots of five friction bands, and lock by passing once or twice through the centre of the rope. This is clearly shown at fig. 22. Five friction bands are also locked through the rope as shown. This complete, turn to three-quarters of tension strand No. 1; this is locked exactly as tension strand No. 1A,

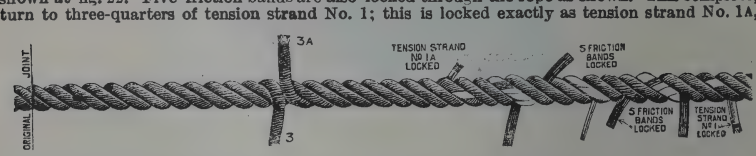


FIG. 22.

five of the friction bands are also locked as previously shown, and the splice should now be as fig. 22.

All loose ends are cut off and this portion is complete. Treat the two other joints in the same way and the splice is complete.

How to put a Rope on the Pulleys.

Put the rope on the small pulley, and as far around the large pulley as it will go; lash it there, but have the lashing so that the rope has freedom to slip through it. Then bar pulley slowly round by hand, or barring engine if there is one, and the rope will fall into its place. The groove of the small pulley and the face of the large pulley where the rope will touch in barring on should be well greased with tallow to prevent wedging. A piece of canvas may also be put on the rim of the large pulley to prevent it cutting the rope. (*Thomas Hart, Ltd.*)

Sizes of Pulleys and Drums.

The sizes of pulleys and drums should preferably be about ten times the circumference of the ropes to be used on the same, or, say, 1 foot in the diameter of the former for each pound of rope per fathom—e.g. a drum 3½ feet in diameter for a rope weighing 3½ lbs. per fathom.

V-Belting.

The capacity of a belt to transmit power depends upon the tension, the coefficient of friction, and the area of contact. By giving a belt the V-shape, the area of contact is greatly increased, for contact is along the sides. The area of contact also is increased by the wedge action of the belt in the groove, which forces the belt against the sides of the groove, and ensures that the entire surface of the belt passing over the pulley actually will be in contact with it. The V-belt gives maximum power transmission for a given width of pulley.

Whether a flat belt or a V-belt should be used depends largely upon the power to be transmitted and the speed at which the belt must be run. The V-belt will be found to operate satisfactorily at speeds as high as 3,500 feet a minute, while with flat belts on small pulleys, speeds up to 10,000 feet a minute are practicable. Single V-belts of $\frac{3}{4}$-in. width, running at 3,500 feet a minute on correctly designed pulleys, will transmit up to 3 h.p. If more power than this is to be transmitted, it will be found better practice to use twin belts, as shown at *a* O, fig. 24A, rather than to increase the size of the belts.

Pulley Grooves for V-Belts.

The pulley groove for a V-belt should be at least $\frac{3}{16}$ in. deeper than the belt thickness, to provide clearance, as indicated in fig. 24A. A clearance of $\frac{1}{4}$ in. is better and usually will be found ample in any case. A V-belt must not bottom in the groove, as this would prevent the proper

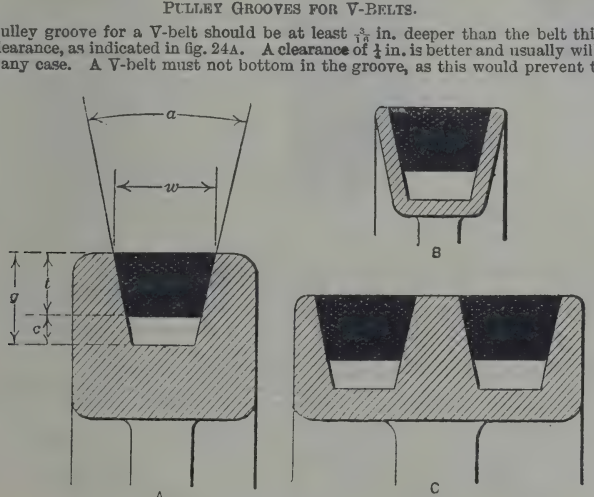


Fig. 24A.

contact between the sides of the belt and the sides of the groove, and would seriously reduce the ability of the belt to transmit power. The width *w* of the pulley groove across the top of the V should be the same as the width of the belt, with a permissible tolerance of $\frac{1}{32}$ in. The sides of the groove, which form the contact surfaces, should be smooth, care being taken to avoid ridges, tool chatter marks, and other defects, as these cause rapid belt wear. The rim of the pulley should be as light as possible, as shown at B, except when a flywheel effect is desired, in which case the mass of metal in the rim should be increased, as shown at A.

Experiments have resulted in a recommended angle *a* of 38° for two-pulley drives. An included angle of 28° is recommended for the smaller pulleys of a three-pulley drive, due to the reduction of angular contact in this arrangement. The thickness *t* of a V-belt should be from 0·5 to 0·6 of the width *w* at the widest part of the V.

The 'Lincona' Balata 'V' Belt Rope.

(Patent.)

(*James Dawson & Son, Ltd., Boultham Works, Lincoln.*)

This driving rope, fig. 24B, consists of a number of sections, each being built up of plies of cotton duck thoroughly impregnated with Balata gum (*Minusops Globosa*). The sections are held together with the Balata gum, and by a specially shaped rivet designed to prevent any creeping of the sections.

The belt rope is built up in such shape that the driving surfaces exactly fit the sides of the pulley grooves, fig. 24C, and so provide a maximum of frictional surface in relation to the cubic measurements of the rope.

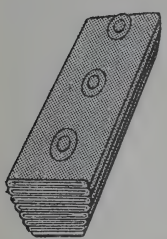


FIG. 24B.

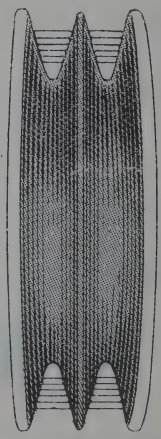
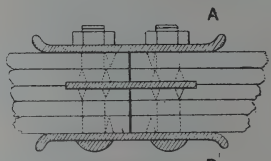
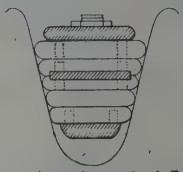


FIG. 24C.



Side Elevation



Section through A.B.

FIG. 24D.

Advantages claimed for the 'Lincona' Balata 'V' belt rope are:—

1. It has a large frictional contact surface with the sides of the pulley groove, distributing the weight of the pull and protecting the internal fibres from side pressure, thereby ensuring long life.

2. The coefficient of friction is high, as no dressing or lubrication is necessary.

3. It can stand a heavy economical working tension on the pulling side. The breaking strain of a 'Lincona' Balata 'V' rope of 1 sq. in. section is 5,000 lbs.

4. As a result of the above it is capable of taking the heaviest loads at the highest speeds. A 'Lincona' Balata 'V' rope of 1 sq. in. section will transmit 60 b.h.p. at 4,000 ft. per minute, and give a satisfactory life and freedom from stretch.

5. Because of its high power transmission, a small number of ropes are required, therefore little power is absorbed in the transmission itself.

6. The joint is a simple splice, which any handy man can learn to make in a few minutes; thus the work of putting on the ropes can be done on the spot and at once.

7. No dressing and no attention needed once the ropes have been fitted.

8. No ill effects from damp or exposed conditions.

This type of rope is being used extensively on steel rolling mill drives, main drives, pumps of all descriptions, fans, D.C. generators, and haulage gearing, and is giving improved service and life.

It can be satisfactorily fitted to grooves already in existence for interstranded cotton ropes, some slight alteration in design from the standard rope being necessary to effect a perfect fit in the groove. New installations should be fitted with pulleys having grooves of an angle of 28°.

When *Jointing*, the belt is drawn together by means of screw clamps, the several sections are cemented and riveted, the butted joints of each section being staggered in such a manner as to ensure the rivets being kept upright.

When fitting or taking up it is important that only the sections of the butted joints on one side are cut. The sections of the other half of the joint then act as a guide to correct cutting.

A fastener capable of holding together the butt ends of a Lincona belt rope has recently been devised; it forms a compact and strong joint which will stand up continuously to the heavy strains which it is required to bear. The arrangement, fig. 24D, consists of three strong metal plates, A, B, and C, provided with spikes (shown dotted), the centre plate having these spikes on both sides. Bolts pass through the plates and bind the latter and the ends of the belt firmly together.

The following table represents length of life and freedom from bearing trouble rather than a high power figure; it will be found to be reliable in practice for speeds up to 6,000 ft. per minute.

'Lincona' Balata 'V' ropes have been tested up to 7,000 ft. per minute and found to transmit the power given in the table.

TABLE SHOWING HORSE-POWER TRANSMITTED BY 'LINCONA' BALATA 'V' BELT ROPE.
(Cross-section area of belt = 1 sq. in. Speed in ft. per minute.)

Speed	1000	2000	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600
H.P. .	12·5	24·7	30·6	31·5	32·7	33·7	34·9	35·9	37·0	37·9	39·0	40·0	40·9	41·8
Speed	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900	5000
H.P. .	42·8	43·7	44·5	45·0	46·3	47·0	48·0	48·7	49·4	50·2	50·8	51·4	52·3	52·5
Speed	5100	5200	5300	5400	5500	5600	5700	5800	5900	6000	6500	7000	7500	8000
H.P. .	53·2	54·1	54·5	55·0	55·7	56·0	56·3	57·0	57·2	57·4	58·8	59·2	58·5	57·0

For any other cross-section area, multiply horse-power by this area.

From the table it will be seen that the horse-power is increasingly transmitted up to 7,000 feet per minute rope-speed, with a falling off noticeable after 4,000 feet per minute due to centrifugal force.

In calculating the number of ropes required for a drive, it is important that allowance should be made if the arc of contact of the rope on the smaller pulley embraces less than 180° of the circumference

The following allowance should be made :—

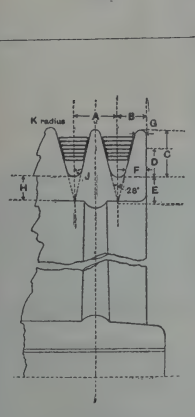
Arc	180°	170°	150°	140°	130°	120°
Percentage of power transmitted .	100	97	95	90	85	80

It must be borne in mind that the arc of contact is lessened if the slack is on the bottom of the drive.

An allowance, depending on the tension that can be put on the ropes, must be made if the drive is vertical or at an acute angle.

'LINCONA' 'V' BELT ROPES, STANDARD BELTS, AND PULLEYS.

FIG.	Area in Sq.Ins.	Min. Pulley Diam.	Dimensions in Ins.									
			A	B	C	D	E	F	G	H	J	K
		Ft. Ins.										
	0·25	1 4	$1\frac{5}{32}$	$\frac{21}{32}$	$1\frac{9}{32}$	$\frac{27}{32}$	$\frac{3}{4}$	$\frac{13}{32}$	$\frac{3}{32}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$
	0·4	2 0	$1\frac{5}{32}$	$\frac{21}{32}$	$1\frac{9}{32}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{32}$	$\frac{3}{32}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$
	0·5	2 0	$1\frac{13}{32}$	$\frac{27}{32}$	$1\frac{9}{16}$	$1\frac{1}{16}$	$\frac{27}{32}$	$\frac{17}{32}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{9}{32}$	$\frac{1}{4}$
	0·65	2 8	$1\frac{13}{32}$	$\frac{27}{32}$	$1\frac{9}{16}$	$\frac{31}{32}$	$\frac{27}{32}$	$\frac{17}{32}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{9}{32}$	$\frac{1}{4}$
	0·8	2 8	$1\frac{11}{16}$	$\frac{31}{32}$	$1\frac{3}{4}$	$1\frac{3}{16}$	$1\frac{5}{32}$	$\frac{19}{32}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{9}{32}$
	1	3 4	$1\frac{11}{16}$	$\frac{31}{32}$	$1\frac{3}{4}$	$1\frac{3}{32}$	$1\frac{5}{32}$	$\frac{19}{32}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{9}{32}$
	1·25	4 0	$1\frac{37}{32}$	$1\frac{1}{8}$	2	$1\frac{1}{4}$	$1\frac{3}{16}$	$\frac{21}{32}$	$\frac{1}{8}$	$\frac{7}{8}$	$\frac{13}{32}$	$\frac{9}{32}$
	1·55	4 2	$2\frac{1}{8}$	$1\frac{3}{16}$	$2\frac{5}{32}$	$1\frac{3}{8}$	$1\frac{15}{32}$	$\frac{11}{16}$	$\frac{5}{32}$	1	$\frac{15}{32}$	$\frac{5}{16}$
	1·75	4 8	$2\frac{1}{8}$	$1\frac{1}{4}$	$2\frac{9}{32}$	$1\frac{7}{16}$	$1\frac{7}{16}$	$\frac{23}{32}$	$\frac{5}{32}$	$1\frac{3}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
	2	4 10	$2\frac{9}{32}$	$1\frac{3}{8}$	$2\frac{9}{16}$	$1\frac{21}{32}$	$1\frac{1}{2}$	$\frac{25}{34}$	$\frac{5}{32}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{11}{32}$
	2·25	5 4	$2\frac{15}{32}$	$1\frac{3}{8}$	$2\frac{19}{32}$	$1\frac{21}{32}$	$1\frac{9}{16}$	$\frac{13}{16}$	$\frac{5}{32}$	$1\frac{5}{16}$	$\frac{17}{32}$	$\frac{11}{32}$
	2·45	5 6	$2\frac{5}{8}$	$1\frac{1}{2}$	$2\frac{3}{4}$	$1\frac{13}{16}$	$1\frac{23}{32}$	$\frac{7}{8}$	$\frac{3}{16}$	$1\frac{3}{8}$	$\frac{9}{16}$	$\frac{13}{32}$



The Dickbalata Element Driving Rope.

(*R. & J. Dick, Ltd., Greenhead Works, Glasgow.*)

This rope is constructed V shape, as shown by fig. 24E. The binder or top portion is made like ordinary Dickbelt (p. 954), with Dickbalata blocks solutioned and riveted to it.

The rope is of very great strength, as can be seen from the horse-power table; it is claimed to give practically double the power of cotton ropes. It does not need a special expert to fit it; any engineer or belt fitter can make the splice without difficulty and in quick time; the splice is as strong as the main portion of rope.

Fig. 24E.

The Dickbalata Rope has positive grip, no slip, runs in steamy or damp atmospheres without being affected, and without noise; no dressing is needed. Owing to its flexible construction, the rope can be used at short centres if necessary and over small pulleys.

The rope can be supplied with a steel band, placed between the top binder and the blocks, and spliced the same way as ordinary Dickbalata Rope.

The rope can be used for cross-driving.

Horse-Power Table Dickbalata Element Driving Rope.

Speed.	¾-in.	⅞-in.	1-in.	1¼-in.	1½-in.	1¾-in.	2-in.
1,000	3·5	7·0	10·5	13·9	17·4	22·8	27·8
2,000	6·9	13·8	20·7	27·5	34·4	44·9	55·0
2,600	8·8	17·5	26·3	35·0	43·8	57·2	70·0
2,800	9·4	18·8	28·2	37·6	47·0	61·1	75·1
3,000	10·0	20·0	30·0	39·9	49·9	65·0	79·7
3,200	10·6	21·1	31·7	42·2	52·8	68·9	84·3
3,400	11·1	22·2	33·3	44·4	55·5	72·2	88·8
3,600	11·6	23·2	34·8	46·4	58·0	75·4	92·8
3,800	12·2	24·3	36·5	48·6	60·8	79·3	97·1
4,000	12·5	25·0	37·5	50·0	62·5	81·3	100·0
4,200	13·1	26·2	39·3	52·3	65·4	85·2	104·5
4,400	13·6	27·1	40·7	54·1	67·7	88·4	108·1
4,600	14·0	28·0	42·0	55·9	69·9	91·0	111·7
4,800	14·3	28·6	42·9	57·2	71·5	93·0	114·3
5,000	14·6	29·2	43·8	58·4	73·0	94·9	116·7
5,200	15·1	30·1	45·2	60·2	75·3	98·2	120·3
5,400	15·3	30·6	45·9	61·1	76·4	99·5	122·1
5,600	15·6	31·2	46·8	62·3	77·9	101·4	124·5
5,800	15·8	31·7	47·5	63·4	79·2	102·7	126·7
6,000	16·0	31·9	47·9	63·8	79·8	104·0	127·5
7,000	16·5	33·0	49·5	65·9	82·4	107·3	131·7
7,500	16·3	32·5	48·8	65·0	81·3	106·0	130·0

WIRE ROPES.

Lang Lay.

In the 'Lang' Lay all the wires forming the strands, and the strands comprising the rope, are laid in the same direction. These ropes have been used for from 3 to 6 years hauling some 3,500,000 tons of coal, at speeds varying from 5 to 15 miles per hour, over distances up to 220,000 miles.

A Super Driving Rope

of exceptional
FLEXIBILITY
& DURABILITY
built for
maximum
service and
guaranteed
to give it

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BELFAST

F. 982

Dickbalata Element Driving Ropes

PATENT NOS. 235657/24 AND 245291/25.

offer the following positive advantages over any other type of driving rope.

ENORMOUS STRENGTH.	They give practically double the power of any other kind of Rope. The horse-power table is quoted on page 982.
GREAT FLEXIBILITY.	They will work perfectly at short centres or over small pulleys.
POSITIVE GRIP.	The method of manufacture ensures maximum surface contact between rope and pulley groove; consequently there is no slipping.
EASY TO SPLICE.	Any handy-man can perform this operation and make the splice as strong as the rope.
MAINTENANCE COST	is negligible. The rope will run even in steamy or damp atmospheres without attention. No dressing is needed.
CROSS-DRIVE.	An absolutely satisfactory Cross-Drive is ensured by fitting the rope to run with the binders back to back.
INSURANCE.	The danger of fire lurks in the frayed fibres of ropes. Dickbalata Rope will not fray.

Ask any User. He knows

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F. 983

HAULAGE WIRE ROPES, USEFUL SIZES (LANG LAY).

Approximate Diameter.	Circumference of Rope.	Number of Strands.	Number of Wires in Strands.	Number of Wires in Core	Gauge of Wires.	Lay of Strands.	Lay of Rope.
Ins.	Ins.				In.	Ins.	Ins.
$\frac{5}{8}$	2	6	6	1	·072	$2\frac{1}{4}$	6
1	3	6	6	1	·105	3	$7\frac{1}{2}$
$1\frac{1}{4}$	4	6	8	7	·116	$3\frac{3}{4}$	9
2	6·2	6	10	7	·146	$4\frac{3}{4}$	13

Wire Rope Splicing.

LONG SPLICE.

This splice is used for haulage and where endless ropes are required.

Mark off both ends the length required for splicing, which depends on the size of rope, say 48 ft., that is 24 ft. each end. Having marked each end, unlay three alternate strands from each end to within 6 ins. of mark, as shown in fig. 25, L, p. 984.

Cut off the three remaining strands with the core and bend back at mark, as shown in fig. 25, R.

Lock both ends together, close up, so that the long strands pass alternately right and left, as shown in fig. 26.

Grip the rope on one side of the lock with tongs, unlay one short strand and lay up in its place the corresponding long strand until within 4 ft. of the end. To facilitate operations, the short strand may now be cut 4 ft. from the cross, the two ends measuring 8 ft. Lay up the other two long strands, the crosses being 8 ft. apart; next repeat the operations with other side, cutting the ends at 4 ft. and the crosses being 8 ft. apart, as shown in fig. 27.

The next operation is to run the ends in and substitute the core. It is advisable to serve the ends, this gives the outer strands a firm grip on them and prevents loose wires protruding through interstices of the strands. Grip the rope with tongs where indicated by arrow, drive the spike through centre of rope three strands in advance of the strand to be run in, and with the aid of short spike pick the core out, as shown in fig. 28, p. 984.

Run spike back towards the tongs, insert needle over the end in place of the spike, hook spoon under the end, and in same place as the needle, as shown in fig. 29.

Take two or three turns out of the strand and twist it round the rope as indicated by arrow, at the same time bring the handle of the needle and spoon together, as indicated. This forces the strand into centre of rope, and by twisting the needle round the lay the strand will enter the rope one side and force the core out on the other. Cut the core close up to the end of strand, and turn and run the opposite end in exactly the same way.

Run in the other five pairs of ends in exactly the same way as the first pair.

Care should be taken not to run the core too far back, otherwise flat places will occur.

This completes the splice, and if correctly executed there should be very little difference between the splice and any other portion of the rope.

With a Lang's lay rope the ends of the strands are run into the right of each other, as shown in fig. 30.

With the ordinary lay rope the ends of the strands are run into the left of each other.

Wire Rope Socketing.

Wire rope sockets should be made from carefully selected and tested steel of high strength, and be either drop forged or of well-annealed cast steel, depending upon the diameter of the rope to which the socket is attached.

When the work is done in the ordinary way the wires are bent back on each other and the basket of the socket filled in with metal, pins being used to lessen the quantity of metal required. In following this method it is important to have all the wires engaged, otherwise some of them creep back into the rope, thus preventing a perfect contact between the rope and the socket, consequently developing a weakness in the connection due to the disproportionate strain obtained on the strands.

WIRE ROPE SPLICING.

FIG. 25.

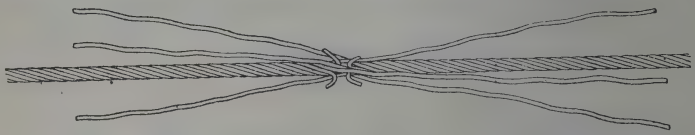

FIG. 26.

FIG. 27.

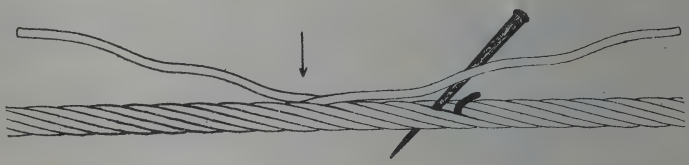

FIG. 28.

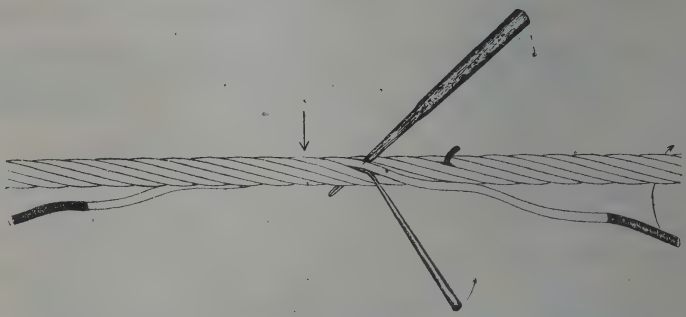

FIG. 29.

FIG. 30.

When sockets are attached in the following manner, the full strength of the rope or the socket is obtained :—

The rope is first served securely with soft wire, fig. 31 (p. 986), and the strands opened, as shown, for a distance equal to the length of the basket of the socket, and the hemp core cut out.

The wires are then separated in each strand, as shown, fig. 32, and well cleaned from all grease by means of petrol.

The wires are next dipped for a few minutes (not more than five) into a solution of equal parts of hydrochloric acid and water, then washed thoroughly in water, and dried. A stronger acid solution than that indicated should not be used.

The wires are then bound together by means of soft wire, as shown by fig. 33.

The socket being warmed, the wires are pushed through the basket of the socket till they are even with, or a little above, the top. The binding then being pulled off, the wires spring out.

Clay is put round the rope at bottom of the socket to prevent metal running through, and then melted white metal is poured into the socket at A, fig. 34, until the socket is filled up, care being taken that the metal is not too hot to take the temper out of the wire.

Ordinary virgin spelter is probably the best metal for socketing wire ropes, but this has to be used with caution, as it can be heated up too high unless the workman is very careful. As soon as it begins to char a pine stick (a match will do) it should be used.

Another mixture that is recommended is 80 per cent. zinc and 20 per cent. tin; this has a low melting point and consequently is not apt to affect the wires. (*Bruntons, Musselburgh.*)

The Coal Mines Act of 1911 requires that the filling metal should not have a melting point above 750° F. Cast zinc is not good as a filler, as its melting point is high—786·9° F.—and it is liable to be heated considerably above this temperature.

Blackett's Wire-Rope Socket.

Fig. 35 represents a section of Blackett's wire-rope socket. The cap or socket, A, made of iron or steel, and fitted with a lining, B, of some soft metal, is placed round the rope-end, C, which is brought into proper position, and then forcibly driven outwards against the lining, B, within

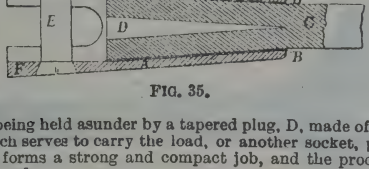

FIG. 35.

the socket, the wire ends being held asunder by a tapered plug, D, made of soft metal similar to the lining, B. A bolt, E, which serves to carry the load, or another socket, passes through a double eye. This arrangement forms a strong and compact job, and the process of socketing can be easily and rapidly performed.

Attaching ropes to joints or sockets by means of pins or rivets driven through the former is a detrimental, if not a dangerous, procedure.

Wire Rope Lubrication.

According to the operating temperatures that may be involved, and the possibility of the presence of an excess of water, the viscosity of a wire rope lubricant should be 1,000 seconds Saybolt at 210° F., or somewhat lower. In warm climates, or when the ropes are adjacent to ovens or furnaces, where there is danger of the lubricant becoming thinned down to such an extent that it will drip off, it is advisable to use a lubricant of about 1,000 seconds viscosity at the temperature prevalent under operating conditions.

On the other hand, in relatively cold districts, it is advisable to use a somewhat thinner lubricant selected in accordance with the range of the operating temperatures involved.

Wire rope lubricants should, in general, be straight mineral petroleum products, devoid of fillers or thickening mediums, i.e. whatever the viscosity, it should be an inherent property of the lubricant, not an artificial characteristic which cannot be depended upon. Greases or soap-thickened mineral oils are quite unsuited to wire lubrication.

Application of Wire Rope Lubricants.

As a general rule, wire rope lubricants must be applied in a heated condition.

The best method of treating wire ropes is to use a form of split box for the lubricant which can be parted to permit it to be placed around the rope, the hole through which the rope passes being on the parting line. The lubricating box may be made from wood or metal. The shape of the box is determined somewhat by the angle or position of the rope. For horizontal ropes, a V-shaped box or trough with holes at each end near the bottom is generally used. Conical shaped

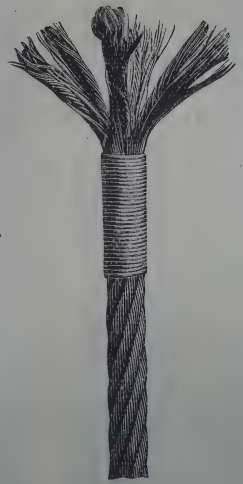

FIG. 31.

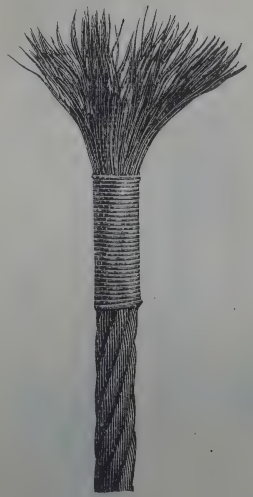

FIG. 32.

FIG. 33.

FIG. 34.

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WRIGHTS' "KEYSTONE" STRAND CRANE AND LIFT ROPES

are from 12½ to 17½ per cent stronger than round strand ropes and can be made absolutely non-rotating, while the wear due to friction is reduced by 50 per cent.

The peculiar formation of the strands in Wrights' "Keystone" Crane, etc., Ropes causes the strands to bed themselves under pressure in keystone fashion into the rope, rendering the rope proof against crushing and deformation in use, while the tendency to stretch is greatly reduced by a special process of manufacture.

In order to prevent the expense, delay and trouble involved by the replacement of practically unworn, yet unserviceable, Lift Ropes, Wrights' have now introduced a new type of elliptically stranded rope, "WRIGHTS' 'NORIBON' SUPER-DUCTILE ROPE," in which the defects of the old types of flattened strand ropes are eliminated.

In both of these ropes, instead of the specially shaped wire cores hitherto used with flattened strand Crane and Lift Ropes, cores composed of round wires are used as foundations for the strands. By this construction the rope is not only more flexible, but its life is considerably prolonged, as the round wire core successfully withstands the constant bending it is subjected to, and does not injure the surrounding round wires.

Illustrations and full particulars of these Ropes will be sent on request.

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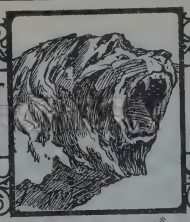
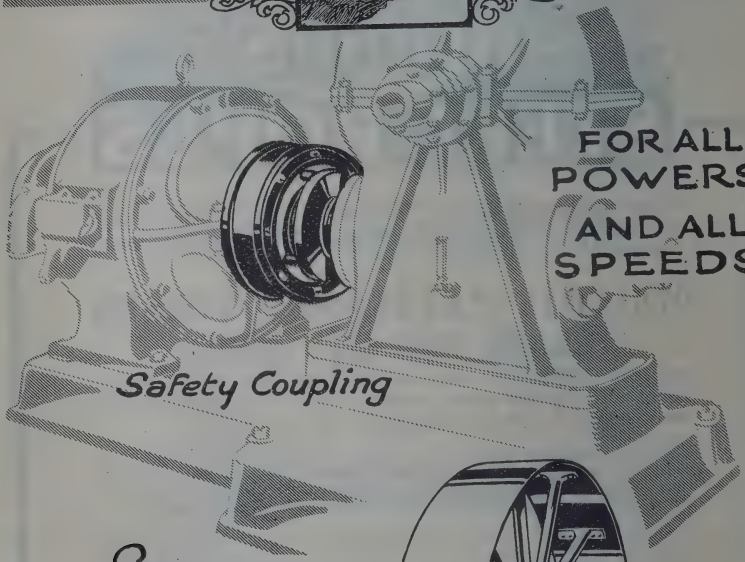
See Articles on Flattened Strand Ropes and on Locked Coil Ropes, pages 2604, 2605, 2606.

HELE-SHAW CLUTCHES





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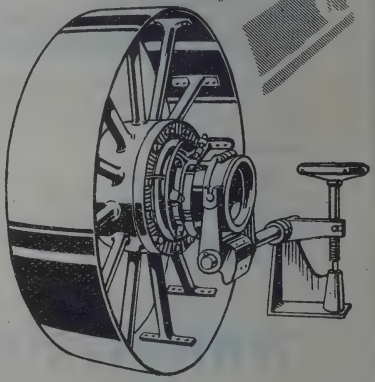

THE BRITISH HELE-SHAW PATENT CLUTCH CO LTD
OLDHAM ENGLAND

F. 987

boxes or containers are used for vertical ropes, the rope passing through a hole at the small end of the cone. Boxes of the kind described can be readily built in the average plant, with suitable provision for rendering it sufficiently tight to prevent the lubricant from leaking out even when reduced in viscosity by heating. The slow passage of the rope through such a bath of heated compound will not only ensure thorough coating of the surface but also will cause the lubricant to penetrate to the inner strands. Further working of the rope over the sheaves before the lubricant has time to cool entirely will aid in bringing about maximum penetration.

It is good practice to apply lubrication at least every six months, and every three months under some conditions.

Horse-Power required for Haulage.

TABLE SHOWING H.P. REQUIRED FOR MAIN AND TAIL HAULAGE AT 10 MILES PER HOUR.

Actual Incline in Inches per Yd.	Virtual Incline in Inches per Yd.	Load in Tons.										
		5	7·5	10	15	20	25	30	35	40	45	50
—2	0	0	0	0	0	0	0	0	0	0	0	0
—1	1	8·3	12·5	16·6	25	33·2	41·4	50	58	66·4	76	80·8
0	2	16·7	25	33·3	50	66·6	83	100	116	133	150	166
1	3	25	37·7	50	75	100	125	150	175	200	225	250
2	4	33·4	50	67·5	100	134	167	200	233	270	300	334
3	5	41·5	62	83·5	125	167	208	250	290	334	375	416
4	6	50	75	100	150	200	250	300	350	400	450	500
5	7	58·3	87	117	175	234	294	350	408	468	525	588
6	8	66·3	100	133	200	267	333	400	465	532	600	666
7	9	75	112	150	225	300	375	450	520	600	675	750
8	10	83·5	124	166	250	333	420	500	580	664	750	830
9	11	91	137	183	275	366	459	550	640	732	825	918
10	12	99	150	200	300	400	500	600	696	800	900	1000
11	13	108	162	217	325	433	542	650	755	868	975	1080
12	14	116	174	233	350	466	584	700	815	932	1050	1168

TABLE SHOWING H.P. REQUIRED FOR ENDLESS ROPE HAULAGE ON ROAD 1,000 YARDS LONG.

Actual Incline in Inches per Yd.	Virtual Incline in Inches per Yd.	Output in Lbs. per Minute.																
		200	300	400	500	600	700	800	900	1000	1250	1500	1750	2000	2250	2500	2750	3000
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
—1	1	·5	·75	1	1·2	1·5	1·7	2	2·3	2·5	3·1	3·7	4·4	5	5·6	6·2	6·9	7·5
0	2	1	1·5	2	2·5	3	3·5	4	4·6	5	6·3	7·6	8·9	10	11·4	12·7	14	15
1	3	1·5	2·3	3	3·8	4·6	5·3	6	6·8	7·6	9·5	11·4	13·3	15·2	17	19	21	23
2	4	2	3	4	5	6	7	8	9	10	12·6	15	17·6	20	23	26	28	30
3	5	2·5	3·8	5	6·3	7·6	8·9	10	11·4	12·7	15·8	19	22·3	25·4	28	32	35	38
4	6	3	4·5	6	7·6	9	10·6	12	13·7	15·2	19	22·8	26·6	30·4	34	38	42	45
5	7	3·5	5·3	7	8·8	10·5	12·4	14	16	17·7	22	26·5	31	35	40	44	49	52
6	8	4	6	8	10	12	14·2	16	18·2	20·4	25·3	30·4	35	41	45	51	55	60
7	9	4·5	6·8	9	11·4	13·7	16	18	20·5	22·8	28·5	34	40	45	51	57	63	68
8	10	5	7·6	10	12·6	15·2	17·7	20	22·5	25·3	31·7	38	44	51	57	63	69	76
9	11	5·5	8·3	11	14	16·7	19·5	22	25	27·8	34·7	41·7	49	55	62	69	76	83
10	12	6	9	12	15·2	18·2	21·3	24	27·3	30	38	45	53	61	68	76	83	90
11	13	6·5	9·8	13	16·4	19·8	23	26	29·6	33	41	49	57	66	74	82	90	98
12	14	7	10·6	14	17·7	21·3	24·8	28	31·8	35·4	44	53	62	71	80	88	97	106

(*Ernest Scott and Mountain.*)

CLUTCHES.

Friction Clutches.

Fig. 36 is one of the simplest forms of friction clutch. Part A clutches with part B (which is keyed to the shaft) by advancing the latter so that the conical surfaces are pressed together; these surfaces are sometimes covered with leather or fibre in order to increase the frictional resistance. When the members are mounted on separate shafts, it is generally advisable to mount

the sliding member on the driven shafts so that it may be at rest when not engaged. Where oil is likely to lodge between the two parts, small escape holes should be drilled parallel to the shaft axis through one of the members. These holes also allow of the escape of any air which may be trapped between the faces.

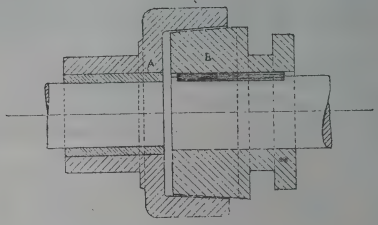

FIG. 36.

THE WESTON FRICTION COUPLING.

This device is probably more frequently used as a brake than as a clutch, but is equally suitable for both purposes. In the design shown in fig. 37, the muff A is keyed to the shaft S, but can be moved along the same by means of a fork which fits into the groove at the right-hand end. This muff A is provided with several feathers F around its inside surface (or the inside surface

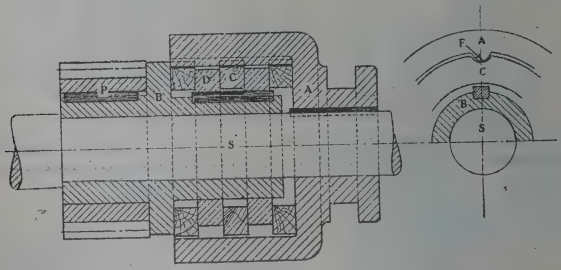

FIG. 37.

may be hexagonal), and into these are fitted the annular discs C. These discs are sometimes made of hard wood, but may be of iron. The member B, riding freely upon the shaft S, has a pinion P (or pulley) keyed to the outer end, and the metal rings D keyed to the sleeve. The rings D are free to move longitudinally along the sleeve, and are clear of the feathers F. Similarly the discs C are clear of the key in the sleeve B. On pressing A forward the axial force P is exerted on each of the rubbing faces and the frictional or turning effort increases with the number of rings.

The principle of the Benn and Hele-Shaw clutches is identical with the above.

THE HELE-SHAW CLUTCH.

In this form of clutch, fig. 38 (for motor cars), all the plates have driving notches either on their outer or inner circumference. The outer plates, which are made of high-grade phosphor bronze, are driven by the engines, and the inner plates of mild steel drive the clutchshaft and so transmit the power to the gear-box. The clutch case, marked A, is bolted to the flywheel and so revolves with the engine. Around the inner side of this case there are teeth or feathers which engage with the notches in the outer (phosphor bronze) plates, so that these outer plates always revolve with the engine. Supported by a ball bearing on the end of the crankshaft is a steel core shown at B, which is connected with the clutch shaft C. This core, like the case, has driving teeth, but on the outer side, and these engage with the inner (steel) plates. There is a sleeve D sliding on the shaft and ending in a disc E, which presses the inner and outer plates together. This presser, as it is called, is normally kept tight against the plates by the pressure of the main clutch spring F,

the other end of which is held by the spring adjusting cap G, screwed into the boss on the end of the case. In this way it is arranged that no thrust is exerted on the engine or the gear-box while the clutch is engaged. The spring adjuster is locked in position by the peg spring H, which can be raised out of engagement while the spring pressure is altered by screwing up the adjuster.

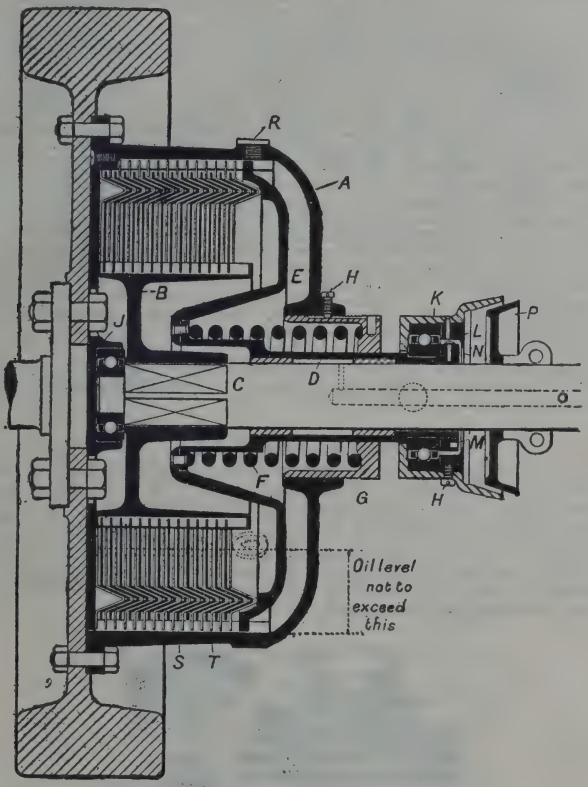

FIG. 38.—Sectional Elevation of the 'Hele-Shaw' Clutch bolted in position on Flywheel.

A, outer dust-proof case which forms oil bath; B, steel core; C, clutch shaft; D, actuating sleeve; E, presser; F, central control spring; G, adjusting nut; H, locking screws; J, retaining plate; K, actuator; L, external check nut; M, internal check nut; N, locking device; P, clutch brake; R, oil plugs; S, driven steel disc; T, driving bronze disc.

While the full spring pressure is keeping the outer and inner plates pressed together, the power of the engine will be transmitted to the gear-shaft.

To disengage the clutch the presser is moved back by means of the actuator K, to take the pressure off the plates. This actuator has two pins engaging with the pedal levers below the foot pedal; the motion is transmitted to the presser through the ball-bearing and the lock nut M. This latter is prevented from slacking back by a simple locking device.

When the pressure has been taken off the plates, these might tend to stick together on account of the oil. To prevent this, the outer plates are fitted with small flat springs which are in

compression when the clutch is engaged. When the presser slides back, the small springs throw the outer plates apart and make the clutch quite free. Occasional breakages of these springs having occurred after prolonged use, a new type of laminated spring, which is quicker in action and as durable as the plates themselves, is now being fitted.

In plate clutches of every form there is inevitably a slight drag, caused by the skin friction of the film of oil between the plates, which tends to keep the clutch shaft revolving when the clutch is out of gear. To mesh first speed or reverse, it is necessary that this shaft should be stopped; accordingly the actuator terminates in a cone which presses up against a corresponding coned part P revolving with the shaft. This constitutes a powerful clutch brake and frees even the largest size of clutch without difficulty. The coned brake piece is made adjustable to allow for wear of the plates.

When the clutch is let in slowly the slight friction caused by the oil between the plates tends to slowly start the car moving, and this starting effort increases till the whole of the spring pressure comes upon the plates. The oil is then forced out from between the surfaces and the plates come into close contact, forming a solid pack and transmitting the full power of the engine.

In practice it is found that the V-grooved twin plates are approximately three times as powerful as the same number of flat plates under the same pressure, and hence for the same work require but one-third of the spring pressure, or pedal pressure, to declutch. The plates being well separated right up to the point of work, and then only touching at the side of the V-grooves, free circulation of oil and extremely rapid dissipation of heat are ensured, so that the plates never burn the oil and may be engaged indefinitely without causing undue heat, whilst their working condition always remains constant. Further, in industrial work the clutch is capable of long-period slipping as part of its regular work. The V-groove in the twin plates adds so greatly to their transverse strength that buckling and distortion are impossible. Even under the most unfavourable working conditions, such as when through accidental loss of oil extreme heat is set up, the V-grooved plates still retain their shape.

The clutches are also made of a light type in which the outer case and liner with its teeth, also the presser, actuator, and other parts, are made by a patented process from pressed steel in place of being cast as in the standard patterns.

The Benn Friction Clutch.

In this clutch (Type H), fig. 39, the friction plates move axially, practically bear against the entire faces of the drum, and are continuous. As a result of this construction the diameter, for a given power, is relatively small. As the movements of the plates are axial and not radial, they are unaffected by centrifugal force and the drum being relieved from bursting strains the clutch is suitable for high speeds. The lever stops H, as they approach, show at a glance the amount of wear and compensation, for this can be made by screwing in the plate M one or two notches. By screwing out the ring M and slacking back two set screws, the interior parts can be withdrawn without disturbing the shafts or parts keyed thereto.

The construction and action of the clutch is as follows:—

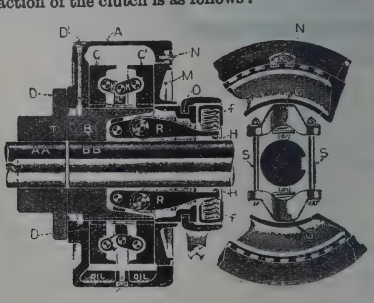

Fig. 39.

The boss T of drum A is keyed to the shaft AA, and the driving boss B to the shaft BB. On the driving boss B, the friction plates CC′ are free to slide on feathers DD. These plates CC are connected by toggles KK, which, in turn, are connected by radial links LL to the levers RR. The ends of these levers RR carry compression springs FF, having their outer ends seated in the yokes GG. These yokes are connected to each other by the bolts SS, thus forming an equalising member, which absolutely *ensures uniform pressure* between all friction surfaces throughout the clutch. The cover M, forming one end of the drum, is accurately adjustable, and is notched to receive the lock plate N. The lever stops HH are to enable the position of the toggles KK to be ascertained from outside the drum.

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F. 991

The figure shows the condition of the clutch when engaged, i.e., the plates bearing against M and A, the muff O in its inmost position, springs F in compression, the toggles KK in their most advantageous position (nearly straight), and the clutch locked by the radial link L being beyond the centre. On withdrawing the muff O the link L is pulled towards the right, the toggles KK are drawn towards the centre, and the plates O withdrawn from the drum faces.

The Johnson Friction Clutch.

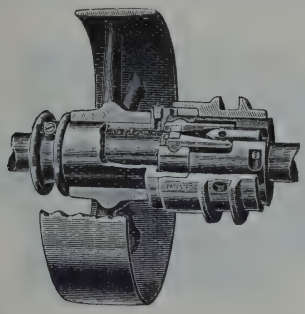


Fig. 40.—Clutch with Pulley Mounted on Hub.

This clutch, figs. 40, 41, consists of a body fastened to the shaft and carrying a split ring into which are inserted a pair of levers. A curved shaped wedge, which is made part of a sliding sleeve, forces the levers apart, expands the ring, bringing its outer surface into frictional contact with the inner surface of the friction cup, the hub of which is made to suit requirements. One screw which moves two taper blocks, set into the levers, adjusts the contact of the ring and cup to any degree.

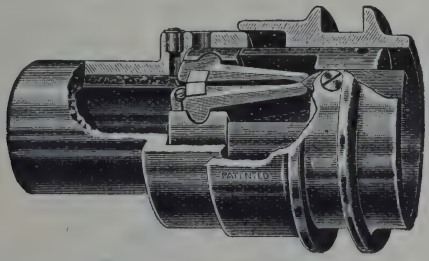


Fig. 41.—Section broken away, showing Clutch disengaged.

Patent Automatic Trip Centrifugal Clutch.

This clutch, fig. 42, has been designed for use with electric motors, driving any class of machinery, *to enable the motor to start without load and to automatically pick up the load* when a certain speed has been attained.

For three-phase and two-phase motors of the squirrel-cage type, as well as for all single-phase induction motors which possess a low-starting torque, a clutch of this description is most essential.

The clutch consists of a cast-iron body (B), keyed to motor shaft and provided with machined slides to receive the slippers (S), and with fulcrum pins (F) to carry the trip levers (L).

The slippers (S) are of cast iron, machined to suit the slides in body (B), and are shod with 'Ferodo' friction surface linings and fitted with pins (P) to carry rollers (A).

The trip levers (L) are cam-shaped to bear against the rollers (A) and hold the slippers (S) away from the friction rim (R). They are held in position by the springs shown, the tension on which may be adjusted by means of the adjusting bolts (T).

The action of the clutch is as follows:—When the motor has reached a certain speed, the centrifugal force of the levers (L) overcomes the tension of the springs, causing the levers to open outwards, and thereby releasing the slippers (S), which move outwards against the friction rim (R) and automatically pick up the load.

When the current is cut off, the levers are gradually returned to their former position by means of the springs, and withdraw the slippers from contact with the friction rim.

The clutches are *designed to engage at 75 per cent. of normal speed*, but the springs are provided with adjusting bolts to allow the slippers to come into operation at any desired speed between 50 per cent. and 90 per cent. of normal speed.

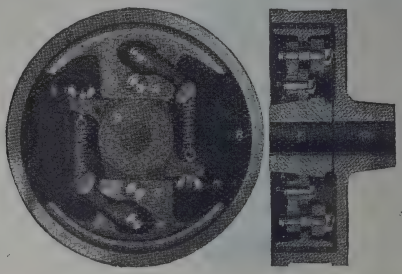


FIG. 42.

By this design of clutch *full advantage of the weight of the slippers* for the required frictional contact is secured, *thereby enabling the various parts to be as light as possible, and reducing the time of rubbing of the friction surfaces to a minimum.*

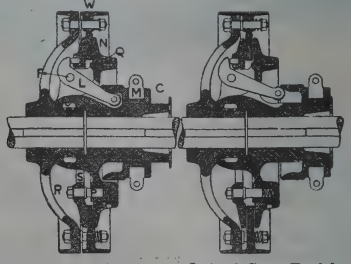
These clutches are made by Frank Wigglesworth & Co., Ltd., in sizes from 6 ins. to 30 ins. and capable of transmitting from 0·7 to 500 horse-power at a speed of 500 revolutions per minute. The power increases almost in proportion to the cube of the speed and fourth power of the size.

HIGH-SPEED DISC FRICTION CLUTCH.

The general design allows this type of clutch, fig. 43, to be run at very high speeds, and forms an ideal clutch in connection with electrical machines.

End pressure is not required to keep the clutch in or out of gear, and all projecting parts are shrouded.

Its construction is as follows:—



In Gear Position. Out of Gear Position.

FIG. 43.

The body (B) is a cast-iron circular disc, with boss bored and keywayed to suit shaft, and having lugs cast on the inside, forming fulcrums for levers (L).

Driving pins (*p*) are fitted into the body (B), which carry the inside annular friction ring (S).

The levers (L) are of steel, and having friction rollers fitted to one end to allow of easy movement of sliding collar over them.

The sliding collar is of cast iron, having extended circular flange, the inside being tapered in order to depress the ends of levers (L). It is complete with cast-iron clams (M), which receive the momentary pressure from operating lever for putting clutch in and out of gear. A spring grease lubricator is fitted to clams (M).

The shell (R) is a cast-iron circular bell-shaped disc, with boss bored and keywayed to suit shaft, and to its extreme diameter the annular disc is fixed.

The internal boss (J) is bushed with gun-metal, and forms a bearing for the extended boss of body (B), thereby ensuring perfect alignment of clutch. Grease lubricators are fitted to this bearing.

Its action is as follows:—

When the clutch is put into gear, the sliding collar (C) is moved (by means of operating lever) from the out-of-gear position (shown by dotted lines) to position shown on drawing, and depresses the ends of levers (L), their opposite ends pressing hard on the annular ring (S) gripping the annular disc against the friction face of adjusting ring (N).

When the clutch is put out of gear the springs shown force the rings clear of the ring (W), which also moves clear of the friction face on ring (N), as shown by out-of-gear position.

Adjustment is made by rotating the ring (N), and afterwards locked by locking screw (Q).

These clutches are made by Frank Wigglesworth & Co., Ltd., in sizes from 12 ins. to 46 ins., which are capable of transmitting from 3 to 1,200 horse-power at speeds from 10 to 1,500 revolutions per minute. The power transmitted varies directly as the revolutions.

Coil Clutch.

The clutch shown in fig. 44 consists of a bushed driving plate (*c*) mounted on a shaft and having lugs cast on its face to engage the transmitting coil (*a*). A drum (*b*) of chilled material is keyed to the shaft adjacent to the driving plate. The transmitting coil (*a*), of special steel, having a highly-finished internal surface, is mounted on the drum and has one end engaged with the driving plate lugs, whilst the other is free to be operated. A sliding member (*d*) is mounted on the shaft beyond the drum, its function being to pull the free end of the coil through a steel lever (*e*), which is pivoted on an extension of the driving plate (*c*), and engages the free end of the coil.

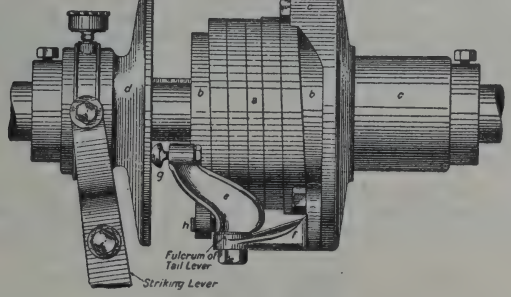


Fig. 44.

In engaging the clutch, the plate (*d*) is moved towards the drum, thereby tilting the lever (*e*) and tightening the free end of the coil, which is contracted and gradually tightens on to the drum (*b*), causing the different members of the clutch to be locked together. The action is similar to that of a man tightening the free end of a rope on a revolving capstan.

The clutch, made by the Coil Clutch Co. Ltd., Johnstone, is simple in construction and compact, and is used in colliery haulage gear, heavy cranes, and rolling mills.

The Wallace Patent Centrifugal Multi-groove Clutch.

(*British Hele-Shaw Patent Clutch Company Ltd., Oldham.*)

This clutch (fig. 45) transmits power by the action of slipper blocks acted upon at speed by centrifugal force, thus creating frictional contact with the interior face of the clutch, and developing driving power rapidly as the speed increases. The patent lies in the use of grooves on the friction surfaces, giving superior grip over flat faces, and also in the fact that lubricant is introduced, which preserves the wearing surfaces, and ensures smooth action and long service.

The clutch consists of a spider—mounted on the motor as the driver portion—which carries on radial guides four movable slippers, which, by centrifugal force, transmit the drive to the case with its dust- and oil-tight cover. The clutch is spring-controlled.

When the clutch begins to drive at just over three-quarter speed the oil collects in special groove extensions, leaving the friction surfaces practically dry at full speed, thus preventing further slippage. For quick pick-up little oil is used, for later pick-up more oil.

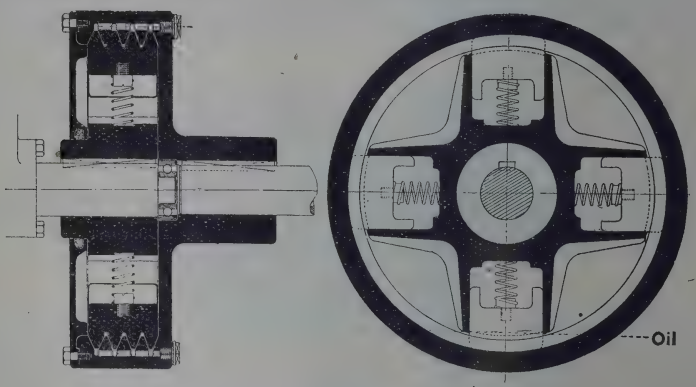


FIG. 45.

The great advantage of the clutch lies in the fact that the motor can start under no load, and as speed is developed the load is applied gradually and automatically, thus reducing strain and wear and tear. The use of the clutch on three-phase motors of the squirrel-cage type cuts down the initial heavy draught on the line and so facilitates starting.

These clutches are particularly adaptable and valuable in starting up individually driven machines under full load. In these cases one part of a centrifugal coupling clutch is mounted on the armature shaft and the other part is mounted on the machine shaft, thus giving perfect connection, reduced starting strain, and driving at full speed like a solid coupling.

For group driving, clutches built within a pulley and mounted on the motor shaft give perfect connection where belt or rope pulley is required. In these cases the clutch case generally forms the pulley, the whole running on ball bearings.

The clutches are made in sizes from 4 ins. to 36 ins., or as required.

Magnetic Clutches.

These consist of two members—the field or driving member, which carries the magnetising winding, and the armature, or driven member. In the design, by the Igranic Electric Co., shown in fig. **46**, these members are carried on the face of annular spring steel plates attached to the

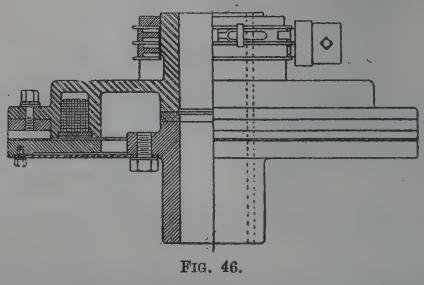


FIG. 46.

driving and driven hubs. Normally the members are held apart, but when the current is supplied to the windings of the field member they are magnetically drawn together, the flexibility of the spring steel plates allowing the necessary movement. The power is then transmitted entirely by

the friction. The engaging surface, fitted externally to the poles of the field member, is composed of woven asbestos and brass wire, and stands proud of the pole faces so as to prevent these coming into contact with the armature. This type of clutch can pick up the load gradually, and can be controlled from remote positions.

Note on Clutches.

In selecting a clutch, attention must be given to the starting torque required in overcoming the inertia of the part, means of stopping quickly in case of accident, and the effect of centrifugal forces on engaging parts in retarding their release or in throwing the members out of action.

Friction Surfaces.

In friction clutches the mating surfaces are sometimes of special materials in order to increase the grip. These materials are usually secured to the body of the clutch by pins, and trouble occasionally arises through the pins shearing. Preferably the fabric should be secured to the body with brass bolts. For low speeds and light pressures wooden surfaces are very suitable, but under opposite conditions the wood becomes charred. When the mating surfaces are of steel one of these should be casehardened. Steel should not be used with cast iron unless the latter has been chilled. In general, close-grained cast iron on cast iron gives the best results. A soft material should not be used with a metal which tends to crumble, as hard particles of the latter get imbedded in the former, and severe scoring results.

(*Professor Dempster Smith.*)

Ferodo Friction Linings.

(*Ferodo Ltd., Chapel-en-le-Frith.*)

Ferodo Brake and Clutch Linings are fabrics of distinct forms, i.e. fibre cotton base, and bonded asbestos, the object and use of each being to provide a surface which in rubbing contact with metal gives a high coefficient of friction which rises with the temperature and is not physically affected by the presence of oil or water—in fact, a damp or greasy surface improves the durability of Ferodo friction linings, but decreases their frictional value in proportion to the quantity and nature of the lubricant present.

Tests on Ferodo fibre prove the average coefficient of friction to be 0·5; the maximum obtained being 0·7—the temperature limit for the fabric being about 230° F.; the material has great mechanical strength and wearing qualities.

Tests on Ferodo bonded asbestos prove the average coefficient of friction to be 0·3 and that the efficiency of the fabric is maintained at any temperature up to 500° F. (260° C.).

Ferodo Fabrics form linings which do not score or seize under any speed or pressure and allow a smooth gradual engagement against dry metal surfaces. The high coefficient of these materials renders very fine angle cones unnecessary. The angles recommended range between 24° and 34° (included).

For flat-plate clutches, Ferodo Friction Linings are made up in the form of circular discs, either jointless or with a close butt joint stretched with fine soft metal wire.

Chekko Friction Linings.

(*Cresswell's Asbestos Co., Ltd., Wellington Mills, Bradford.*)

These linings are made from 100 per cent. pure long asbestos fibre woven into brass wire in one solid piece. They are made in sheet from 2 in. to 12 in. wide, and in thickness varying from $\frac{3}{8}$ in. to $\frac{3}{4}$ in. The sheeting when cut to the required size is fastened to wood foundation blocks by means of counter-sunk brass screws, which screw into metal nuts, the latter lying in slots cut in the wood. In the case of a steel band being lined with the material, screws pass through the band and screw into nuts on the outside of the band, or aluminium rivets may be used for the purpose.

The average coefficient of friction of Chekko is given by the makers as 0·35 against cast iron or steel.

Flat-plate Chekko clutch rings are made up in the stitched joint circular rings or discs hydraulically moulded, and also supplied cut from sheets.

SECTION XIX

PART II

CHAIN GEARING.

(Association of British Driving Chain Manufacturers (A.B.D.C.M.).)

[NOTE.—The British Standard Dimensions for Steel Roller Chains and chain wheels and the clauses relating thereto, contained in Specification No. 228—1925, were adopted by the British Engineering Standards Association from a report presented by the Association of British Driving Chain Manufacturers, which co-operated throughout in the preparation of the Specification.]

The adaptability and high efficiency of chain gearing for the transmission of power is now extensively recognised. Although the advantages of chain driving are not yet fully appreciated, the attention of power users and engineers when considering methods of transmission should be directed towards embodying chain drives of suitable type.

Although belts, ropes, and the several forms of toothed wheel gearing will always have their place, chain drives can in many cases be employed with greater advantage. Chain gearing ensures a positive transmission, at the same time affording a beneficial measure of elasticity. The average efficiency of a well-designed chain drive when new is 99 per cent., and the loss of power will not exceed about 2 per cent. at the end of its useful life. Thus, chain gearing has a higher maintained efficiency than any other form of transmission.

The initial tension required with a belt is unnecessary with a chain, and the bearing friction due to it is therefore eliminated.

Chain drives can be used under very varying conditions in respect of:—(*a*) Speed ratios, which can be readily modified; (*b*) centres of shafts (chain gearing can be used at centres which are too long for spur gear and too short for belts or ropes); (*c*) nature of the load; (*d*) temperature; (*e*) humidity; (*f*) power to be transmitted.

TYPES OF CHAINS.

The two general types of power transmission chains are shown by figs. 1 and 2. Speaking generally, the Inverted Tooth type is employed where silence is a consideration, and the Bush Roller type for general applications.

FIG. 1.—Inverted Tooth Type.

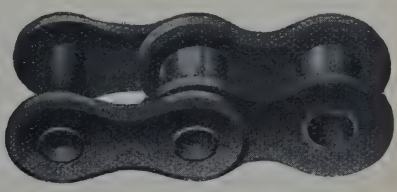


FIG. 2.—Roller Type.

Desirable Conditions for Application of Chain Gearing.

The following statement, prepared by the Association of British Driving Chain Manufacturers, shows the approximate limits that usually obtain in the economical application of chain gearing; where proposed drives are not within these limits, the chain manufacturer should be consulted.

Gear Ratio (maximum): Roller Type, 7 : 1; Inverted Tooth Type, 7 : 1.

Chain Speed.

Normal maximum, assuming the number of teeth is 19.

Pitch.	Roller type. Feet per min.	Inverted tooth type. Feet per min.
Up to ¼ in. pitch	1,000	1,500
⅜ in. and ½ in. „	1,000	1,400
1 in. and 1½ in. „	900	1,350
1½ in. and 1¾ in. „	900	1,300
2 in. and 2½ in. „	800	1,250
3 in. „	700	1,200

Number of Teeth in Wheels.

Minimum	Roller type 17	Inverted tooth type 19
Maximum	„ 120	„ „ „ 134

This applies only to inverted tooth chains with a profile based on a 60° link face angle.

In cases where the chain speed is substantially less than shown above, for any given pitch, the number of teeth in the pinion may be reduced, but it must be borne in mind that within limits the greater the number of teeth in pinion the longer will be the life, and the higher the efficiency, of the drive.

Centre Distance between Shafts.

The following expression gives limiting values of centre distance for drives running under ordinary conditions with steady loads, at chain speeds between 1,500 and 300 feet per minute:

$$\text{Maximum centres (in feet)} = 20 \sqrt{\frac{\text{teeth in wheel}}{\text{r.p.m. of pinion}}}$$

Where the chain speed is less than 300 feet per minute, the centre distance should not exceed:

$$\tfrac{1}{3} \sqrt{\text{Pitch} \times \text{teeth in wheel} \times \text{teeth in pinion.}}$$

The values will hold up to inclinations of 60° when the wheel is above the pinion, and up to inclinations of 45° when the pinion is above the wheel; for greater inclinations than these, for impulsive or irregular loading, or where any special considerations enter into the installation or running of a drive, the chain manufacturer should be consulted.

(*a*) *Desirable Minimum.*—The centre distance should be such that the arc of contact between the chain and any wheel is not less than 120°, and with at least 7 teeth in engagement.

(*b*) *Adjustment.*—It is advisable to provide suitable means for the adjustment of the centre distance, and the normal minimum amount of this adjustment should be 1½ times the pitch of the chain.

In some cases adjustment can only be obtained by the use of a jockey wheel, which must engage with the slack side of the chain and have machine-cut teeth.

(*c*) *Chain Length.*—It is desirable that the number of pitches in the chain should not be a multiple of the number of the teeth in either the pinion or the wheel.

Disposition of Drives and Direction of Rotation.

It is preferable that the positions of the driving and driven shafts shall be such that the slack or non-driving free length of the chain will not be inclined at a greater angle than 60° to the horizontal, otherwise adjustment will have to be made frequently.

Drives should be so arranged in relation to the direction of rotation of the shafts that the tight or driving free length of the chain will be uppermost.

Subject to the foregoing, it is preferable when chain cases are fitted that the pinion should be above the wheel.

Clearance.

The normal allowance for clearance over the back of a chain mounted upon a wheel is an amount equal to half the pitch of the chain. When, however, a chain case is fitted an extra amount of clearance above this should be allowed.

The clearance for sag should be greatest at a point somewhere midway along the free portions of the chain, and this clearance should be allowed for both above and below each free portion of chain.

The minimum amount of clearance is

$$\frac{\text{Centre distance between wheels (in inches)}}{12} + \tfrac{1}{4} \text{ in.}$$

The width inside a chain case, and therefore the amount of clearance at the sides of the chain, will frequently be determined by the width of the wheel boss; where this condition does not obtain, and for drives where no case is fitted, a minimum clearance of $\frac{3}{8}$ in. plus $\frac{1}{8}$ in. per foot of centre distance should be allowed.

The clearance between the rivets of inverted tooth chains running in multiple should be $\frac{3}{8}$ in. for pitches up to and including $\frac{3}{4}$ in.; for 1 in. pitch and upwards allow $\frac{1}{2}$ in.

Lubrication.

The provision of chain cases is advisable for all drives where the chain speed exceeds 1,000 ft. per minute, and for drives below this speed when the surrounding air is charged with particles which may adhere to the chain.

Efficient lubrication of chains is of the utmost importance and is, needless to say, more easily obtained where drives are encased.

Drives with a chain speed in excess of 1,350 ft. per minute, those employing a wide chain, or more than one chain, should be fitted with the sump type of chain case, and a pump to deliver oil to the working face of the chain. For lower speeds and narrow chains it will be sufficient to provide an oil-bath case and allow the chain to dip into the oil whilst running.

A drip feed lubricator delivering oil to the inner face of inverted tooth chains, or between the inner and outer plates of roller chains, may be used when the chain speed is not greater than 1,000 ft. per minute. A splash guard should then be fitted to prevent the oil being thrown on to adjacent objects. One drip should be provided for each 3 in. width of inverted tooth chain, and 2, 3, or 4 drips for roller chains, depending upon whether a single, a duplex, or a triplex chain is used.

Erection.

Chain wheels must be rigidly mounted on shafts which are parallel and truly horizontal, and the teeth of the wheels must be in correct alignment.

Where possible, wheels should be placed close to bearings, and must run true on their shafts.

Care should be taken that the chain connection is properly secured.

Before starting up the drive the chain should be lubricated and centres adjusted to take up any undue slack. No tension should be put upon the chain.

Maintenance.

Periodic examination is advisable to ascertain:

(*a*) If correct alignment of the wheels has been maintained; (*b*) if undue wear is taking place; (*c*) if adjustment of chain is needed; (*d*) if the chain requires cleaning; (*e*) if lubrication is being effectively carried out.

Improved service usually results when chains are removed from time to time for cleaning. They should be washed with paraffin and, after draining, thoroughly lubricated before being again used.

When replacing worn chains by new ones always ascertain that undue wear has not taken place on the teeth of the wheels.

A.B.D.C.M. STANDARDS FOR ROLLER CHAINS.
'SHORT PITCH' SERIES. (0·375 – 0·75 in. PITCHES.)

Association Chain No.		Pitch.	Max. Roller Diam.	Min. Width between Plates.		Tooth Width.			
						Narrow.		Wide.	
Narrow.	Wide.			Narrow.	Wide.	Max.	Min.	Max.	Min.
3 N	3 W	0·375($\frac{3}{8}$)	0·250	0·155	0·230	0·141	0·134	0·213	0·204
Cycle Sizes.		0·5($\frac{1}{2}$)	0·305	0·130	0·192	0·117	0·110	0·176	0·168
4 N	4 W	0·5($\frac{1}{2}$)	0·335	0·205	0·305	0·189	0·181	0·285	0·275
5 N	5 W	0·625($\frac{5}{8}$)	0·400	0·255	0·380	0·237	0·228	0·356	0·345
6 N	6 W	0·75($\frac{3}{4}$)	0·475	0·310	0·460	0·290	0·279	0·433	0·420

All dimensions are in inches.

1·0–3·0 PITCHES. 'SHORT PITCH' SERIES. (1·0 in. to 3·0 in. PITCHES.)

Chain No.	Pitch.	Maximum Roller Diam.	Minimum Width between Plates.		Tooth Width.			
					Narrow.		Wide.	
			Narrow.	Wide.	Max.	Min.	Max.	Min.
Refer to individual members' catalogues.	1·0	0·625	0·500	0·670	0·472	0·458	0·635	0·618
	1·25	0·750	0·560	0·770	0·530	0·514	0·731	0·712
	1·5	0·850	0·625	0·875	0·592	0·575	0·830	0·810
	—	1·000	—	1·000	—	—	0·952	0·928
	1·75	1·000	0·750	1·000	0·712	0·693	0·952	0·928
	—	1·100	0·875	1·220	0·832	0·810	1·163	1·135
	2·0	1·150	0·875	1·220	0·832	0·810	1·163	1·135
	2·25	1·350	—	1·350	—	—	1·288	1·257
	2·5	1·550	—	1·500	—	—	1·432	1·398
	3·0	1·900	—	1·800	—	—	1·720	1·680
	—	2·000	—	1·500	—	—	1·432	1·398

All dimensions are in inches.

NOTE.—The narrow series is not recommended for general use.

TOOTH CUTTER FORMS.

For the convenience of chain users and to ensure complete interchangeability, the Association has standardised tooth forms which, while not being identical with any of the existing forms,

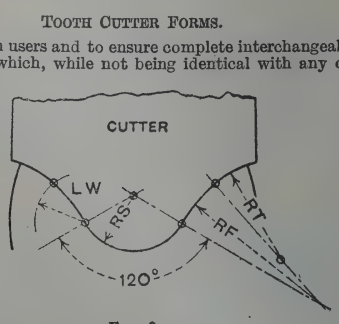


FIG. 3.

incorporate the essential features of each. The general construction is shown in fig. 3. It consists of a *roller seating*, *working faces*, and *topping curves*, all of which are arcs of circles.

The angle of 120° subtending the roller seating has its origin at the centre of the diameter of the roller seating. The working faces are comparatively flat curves tangential to the roller seating, and the topping curves are tangential to the working faces and of such a radius as to give a suitable height of tooth. The dimensions of tooth forms for the Association Standard Chains are given in the following table:

Roller Diameter.	Cutter No.	No. of Teeth to Cut.	R.S. Radius of Roller Seating.	R.F. Radius of Working Face.	L.W. Length of Working Face.	R.T. Radius at Top of Tooth.
0·250	1	9–12	0·126	0·45	—	0·45
	2	13–19	0·126	1·125	0·12	0·18
	3	20 and over	0·126	3·825 min.	0·154 min.	0·052 max.
0·335	1	9–12	0·169	0·6	—	0·6
	2	13–19	0·169	1·5	0·16	0·24
	3	20 and over	0·169	5·1 min.	0·205 min.	0·07 max.
0·400	1	9–12	0·202	0·75	—	0·75
	2	13–19	0·202	1·875	0·20	0·3
	3	20 and over	0·202	6·375 min.	0·256 min.	0·087 max.
0·475	1	9–12	0·240	0·9	—	0·9
	2	13–19	0·240	2·25	0·24	0·36
	3	20 and over	0·240	7·65 min.	0·307 min.	0·105 max.
0·625	1	9–12	0·316	1·2	—	1·2
	2	13–19	0·316	3·0	0·32	0·48
	3	20 and over	0·316	10·2 min.	0·41 min.	0·14 max.
0·750	1	9–12	0·379	1·44	—	1·44
	2	13–19	0·379	3·6	0·384	0·576
	3	20 and over	0·379	12·24 min.	0·492 min.	0·168 max.
0·850	1	9–12	0·429	1·632	—	1·632
	2	13–19	0·429	4·08	0·435	0·653
	3	20 and over	0·429	13·872 min.	0·558 min.	0·190 max.
1·000	1	9–12	0·505	1·8	—	1·8
	2	13–19	0·505	4·5	0·48	0·72
	3	20 and over	0·505	15·3 min.	0·615 min.	0·21 max.
1·100	1	9–12	0·556	2·1	—	2·1
	2	13–19	0·556	5·25	0·56	0·84
	3	20 and over	0·556	17·85 min.	0·717 min.	0·245 max.
1·150	1	9–12	0·581	2·208	—	2·208
	2	13–19	0·581	5·52	0·589	0·883
	3	20 and over	0·581	18·768 min.	0·754 min.	0·258 max.
1·350	1	9–12	0·682	2·592	—	2·592
	2	13–19	0·682	6·48	0·691	1·037
	3	20 and over	0·682	22·032 min.	0·886 min.	0·302 max.
1·550	1	9–12	0·783	3·0	—	3·0
	2	13–19	0·783	7·5	0·80	1·2
	3	20 and over	0·783	25·5 min.	1·025 min.	0·35 max.
1·900	1	9–12	0·960	3·6	—	3·6
	2	13–19	0·960	9·0	0·96	1·44
	3	20 and over	0·960	30·6 min.	1·23 min.	0·42 max.
2·000	1	9–12	1·010	3·6	—	3·6
	2	13–19	1·010	9·0	0·96	1·44
	3	20 and over	1·010	30·6 min.	1·23 min.	0·42 max.

All dimensions are in inches.

Wheels.

It is of the utmost importance that chain wheels should have their teeth accurately machined with cutters of correct form. Pinions should preferably have an odd number of teeth to equalise wear on the chain.

(*a*) *Section Profile of Teeth for Roller Chains.*—Chain wheel blanks should be machined as indicated in fig. 4.

Roller Chain Wheels Tooth Profile.

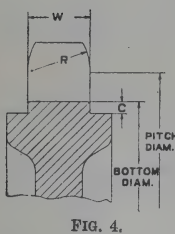


FIG. 4.

Pitch diam. . . .	= Chain pitch cosec $\frac{180°}{\text{Number of teeth.}}$
Bottom diam. max.. .	= Pitch diam. minus max. roller diam.
Tolerance on bottom diam.	= Minus 0·001 in. per 1 in. pitch diam., but in any case to be within the following limits: min., 0·005 in.; max., 0·020 in.
W (mean width of tooth)	= (95 % of width between chain inner plates), minus 0·01 in.
Tolerance on W . . .	± (1 % of width between chain inner plates), plus 0·002 in.
R (Tooth side radius) .	= Roller diameter.
C (minimum shroud depth)	= $\frac{\text{Chain pitch} - \text{R}}{2} + \frac{0{\cdot}8 \text{ pitch}}{\text{Number of teeth.}}$

Measuring Loads.

To ensure interchangeability of chains it is necessary that measurements be taken under similar conditions.

It is, therefore, necessary that chains be measured before oiling, but after the test load of one-third the breaking strength has been applied, and that at the time of measurement the chain should be supported horizontally throughout its entire length.

As the necessary load should bear a definite relation to the breaking load of the chain, and inasmuch as actual breaking loads, in practice, are approximately in the ratio of pitch^2, the measuring load is taken as equal to (Pitch^2 × 112) lbs. For the 'long pitch' series the measuring loads are the same as for the 'short pitch' series of corresponding strength.

Measuring Length and Tolerance.

The actual length of test chains for measuring purposes is taken as 50 pitches for all pitches of chain, and a tolerance of 0·1 per cent. per pitch per length of 50 pitches is allowed in excess of the theoretical length.

'Long Pitch' Series.

A standard 'long pitch' series of chains is formed from the standard series by using rollers, bushes, and rivets of a given pitch, but with inner and outer plates having twice the pitch.

Profiles of Teeth.

As for standard series of roller chains, but based on half the nominal pitch of a long pitch chain.

Cutters.

As for standard series of roller chains. (That is, for a given roller diameter a standard cutter may be employed for both standard or long pitch chains.)

Use all the power you pay for

NO power waste by slip or friction occurs with Chain Drives and they remain unaffected by atmospheric conditions. First cost is low, maintenance costs are negligible, and erection is a simple matter for any works engineer.

Machines fitted with Renold Chain Drives are enabled to run at high and unvarying speeds with absence of snatch or vibration.

RENOLD STANDARD DRIVES

1 TO 100 H.P. CHAIN DRIVES
DELIVERED FROM STOCK

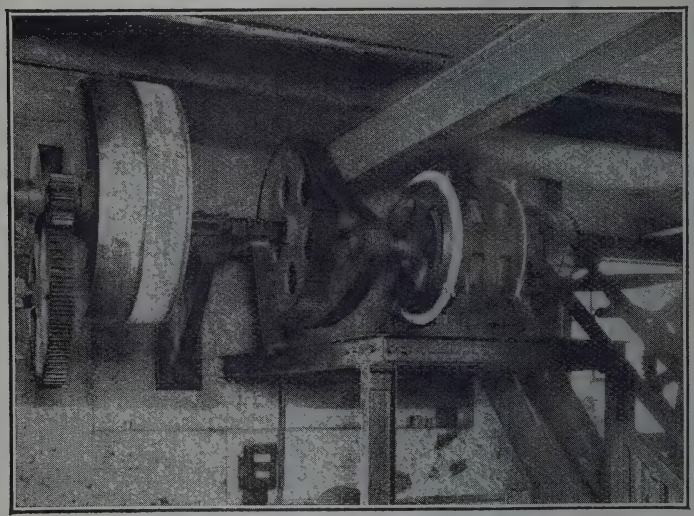
HANS RENOLD LIMITED
DIDSBURY, MANCHESTER

F. 1002

Westinghouse Morse

ROCKER-JOINT

CHAIN DRIVES



A 25 H.P. WESTINGHOUSE MORSE CHAIN DRIVE DESIGNED FOR THE JOB

IT COSTS NO MORE TO HAVE A DRIVE ACCURATELY DESIGNED

and with the Morse Rocker-Joint Chain you ensure ABSENCE of SLIDING FRICTION AT THE JOINT—hence highest sustained efficiency with great durability.

Have you had our Handbook?

THE WESTINGHOUSE MORSE CHAIN COMPANY LIMITED.
(Ref.K.), LETCHWORTH, HERTS.

Chain Wheels.

Pitch Diameters.

The following table gives correct pitch diameters (P.D.) for all types of chain having a pitch of 1 inch. The pitch diameters for wheels to suit other pitches of chain are directly proportional to the pitch of the chain.

No. of Teeth.	P.D.	No. of Teeth.	P.D.	No. of Teeth.	P.D.	No. of Teeth.	P.D.
9	2·924	32	10·202	55	17·517	78	24·835
10	3·236	33	10·520	56	17·835	79	25·153
11	3·549	34	10·838	57	18·153	80	25·471
12	3·864	35	11·156	58	18·471	81	25·790
13	4·179	36	11·474	59	18·789	82	26·108
14	4·494	37	11·792	60	19·107	83	26·426
15	4·810	38	12·110	61	19·425	84	26·744
16	5·126	39	12·428	62	19·744	85	27·063
17	5·442	40	12·746	63	20·062	86	27·381
18	5·759	41	13·063	64	20·380	87	27·699
19	6·076	42	13·381	65	20·698	88	28·017
20	6·392	43	13·700	66	21·016	89	28·335
21	6·710	44	14·018	67	21·335	90	28·654
22	7·027	45	14·336	68	21·653	91	28·972
23	7·344	46	14·654	69	21·971	92	29·290
24	7·661	47	14·972	70	22·289	93	29·608
25	7·979	48	15·290	71	22·607	94	29·927
26	8·296	49	15·608	72	22·926	95	30·245
27	8·614	50	15·926	73	23·244	96	30·563
28	8·931	51	16·244	74	23·562	97	30·881
29	9·249	52	16·562	75	23·880	98	31·200
30	9·567	53	16·880	76	24·198	99	31·518
31	9·885	54	17·198	77	24·517	100	31·836

The Westinghouse Morse Rocker-Joint Chain.

(*The Westinghouse Morse Chain Co. Ltd.*)

These chains, fig. 5, form an important departure in silent chain driving. Until their introduction the principal objection to chains was found in the rapid wear and consequent stretch. This is necessarily present with all chains having round joint-pins, friction due to sliding surfaces

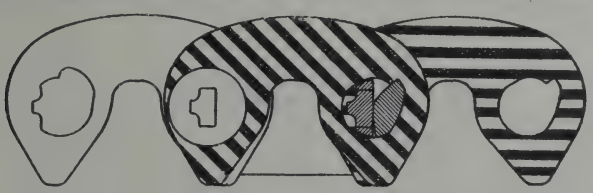


Fig. 5.

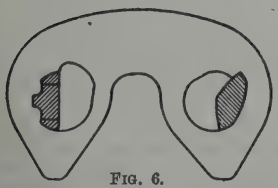


Fig. 6.

Fig. 7.

being unavoidable. A very ingenious feature is the joint, which consists of two pieces, fig. 7, i.e. the rocker and seatpin, the former being provided with a knife edge which rocks on the face of the latter when the joint passes on or off the wheel. The bearing surface extends throughout the width of the chain. The pins for all practical purposes are an integral part of the link, fig. 6,

hence the only motion which takes place at the joint is a rocking movement. This ensures absence of sliding friction, which means the reduction of wear at the joint to the minimum, with consequent maximum life and efficiency. The shape of the tooth permits silent running, even under high speed.

Another important departure in the Westinghouse Morse chain drive is that represented by the No. 25 reinforced type chain—shown in fig. 8. In this construction the outer links are all knit together by short rivets and spacing pieces, adding very considerably to the material strength of the chain; also distributing the load more equally, and enabling the chain to run at higher speeds than has hitherto been possible.

The greatest ratio of gearing under favourable conditions with the Westinghouse chains is 10 : 1. The following table gives the various pitches manufactured and the maximum permissible R.P.M. (revolutions per minute) for each:

Max. R.P.M. .	4,000	2,000	1,600	1,400	1,100	1,000	800	700	600	500	400	250
Pitch in ins. .	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	·9	1	1·2	1·25	1·5	1·75	2	3

The chain width depends on the speed, determined as follows:—

$$\text{Speed} = \frac{N \times P \times \text{R.P.M.}}{12} = \text{F.P.M.} \qquad \text{Load} = \frac{\text{H.P.} \times 33{,}000}{\text{F.P.M.}} = \text{total load on chain in lbs.}$$

where,

H.P. = Maximum horse-power;
N = No. of teeth;
P = Circular pitch in inches;
F.P.M. = Feet per minute.

This total load divided by the load per inch width advised gives the width of the chain.

Average permissible loads per inch in width for general machine-shop drives are as follows:—

Lbs. per inch wide .	65	85	105	125	160	200	220	240	300	400	500	800
Pitch in ins. . .	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	·9	1	1·2	1·25	1·5	1·75	2	3

Good chain speeds or average machine-shop drives are from 1,200 to 1,500 ft. per min.

As no friction due to sliding surfaces takes place, however, Westinghouse chains can be run at speeds which would, owing to centrifugal force, throw off all lubricant, and drives of this make are now transmitting light loads satisfactorily at 3,000 ft. per min. chain speed.

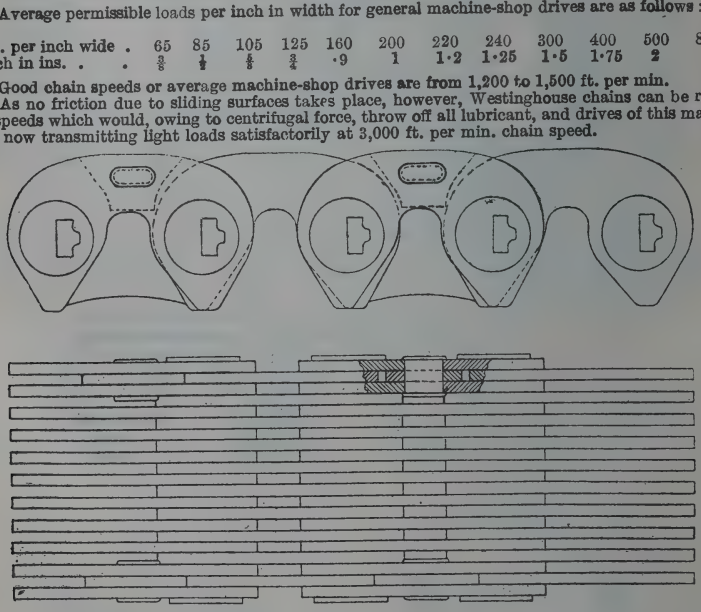


FIG. 8.

In view of its special joint construction, the Westinghouse Morse rocker-joint chain is claimed to surpass all others in point of size and strength, and the fact of being able to manufacture so large a size of silent chain as the 3-in. pitch in widths up to 24 ins. has resulted in such chain drives being applied for transmissions up to even 5,000 h.p. in a single drive.

The Westinghouse Morse chains are made in nineteen different types and pitches by the Westinghouse Morse Chain Co. Ltd., The Chaineries, Letchworth, Herts, and single drives can be furnished for transmitting from $\frac{1}{4}$ h.p. up to 1,000 h.p.

SECTION XIX

PART III

TOOTH GEARING.—WORM GEARING—VARIABLE-SPEED GEAR—LINK MOTION.

The word 'diameter,' when applied to gears, is always understood to mean the pitch diameter.

Diametral pitch of the gear is the number of teeth to each inch of its pitch diameter.

If a gear has 40 teeth and the pitch diameter is 4 ins., there are ten teeth to each inch of the pitch diameter, and the diametral pitch is 10, or in other words, the gear is 10 diametral pitch.

Circular pitch is the distance from the centre of one tooth to the centre of the next tooth, measured along the pitch circle.

If the distance from the centre of one tooth to the centre of next tooth, measured along the pitch circle, is $\frac{1}{4}$ in., the gear is $\frac{1}{4}$ in. circular pitch.

The diametral pitch given, to obtain the circular pitch divide 3·1416 by the diametral pitch.

If the diametral pitch is 4, divide 3·1416 by 4, and the quotient, ·7854 in., is the circular pitch.

The circular pitch given, to obtain the diametral pitch divide 3·1416 by the circular pitch.

If the circular pitch is 2 ins., divide 3·1416 by 2, and the quotient, 1·5708, is the diametral pitch.

The number of teeth and the diametral pitch given, to obtain the pitch diameter divide the number of teeth by the diametral pitch.

If the number of teeth is 40, and the diametral pitch 4, divide 40 by 4, and the quotient, 10, is the pitch diameter.

The number of teeth and the diametral pitch given, to obtain the whole diameter or size of blank of gear, add 2 to the number of teeth and divide by the diametral pitch.

If the number of teeth is 40, and the diametral pitch is 4, add 2 to the 40, making 42, and divide by 4; the quotient, $10\frac{1}{2}$, is the whole (or outside) diameter of the gear or blank.

The number of teeth and the diameter of the blank given, to obtain the diametral pitch add 2 to the number of teeth and divide by the diameter of the blank.

If the number of teeth is 40 the diameter of the blank is $10\frac{1}{2}$ ins., add 2 to the number of teeth, making 42, and divide by $10\frac{1}{2}$; the quotient, 4, is the diametral pitch.

The pitch diameter and the diametral pitch given, to obtain the number of teeth multiply the pitch diameter by the diametral pitch.

If the diameter of the pitch circle is 10 ins., and the diametral pitch is 4, multiply 10 by 4 and the product, 40, will be the number of teeth in the gear.

The whole diameter of the blank and the diametral pitch given, to obtain the number of teeth of the gear multiply the diameter by the diametral pitch and subtract 2.

If the whole diameter is $10\frac{1}{2}$ and the diametral pitch is 4, multiply $10\frac{1}{2}$ by 4, and the product, 42 less 2, or 40, is the number of teeth.

The thickness of a tooth at the pitch line is found by dividing the circular pitch by 2, or divide 1·57 by the diametral pitch.

If the circular pitch is 1·047 inch, or the diametral pitch is 3, divide 1·047 by 2, or 1·57 by 3, and the quotient, ·523 inch, is the thickness of tooth.

The whole depth of a tooth is found by dividing 2·157 by the diametral pitch.

If the diametral pitch of a gear is 6, the whole depth is 2·157 divided by 6, equals ·3595.

The whole depth of a tooth is about $\frac{11}{16}$, or exactly 6·866 of the circular pitch.

If the circular pitch is 2, the whole depth of tooth is about $\frac{11}{16}$ of 2 ins., or $1\frac{3}{8}$ in. nearly.

The distance between the centres of two gears is found by adding the number of teeth together, and dividing half the sum by the diametral pitch.

If two gears have 50 and 30 teeth respectively, and are 5 pitch, add 50 and 30, making 80, divide by 2, and then divide the quotient, 40, by the diametral pitch, 5, and the result, 8 ins., is the centre distance. *(Brown and Sharpe.)*

The foregoing definition of the *diametral pitch*, which may also be expressed as the number of teeth in the wheel divided by the pitch circle diameter, is very commonly used. Others again understand the diametral pitch to be the reciprocal of the above, viz. pitch circle diameter divided by the number of teeth, and this definition appears to be the most logical one. Where the latter definition is used, the quantity, 'number of teeth divided by the diameter,' is known as the 'pitch number,' and is written, '4's pitch,' or '5's pitch,' as the case may be.

On the continent of Europe the 'Module' is commonly adopted. All dimensions are in millimetres, and the module is the addendum or the pitch diameter in millimetres divided by the

number of teeth in the wheel. The pitch diameter is the module multiplied by the number of teeth in the wheel.

Pitch Line or Circle.—The circle upon which the pitch is measured, and the circumference by which the diameter, or the velocity of the wheel, is measured.

Chordal Pitch.—A straight line drawn from the centres of two contiguous teeth upon the pitch line.

Line of Centres.—The line between the centres of two wheels.

Radius of a wheel.—The semi-diameter running to the periphery of a tooth.

Pitch Radius.—The semi-diameter running to the pitch line.

Length of a Tooth.—The distance from its base to its extremity.

Depth of a Tooth.—The distance from face to face, measured at the pitch line.

Breadth of a Tooth.—The distance between the sides.

A Trundle, Lantern, or Wallover—that is, a pinion constructed of round bars or solid cylinders set in two discs—can be operated uniformly by a wheel with any number of teeth, but must have at least 8 staves.

The number of teeth in each pinion should preferably be to the number of teeth in its wheel as 1 : 3·59, and the ratio should never exceed 1 : 6.

When a *Pinion is driven by a wheel*, the number of teeth in the pinion should not be less than 8.

When a *Wheel is driven by a pinion*, the number of teeth in the pinion should not be less than 10.

The *Number of Teeth* in a cast wheel, particularly in mill gearing, should always be prime to the number of the pinion; that is, the number of teeth in the wheel should not be divisible by the number of teeth in the pinion without a remainder. This is in order to prevent the same teeth coming together so often as to cause an irregular wear on the same. An odd tooth introduced into a wheel is termed a *hunting* tooth or cog.

To compute the Pitch of a Wheel.

RULE.—Divide circumference at the pitch line by the number of teeth.

EXAMPLE.—A wheel 40 ins. in diameter requires 75 teeth; what is its pitch?

$$\frac{3{\cdot}1416 \times 40}{75} = 1{\cdot}6755 \text{ ins.}$$

To compute the Chordal Pitch.

RULE.—Divide 180° by the number of teeth, ascertain the sine of the quotient, and multiply it by the diameter of the wheel.

EXAMPLE.—The number of teeth is 75, and the diameter 40 ins.; what is the chordal pitch?

$\frac{180}{75} = 2°\ 24'$ and sine of $2°\ 24' = {\cdot}04188$, which $\times\ 40 = 1{\cdot}6752$ in.

To compute the Diameter of a Wheel.

RULE.—Multiply the number of teeth by the pitch, and divide the product by 3·1416.

EXAMPLE.—The number of teeth in a wheel is 75, and the pitch 1·675 inches; what is the diameter of the wheel?

$$\frac{75 \times 1{\cdot}675}{3{\cdot}1416} = 40 \text{ inches.}$$

To compute the Number of Teeth in a Wheel.

RULE.—Divide the circumference by the pitch.

To compute the Diameter when the True Pitch is given.

RULE.—Multiply the number of teeth in the wheel by the true pitch, and again by ·3184.

EXAMPLE.—Taking the elements of the last example,

$$75 \times 1{\cdot}675 \times {\cdot}3184 = 40 \text{ inches.}$$

To compute the Number of Teeth in a Pinion or Follower to have a given Velocity.

RULE.—Multiply the velocity of the driver by its number of teeth, and divide the product by the velocity of the follower.

EXAMPLE 1.—The velocity of a driver is 16 revolutions, the number of its teeth, 54, and the velocity of the pinion, 48; what is the number of its teeth?

$$\frac{16 \times 54}{48} = 18 \text{ teeth.}$$

EXAMPLE 2.—A wheel having 75 teeth is making 16 revolutions per minute; what is the number of teeth required in the pinion to make 24 revolutions in the same time?

$$\frac{16 \times 75}{24} = 50 \text{ teeth.}$$

To compute the Proportional Radius of a Wheel or Pinion.

RULE.—Multiply the length of the line of centres by the number of teeth in the wheel for the wheel, and in the pinion for the pinion, and divide by the number of teeth in both the wheel and pinion.

To compute the Diameter of a Pinion when the Diameter of the Wheel and Number of Teeth in the Wheel and Pinion are given.

RULE.—Multiply the diameter of the wheel by the number of teeth in the pinion, and divide the product by the number of teeth in the wheel.

EXAMPLE.—The diameter of a wheel is 25 inches, the number of its teeth 210, and the number of teeth in the pinion 30; what is the diameter of the pinion?

$$\frac{25 \times 30}{210} = 3{\cdot}57 \text{ inches.}$$

To compute the Number of Teeth required in a Train of Wheels to produce a given Velocity.

RULE.—Multiply the number of teeth in the driver by its number of revolutions, and divide the product by the number of revolutions of each pinion, for each driver and pinion.

EXAMPLE.—If a driver in a train of 3 wheels has 90 teeth, and makes 2 revolutions, and the velocities required are 2, 10, and 18, what are the number of teeth in each of the other two?

$$10 : 90 :: 2 : 18 = \text{teeth in 2nd wheel.}$$
$$18 : 90 :: 2 : 10 = \text{teeth in 3rd wheel.}$$

To compute the Circumference of a Wheel.

RULE.—Multiply the number of teeth by their pitch.

To compute the Revolutions of a Wheel or Pinion.

RULE.—Multiply the diameter or circumference of the wheel, or the number of its teeth, as the case may be, by the number of its revolutions, and divide the product by the diameter or circumference of the wheel, or number of teeth in the pinion.

EXAMPLE.—A pinion 10 inches in diameter is driven by a wheel, 2 feet (24 inches) in diameter, making 46 revolutions per minute; what is the number of revolutions of the pinion?

$$\frac{24 \times 46}{10} = 110{\cdot}4 \text{ revolutions.}$$

To compute the Velocity of a Pinion.

RULE.—Divide the diameter, circumference, or number of teeth in the driver, as the case may be, by the diameter, &c., of the pinion.

When there are a Series or Train of Wheels and Pinions.

RULE.—Divide the continued product of the diameter, circumference, or number of teeth in the wheels, by the continued product of the diameter, &c., of the pinions.

EXAMPLE 1.—If a wheel of 32 teeth drive a pinion of 10, upon the axis of which there is one of 30 teeth driving a pinion of 8, what are the revolutions of the last?

$$\frac{32}{10} \times \frac{30}{8} = \frac{960}{80} = 12 \text{ revolutions.}$$

EXAMPLE 2.—The diameters of a train of wheels are 6, 9, 9, 10, and 12 inches; of the pinions, 6, 6, 6, 6, and 6 inches; and the number of revolutions of the driving-shaft or prime mover is 10; what are the revolutions of the last pinion?

$$\frac{6 \times 9 \times 9 \times 10 \times 12 \times 10}{6 \times 6 \times 6 \times 6 \times 6} = \frac{583200}{7776} = 75 \text{ revolutions.}$$

To compute the Proportion that the Velocities of the Wheels in a Train should bear to one another.

RULE.—Subtract the less velocity from the greater, and divide the remainder by one less than the number of wheels in the train; the quotient is the number, rising in arithmetical progression from the less to the greater velocity.

EXAMPLE.—What should be the velocities of 3 wheels to produce 18 revolutions, the driver making 3?

$$18 - 3 = \frac{15}{2} = 7{\cdot}5 = \text{number to be added to the velocity of the driver}$$

$$= 7{\cdot}5 + 3 = 10{\cdot}5, \text{ and } 10{\cdot}5 + 7{\cdot}5 = 18 \text{ revolutions.}$$

Hence 3, 10·5, and 18 are the velocities of the three wheels.

To compute the Diameter of a Wheel for a given Pitch and Number of Teeth.

RULE.—Multiply the diameter, in the following table (page 1009), for the number of teeth by the pitch, and the product will give the diameter at the pitch circle.

EXAMPLE.—What is the diameter of a wheel to contain 48 teeth of 2·5 inches pitch?

$$15{\cdot}29 \times 2{\cdot}5 = 38{\cdot}225 \text{ inches.}$$

To compute the Pitch of a Wheel for a given Diameter and Number of Teeth.

RULE.—Divide the diameter of the wheel by the diameter in the table (page 1009) for the number of teeth, and the quotient will give the pitch.

EXAMPLE.—What is the pitch of a wheel when the diameter of it is 50·94 inches, and the number of its teeth 80?

$$\frac{50{\cdot}94}{25{\cdot}47} = 2 \text{ inches.}$$

To compute the Number of Teeth of a Wheel for a given Diameter and Pitch.

RULE.—Divide the diameter by the pitch, and opposite to the quotient in the table (page 1009) is given the number of teeth.

FORMULÆ FOR DETERMINING THE DIMENSIONS OF GEARS BY THE METRIC PITCH.

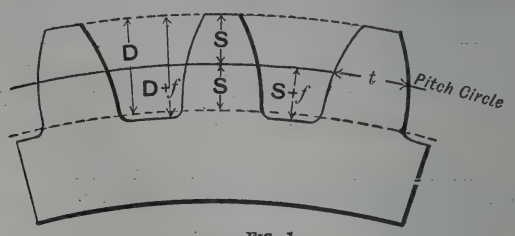


FIG. 1.

M = module; D′ = pitch diameter of gear; D = whole diameter of gear; N = number of teeth in gear; D″ = working depth of teeth; t = thickness of teeth on pitch line; f = amount added to depth for clearance.

Then

$$M = \frac{D'}{N} \text{ or } \frac{D}{N+2}. \qquad D' = N\,M. \qquad D = (N+2)\,M.$$

$$N = \frac{D'}{M} \text{ or } \frac{D}{M} - 2. \qquad D'' = 2\,M. \qquad t = M\,1{\cdot}5708. \qquad f = \frac{M\,1{\cdot}5708}{10}.$$

The module is equal to the part marked 'S' in fig. 1, measured in mm. and parts of mm.

RELATION BETWEEN MODULE AND DIAMETRAL PITCH.

Module.	Diametral Pitch.	Module.	Diametral Pitch.	Module.	Diametral Pitch.	Module.	Diametral Pitch.
0·5	50·800	2·5	10·160	6	4·233	14	1·814
0·75	33·867	3	8·466	7	3·628	15	1·693
1	25·400	3·5	7·257	8	3·175	16	1·587
1·25	20·320	4	6·350	9	2·822	17	1·494
1·5	16·933	4·5	5·644	10	2·540	18	1·411
1·75	14·514	5	5·080	11	2·309	19	1·336
2	12·700	5·5	4·618	12	2·117	20	1·270
2·25	11·288			13	1·954		

Pitch of Wheels.

A TABLE TO COMPUTE THE DIAMETER OF A WHEEL FOR A GIVEN PITCH, OR THE PITCH FOR A GIVEN DIAMETER.

From 8 to 192 teeth.

No. of Teeth.	Diameter.	No. of Teeth.	Diameter.	No. of Teeth.	Diameter.	No. of Teeth.	Diameter.	No. of Teeth.	Diameter.
	Ins.		Ins.		Ins.		Ins.		Ins.
8	2·61	45	14·33	82	26·11	119	37·88	156	49·66
9	2·93	46	14·65	83	26·43	120	38·2	157	49·98
10	3·24	47	14·97	84	26·74	121	38·52	158	50·3
11	3·55	48	15·29	85	27·06	122	38·84	159	50·61
12	3·86	49	15·61	86	27·38	123	39·16	160	50·93
13	4·18	50	15·93	87	27·7	124	39·47	161	51·25
14	4·49	51	16·24	88	28·02	125	39·79	162	51·57
15	4·81	52	16·56	89	28·33	126	40·11	163	51·89
16	5·12	53	16·88	90	28·65	127	40·43	164	52·21
17	5·44	54	17·2	91	28·97	128	40·75	165	52·52
18	5·76	55	17·52	92	29·29	129	41·07	166	52·84
19	6·07	56	17·8	93	29·61	130	41·38	167	53·16
20	6·39	57	18·15	94	29·93	131	41·7	168	53·48
21	6·71	58	18·47	95	30·24	132	42·02	169	53·8
22	7·03	59	18·79	96	30·56	133	42·34	170	54·12
23	7·34	60	19·11	97	30·88	134	42·66	171	54·43
24	7·66	61	19·42	98	31·2	135	42·98	172	54·75
25	7·98	62	19·74	99	31·52	136	43·29	173	55·07
26	8·3	63	20·06	100	31·84	137	43·61	174	55·39
27	8·61	64	20·38	101	32·15	138	43·93	175	55·71
28	8·93	65	20·7	102	32·47	139	44·25	176	56·02
29	9·25	66	21·02	103	32·79	140	44·57	177	56·34
30	9·57	67	21·33	104	33·11	141	44·88	178	56·66
31	9·88	68	21·65	105	33·43	142	45·2	179	56·98
32	10·2	69	21·97	106	33·74	143	45·52	180	57·23
33	10·52	70	22·29	107	34·06	144	45·84	181	57·62
34	10·84	71	22·61	108	34·38	145	46·16	182	57·93
35	11·16	72	22·92	109	34·7	146	46·48	183	58·25
36	11·47	73	23·24	110	35·02	147	46·79	184	58·57
37	11·79	74	23·56	111	35·34	148	47·11	185	58·89
38	12·11	75	23·88	112	35·65	149	47·43	186	59·21
39	12·43	76	24·2	113	35·97	150	47·75	187	59·53
40	12·74	77	24·52	114	36·29	151	48·07	188	59·84
41	13·06	78	24·83	115	36·61	152	48·39	189	60·16
42	13·38	79	25·15	116	36·93	153	48·7	190	60·48
43	13·7	80	25·47	117	37·25	154	49·02	191	60·81
44	14·02	81	25·79	118	37·56	155	49·34	192	61·13

NOTE.—The pitch in this Table is the chordal pitch (p. 1006).

Construction of Teeth of Wheels.

P = pitch—the distances between the centres of two teeth in the pitch circle.

Wheel.

D = diameter. M = number of teeth.

Pinion.

d = diameter. m = number of teeth.

EXAMPLE (fig. 2).—Draw the radius, Rr, and pitch circle, PP. Through r draw the line oo' at an angle of 75° to the radius Rr.

Half the angle between two teeth in the { wheel, $v = \frac{180}{M}$ . . . 1. ; pinion, $V = \frac{180}{m}$ . . . 2.

Diameter of the { wheel, $D = \frac{d \sin V}{\sin v}$ . . 3. ; pinion, $d = \frac{D \sin v}{\sin V}$. 4.

$D : d = \sin V : \sin v$.

Pitch (chord) of teeth in the pitch circle { wheel, $P = D \sin v$. 5. ; pinion, $P = d \sin V$. 6.

Number of teeth about { wheel, $M = \frac{3{\cdot}14D}{P}$. 8. ; pinion, $m = \frac{dM}{D}$ . . 9.

Approximate pitch in the wheel, $P = 0{\cdot}028D$ 7.

Depth of tooth, $a = 0{\cdot}46P$* . . . . . 10.

Bottom clearance, $b = 0{\cdot}4P$ . . . . . 11.

Length to pitch line, $c = 0{\cdot}3P$ . . . . . 12.

Distance ro, $d = \frac{P(m+6)}{2(m-11)}$ . . . . . 13.

Distance ro', $e = 0{\cdot}11P\sqrt[3]{m}$ . . . . . 14.

Teeth of very much less length are now used. A length of only half the pitch is ample, the liability to break being greatly reduced.

Mr. M. Longridge considers it sufficient if one pair of teeth engage just before the previous pair go out of contact.

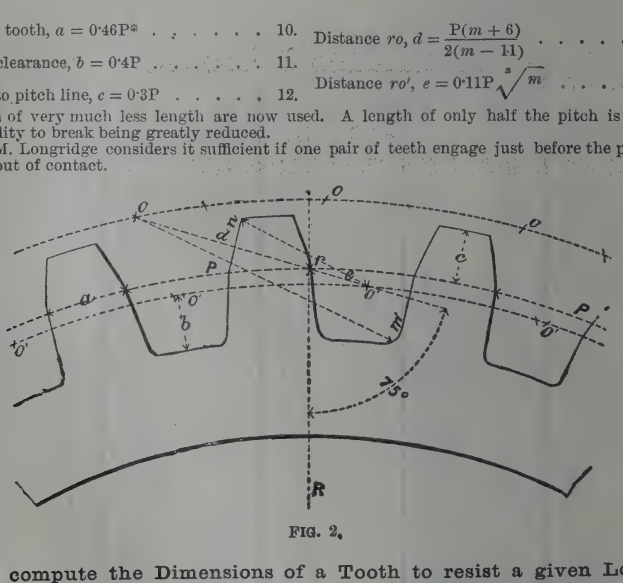


FIG. 2.

To compute the Dimensions of a Tooth to resist a given Load.

RULE.—Multiply extreme load, S, in lbs., at pitch line of wheel, by length, l, of tooth in decimals of a foot; divide product by coefficient, κ, of material of teeth, and quotient will give product of breadth, f, and square of depth, a; f and a both being in inches.

Or, $$\frac{Sl}{\kappa} = fa^2;$$

from which $$f = \frac{Sl}{\kappa} \div a^2, \qquad a = \sqrt{\frac{Sl}{\kappa} \div f}, \qquad l = fa^2 \times \frac{\kappa}{S}.$$

The value of κ for cast iron used for this purpose may be taken at 60, and for hardwood at 80.

EXAMPLE.—The load, S, at the pitch line of a cast-iron wheel is 4,886 lbs.; what should be the breadth, f, of the teeth, the length being 2 inches, and the pitch, P, 3 inches?

$l = 2 \div 12 = {\cdot}167$ feet. $\qquad a = {\cdot}46 \times 3 = 1{\cdot}38$ inches.

* If a wheel of more than 80 teeth is to gear a pinion of less than 20 teeth, and the wheel and pinion are of the same kind of materials, take the thickness of the tooth in the { wheel, $a = P\left(0{\cdot}42 + \frac{m}{700}\right)$ . . 15. ; pinion, $a = 0{\cdot}5P\left(1 - \frac{m}{350}\right)$. 16.

A rack is to be considered as a wheel of 200 teeth.

Therefore

$$f = \frac{4886 \times \cdot 167}{60} + (1 \cdot 38)^2 = 7 \cdot 16 \text{ inches.}$$

A tooth running at a low velocity may be materially reduced in its dimensions compared with one running at a high velocity and with like stress.

Experience has proved that a cast-iron tooth with a pitch of 3 inches and a breadth of 7·5 inches will transmit, at a velocity of 6·66 feet per second, 60 horse-power.

To compute the Depth of a Cast-iron Tooth.

1. *When the load is given.*

RULE.—Extract the square root of the load and multiply it by ·02.

EXAMPLE.—The load to be borne by a tooth is 4,886 lbs.; what should be its depth?

$$\sqrt{4886} \times \cdot 02 = 1 \cdot 4 \text{ inches.}$$

2. *When the Horse-power is given.*

RULE.—Extract the square root of the quotient of the horse-power divided by the velocity in feet per second, and multiply it by ·466.

EXAMPLE.—The horse-power to be transmitted by a tooth is 60, and the velocity of it at its pitch line is 6·66 feet per second; what should be the depth of the tooth?

$$\sqrt{\frac{60}{6 \cdot 66}} \times \cdot 466 = 1 \cdot 398 \text{ inches.}$$

To compute the Horse-power Transmitted by a Wheel.

RULE.—Multiply the pressure at the pitch line by its velocity in feet per minute, and divide the product by 33,000.

EXAMPLE.—What is the horse-power transmitted by a wheel of the dimensions and velocity given in the preceding examples?

$$\frac{4886 \times 6 \cdot 66 \times 60}{33000} = 59 \cdot 16.$$

For the working load on machine-cut spur wheels Mr. W. Lewis gives the following law:—

$$S = y p b f,$$

where S is the total load in lbs., p the pitch in inches, f the permissible load, and y a factor which varies with the shape of the tooth.

The values of f and y are given in the tables below:—

LEWIS'S VALUES OF f.

Speed in Feet per Minute.	100 or less.	200	300	600	900	1,200	1,800	2,400
Cast iron . .	8,000	6,000	4,800	4,000	3,000	2,400	2,000	1,700
Steel . . .	20,000	15,000	12,000	10,000	7,500	6,000	5,000	4,300

LEWIS'S VALUES OF y.

Number of Teeth.	Involute (20 deg. obliquity).	Involute (15 deg. obliquity) and Cycloidal.	Radial Flanks.	Number of Teeth.	Involute (20 deg. obliquity).	Involute (15 deg. obliquity) and Cycloidal.	Radial Flanks.
12	0·078	0·067	0·052	27	0·111	0·100	0·064
13	0·083	0·070	0·053	30	0·114	0·102	0·065
14	0·088	0·072	0·054	34	0·118	0·104	0·066
15	0·092	0·075	0·055	38	0·122	0·107	0·067
16	0·094	0·077	0·056	43	0·126	0·110	0·068
17	0·096	0·080	0·057	50	0·130	0·112	0·069
18	0·098	0·083	0·058	60	0·134	0·114	0·070
19	0·100	0·087	0·059	75	0·138	0·116	0·071
20	0·102	0·090	0·060	100	0·142	0·118	0·072
21	0·104	0·092	0·061	150	0·146	0·120	0·073
23	0·106	0·094	0·062	300	0·150	0·122	0·074
25	0·108	0·097	0·063	Rack	0·154	0·124	0·075

A series of experiments recently made by Prof. G. H. Marx at the Stanford University, Cal., with ten diametral pitch cast-iron 14½ deg. involute gears, shows that the pitch of the gears given by Lewis's formula is somewhat on the heavy side. The Lewis expression is based upon the theory of flexure under the assumption that the entire load is borne by a single tooth, the point of application of the load being the extreme end of the tooth and the direction of the acting force being normal to the tooth profile at that point. The effects of the compressive and shear components are ignored.

Rupture is assumed to take place on a plane section, the position of which is determined by inscribing a parabola of uniform strength with the vertex lying at the intersection of the centre line of the tooth and line of action of the force. The dangerous section is the plane section containing the points of tangency of the parabola with the tooth outline. These assumptions and change in stress with change in speed are too severe for accurate machine-cut gears.

In view of the fact, however, that gears, although originally accurately cut and mounted, when run under severe conditions wear away from their true form and tend to take the load on one pair of teeth, it would be unwise to discard the values given by Lewis until some data, more complete than that presented by Prof. Marx, are available. It is known that small test specimens sustain higher stresses than large pieces, and for this reason the values obtained for ten diametral pitch gears may be misleading when applied to larger pitches.

Mill Gearing.

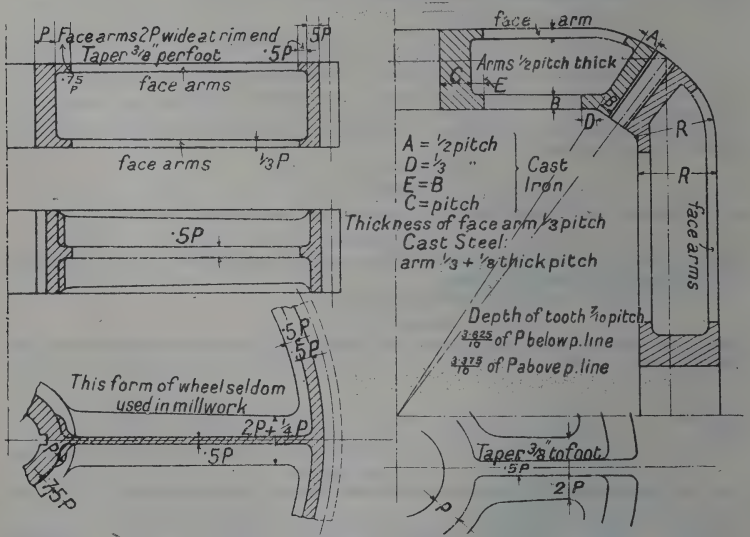


FIG. 3.

Fig. 3 shows the proportions of tooth, arm, faces, bosses, etc., commonly used in mill gearing.

(J. Nuttall.)

To Design Wheel Teeth.

EPICYCLOIDAL TEETH.

The correct curves of wheel teeth on the epicycloidal principle are drawn by rolling curves. The same rolling circle is needed for both points and flanks of every wheel in a set. Let A, fig. 4, represent the pitch circle of a wheel, and B the rolling circle. A notch is cut in the edge of B, and a steel point placed firmly in a small clamp, fig. 5, so that its point is on the circle. If this circle be now pressed against A and steadily revolved it will describe a curve on a piece of finely sandpapered tin plate, *t*, laid beneath, as shown at *c*. This is the curve of the tooth point.

Similarly if D, fig. 6, is the template of the inside of the pitch circle of the wheel, the same process will give the curve *e* for the flanks of the teeth. It is considered best practice to make two wheels to suit each other rather than a set; when this is done the points of wheel teeth and the

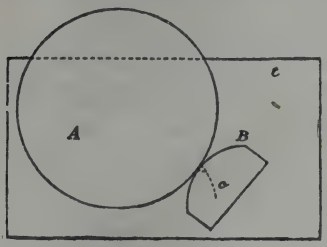


FIG. 4.

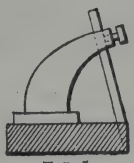


FIG. 5.

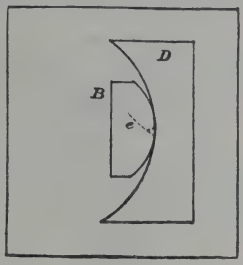


FIG. 6.

flanks of the pinion are described with one rolling curve whose diameter is the radius of the pinion, while the points of the pinion teeth and the flanks of the wheel teeth are described with a rolling circle whose diameter is the radius of the wheel.

CYCLOIDAL TEETH.

In this class of gear the mating parts of a pair of wheels are convex and concave, and a comparatively large surface is in contact with a resulting small amount of wear. As the teeth profiles are developed by two circles which roll inside and outside the pitch circle, and the path of contact is made up of two curves which change their direction at the pitch point, i.e., the point of intersection of a line drawn through the wheel centres and the pitch circles, it is essential for quiet running and no back lash that the shaft centres are exactly correct. Should the centres be initially incorrect or become so due to wear at the bearing or journal, all rolling motion is lost and excessive noise and wear will result. Cycloidal gears are very difficult to accurately generate in the machine, and in the case of a set of wheels from 12 teeth to rack, with profiles generated by rolling circles greater in diameter than half the diameter of the smallest pinion, the flanks are under-cut and cannot be hobbed or cut with a rotary cutter. A rolling circle $\frac{5}{8}$ in. diameter is the smallest pinion in the set that has been generally preferred.

By making the diameter of the rolling circle equal to the radius of the smallest pinion the teeth have radial flanks and are thinner at the root than at the pitch line, but when the rolling circle is less than the radius of the smallest pinion the teeth are thicker at the root than at the pitch line and such teeth can be cut with a rotary cutter. As the diameter of the rolling circle decreases the angle of obliquity of action or angle of pressure increases. Cycloids are difficult to draw correctly, and the true curves are usually approximated by circular arcs by the pattern-maker when striking out the pattern, thus introducing a possible error. Whilst this class of gear has good wearing qualities, high speeds have made its defects, which are scarcely noticeable at low speeds, very pronounced, and it has been largely displaced by involute gearing.

INVOLUTE TEETH.

Involute teeth have the advantage of being a continuous curve from root to point, and all involute teeth of the same pitch will correctly gear together.

Let AB and CD, fig. 7, be the pitch circles of any two wheels, and EF their line of centres. Through the intersection of the pitch circles and EF draw MN, making an angle with EF of about 75°. In the figure it is drawn at 60° for plainness. Circles *nn* and *ss* are drawn touching MN. These two circles are the base circles from which the teeth curves are described. The method is then the same as with the epicycloidal tooth, but the rolling circle is simply a straight edge, as shown at K, fig. 8.

The path of contact in involute teeth gears is a straight line, tangential to the base circle, and permits of the teeth meshing correctly together when the shaft centres are slightly inexact. Should the wheel centres be slightly in excess of their correct dimension the angle of the path of contact is increased, but it still cuts the pitch lines at the pitch point; the same tooth profiles are obtained, and the disadvantages are a slightly increased back lash and pressure on the journals. The mating parts are both convex, the surface in contact is small, and the wear large in comparison with cycloidal gears. An angle of obliquity of action, equal to 14½°, has hitherto been in general use, but the tendency to-day is to use a 20° to 22½° obliquity and a smaller tooth addendum. With the 14½° pressure angle and height of tooth above the pitch line of 0·318 pitch there is excessive relative sliding at the points of the teeth, thereby causing extensive local wear, and with a 12-tooth pinion engaging with a straight-toothed rack, having an included angle of 29°

between the working faces, there is severe interference between the flanks of the pinion teeth and the points of the rack teeth, which, if cut away, reduces the path of contact to less than a pitch length. To avoid such, the shape of both mating teeth have to be modified if the angle and minimum number of teeth (12) are adhered to. Up to the present the practice has been to

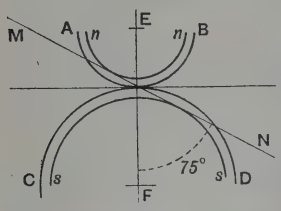


FIG. 7.

FIG. 8.

modify the shape of the tooth by making the flanks of the pinion teeth radial and rounding off the faces of the rack teeth. The introduction of this uncertain quantity has led many practitioners to adopt the 20° or 22½° angle of obliquity where the true form can be obtained without interference at the working surfaces.

With an angle of obliquity of 20° to 22½° the pressure at the bearings is increased 5 to 6 per cent. With a pinion of 28 teeth and angle of pressure of 14½° interference is avoided, as is also the case with a 20-tooth pinion having pressure angle of 20°. Interference may be avoided in a 12-tooth pinion by decreasing the addendum to ⅝ module when the angle of obliquity is 20° or ⅞ module when the angle of obliquity is 22½°. In both cases a minimum arc of contact equal to 1⅛ pitch can be obtained. Such teeth are termed 'stub' teeth, and in comparison with the standard tooth are thicker at the roots and therefore stronger. Further, by removing the points of the teeth where the sliding action is greatest, a better rolling action results, and the efficiency of the gear is increased.

SPUR GEARING.

It has been observed by Mr. S. H. Rowley that defects are at times noticed in cut gears, generally manifested in noisy running. If the noise be what is termed a revolution noise, it is generally due to a thick tooth or teeth, caused by inaccurate spacing. Some wheels will be found to run quietly in one direction and noisily in the opposite. Investigation will show that the teeth have not been cut radially. Both these defects are due to careless work from the ordinary type of gear cutters using disc cutters, and are the outcome of inaccurate setting. If neither of these faults can be found, then look to the form of tooth, and it can be stated almost with certainty that it is a hobbed gear, and the hob used is of faulty shape.

These are all faults apart from erecting, as it is well known that gears running out of alignment, and also at too close centres, will produce a noise, besides numerous other causes which might be enumerated.

Speaking in broad terms of teeth in general, for strength, a flank as broad as possible is desirable; for efficiency, a short line of action; and for quietness and smoothness of running, a longer one.

For accurately checking a tooth, more especially of a pinion, it is necessary when setting the tooth micrometer to make an allowance on account of the chordal arc differing from the tangent, thus altering the width; also the location of the pitch line on the sides of the teeth falling below the position in the middle of the tooth calls for a correction in the addendum.

For spur gearing running at high speeds, say of over 1,200 ft. per min. on the pitch line (general engineering work and not motor gears is here referred to), the following practices are adopted to eliminate noise. Employ fine pitches with wide faces, in preference to coarse pitches and narrow faces. Practice has altered very considerably in this direction in recent years. The teeth, instead of being cut parallel to the face, are sometimes cut on an angle, or more strictly spiral, the wheel being of one hand and the pinion of the opposite. The objection is the side thrust which is set up. To overcome this, a double helical is often used, which is a costly form of gearing, and when made solid often unsatisfactory. Experiences with different angles for the single helical go to show that with a gear of normal face an angle of about 15° gives good results—silent running combined with only slight end thrust. If it be possible to increase the face, the angle may be reduced. Phosphor bronze and steel have proved more

silent than both wheels of the same metal. Fibre wheels have also been used with good results, and when flanged with metal plates for quite considerable powers; their life is not, however, a very long one. If the load be a heavy one, the most general practice is to use a raw-hide pinion. If this be properly made and treated, it will often outlast a cast-iron wheel, and is as durable and strong as, if not stronger than, cast iron to resist shocks.

Mr. Daniel Adamson * states that in 1899 he adopted for the teeth of spur wheels on cranes an addendum of 0·25 pitch with a dedendum of 0·32 and angle of obliquity of 14½°. These proportions do not, however, prevent 'interference' if a straight-sided rack tooth is used, as is desirable for reason of accurate reproduction. To avoid this objection the angle of obliquity must be increased to 22½° if a 12-tooth pinion is to be the least of the series; but if 14 teeth can be adopted, then 20° is sufficient.

In addition to facilitating accurate construction, by permitting generation, these modifications have a further advantage in giving a stronger form of tooth, thus allowing a finer pitch to be used for given diameters of wheel and pinion. Reducing the pitch in this manner increases the number of teeth in contact, improves the durability, and reduces the noise. The rate of wear is also reduced when more teeth are in gear simultaneously, because the contact between the teeth takes place nearer the pitch line, where there is less relative sliding, and for the same reason the loss of power by friction between the teeth is reduced.

The theoretical number of teeth (stub) in contact depending upon the number of teeth in the wheel and pinion are given in the table below.

DURATION OF CONTACT.

For Involute Teeth 20° Obliquity. Addendum, one-quarter of Circular Pitch.

No. of Teeth.	12	15	20	30	36	45	60	75	100	150
12	1·17	1·19	1·21	1·25	1·26	1·28	1·29	1·30	1·32	1·33
15	1·19	1·21	1·24	1·27	1·29	1·30	1·32	1·33	1·34	1·35
20	1·21	1·24	1·27	1·30	1·32	1·33	1·35	1·36	1·37	1·38
30	1·25	1·27	1·30	1·33	1·35	1·36	1·38	1·39	1·40	1·41
36	1·26	1·29	1·32	1·35	1·37	1·38	1·40	1·41	1·42	1·43
45	1·28	1·30	1·33	1·36	1·38	1·40	1·41	1·42	1·43	1·44
60	1·29	1·32	1·35	1·38	1·40	1·41	1·43	1·44	1·45	1·46
75	1·30	1·33	1·36	1·39	1·41	1·42	1·44	1·45	1·46	1·47
100	1·32	1·34	1·37	1·40	1·42	1·43	1·45	1·46	1·47	1·48
150	1·33	1·35	1·38	1·41	1·43	1·44	1·46	1·47	1·48	1·49

The factors to be considered when estimating suitable proportions to resist wear are:

P = load to be transmitted at the pitch-line; N = number of revolutions per min.; e = estimated number of teeth in contact; b = breadth of the teeth.

The average of 50 examples, by Mr. R. Livingstone, of raw-hide pinions 'in service and giving satisfaction' gives $\frac{PN}{b} = 112{,}000$, and $\frac{P}{b} = 115$ lbs. per inch of face. Lasche gives three examples of Delta-metal pinions working satisfactorily with steel wheels on crane motors in which the average for $\frac{PN}{eb} = 100{,}000$. For steel pinions gearing with steel wheels in intermittent crane work, Mr. Adamson has found that a maximum of 130,000 for $\frac{PN}{eb}$ and 53,300 for raw-hide pinions under similar conditions, works quite satisfactorily.

With regard to speed, Mr. W. H. Thornberry gives 1,800 ft. per min. as the greatest at which ordinary cast iron wheels may be safely run, and 3,000 ft. per min. for machine-cut wheels. The same authority quotes examples up to 4,000 and 5,000 ft. per min., but recommends caution

* See Proc. Inst. of Mech. Engrs., 1916.

before adopting such speeds. A pair of mortise teeth bevel wheels at Niagara transmits 1,100 h.p. at 3,930 ft. per min. These have 43 and 33 teeth, $5\frac{1}{2}$ pitch and 20 ins. face. After $6\frac{1}{2}$ years these wheels were running satisfactorily, except that the wooden teeth only lasted 6 to 8 weeks. At the same place a pair of cast steel bevel wheels transmitted 1,300 h.p. at 3,900 ft. per min. The teeth were 20 ins. wide, 5 ins. pitch, and whilst satisfactory as far as abrasion is concerned they occasionally gave trouble by breaking out.

Christie states that a pair of spur wheels transmitted 3,300 h.p. at 2,500 ft. per min., and the load on the teeth was nearly 2,100 lbs. per in. of face. The pinion was made of fluid pressed steel containing 0·86 per cent. C, 0·51 per cent. Mn, 0·27 per cent. Si. The wheel was an annealed steel casting containing 0·47 per cent. C, and 0·66 per cent. Mn.

The pinion should always be of harder material than the wheel, in order to equalise the wear. Mild steel gearing up to, say, 0·3 per cent. carbon gives trouble by abrasion, and also by change of form due to the percussive action experienced under heavy loads. High carbon steel, say 0·6 per cent. carbon or above, or nickel steel, should be used, and preferably the latter, as it meets all requirements without a complicated heat treatment.

In gearing, large revolving masses—as, for example, armatures of motors—should be separated from adjoining masses such as large gear wheels of the second motion, by some elastic medium such as a length of shafting or a flexible coupling (page 1081). This is intended to allow for slight variations in the angular velocity, due to unavoidable errors in cutting the teeth, to take place without giving rise to destructive loads between the teeth. The stresses due to inaccuracies in the spacing of the teeth may exceed the working stress. With an error of only 0·2 per cent. in the pitch the excess load due to acceleration and retardation may amount to as much as 28 times the load transmitted. Such loads increase as the square of the mean pitch-line velocity and as the mass of the wheel considered.

MAAG GEARING.

(*Sulzer Bros.*, 31 *Bedford Square, London, W.C.* 1.)

Maag gearing introduces certain novel features both in the production of gears and the shape of tooth, which are claimed to overcome the defects inherent in the ordinary standard form of gearing.

The method of cutting Maag gears is on the generating principle, producing theoretically correct involute tooth profiles *free from any standardisation.*

The arrangement is not confined to a special pressure angle, nor to any standard proportions of tooth, there is, therefore, a free choice in the pitch allowed; it is immaterial whether the pitch be 3 diametral, 3·23 diametral, 12·57 mm., or $1\frac{1}{16}$ in., etc.

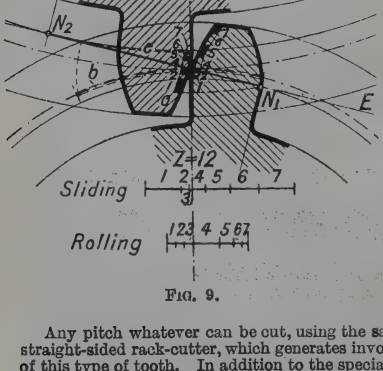


FIG. 9.

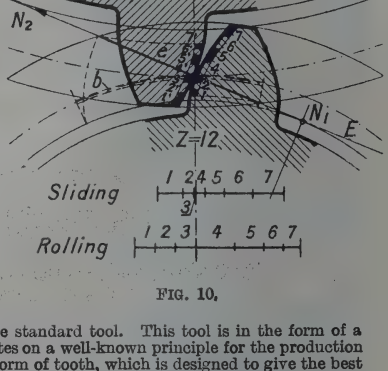


FIG. 10.

Any pitch whatever can be cut, using the same standard tool. This tool is in the form of a straight-sided rack-cutter, which generates involutes on a well-known principle for the production of this type of tooth. In addition to the special form of tooth, which is designed to give the best theoretical shape for each individual set of gears, the Maag gears are noticeable for the fact that the tooth surfaces are case-hardened and ground with mathematical precision on the generating principle; this is accomplished by means of simple saucer-shaped grinding wheels, in which the projection of the edge of the wheel forms the plane of an imaginary straight-sided rack. Two such wheels set at the correct angle thus form the sides of the rack, and involutes

are generated by grinding in the same manner as in the gear-cutting machine. As the edge of these saucer-shaped discs must always lie in a true plane, it is obvious that the surfaces generated must be perfect involutes, and the wear of the grinding discs only affects the thickness of the individual tooth ; this is, however, compensated for by an automatic device which automatically keeps the planes of the grinding wheels in their exact position.

In the Maag system, the shape of the tooth and the accuracy with which it is formed enable, it is claimed, much higher loads and much higher speeds to be obtained than with any other form of gearing. Thus, for example, there are applications of Maag gearing which operate at peripheral speeds of 10,000 ft. per min. and even up to 15,000 ft. per min., while the load per inch width of tooth can be taken as at least double that possible with the double helical form of gearing. An important example is in the new Swiss locomotives of 2,500 B.H.P., where the Maag gearing has replaced the ordinary double helical type.

Fig. 9 represents two teeth of a standard drive 12/24 as made by the common series-cutter method and is in frequent use in machine tools, cranes, etc. Fig. 10 shows teeth of the same drive made by the Maag method.

The most conspicuous difference is in the roots of the teeth. The teeth of both drives are thickest near the base circles, but while these circles are located in fig. 9 very near the pitch circles, and therefore far away from the root-circles, they appear in fig. 10 shifted much farther towards the root-circles. It is easily seen, then, that the radial extensions of the profile in fig. 9, due to their length, converge greatly towards the root-circles, weakening the teeth, especially the one of the 12-tooth pinion. This is not noticeable in fig. 10, the radial profile extensions being short.

Since with the use of series-cutters all teeth are equally thick at the pitch line, that is, equal to half the pitch, the teeth must be weaker at the root the smaller the number of teeth in the gear. Fig. 10 shows that this is not the case with Maag gears ; for by proper distribution of addendum and dedendum, as well as thickness at the pitch lines, a nearly equal thickness of tooth at the root in both wheels is secured.

Taking the thickness of tooth of the 12-tooth pinion as equal to 1, this thickness for the same pitch in the Maag gear is 1·31, which means that the tooth could be loaded $1 \cdot 32 = 1 \cdot 7$ times as heavily, or for the same load a pitch 1·31 times smaller, or a tooth number 1·31 times larger could be used ; in other words, in place of a drive 12/24 made by the series-cutter method a Maag drive 16/32 could be built into the same centre distance, and this fact, even if it were alone, would greatly improve the conditions of mesh and wear.

Heat-Treated Gears.

The conditions under which gear wheels are employed can generally be considered as coming under two heads : (1) For the purpose of transmitting power under approximately constant conditions of load and speed ; and (2) under conditions which subject the wheels to shock or reversal of stress.

In the first case, resistance to wear is the chief consideration, and for this purpose case-hardened gears are eminently suited, but under the second condition oil-hardened gears of special steel are usually necessary. Cast-steel gears are frequently used where resistance to wear is the principal consideration and where the number of gears required are few. Should the gears be small these are usually cast from a pattern, but if large they are frequently machine-moulded, and in both cases sufficient is left on the teeth to ensure their cleaning up in machining. Where a large number of gears are required, it has become the practice to obtain these from mild steel stampings, the teeth being roughly formed in the process and subsequently by the cutter in the machine. Such gears are extensively used in their soft state, but where the conditions of wear are somewhat severe, these are usually case-hardened. Where the speeds are high and conditions very severe, such teeth are liable to chip, and an alloy steel of nickel or nickel chrome is substituted. The alloys commonly used are nickel (3 to 5 per cent.), and nickel chrome (carbon ·15, chrome ·5 to 1·5, nickel 1·5 to 5). Chrome vanadium compositions are also being used for case-hardening gears. These gears should be carburised at a temperature of 880° C. and allowed to cool in the box, afterwards they should be reheated to about 820° C. and quenched in water. This procedure gives a tougher core than is obtained when the steel is quenched direct from the carburising temperature. It may be necessary to protect some parts against carburising. For this purpose a shield of copper, copper-plating, or asbestos pad secured with the fireclay, are frequently employed.

Oil-Toughened Gears.

In this case the straight nickels and nickel chrome steels are most extensively used. With such gears it is advisable to anneal these after rough machining in order to break down crystallisation set up during forging. The annealing temperature for these steels should be about 800° C., and the quenching temperature about 820° C. For moderate service conditions nickel chrome steel which has been cooled off in an airblast has been found to give excellent results.

Heat-Treatment for Gears.

In order to treat chrome-nickel steel gears of 8 diametral pitch so that they will have a soft core suitable to withstand shock, first heat the gears in carburising pots to 1,600° F., for seven hours. Then remove the pots from the furnace and allow the box and work to cool overnight. The next morning empty the pots and reheat the gears to 1,400° F. Then take out and quench in oil. This is known as the refining heat. Reheat the gears to 1,450° F., and quench in water, and the gears will be found to be properly hardened. Several gears should be treated in this way, and the teeth should be broken from one in order to ascertain the depth of case on the teeth, which should be $\frac{1}{32}$ in. (*'Machinery.'*)

Non-Resonant Gears.

Raw-Hide Pinions.

When a raw-hide pinion is adopted, the minimum number of teeth should be, if possible, twenty, and in no case should less than fifteen be used. Practice varies as to the shrouding, some users preferring gun-metal with the teeth cut through, and others steel plates solid. To ensure the metal wheel coming in contact with the hide only, the pinion faces should be made slightly wider than the wheel. It is advisable to have the faces at least three times the pitch.

Lubrication.

It is common knowledge that no grease nor oil should be allowed near a raw-hide gear, yet there is no rule more frequently disregarded than this, the result being speedy destruction of the pinion. If the hide, when in use, should become unduly dry, a sparing coat of raw linseed oil will tend to preserve it.

Ordinary hydrocarbon oil is most destructive to raw-hide pinions. One of the best compounds for the purpose is given in *Marine Engineering of Canada*, as follows :—Plumbago, 15 per cent.; rosin oil, 55 per cent.; rosin, 30 per cent.

Cloth and paper pinions can be lubricated, without injury, with ordinary oil.

Resilient Steel Gears

(Seymour's Patent).

These gears are designed and constructed specially for drives where the strength and durability of steel gears is necessary, but where the noise accruing from their use would not be permissible.

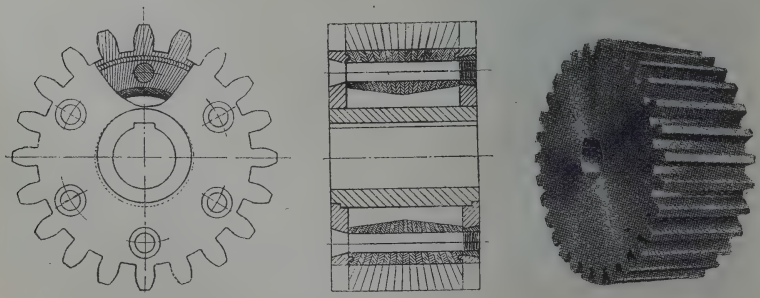


Fig. 11.—Section of Pinion with a portion of end-plate cut away.

The portion of the gear-wheel from which the teeth are formed is made up of steel laminæ, having an ultimate tensile stress of 45 tons, the boss and shroud plates being constructed of cast or forged steel.

The resilience of the working surfaces of the teeth afforded by this method of construction is sufficient to render the running of the gears as noiseless (even when the same are considerably overloaded) as gears constructed of raw hide, paper, and woven fabrics.

On account of the superior strength and durability of steel over the other substances named, the resilient steel gears transmit many times the load for any given size of tooth, and their life is longer proportionally.

Owing to the internal system of automatic lubrication, only the necessary amount of lubricant is supplied to the surfaces of the teeth, thus preventing waste and effecting a saving of 3¼ to 4 per cent. of the power transmitted.

Important improvements in the construction of these gears have been made, notably the connecting together of the lateral extremities of the laminæ by welding, thus the laminæ are firmly secured together independently of the support supplied by the shroud plates and bolts.

These gears have been successfully applied to almost every class of drive, including mine and quarry machinery and haulage, electric motor drives, pumps, air compressors, machine tools, cranes, etc. etc.

Resilient steel gears are being constructed for transmitting ever increasing horse-power, some under construction now have been designed to transmit upwards of 750 h.p. at 1,800 ft. per minute.

Fig. 11 shows laminæ and shroud plates held together with bolts.

The cavity between the boss and the laminæ is the receptacle for the lubricant; centrifugal force propels the lubricant radially outwards between the laminæ, thus efficiently lubricating the entire working surface of the teeth.

The power transmitted by such gears can be calculated from the following formula:—

$$F = \frac{HP \times 1000}{K \times N \times R}$$

where,

F = Face of pinion in inches; N = No. of teeth; K = Factor for each pitch (see table); R = Revolutions of pinion per minute; HP = Horse-power to be transmitted.

Circular Pitch . .	¼″	⅝″	⅜″	⅞″	1″	1¼″	1½″	1¾″	2″	2¼″	2½″	3″
Factor K . . .	·225	·35	·505	·689	·9	1·41	2·03	2·75	3·6	4·55	5·63	8·1
Diametral Pitch . .	6	5	4	3½	3	2½	2¼	2	1¾	1½	1¼	1
Factor K . . .	·246	·355	·555	·723	·975	1·41	1·74	2·22	2·92	3·93	5·67	8·9

Helical-Teeth Gearing.

This form of gearing has been somewhat extensively adopted, especially in cotton-spinning machines. It consists, when the direction of the motion is simply to be changed to an angle of 90°, in forming the teeth upon the periphery of the pair at an angle of 45° to the respective axes of the wheels, as in figs. **12** and **13**. It will then be perceived that if the sloped teeth be presented to each other in such a way as to have exactly the same horizontal angle, the wheels will gear together, and motion being communicated to one axis, the same will be transmitted to the other at a right angle to it, as in a common bevel pair. Thus, if the wheel A upon a horizontal shaft has the teeth formed upon its circumference at an angle of 45° to the plane of its axis, it can gear with a similar wheel, B, upon a vertical axis. Let it be upon the driving-shaft, and the motion will be changed in direction, as if A and B were a pair of bevel wheels of the ordinary kind, and, as with bevels generally, the direction of motion will be changed through an equal angle to the sum of the angles which the teeth of the wheels of the pair form with their respective axes. The objection in respect of lateral or end pressure may, in the case of a vertical shaft, be partly got over by sloping the teeth so that the tendency is to lift the shaft, and not force it down into the stop bearing: this would act to keep the wheels in close contact, by reason of the weight of the vertical shaft, and at the same time reduce the friction between the end of that shaft and its stop bearing. This renders this form of gearing preferable to skew bevels when employed upon vertical shafts.

The gears shown by figs. 12 and 13 may be turned up in the lathe, because the teeth are simply portions of spirals wound about the circumference of the wheel. For a pair of wheels of equal diameter a cylindrical piece equal in length to the required breadth of the two wheels is turned up in the lathe, and the teeth may be cut in the same manner as cutting a thread in the lathe;

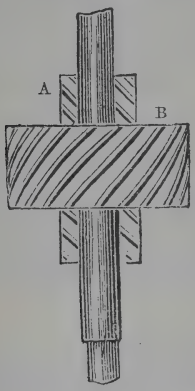


FIG. 12.

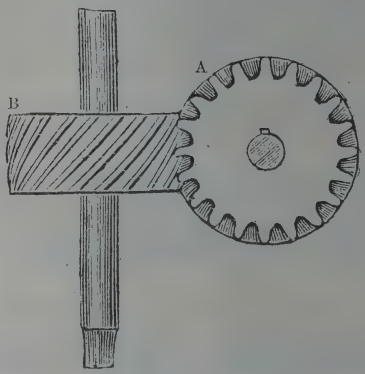


FIG. 13.

that is to say, by traversing the tool the requisite distance per lathe revolution. In pitches above about $\frac{1}{4}$ inch it will be necessary to shape one side of the tooth at a time, on account of the breadth of the cutting edges. After the spiral (for the teeth are really spirals) is finished, the piece may be cut in two in the lathe, and each half will form a wheel.

Double Helical-Teeth Gearing.

When correctly designed and accurately cut, double helical gearing possesses advantages both in principle and utility which cannot be obtained from any other type of gearing. The advantages are as follows :—

1. Continuity of engagement, which reduces vibration and enables a greater load to be transmitted.

2. Pinions with a small number of teeth can be used, and in this way high ratios can be obtained without using a wheel of abnormal diameter.

3. A higher efficiency than in the case of straight-toothed gearing is obtained. This is due to the different action of the teeth during engagement. In straight cut gears the line of contact lies parallel to the axis of rotation, and consequently the phases of engagement are constantly changing, and the action is uneven. With double helical gearing the line of contact is a curve extending diagonally across the tooth, and all phases of engagement occur simultaneously.

4. Silent running at high speeds is obtained, owing to the gradual engagement and absence of vibration. There is no necessity for using soft pinion materials, such as raw hide or fibre.

It is generally found that a forged steel pinion gearing with a cast-iron wheel gives the best results, if the horse-power is not too high. In certain cases, where high horse-powers or sudden overloads are to be transmitted, pinions made from high carbon or nickel steel, gearing with cast steel wheels should be used.

Spiral Angle of Teeth.

The angle now generally adopted for continuous cut helical gears is 45° when cut by means of end milling process, and 30° when cut on the Sykes' Patent shaping process, which gives a continuous tooth with sharp apex. Staggered helical gears are usually 23°.

A helical gear, six pitches wide, and with 23° spiral angle, gives the desired continuity of engagement; with steeper angles the face width may be proportionately less, providing the loss of space in the centre is the same or less. With continuous teeth, *i.e.* no space loss, continuity is obtained with correspondingly less face width. A 30° spiral angle has continuity of engagement when the width of the gear is four times the pitch.

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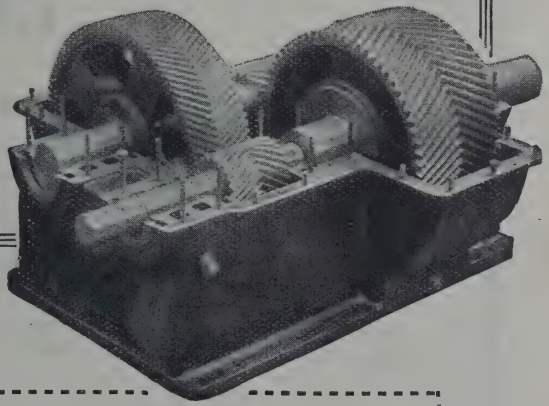

80
1—43

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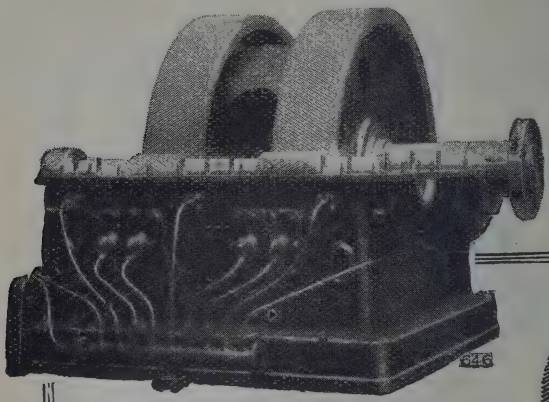

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Strength of Double Helical Gearing.

For mill and other gears subjected to heavy shock the following particulars and formulæ (*The Power Plant Co. Ltd.*) are applicable to double helical gears with staggered or continuous teeth cut by a generating process using hobs, or the Sykes' shaping system, with a spiral angle of 30° or 23° and face width of six times the pitch, for ratios up to six to one, afterwards increasing with ratio.

Let p = pitch in inches; P = tooth pressure in lbs. at pitch line; W = width of face in inches; V = pitch line velocity in feet per min.; r = ratio of reduction; K = permissible stress (taken from curve, fig. 14):

$$P = \frac{B.H.P. \times 33000}{V} = \frac{p.W.K.}{2}$$

For ratios up to 6 to 1 $$p = \sqrt{\frac{P}{3 \times K}}.$$

For ratios between 6 and 10 to 1, $W = rp$; $$p = \sqrt{\frac{2{\cdot}5P}{rK}}.$$

For ratios above 10 to 1 special treatment is advisable, and no fixed rules can be laid down; each drive should be considered with regard to the general conditions.

Proportions of Teeth.

Thickness of tooth $= \frac{P}{2}$; Addendum $= \frac{{\cdot}89 \times P}{\pi}$; Dedendum $= \frac{1{\cdot}05 \times P}{\pi}$.

In the case of helical gears with continuous teeth, the formulæ vary according to the kind of machinery for which the gears are intended, and they are very numerous.

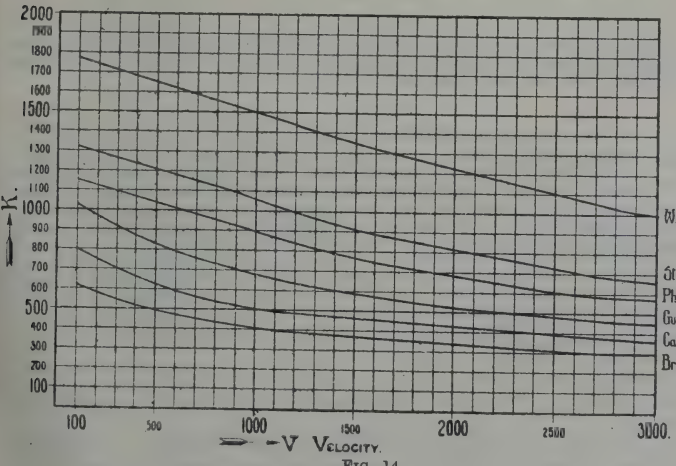


Fig. 14.

Bevel-Wheel Teeth.

A and B, fig. 15, are a pair of bevel wheels revolving on shafts OD and OE. Join OC through the pitch contact of the wheels, and join DE at right angles to OC, and cutting the axes of revolution at D and E. Then OD and OE will be the virtual or instantaneous radii of the wheels

A and B, and these radii are those of two spur wheels which will gear similarly to the wheels A and B, and must be used as the base lines or radii on which the teeth of the bevel wheels A and

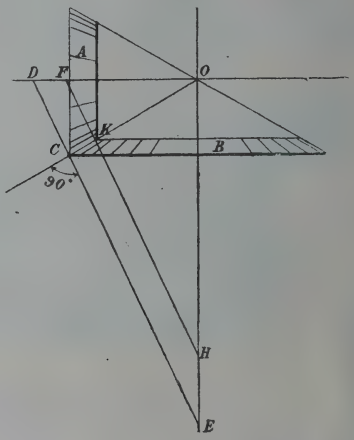


FIG. 15.

B must be designed. Similarly, KF and KH are the radii for designing the inner ends of the teeth. The finished tooth lies evenly between the two end shapes thus found.

GEES TEETH.

Gees teeth are suited to run in one direction only. Their working faces are of any ordinary form, and their idle faces are described with very small rolling circles. This gives a very sloping back to the teeth. They are very strong and run quietly.

Turbine Gears.

This name has come into use for gears running at very high pitch line velocities (3,000 to 18,000 ft. per min.), and applied either to reduce speed of steam turbine to that of mill shaft, standard speed electric generator, propeller, etc., or to increase speed from high speed internal combustion engines, electric motors, etc., to that of rotary pumps, blowers, and compressors.

For such purposes helical gears are almost universally used, as they possess among other advantages an efficiency of 98 per cent. To obtain smooth running the utmost accuracy in the cutting of the teeth is requisite. The teeth may be cut by the end milling, planing, shaping or hobbing processes. The latter processes have the advantage that the teeth are automatically generated by involute cutters, i.e. with rack cutters or hobs having straight sides, or pinion cutters generated with great precision to exact involute contour from a straight-sided rack represented by a grinding wheel. A creeping motion is provided in some of the most recent designs of gear hobbing machines, so that any inaccuracy in the master worm wheel is distributed in spirals on the gear wheel, instead of being parallel to the axis.

Helical gears for geared turbines are invariably made with involute teeth, and the angle of obliquity of the tooth adopted is usually 14½°. The bottom of the tooth must be well rounded and have no sharp corners. The angle of the tooth relative to the axis now commonly used is about 30°.

The Power Plant Co. Ltd. of West Drayton use for the pinions, alloyed steels (nickel or chrome nickel steel) and for the wheels above velocities of 3,000 ft. per min., forged steel rims.

The calculation must start from the requisite pinion diameter to transmit a given load without exceeding the very narrow limits within which bending and twisting are allowed.

With gears where the pinion active face exceeds three times the pitch diameter, three bearings are invariably required for the pinion, to resist bending. The slightest inaccuracies in pitching and setting of the wheels, and comparatively small bending and twisting strains are liable to affect turbine gears very adversely, but these effects can be counteracted by special designs such as the wheels with the pressure compensating device as manufactured by the above company.

PITCH.

Fine pitches give silent running at high speeds, and a normal pitch, that is, the pitch measured at right angles to the teeth, of 0·583 in. (or $\frac{7}{12}$ in.) has been largely used in this country. For small pinions, or where extreme silence is of importance, 0·4 in. in pitch has been used. For turbine gears the pitch for a pinion having at least thirty teeth may be found from the expression :

$$p = \frac{P}{WK},$$

where,
p = pitch in inches; P = total tooth load in lbs.; W = width in inches; K = constant corresponding to the velocity. (See fig. 15A.)

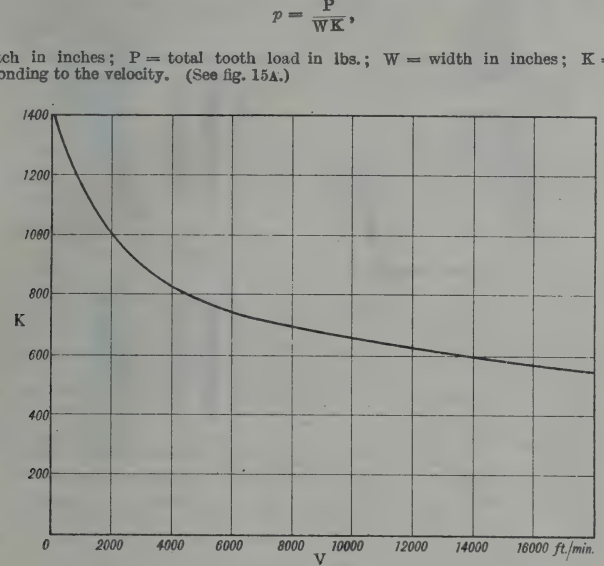


FIG. 15A.

The expression applies to teeth with normal addendum and dedendum.

The materials in turbine gearing are never highly stressed ; gears are designed primarily for wear, and this gives a much greater factor of safety than would be employed were they to be designed for considerations of strength alone.

An ample supply of oil is imperative, not only to lubricate the teeth, but also to carry off the heat generated. For this purpose it is usual to have $\frac{1}{4}$ in. to $\frac{5}{16}$ in. nozzles of about 5 ins. pitch squirting oil under a pressure of 10 to 20 lbs. per square inch on to the line of contact between the gear wheels. The quantity of oil is about 1 gallon per minute per 100 to 150 h.p. transmitted. The case must be well drained, otherwise if the wheel dips into the oil at the bottom much heat will be generated by the churning of the oil.

The power transmitted by a pinion depends upon the allowable tooth speed, load per inch run, and the distortion due to the deflection and twist of the pinion, which must be so small that the distribution of the load on the teeth is uniform. Tooth speed up to 120 ft. per second is common.

The load on the teeth is generally reckoned in pounds per inch run, and is of course the same whether per axial inch or per inch of tooth along the helix. It is determined by the safe bending stress, pressure at point of contact, and by the danger of the oil film failing. The bending stresses are usually low and ignored. For similar crushing stress on the material of the tool, the load (p) per inch run in pounds = ad ; where d is the pitch diameter of the pinion in inches and a is a constant. The stress on the oil film will obey some such law as $p = bd^n$. Mr. H. M. Martin (see *Engineering*, August 11, 1916) gives $n = \frac{1}{2}$. The conditions mean that up to a certain diameter $p = ad$, and that above it $p = bd^{\frac{1}{2}}$.

Messrs. Parsons take $a = 80$ and $b = 175$, but values of $b = 250$ have been used.

The distortion of the pinion is made up of two items—the twist due to the torque transmitted and the bending due to the load on the teeth. The load on the tooth is assumed to be uniform, and the effective diameter of the pinion is the pitch diameter.

FIG. 16.

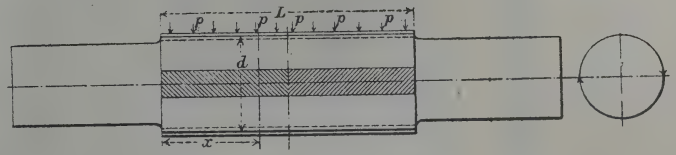


FIG. 17.

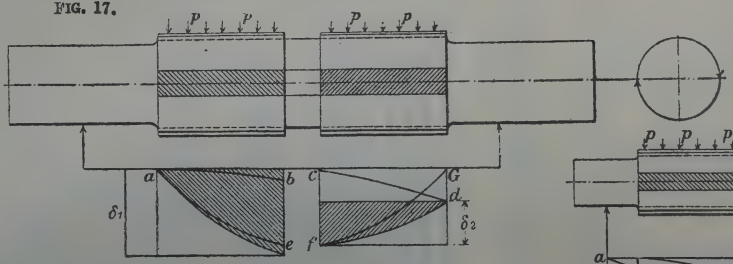


FIG. 18.

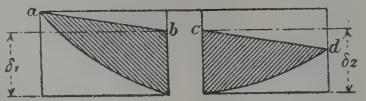
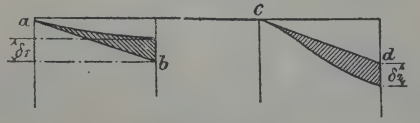


FIG. 20.



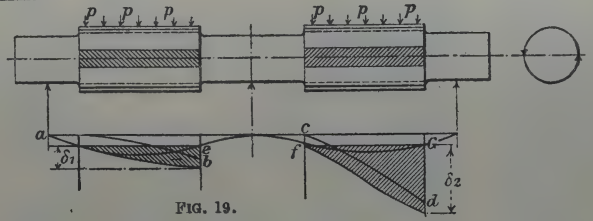


FIG. 19.

At any point x in fig. 16, the torque T is:

$$\frac{pxd}{2} = \frac{2fI}{d} = \frac{\pi f d^3}{16}$$

where f is the shear stress at the circumference of the pinion, and I is the polar moment of inertia or $\frac{\pi d^4}{32}$. Hence it follows that $f = \frac{8px}{\pi d^3}$. If N is the modulus of rigidity, which for steel is 12,000,000 lbs. per sq. in.:

$$\frac{dy}{dx} = \frac{f}{N} = \frac{8px}{\pi N d^3}$$

$$y = \frac{4p}{\pi N} \cdot \frac{x^2}{d^3}$$

which is a parabola. The twist in the first half of the pinion is:

$$y_1 = \frac{p}{\pi N} \cdot \frac{l^2}{d^3}$$

and in the second half:

$$y_2 = \frac{3p}{\pi N} \cdot \frac{l^2}{d^3}$$

There are two cases to consider: the case where there is no centre bearing and the pinion is supported from the ends, as in fig. 17, and the case where there is a centre bearing, as in fig. 19.

The deflection of the pinion can be calculated in the usual way, and is shown by the curves *ae* and *fg*. To this must be added the twist, as shown by the curves *ab* and *cd*. Adding these together, the total distortion is shown by the shaded area, the maximum distortions in each half of the pinion being δ_1 and δ_2. The gap shown in the middle of the pinion is to enable the hob to clear the teeth in each half.

If, in the case of a pinion with a centre bearing, the pinion took up the position *abcd* shown in fig. 20, the effect of the distortion of the pinion is reduced.

In the case of a pinion without a centre bearing, the effect is only small, as shown in fig. 18.

In the case of a pinion without a centre bearing the bending is the chief consideration, whereas in the case of a pinion with a centre bearing the twist is the chief thing.

The allowable distortion should not exceed $\frac{1}{1000}$ in.

(*Prof. Gerald Stoney, F.R.S., D.Sc.*, '*Trans. Manchester Assoc. of Engineers*,' 1919.)

A load of 300 lbs. per in. of tooth (measured axially) is a good average figure. Usually the pinion is made of nickel steel or chrome steel. The torsional stress in high-speed shafts varies from 1,500 to 2,500 lbs., and in the low-speed shafts from 3,000 to 3,500 lbs.

Pitches as high as 0·9 in. have been used for high-speed pinions, and 2 ins. for second reduction pinions.

Single reduction gears having a velocity ratio of 28 to 1 have been used, but this value is extreme.

WORM GEARING.

High Efficiency Gearing.

There are two types of worm gear, namely, one in which the worm is parallel throughout its whole length and the other in which the worm is curved along its face to suit the curvature of the worm wheel. The former is known as the 'parallel' worm gear and the latter as the 'Hindley' or 'globoidal' worm gear.

Hitherto worm gears have been generally used for the transmission of motion from one member to another: all this has now changed, the introduction of machine-cut worm gear of high precision and the increased knowledge of the nature of tooth contacts has resulted in the use of worm gear for the transmission of large horse powers, with very high efficiencies.

Formerly it was considered correct to make the threads of all worm gear straight sided on a linear section through the axis of the worm, and to take the pitch line midway down the working depth of the threads, thus, for the parallel gear this section showed the threads to be a pure rack and for the globoidal gear a similar rack formation but with the threads pointing radially to the centre of the worm wheels. Actually these two types are very closely related because a parallel worm can be regarded as being a globoidal worm which has been made to suit a worm wheel of infinite diameter.

The construction of the threads of the parallel worm to correspond to that of a rack gives involute profiles to the worm wheel teeth on the central section, as shown in fig. 21, and with the Hindley gear, shown in fig. 22, a shape corresponding to the threads of the worm, consequently giving teeth in simultaneous contact. It would therefore appear as if these two types were quite correct in every way: involute tooth engagement for the parallel worm, and a complete tooth engagement for the Hindley worm. Actually these conditions only apply on the central plane. Neither is the involute tooth profile nor the attractiveness of the Hindley type maintained; their value is entirely lost on all other planes owing to the curvature of the face of the worm wheel. Whenever straight-sided threads are used for worms, whether for the parallel or the Hindley type, the teeth on other planes than the central one are not, and cannot be, wholly conjugate to the threads of the worms, because the hob during cutting unavoidably removes too

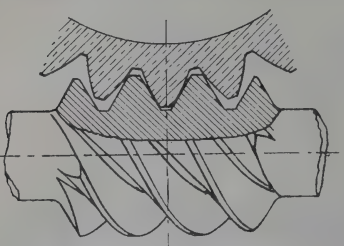


FIG. 21.—Parallel Worm Gear.

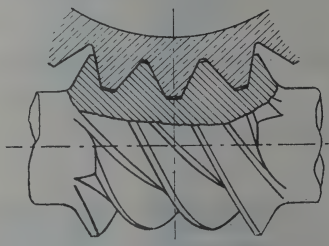


FIG. 22.—Hindley Worm Gear.

much metal from the wheel teeth. The result is that in actual practice neither of these worms transmits uniform velocities to the worm wheels, and instead of the contact being mainly on the leaving side it is almost wholly on the entering side, thus giving a higher coefficient of friction and a lowering of the overhaul efficiency of the gears. Worm gear, unless correctly designed, does not transmit a uniform velocity from one member to another. A close approximation is obtained with gears of comparatively fine pitch, and in those of a high lead angle any error is sometimes concealed by the adjacent thread being in action in such a manner that by sustaining an extra proportion of the load distribution the variable velocity period is tided over. Even the inertia of the parts may prevent a change in the velocity of the engaging pair, but this is detrimental to the gears. To consider a worm gear as a kind of a development from the screw is fundamentally wrong. The pitch surfaces of the worm gear are cylinders lying at right angles

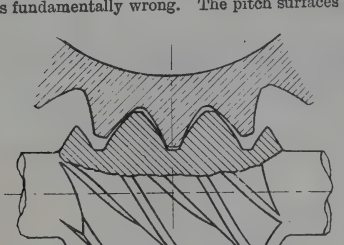


FIG. 23.—F.J. Worm Gear.

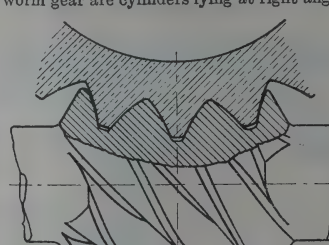


FIG. 24.—Enveloping Worm Gear.

to each other, hence they only touch at one point, whereas in a screw and nut the pitch surfaces coincide. Expressed in simple language, one can say that, consistent with the transmission of uniform velocity, the normal to the surfaces from the point of contact must always cut the central plane which contains the axis of the wheel, at a point on the straight line lying on the wheel pitch cylinder, and consequently tangential to the pitch cylinder of the worm. Thus, for every point of intersection between a worm thread and the zone of contact, there is a definite relation between its angular and longitudinal positions. If contact takes place at any other point than this intersection, it does so to the detriment of the transmission of uniform velocity.

The mathematical investigations carried out by Mr. F. J. Bostock have shown that the usual rack formation of the threads of the parallel and the globoidal worms is entirely wrong. Fig. 23 shows the correct form of worm threads for the parallel worm and is known as the 'F.J.' Worm Gear,

manufactured by Messrs. David Brown & Sons (Huddersfield) Ltd. In this gear, instead of the threads being straight-sided on a section containing the axis of the worm, they are straight-sided on a section taken at a predetermined distance away from the axis, and the pitch line, instead of being taken halfway down the working depth, is taken at the bottom of the working depth or at the throat diameter of the worm wheel. This gear has been largely used for the propulsion of buses and lorries in this country and America, and upon test by the N.P.L. gave an efficiency of 97·3 per cent.

The corresponding correct form of threads for the globoidal type is shown in fig. 24, which was also the result of Mr. Bostock's investigations, and is manufactured by Bostock & Bramley, Leeds. The difference between this and the 'F.J.' gear is that the former has been made to suit a worm wheel of finite diameter, whilst the latter has been made to suit a worm wheel of infinite diameter, the cross section of the two worms on a plane containing the axis of the worm wheel being, as one would expect, identical. The zones of contact are almost identical, consequently they both have the same characteristics. In the same way that the parallel worm will correctly mesh with any worm wheel of infinite diameter or less, so the enveloping worm will correctly mesh with any worm wheel of the diameter for which it is made or less. The threads of both these worms are generated on straight line systems and lend themselves to easy rectification after hardening. It will be readily apparent that, whilst in construction these gears are similar, the globoidal type has, however, a greater closeness of fit between the threads of the worm and the teeth of the wheel, consequently it has a greater load-carrying capacity than the 'F.J.' The 'F.J.' gear is the perfect form of the parallel worm gear and the enveloping worm gear the perfect form of the globoidal worm gear.

Although the ordinary involute type of parallel worm gear has certain inherent defects, it is still largely used for drives in which the maximum load-carrying capacity and efficiency are not required. The following observations are therefore applicable:

Pitch.—The distance from one tooth to the next, measured along the pitch line, is called 'the pitch,' and when measured along a line parallel to the axis of the worm is called the 'linear pitch.' The normal pitch is that measured normal to the thread, whilst the circular pitch is measured circularly at right angles to the axis. The circular pitch of the wheel is equal to the linear pitch of the corresponding worm.

Lead.—The distance travelled, parallel to the axis, by a thread when making one revolution round a worm is termed 'the lead,' and is equal to the number of threads multiplied by the pitch. As the thread or helix travels round and along the worm it makes an angle with the axis, or to a line parallel to it. This angle is called the 'spiral angle,' and its complement the 'lead angle.' The lead bears quite important relation to the efficiency and durability of worm gears. The maximum efficiency of a worm gear may be expressed by the equation:—

$$\eta = \frac{\tan\theta}{\tan(\theta+\mu)}\text{; the reversed } \eta = \frac{\tan(\theta-\mu)}{\tan\theta};$$

where θ is the lead angle, and μ is the angle of coefficient of friction.

These two equations show that the maximum efficiency is obtained when the lead angle approximates 43°−40′, and that an efficiency of 50 per cent. is obtained when the worm angle is equal to the friction angle, at which point the gear is irreversible. In order to obtain a high angle, it is necessary to keep the diameter of the worm as small as possible. This also has the effect of reducing the rubbing velocity.

Influence of Speed on Pressure.—It has been stated that the permissible pressure multiplied by the velocity is practically constant. This is not so. Within the usual limits the law appears to be that the permissible pressure varies almost inversely as the cube root of the velocity. Various materials are suitable for different pressures; for light loads, at low speeds, the combination may be a cast-iron wheel and mild steel worm; for heavier loads, a cast-iron wheel and a hardened steel worm; for heavy loads, a phosphor bronze wheel and a hardened and ground worm.

Worm gear, unless correctly designed, does not transmit a uniform velocity from one member to another. A close approximation is obtained with gears of comparatively fine pitch, and in those of a high lead angle any error is sometimes concealed by the adjacent thread being in action in such a manner that by sustaining an extra proportion of the load distribution the variable velocity period is tided over. Even the inertia of the parts may prevent a change in the velocity of the engaging pair, but this is detrimental to the gears. To consider a worm gear as a kind of a development from the screw is fundamentally wrong. The pitch surfaces of the worm gear are cylinders lying at right angles to each other, hence they only touch at one point, whereas in a screw and nut the pitch surfaces coincide. Expressed in simple language, one can say that, consistent with the transmission of uniform velocity, the normal to the surfaces from the point of contact must always cut the central plane which contains the axis of the wheel, at a point on the straight line lying on the wheel pitch cylinder, and consequently tangential to the pitch cylinder of the worm. Thus, for every point of intersection between a worm thread and the zone of contact, there is a definite relation between its angular and longitudinal positions. If contact takes place at any other point than this intersection, it does so to the detriment of the transmission of uniform velocity.

Thermal Considerations.—All frictional losses produce heat, and if the amount of heat generated be greater than the amount radiated, dissipated, or conducted away, the temperature of the gear unit will rise. When it rises above a certain point (about 250° F.), the oil film breaks down and lubricating value ceases, but they are usually run at a nice warm temperature (150° F. to 175° F.).

Thus one requires to know, in addition to the foregoing, the load factor or the proportional time the gears will run on various loads, and the thermal capacity of the case or how many B.Th.U.'s it can dissipate at various temperatures. By this data one can predetermine the temperature rise of the gear unit at the end of any period of running under a certain load factor.

Worm Milling.—Worms are usually supplied solid with their shafts and a bearing on each side of the thread. In order to guarantee concentricity and uniformity of size, a practice is made of grinding of worms on their outside diameters of the thread and journal before the cutting operation. For machining such worms special machines have been devised, and in these the worm is generally caused to travel spirally in front of the cutter, thus milling a thread space for each longitudinal travel of the table. The cutter spindle is carried in a swivelling head which enables it to be set at any angle to suit the spiral of the worm to be cut.

Cutter Form Generation.—The rotary cutter at first sight appears to be quite a straightforward matter, with its contour made to correspond with the space of the worm thread. Such, however, is far from being the case, as its actual contour is quite different from the thread space which it cuts in the worm blank, as will be seen from fig. 25. This apparent paradox

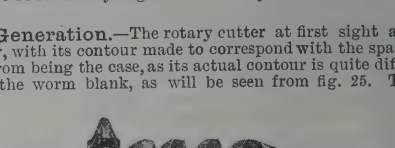


FIG. 25.—Worm and its Cutter.

is caused by the interference of the cutter with the side of the worm thread, and it will be understood when it is remembered that the worm thread is an endless spiral. As a rotary cutter must be circular in shape, and as a circle and spiral cannot coincide, it is obvious that the contour of the circular cutter cannot coincide with the thread space of the spiral worm. The base of the worm thread system is a straight line. In the system of cutter generation a straight edge tool is set to an angle corresponding to the pressure angle of the worm to be cut, and is then made to traverse in a spiral path corresponding exactly with the spiral of the worm. Thus a generating tool is mounted in a worm milling machine in the same position and manner as the worm which is to be cut, its straight edge accurately representing one side of the worm thread. When it has generated one side of a white metal blank it is indexed to the other side, thus forming the contour of the required cutter.

Hobs—Manufacture and Sharpening.—The teeth of worm wheels are of such construction that they do not lend themselves to operations of planing, shaping or milling like other forms of gearing: they can only be produced by a process of generation by means of a cutting tool called a 'hob.' Whilst it is true that the spiral angle pitch, the number of threads, and pitch diameter in the hob must correspond with that of the worm, yet both the outside and bottom diameters of the hob are made larger in order to provide requisite clearance in the roots of the teeth. The hob throughout is gashed along its length normal to the spiral angle for the purpose of providing a cutting face, whilst the teeth are relieved in order to provide a cutting clearance. As the shape and contour of the wheel teeth are entirely dependent upon the design and accuracy of the hob, it is necessary that this tool should receive the most careful supervision in all stages of its manufacture and subsequent regrinding. Hobs are generally made with their cutting faces radial; it is therefore essential that they should be sharpened radially, or an alteration in shape will result. The same, of course, applies to ordinary rotary cutters. It will be appreciated that as a hob is sharpened its diameter is reduced, but with a reamer hob the reduction in diameter is only a few thousandths of an inch in the whole length of the teeth, thus uniformity of shape is retained.

Worm Wheel Generating.—Generally the worm wheels are rough turned on automatics and turret machines, and pass from thence to the worm wheel section for rough cutting of the teeth, after which they are finished, turned, and finally the teeth undergo a reamering or finishing operation. In no small measure is the interchangeability and high efficiency of the wheels due to this reamering operation.

The generating of the teeth of the worm wheel is carried out in a machine as illustrated in fig. 26, the blank being mounted upon a revolving table, which is positively driven at a predetermined speed, according to the ratio of the gears being cut, whilst the hob is caused to travel longitudinally across the face of the wheel. Owing to the spiral of the hob it is necessary to compensate for its longitudinal travel by means of a differential, whilst the rate of travel or feed can be varied at the will of the operator.

A special feature of the mounting of the worm wheel on the table is made. A hardened and ground micrometer adapter carries the arbor, which supports various other adapters to suit the locating register of the worm wheel blanks, the micrometer being adjusted until the specified distance from the locating face of the blank to the axis of the hob is obtained.

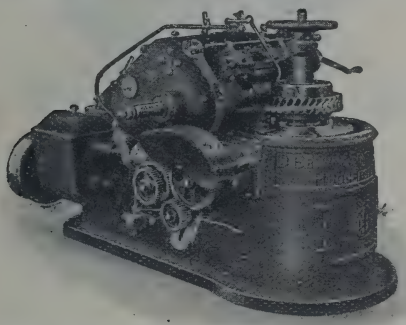


FIG. 26.—Worm Wheel Generator (*David Brown & Sons (Huddersfield) Ltd.*).

To facilitate setting up, and to test the true running of the registers and worm wheel blank, the drive to the table is arranged so that it can be disconnected in order that the operator may be able to revolve the table by hand and so, by means of a clock indicator, test the accuracy of the mounting.

The head which slides horizontally along the bed towards the worm wheel contains the whole of the mechanism for driving the hob and traversing the hob slide. The latter is mounted on the head at an angle normal to the direction of the stress, so as to present the maximum bearing area to the very best advantage.

The main drive is taken from a single pulley fitted with an internal friction clutch in conjunction with a four-speed gear box. The drive is then transmitted in one case directly to the index change wheels for driving the table, and in the other to the worm wheel mounted on the hob spindle.

It should be mentioned that the dividing wheel is of greater diameter than the largest blank which the machine will cut, and a neat design is effected by allowing the cuttings to fall through the arms of the table into the bed of the machine, from whence the cutting lubricant is drained.

Worm and Wheel Inspection.

For testing the accuracy of the pressure angle a knife edge protractor is placed along the side of the thread and the angle read to plus or minus a few minutes. This is carried out in a worm gear testing machine, illustrated in fig. 27, which has been designed to enable the various testing operations to be performed on both worms and wheels. These can be tested separately as individual pieces, or in combination when mounted together at the specified centre distance. The bed consists of two slides at right angles, one carrying a pair of adjustable centres and the various testing appliances, whilst the other slide carries an adjustable arbor adapter, which is controlled by a micrometer screw, enabling it to be set at any required distance from the other slide, so giving correct centres for the worm and wheel under test. This machine is most conveniently operated, as it can be worked from either side, thus allowing the operator to be in the most advantageous position to carry out all the necessary tests. Other instruments are used on it for testing concentricity and lead.

The process of case-hardening worms is exactly the same as for other work, but although every precaution be taken some little distortion is bound to occur. They therefore require straightening so that their pitch diameter runs true; for this purpose a clock indicator on a testing machine is used in conjunction with the straightening press, and by means of a ball placed in the space this operation can be accurately and quickly performed.

Interchangeability of the worm wheel is ensured by the use of a double ball micrometer which measures the comparative pitch diameters.

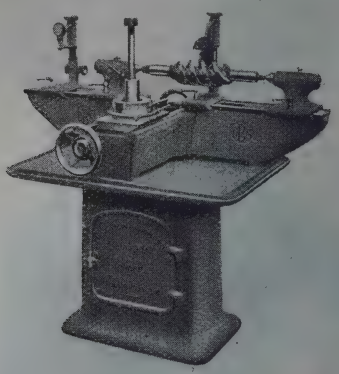


FIG. 27.—Testing Worm for Accuracy of Pressure Angle.

The final inspection is made on a testing machine, where the gears undergo a more rigorous test. The wheels are tested for concentricity of cutting and the distance from the centre of the worm axis to the locating face, after which they are tested together to verify the centre distance.

Worm Gear Application.

Worm reducing gear units are with great advantage coupled direct to electric motors, enabling reductions in speed from 4 : 1 to 100 : 1 in a silent and efficient manner, and when both of them are mounted on the common baseplate they represent a simple, sound and economical proposition.

On account of their ability to withstand considerable overload for short periods they lend themselves admirably for intermittent work, because for the work they are called upon to do they can be made relatively small; therefore they are of great use in crane work and for starting purposes of electric motors, steam, gas, and oil engines.

Horse Power Formula.

$$H.P. = K \times A \times T \times r^{\frac{2}{3}} \times R^{\frac{2}{3}} \times S$$

where,

K = constant; A = projected area of worm wheel in sq. ins.; T = teeth in contact; r = pitch radius of worm in ins.; R = revs. per minute of worm; S = function of lead angle.

For K, use :

Hardened mild steel worm and phosphor bronze wheel		K = 0·14
Soft	" " " " "	K = 0·1
Hardened	" " cast iron wheel	K = 0·08
Soft	" " " "	K = 0·07

For intermittent work multiply the above by 1·3.

For T, use :

Worm Threads	1	2	3	4	5	6	7	8
T	1·4	1·5	1·66	1·8	1·9	2	2·1	2·2

For S, use ;

Lead Angle	5°	10°	15°	20°	25°	30°	35°	40°	45°
S	0·09	0·18	0·27	0·36	0·45	0·55	0·65	0·77	0·9

Example:—What is the H.P. of a case-hardened worm, 2 threads, 1½" pitch, 3" pitch diameter, 17½° lead angle, 2½" face (projected area say 2½ sq. ins.), revolving at 1,000 r.p.m. and driving a phosphor bronze worm wheel?

$$H.P. = \cdot 14 \times 2\tfrac{1}{2} \times 1 \cdot 5 \times 1 \cdot 31 \times 100 \times \cdot 315 = 19 \cdot 5$$

REDUCTION GEAR.

H-R Gear.

(J. Stone & Co., Ltd., Deptford, London, S.E. 14.)

With this gear, using the worm gear as its base, it is possible to give any speed ratio in a very compact size, *i.e.* in the small space of 12 ins. × 12 ins. × 12 ins., any ratio up to 20,000 to 1 can be obtained, while for larger ratios compound gears take up little or, in some cases, no more space than for small ratios.

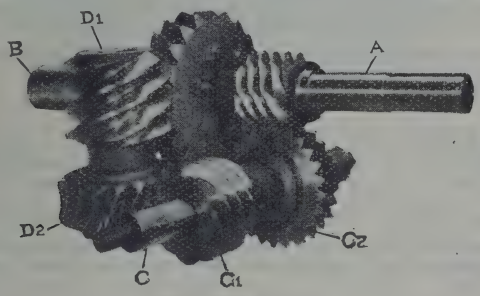


FIG. 28.

The arrangement adopted in a standard type of reduction gear is shown by fig. 28. The driving shaft A transmits power from the prime mover through a worm mounted on the shaft to a worm wheel C_2 arranged on shaft C. The shaft C is extended to carry a worm C_1, and the power is transmitted through this worm to a worm wheel D_2, mounted on shaft D transverse to the shafts A and C. This shaft in turn carries a worm D_1, which transmits the power through a worm wheel arranged on the driven or slow speed shaft B, so that the essence of the invention is the placing of gear shafts around the periphery of the driving worm and the driven worm wheel, thus permitting the first and final shafts to be arranged co-axially.

The efficiency of the gear is 70 to 90 per cent. in gears having ratios up to 250 to 1. This efficiency is maintained throughout the life of the gear. As the gear is always running in an oil-bath and its design is such that low tooth pressure and efficient helix angles are obtained, it is durable and silent in operation.

There are over 300 standard H-R Gear ratios, from 10 to 1 to 50,000 to 1, to select from.

In addition to secondary motion shaft, intermediate drives, both vertical or horizontal plane, may be incorporated in any standard box.

Ratios from 10 to 1 up to 50,000 to 1 can be obtained in standard gear-boxes. The size of a particular gear-box for a given ratio or load-carrying capacity is very compact and is claimed to be smaller than any other type of gear.

Since each gear ratio represents only the cube of the actual ratio required, only a small ratio on each train of gears is necessary, consequently exceedingly efficient worm lead angles are obtainable; thus with a gear ratio 64 to 1, each train of gears requires a ratio of 4 to 1 and a lead angle of 45°, each gear train having an efficiency of 95 per cent., so that the over-all efficiency would be not less than 85 per cent. With the ordinary type of worm gear having a single worm and wheel, for such a gear ratio only a single start worm could be employed having a lead angle of, say, 7°, which would give an efficiency of not more than 65 per cent. Even if very fine pitch and a 2-start worm were employed, it would be impossible to obtain an efficiency exceeding 75 per cent.

An exceedingly important feature of the H-R Gear, particularly where employed with large ratios and where space restrictions come in, is its load-carrying capacity. The maximum permissible loading on any worm-gear tooth depends entirely upon the rubbing velocity, and it will be seen that in the H-R Gear the rubbing velocity of the final worm and worm wheel is broken down very considerably through the first two trains of gears. In addition, because of the comparatively small ratios on each train, the minimum number of teeth and maximum pitch can be employed. On the very large ratio gears it is possible to load the gear teeth almost up to the yield point of the material of the worm wheel.

The H-R Gear is claimed to be the only absolutely silent gear which provides for a co-axial drive; this, in many cases, is a most important feature.

The gear has been applied to every kind of machinery.

VARIABLE-SPEED GEAR.

The 'VSG' Mark III. Hydraulic Variable-Speed Gear.

(The Variable Speed Gear, Ltd., Broadway, Westminster, S.W. 1.)

This gear consists of two units, viz. an 'A' end or pump unit (fig. 29), and a 'B' end or hydraulic motor (fig. 30). These 'A' and 'B' ends can be opposed to one another directly with a common connecting plate termed a 'valve plate,' forming a type 'C' gear, or they can be separated to any reasonable distance and connected by piping, each unit having a separate valve plate, forming a type 'K' gear.

The flexibility of arrangement possible with the 'VSG' gears is a valuable feature, particularly so where considerations of space enter into account. Oil, which is practically incompressible, is the medium of transmission of power, and as this is supplied under pressure to the most important working surfaces and the whole of the machine casing is filled with oil, lubrication is perfect and wear negligible.

In certain instances machines are arranged to run with empty cases, and when this is so, special arrangements are made for the lubrication of the working parts.

Construction.

The 'B' end or hydraulic motor is generally similar in construction to the 'A' end or pump unit, which is fully described in the 'Pump' section, p. 1335, a number of its components being identical with those of the 'A' end. For the majority of purposes no controls or relief valves are necessary in the 'B' end, and the tilting box is usually fixed, giving the 'B' end a fixed capacity.

Where cooling is desirable, a water cooling coil is fitted in the 'B' end around the cylinder barrel.

Whilst in most cases 'Michell' type bearings are fitted to take the thrust and radial load behind the socket ring in the 'B' end, in certain special equipments 'VSG' 'B' ends are fitted with roller bearings.

Operation of the Gear.

When a 'VSG' gear is ready for running, the entire space within the cases and valveplate of the type 'C,' and valveplates and piping in the type 'K,' is filled with oil.

A definite portion of the oil is enclosed within the 'cylinders' ahead of the pistons, valveplate port passages, and piping of type 'K.' This is the working oil used in transmitting energy, the case oil not being subject to pressure.

Assuming the tilting box with its socket ring is set at the neutral position (*i.e.* perpendicular to the mainshaft), the 'A' end mainshaft, if rotated, will carry with it the socket ring and the cylinder barrel, together with the pistons and connecting rods. The pistons will not reciprocate or move to and fro in the cylinders, and as there will be no delivery from the pump, the 'B' end will remain stationary.

If the control be moved a little, so as to move the top of the tilting box away from the 'valve-plate,' and the 'A' end mainshaft is rotated in a clockwise direction (looking on its shaft end) all the pistons as they move down on the right-hand side will be driven in towards the valveplate, expelling the oil contained in the cylinders through the cylinder ports and the large port in the same side of the valveplate. The 'B' end, as is explained later, will then commence to rotate at a speed corresponding to the amount of delivery given by the 'A' end.

The pistons on the left-hand side of the 'A' end will, as they ascend, be drawn away from the valveplate, and their cylinders will fill with oil from the valveplate port facing them.

It should be noted that when a piston reaches the top or highest position in its revolution, and also the lowest position, it for an instant makes no end movement. This corresponds with the cylinder port crossing the top or bottom lands or spaces between the two valveplate ports.

The quantity of oil forced through the valveplate port depends upon the length of stroke imparted to the pistons and consequently upon the angle at which the tilting box stands.

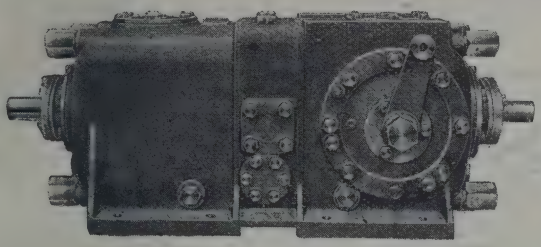
The 'B' end is an inversion of the 'A' end, and the 'B' end socket ring is carried normally at a fixed angle of about 20°, the top of the tilting box lying back from the valveplate, and when the 'B' end mainshaft is rotated the 'B' end pistons will make their full stroke as they pass between the bottom and top pistons.

The oil expelled by the 'A' end pistons through the pressure port of the valveplate enters the 'B' end cylinders facing that port and exerts pressure on the pistons in those cylinders.

Due to the socket ring being held in the tilting box, the pistons cannot move except by rotating the socket ring on its bearings in the inclined plane in which it is held, thereby converting the reciprocating motion of the pistons into rotary motion.

The socket ring therefore revolves and carries with it the mainshaft to which it is connected by the universal joint. The 'B' mainshaft in turn rotates its cylinder barrel, and the whole of the 'B' end rotating group revolves in the opposite direction to the rotation of the 'A' end mainshaft.

The speed of rotation of the 'B' end mainshaft depends upon the quantity of oil delivered by the 'A' end. For example, if each cylinder has a capacity of, say, 3 cu. ins., one complete revolution of the 'B' end group of 11 cylinders would transfer 33 cu. ins. of oil from the right-hand side to the left-hand side. If the top of the 'A' end tilting box be tilted away from the valveplate



Type "C" "VSG Mark III" Variable Speed Gear, fitted with Lever Control.

"VSG"

HYDRAULIC VARIABLE SPEED TRANSMISSION GEARS

Infinite variation of speed without steps, forward and reverse. Perfect and easy control. High starting torque. Low maintenance costs. Eminently suitable for controlling machinery for industrial purposes, viz.:—

Annealing Furnaces
Cable-Making Plant
Colliery Plant
Conveyors
Coilers for Belts, etc.
Foundry Plant
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Paper-Making Machinery
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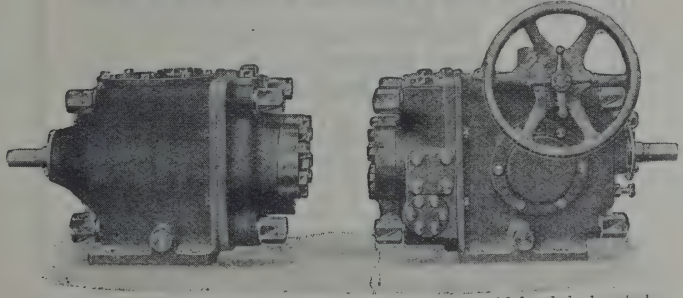

Type "K" "VSG Mark III" Variable Speed Gear, fitted with handwheel control.

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THE 'VSG' MARK III. HYDRAULIC VARIABLE-SPEED GEAR.

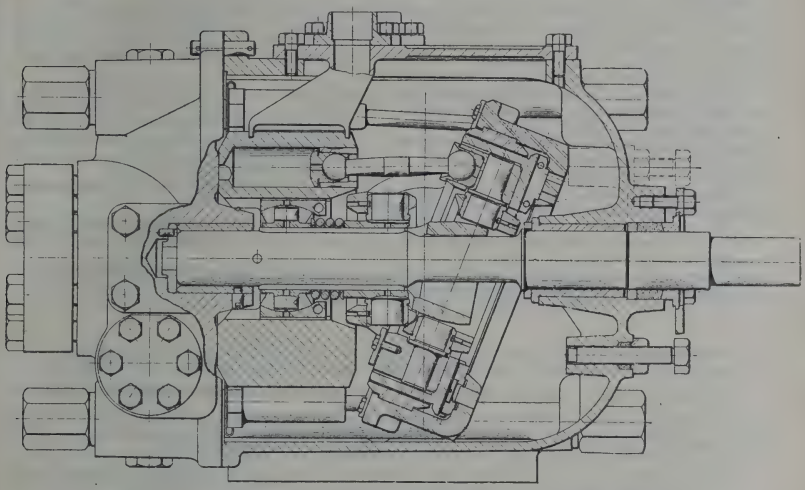

FIG. 29.—Vertical section through 'VSG' Mark III. 'A' end, fitted with lever control.

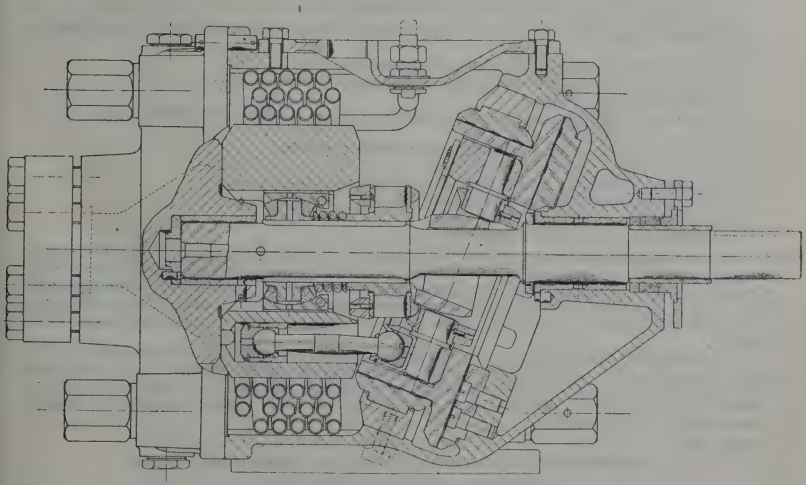

FIG. 30.—Vertical section through 'VSG' Mark III. 'B' end, fitted with Michell type bearings.

sufficiently to cause the socket ring to impart a small stroke to the 'A' end pistons corresponding to an output from each cylinder of, say, 0·01 cu. in., all the 11 pistons of the 'A' end will together transfer 0·11 cu. in. of oil from the left-hand to the right-hand side at each revolution of the mainshaft.

On the basis of the capacity of the 'B' end cylinders per revolution being 33 cu. ins., 300 revs. of the 'A' end mainshaft at this degree of tilt will be necessary to rotate the 'B' end mainshaft once. If, however, the 'A' end socket ring be tilted still farther, the output of the 'A' end will be greater and the 'B' end mainshaft will rotate proportionately faster, until at full stroke both ends are at the same speed.

So far reference has been made to tilting the 'A' end socket ring in one direction only, namely, by moving the top of the tilting box away from the valveplate. If, however, it be moved in the opposite direction, the oil will be discharged through the left-hand port instead of through the right-hand port as previously; this will cause the 'B' end group to rotate in the opposite direction to that in which it has previously revolved, and it will now correspond in direction of rotation with the 'A' end mainshaft, viz.: clockwise. The gear is therefore fully reversible.

When the 'A' and 'B' ends are of equal capacity, the speed of the 'B' end mainshaft is being rotated in either forward or reverse directions.

For some purposes 'A' and 'B' ends of different capacity are combined, usually a large 'B' end being employed thereby giving a fixed reduction ratio as well as variable and reverse speeds.

Where a reduction or step-up gear is necessary on either the input or output shaft of the gear, this can, in many cases, be arranged within the gear casing.

Control.

Various types of control can be fitted, the purpose of all of which is to vary the angle of the 'A' end tilting box and thereby the delivery of the pump. The most usual forms of control are :—

(1) *Lever.*—A simple lever mounted directly on an extension of one of the tilting box trunnions.

(2) *Wheel or Rotary.*—Comprising a shaft carrying a pinion engaging a toothed sector fitted to the top of the tilting box. On this shaft is mounted a handwheel for direct manual operation, or sprocket, bevel, etc., for distant or mechanical control.

(3) *Automatic or Pressure Control.*—This consists of a hand or mechanically operable control combined with an automatic pressure operated device which regulates the speed of the gear automatically to suit the load and obviates the necessity of using skilled operators to safeguard equipments dealing with widely fluctuating loads.

Advantages.

The special properties of the 'VSG' Hydraulic Variable Speed Gear can be summarised as follows :—

(1) Speed change without declutching from prime mover.
(2) Ability to 'inch' and rotate at very low speeds.
(3) High torque at low speed.
(4) Perfectly smooth acceleration and retardation at any constant or variable rate.
(5) Quick reversibility without shock.
(6) Complete positive and simple control in either direction.
(7) Steady speed under fluctuating loads.
(8) Enables constant speed non-reversing prime mover to be used.
(9) Protects complete installation from damage due to overloads.
(10) Reduces labour and operating costs.
(11) Repairs and maintenance negligible.

An important feature inherent in the 'VSG' gear is the braking effect which can be obtained when it is used with a regenerative prime mover, enabling the retardation of masses having large momentum and unbalanced loads to be carried out under absolute control, *e.g.* in the case of a hoist, loads may be lowered at any desired speed, decelerated and held in all positions without the use of mechanical brakes. In fact, the same degree of control is available when lowering as when hoisting.

With electrically driven machinery a distinct advantage is obtained by the use of the 'VSG' gear, inasmuch as the simplest and cheapest type of motor can be installed, *i.e.* squirrel cage induction or shunt wound DC., also controllers and resistances with their attendant heavy current losses are dispensed with, a light load starter only being necessary. Current peaks when starting heavy loads are eliminated.

See also

A CONTINUOUSLY-VARIABLE CHAIN-DRIVEN CHANGE-SPEED GEAR.
"The Engineer," Aug. 27th, 1926.

THE KEENOK PINION AND GEAR.
"The Engineer," Sept. 23rd, 1927.

Straight Line Link Motion.

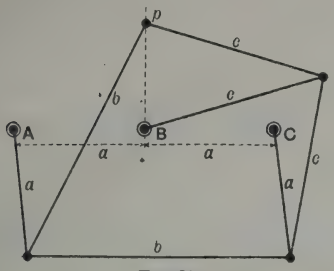

FIG. 31.

Fig. 31 shows a combination of seven links linked together, with three of the links pivoted at A, B, and C. The relative lengths of the links a, b, and c are such that

$$a : c :: c : b,$$

or,

$$c = \sqrt{ab}.$$

In the fig., a and b are in the proportion of 1 to 2, so that

$$c = \sqrt{1 \times 2} = \sqrt{2}.$$

With this arrangement the point p is constrained to move in an *accurately straight line traverse* away from B, towards B, or beyond B, the movement being perpendicular to AC.

So long as the value of c is such that

$$c = \sqrt{ab},$$

the proportionate value of a to b may be varied as desired, though it is not desirable to have this value very disproportionate, as although the straight traverse is still theoretically preserved, the arrangement becomes unstable from a practical point of view, through lack of *stiffness*.

(*H. R. Kempe.*)

SECTION XX

PART I

BEARING PRESSURES—HEATING OF BEARINGS—BALL AND ROLLER BEARINGS (pp. 1039-1054)

(Revised by Professor Dempster Smith, M.B.E., M.Sc., M.I.Mech.E., with contribution on 'Ball and Roller Bearings' by Prof. John Goodman, M.I.C.E., M.I.Mech.E.)

PART II

LUBRICATING OILS, LUBRICATION, AND LUBRICATORS (pp. 1055-1069)

(Contributed by Harold Moore, M.Sc., M.Inst. Pet. Tech., F.C.S., A.I.M.E.)

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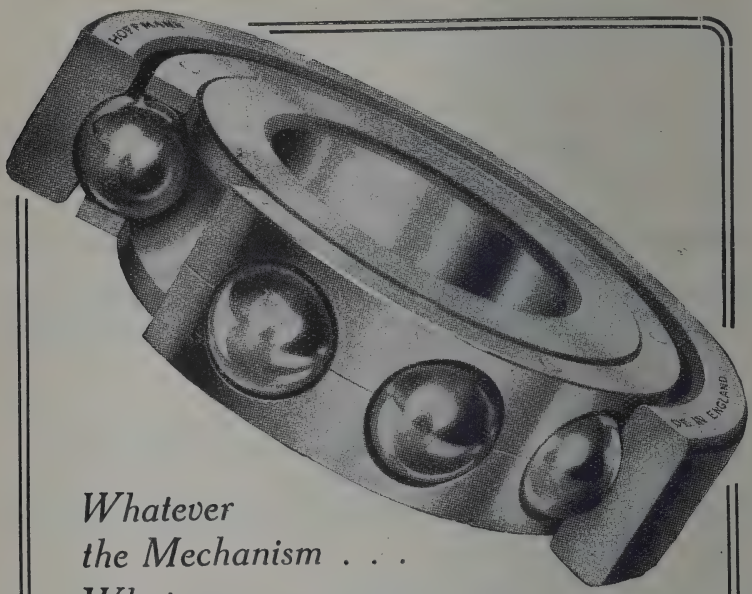

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SECTION XX

PART I

BEARING PRESSURES—HEATING OF BEARINGS—BALL AND ROLLER BEARINGS

(Revised by Professor Dempster Smith, M.B.E., M.Sc., M.I.Mech.E.)

BEARING PRESSURES.*

Pressures on Bearings.

The following table shows the wide variation of pressure in bearings :—

	Lbs. per Sq. In.
Light and fast-running cotton spindle	2 to 5
Light shafting	80 to 100
Heavy shafting	300 to 600
Marine engine crank pins	600 to 900
Crosshead pins (horizontal engines)	1,200 to 1,300
Crank pins " "	800 to 950
Crank shaft (steam load) " "	100 to 150
" " (combined load) " "	150 to 200
Second motion bearings " "	100 to 200
Crosshead slides " "	40 to 50
Intermediate piston rod slides " "	20 to 40
Main bearings (vertical high-speed engines)	200 to 300
Crank pins " "	400 to 550
Crosshead pins " "	1,000 to 1,200
Crosshead slippers " "	40 to 50
Eccentric straps " "	60 to 70
Crosshead pins (locomotive)	1,400 to 1,800
Crank pins "	1,000 to 1,500
Axle bearings (loco. engine and tender)	200 to 250
Railway carriage bearings	300 to 350
Babbitt metal on cast-iron slide	200 to 250

MAXIMUM SAFE PRESSURES ON BEARINGS.

Nature of Bearing.	Safe Load. Lbs. per Sq. In.
Ordinary bearings for shafting :—	
Wrought-iron on cast-iron	250
Wrought-iron on gunmetal	300
Mild steel on cast-iron	300
Mild steel on gunmetal	370
Mild steel on white metal	500
Cast-steel on gunmetal	600
Flywheel shaft	250

At unit pressures of 250 lbs. per sq. in. for cast-iron bearings, and 145 lbs. for bronze bearings, there is difficulty in keeping the boxes from seizing the shaft.

* For Bearing Metals, see METALLURGY, Section XL.

Professor W. C. Unwin carried out a series of experiments with Delta White Antifriction Metal, of which particulars are given. These tests show that this metal heats but little, even with high-bearing pressures :—

Mean Revolutions of Shaft per Minute	Mean Pressure per Square Inch of Journal Surface in lbs.	Mean Temperature in Deg. Fahr.	Mean Moment of Friction in lbs.-in.	Net Pressure on One Step in lbs.	Friction on One Step at Journal Surface in lbs.	Co-efficient of Friction
123	128·35	62·65	9·25	477·5	6·17	0·01292
	256·70	64·00	16·26	955	10·84	0·01135
	385·05	65·75	24·23	1432·5	16·15	0·01128
	513·40	67·70	40·87	1910	27·25	0·01428
315	128·35	73·80	12·00	477·5	8·00	0·01675
	256·70	76·20	17·25	955	11·50	0·01204
	385·05	80·05	26·00	1432·5	17·33	0·01210
	513·40	86·40	44·63	1910	29·75	0·01558

COEFFICIENTS OF FRICTION AND SAFE MAXIMUM PRESSURES FOR VARIOUS LUBRICANTS.

Lubricant.	Coefficient of Friction.	Max. Safe Pressure in Lbs. per sq. in. on Nominal Area.
Olive oil	·00172	520
Lard oil	·00172	570
Sperm oil	·00208	570
Mineral oil	·00176	625
Mineral grease	·00233	625

Heating of Bearings.

SIGNALS FOR INDICATING HEATING OF BEARINGS.

The double iodide of silver and mercury, $AgIHgI_2$, is a pale lemon-yellow powder at ordinary temperatures, and changes to a vivid carmine colour at about 90° to 100° C., the change in both directions being fairly sharp. The copper mercuric iodide, $Cu_2I_2.2HgI_2$, is a vivid scarlet-vermilion at ordinary temperatures, and at 60° to 70° C. it changes to a chocolate-brown. Both these compounds are adapted for use under suitable conditions, but a mixture of the two, consisting of 85 per cent. of the copper salt and 15 per cent. of the silver salt, is more sensitive and gives a greater colour range from vermilion to almost black, the transition being exceedingly sharp.

The compounds may be prepared in a variety of ways. A simple method of preparing the copper salt is by well triturating in a mortar 380 grms. of cuprous iodide with 910 grms. of mercuric iodide, sufficient water being added to form a paste. When thoroughly mixed, the mass is dried in the water-oven, and the dried mass ground to an impalpable powder. Another method is to dissolve the mercuric iodide in excess of potassium-iodide solution, and precipitate the double salt by the addition of copper-sulphate solution. The silver salt can be prepared in a similar manner by double precipitation. Whichever method is adopted the product should be well washed to eliminate soluble impurities, as these appear to retard the colour-change, as well as to affect its character.

To apply the mixture, convert it into a varnish paint or enamel, by incorporating the powder with a colourless varnish medium that will stand moderately high temperatures without softening. A good white-shellac spirit-varnish, such as is used on electrical machinery, has been found suitable for most occasions, but for high temperatures a medium such as is employed in the high-temperature aluminium paints used for steampipes, and which will resist temperatures up to 200° C., is preferable. About 100 grms. of compound to 70 c.c. of medium will be found a mixture of suitable consistence.

A convenient method of applying this heat-detector is first to paint a white circle or ring on the bearing or other place which it is desired to keep under observation, using a zinc-white paint. This white circle is applied to the journal or housing of the bearing, and the detector-paint is applied as a vivid red bull's-eye in the middle of this, thus forming a striking object which is visible from considerable distances. It must be applied to the block of metal as near as possible to the point at which the heat is likely to be generated. It is sometimes desirable to apply the paint to the shaft itself, just where the latter extends beyond the bearing-metal. A convenient method is to apply a broad band of white paint with a narrower band of the red detector paint in the middle. This red band in the middle of the white one is easily seen as the shaft rotates. In any case, after the paint is dry it should be protected with a coat of colourless oil-proof varnish, so that the surface may be occasionally wiped free from dust and dirt. The visibility of the paint against its white background is high, the bright scarlet colour being visible from long distances without effort, and the change at 60° to 70° C. to black is easily observed. It is generally easy to arrange matters so that the detector is placed in a position where it is visible almost without conscious effort; and experience has proved that a workman is easily trained to cast his eye occasionally on the detector, while he could not be depended upon to climb to the spot and feel the bearing on the remote chance of finding it heating. When the paint changes colour there is something wrong with the bearing, but generally speaking it will be found that the matter is taken in time, and that no damage is done, the bearing simply requiring cleaning and adjustment without serious stoppage and expense. (*H. T. Pinnock, 'Journal of the Chemical Society.'*)

BALL AND ROLLER BEARINGS.

(Contributed by John Goodman, M.Inst.C.E.)

BALL BEARINGS

In the earliest cylindrical or radial bearings the balls bore on four points as shown at A, fig. 1,* and corresponding thrust bearings were made, as shown at F. It is impossible, under such conditions, to secure a pure rolling motion for the balls, so that grinding inevitably takes place.

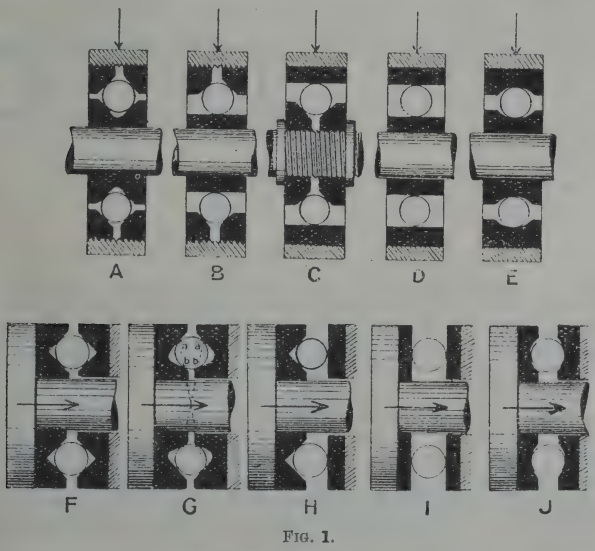

FIG. 1.

* Figs. 1 and 16 are reproduced from Professor Goodman's 'Mechanics applied to Engineering,' by the permission of the publishers, Messrs. Longmans, Green & Co.

The modification shown at G was then tried, but only with partial success. Three point bearings such as those shown at B, C and H, and also many others, were tried, but in every instance the balls grated and developed deep scratches after running for a short time; they were then abandoned for two-point bearings (the outcome of experiments by the writer), shown in D and I. The friction was found to be less, the bearing was cheaper to make, the balls had a true rolling motion, and, consequently, showed no signs of scratching, grinding, or wear; the bearings ran smoothly, and were in every respect a success. In general, a cage was used for keeping the balls in their relative positions, but in some instances it was found that it might be dispensed with. Other experimenters, notably Professor Stribeck, of Berlin, modified the two-point bearing by providing grooved ball races, as shown in E and J. Balls running in such races will support considerably greater loads than when running on plain surfaces which, of course, is a great advantage. The load that may be placed on a bearing of given dimensions, other things being equal, depends upon the relative radius of the groove and that of the balls, the smaller the difference between them the greater the load-carrying capacity; in modern bearings the radius of the groove is about 5 per cent. greater than the radius of the balls. The safe load also depends upon the number and the diameter of the balls, but it is, of course, useless to increase the diameter of the balls at the expense of the races, which must be sufficiently robust to retain their shape under load.

Radial Ball Bearings.

A considerable amount of thought and ingenuity has been expended on the problem of introducing the greatest possible number of balls into a radial bearing.

In the bearing D there is no difficulty in inserting the full number of balls, but in bearings which have grooved tracks as shown at E it is necessary, when assembling, to displace the one race relatively to the other, as shown in Fig. 2, when the bearing can be filled to the extent of half the full number of balls *plus* one. The section through such a bearing is shown in fig. 3.

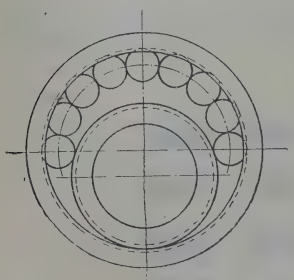

Fig. 2.

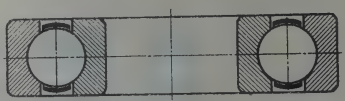

Fig. 3.

Extra balls can be inserted through transverse filling slots in the sides of the grooved tracks, the depth of which must be less than that of the groove, so that the slot does not extend to the middle of the track or in any way interfere with the pathway of the balls; but this condition is not so easily fulfilled as it may appear at first sight. The balls may be quite clear of the filling slot when the bearing is unloaded, but when it is loaded both the ball and the track are distorted to such an extent as to render it possible that the side of the track may be intersected by the filling slot; it is obvious that this is more liable to occur when the radius of the track closest approaches that of the balls. Thus on the one hand a small difference between the radius of the track and the ball is aimed at for the sake of increasing the safe load on the balls, and on the other a larger radius of track has to be used in order to prevent the balls from fouling the filling slot. Thus it is a matter of opinion as to whether the bearing provided with filling slots and a larger number of balls running in a wider track will actually carry a greater load than the bearing without such slots and with a closer fitting track with a smaller number of balls.

In order to overcome the difficulty of inserting the full number of balls, the 'Skefko' bearing is made with the outer ball track a portion of a sphere, the centre of which coincides with the centre of the shaft (fig. 4).* By this arrangement the outer race will swivel relatively to the inner (see fig. 5), when a full number double row of balls can be inserted.

* A filling slot materially reduces the capacity of the bearing to take end-thrust.

The swivelling property of the 'Skefko' bearing also has other advantages. If the housing shifts relatively to the shaft due to a lack of rigidity in the machine frame, or if the shaft itself is out of truth, the bearing will still run perfectly.

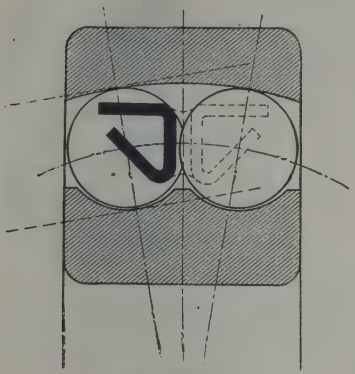

FIG. 4.

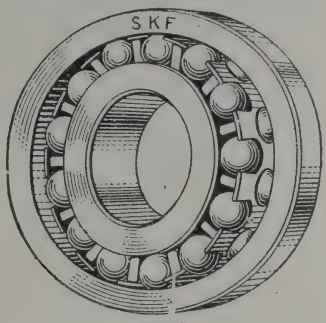

FIG. 5.

In fig. 6 is shown a 'Hoffmann' self-aligning outer race and shell and self-aligning end covers to accommodate errors in mounting. When a bearing is not completely filled with balls it is obvious that a cage must be used or the balls may crowd together and cause trouble. For moderate speeds a light sheet metal cage may be used, but for high speeds a more robust

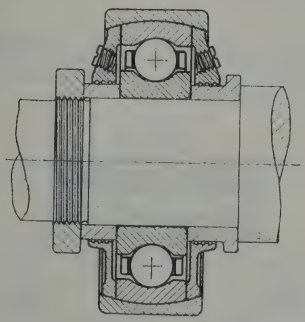

FIG. 6.

cage is necessary, accurately machined all over and fitting on the inner ball race ring to prevent the cage from running eccentrically. At very high speeds the centrifugal force on an eccentrically running cage becomes serious and is certain to give trouble. White metal and aluminium do not possess sufficient strength or hardness; steel, gun-metal, or bronze give the best results.

For long line shafts the 'Hoffmann' bearing, shown in Fig. 7, is mounted in a housing slung on a rocking pin to accommodate expansion of the shafting. The inner race is clamped to the shaft by an adapter or split taper sleeve.

In fig. 8 is shown a bearing hanger for the same purpose by the Skefko Ball Bearing Co. Ltd.

When bearings are required for loads beyond the capacity of a standard ball journal bearing, it is usually cheaper and better practice to use a standard roller journal bearing; or several

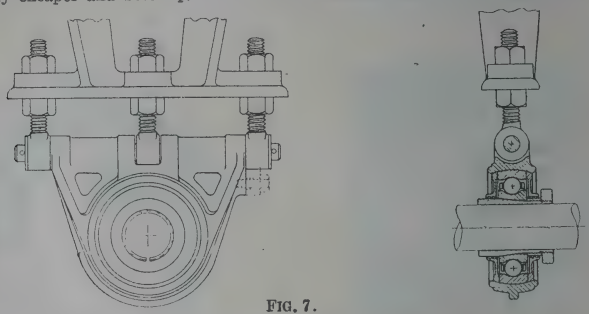

FIG. 7.

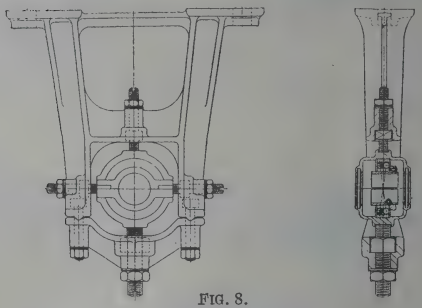

FIG. 8.

standard bearings can be mounted side by side, but there is a difficulty in ensuring that each bearing takes its fair share of the load. Goodman overcomes this difficulty by backing them with linoleum, vulcanised fibre, or hard wood. The housing is spherically mounted to allow it to adjust itself to any want of alignment (fig. 9).*

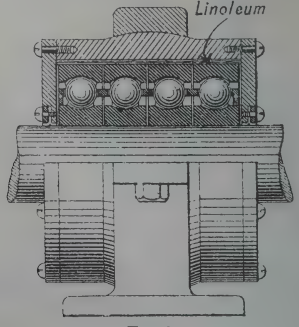

FIG. 9.

* Fig. 9 is reproduced from a paper on 'Roller and Ball Bearings,' *Proceedings of the Institution of Civil Engineers*, vol. clxxxix, 1912, by the permission of the Council.

In all cases, even with single bearings, it is good practice to use a semi-hard backing when mounting ball and roller bearings. The backing acts as a cushion, thereby reducing noise, and it enables the outer ring to adjust itself to any slight lack of alignment.

THRUST BALL BEARINGS.

In thrust bearings there is no difficulty in getting in the full number of balls. A cage is always used. Radial bearings with grooved races will take a certain amount of end thrust, depending upon the radial load on the bearing. For numerical data on this question such a book as Macaulay's 'Ball and Roller Bearings' should be consulted.

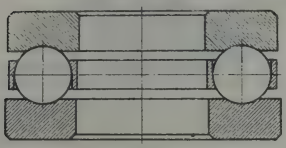

FIG. 10.

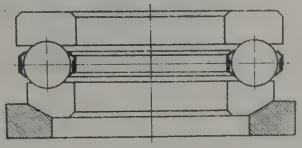

FIG. 11.

If the end thrust and radial load are large, two bearings should be used, the one to take the radial load and the other the end thrust.

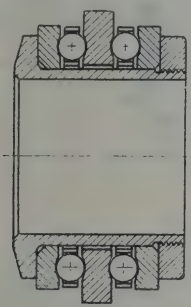

FIG. 12.

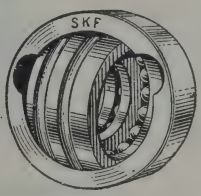

FIG. 13.

Fig. 10 shows a flat ring thrust bearing, and fig. 11 a thrust bearing with a spherical seat to accommodate errors in mounting.

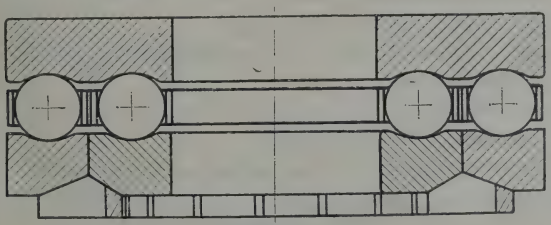

FIG. 14.

Fig. 12 shows a 'Hoffmann' double thrust ball bearing mounted on a sleeve, arranged to take thrust in either direction. The 'Skefko' bearing for the same purpose is shown in fig. 13.

For larger thrust loads multiple ring bearings are used mounted on a seating ring. The 'Hoffmann' bearing of this type, shown in Fig. 14, is provided with an elastic seating ring to ensure the correct proportionate distribution of the load between both rows of balls; the 'Skefko' bearing in fig. 15.

Goodman mounts standard thrust rings on a linoleum backing, as shown in figs. 15 & 16.*

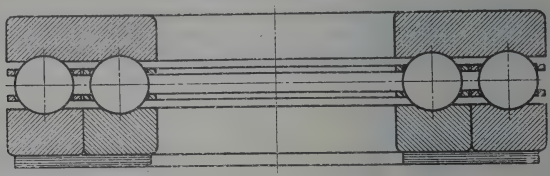

FIG. 15.

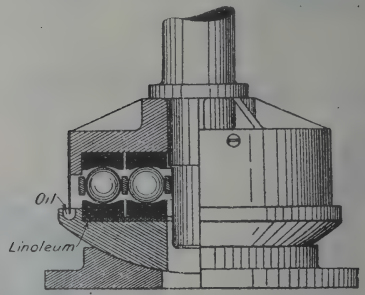

FIG. 16.

Permissible Loads on Ball Bearings.

The safe working load for a given bearing is much greater when the bearing is running at a low than at a high speed. The ruling factor as regards the working load for a ball bearing is the speed of rotation of the balls themselves; thus in the case of two shafts, A and B, each fitted with thrust bearings having the same number and diameter of balls, and both running at the same number of revolutions per minute, if the diameter of the ball path in A were greater than in B, the safe working load would be greater for shaft B than for A.

Let P = The maximum permissible working load in pounds;

d = The diameter of the ball in inches;

D = The diameter of the ball path in inches;

n = The number of revolutions per minute of the shaft;

k = A constant depending upon the form of bearing;

c = A constant;

m = The number of balls in the bearing;

x = A coefficient depending upon the revolutions per minute of the shaft.

Stribeck's formula for radial ball bearings is:—

$$P = 12{\cdot}8\, x\, m\, d^2$$

* Fig. 16 is reproduced from a paper on 'Roller and Ball Bearings,' *Proceedings of the Institution of Civil Engineers*, vol. clxxxix, 1912, by the permission of the Council.

where x has the following values :—

n 0	10	150	300	500	1,000	1,200
x 48·4	36·3	29·04	24·2	20·9	15·62	14·96
n 1,500	2,000	2,500	3,000	4,000	5,000	10,000
x 13·64	12·1	10·56	9·68	8·58	7·7	5·06

Goodman's formula for ball bearings is :—

$$P = \frac{k\ m\ d^n}{nD + ca},$$

where k and c have the following values :—

Type of Bearing.		k	c
Radial.	Flat (i.e. not grooved) races	1,000,000	2,000
	Hollow races of ordinary quality	2,000,000	2,000
	Hollow races of best quality	2,500,000	2,000
Thrust.	Flat (i.e. not grooved) races	500,000	200
	Hollow races of ordinary quality	1,000,000	200
	Hollow races of best quality	1,250,000	200

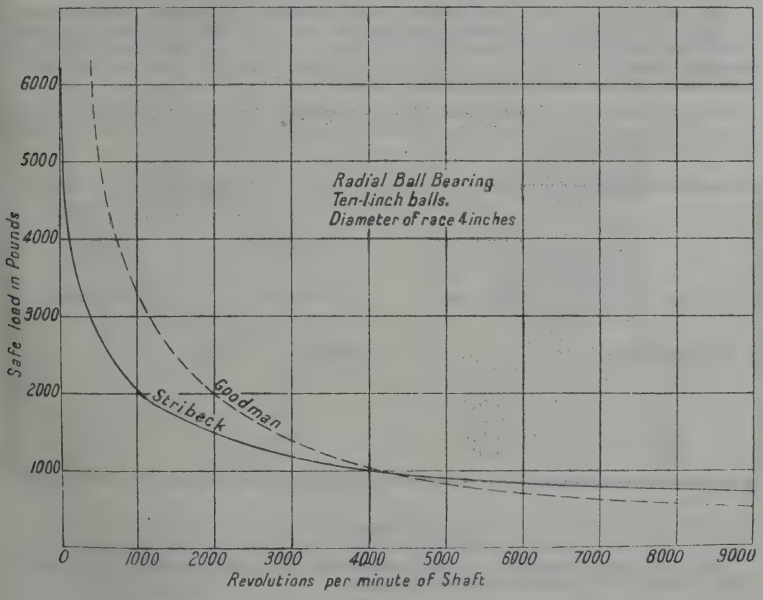

FIG. 17.

A comparison of the results obtained by the two formulæ is shown in fig. 17.

Load tables based on these or similar formulæ are published by most manufacturers. But in all cases other factors should be taken into account, such as the number of hours per day the bearing is likely to run, whether a steady or a fluctuating load, and whether it will be possible to keep it free from dirt, dust, and damp. When bearings are required for special conditions of running it is advisable to consult the manufacturers.

In the 'Skefko' bearing the races must be regarded as flat, but since there are at least twice as many balls in this type of bearing as in other bearings of the same external dimensions, the theoretical load carrying capacity is the same. It is claimed that this bearing will work satisfactorily with a small amount of lateral thrust.

Advantages and Disadvantages of Ball Bearings.

Advantages.

The friction is usually less than one-tenth of that encountered in ordinary bearings as commonly lubricated.

The friction at starting is no greater than when running.

The friction does not increase with the speed.

They require an extremely small amount of oil, the cost of which is negligible.

They occupy much less lateral space on the shaft than an ordinary bearing.

If the bearing is properly treated the wear is extremely small.

Disadvantages.

The first cost is usually greater than that of an ordinary bearing, but this is not invariably the case.

If overloaded, or if lubricated with unsuitable oil the balls pit and peel, and then they make a great deal of noise, especially at high speeds.

They require extreme care in fitting on to the shaft and in the housing.

Power Saving and Reduction of Starting Effort.

The power saving amounts to at least 90 per cent. of the loss due to friction of the best plain bearings, whilst the reduction of starting effort of no less than 99 per cent. means that the acceleration is more rapid, which is of particular importance in machinery where frequent stops and starts are essential. Further, the reserve of power usually required for starting machinery is unnecessary, and the size of the power unit can therefore be reduced.

The enormous saving in power, and still more remarkable reduction in starting effort, are illustrated by a test carried out by the National Physical Laboratory, the results of which are given in the following table:—

	Standard Plain Hanger.		'Hoffmann' Ball-Bearing Hanger (Patent).
	With Needle Lubricator.	With Oil Ring Lubricator.	
Starting effort.	830 in.-lbs.	770 in.-lbs.	0·9 in.-lbs.
Revs. per Minute.	Coefficient of Friction.		
80	0·014	0·015	0·0013
130	0·015	0·014	0·0014
250	0·016	0·013	0·0015
500	0·017	0·012	0·0016

ROLLER BEARINGS.

For heavy loads, particularly where the bearing is subjected to severe shocks, a roller bearing should be used in preference to a ball journal bearing.

The development of the roller bearing has been more difficult and consequently slower than the ball bearing owing to the tendency of the rollers to creep axially, the resultant end-thrust causing friction and consequent wear in the cage and rollers. This creep is invariably caused by

inaccuracy of the tracks and rollers; the smallest error along the length of these alters the relative peripheral speed and destroys pure rolling motion.

Four distinct types of roller bearings have been developed :—

(1) With cylindrical rollers in which the length is considerably greater than the diameter.
(2) With taper roller.
(3) With cylindrical rollers in which the length is equal to the diameter.
(4) With slightly barrelled rollers in which the length is equal to the diameter.

Bearing in mind the basic fact that 'Friction causes Wear,' the following table of coefficients of friction obtained experimentally by Professor Goodman (*Proc. Inst. Civil Engineers*, vol. clxxxix.) affords a sound method of comparison of the merits of the various types, and it will be seen that bearings with short cylindrical rollers are now made combining the efficiency of ball bearings with greatly increased load capacity :—

Type of bearing	Ball.	Short Cylindrical Roller. III.	Taper Roller. II.	Long Cylindrical Solid Roller I.	Long Cylindrical Flexible Roller I.
Coefficient of friction	0·0010 to 0·0015	0·0010 0·0015	0·0020 0·0040	0·0030 0·0100	0·0040 0·0070

(1) *Long cylindrical roller bearing.*—This type of bearing has not proved satisfactory for arduous duty on account of the tendency of the rollers to 'skew.' The difficulty of manufacturing the rollers accurately as regards diameter and parallelism is obviously increased in proportion to the length, and the superimposed bending stresses caused by 'skew' also increase proportionately.

In the 'Hyatt' roller bearing the solid roller is replaced by right- and left-hand helical springs arranged alternately; it is claimed that 'skewing' difficulties are obviated by the flexibility of the rollers.

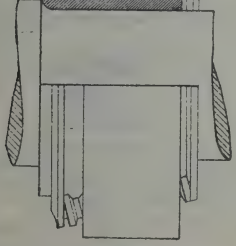

FIG. 18.

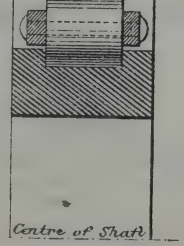

FIG. 19.

(2) *Taper roller bearing.*—Several makes of this type of bearing are now on the market, and it is claimed as advantages that the bearing will support both journal and thrust loads, and can be adjusted to take up wear.

On account of its design the bearing cannot be used singly except where there is a constant end-thrust in one direction.

While this type of bearing is adjustable when new and unworn, it should not be forgotten that under journal load only one half of the stationary race is loaded, and any wear in the track of this race will make it oval, whilst the revolving race and rollers may wear evenly and remain round.

Adjustment subsequent to wear is therefore analogous to forcing a round plug into an oval hole. One of the most successful bearings of this type is the Timken (see fig. 18); it is largely used for motor-car work.

(3) *Short cylindrical roller bearing.*—This type of bearing, fig. 19, was originated and developed in England by the Hoffmann Manufacturing Co., but is now made by many firms. The rollers are solid and have a length equal to their diameter. They are accurately finished on diameter to the same limits as balls, viz. plus and minus 0·0001 ins., and the ends are ground perfectly square. The extreme accuracy of these rollers is illustrated by the fact that they are supplied for use as gauges under a National Physical Laboratory Certificate of Accuracy.

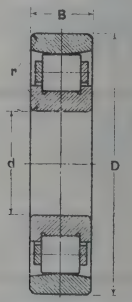

FIG. 20.—Cylindrical Roller Bearing, with convex outer race.

To guide the rollers, the inner race is provided with two lips to form a channel-shape track which, in conjunction with the accuracy with which the tracks and rollers are produced, effectually prevents any tendency to 'skew.' The outer race is a plain annular ring, and the rollers are separated by a cage of solid yellow anti-friction alloy metal.

With these bearings contact is obtained with both tracks along the whole length of the roller, from 70 to 130 per cent., and this 'line contact' gives a load capacity greater than that of a ball bearing of similar size, according to the conditions and nature of the load. The bearings are made with the same external dimensions (bore, outside diameter, and width) as ball journal bearings, and are interchangeable with them with only slight alterations in the mounting.

As the outer race has a plain cylindrical track, the bearing cannot take end-thrust of any sort, and to prevent its slipping sideways off the rollers, the outer race must be definitely clamped endways. This is a definite advantage where a roller bearing is mounted in conjunction with a

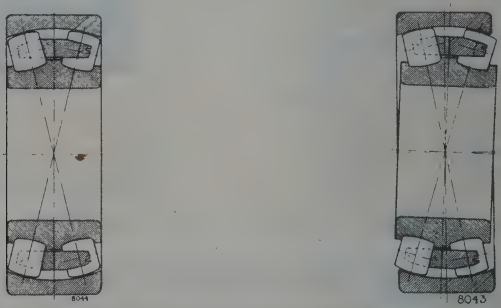

FIG. 21.—Double-row Self-aligning Roller Bearing.

ball bearing, and the outer races revolve, as both can be made an interference fit in the housing to prevent creep. Apart from this, the bearings should be mounted exactly similar to ball bearings.

The Skefko Ball Bearing Co. Ltd. make the outer race slightly convex in order to allow of a small

angular movement of the inner race relative to the outer, which has proved to be very successful in practice in cases in which there is a difficulty in maintaining an exact alignment between the shaft and housing (see fig. 20), but of course it will not take any end-thrust. Where end-thrust has to be dealt with in addition to radial load the bearing shown in fig. 21 is used. It has been

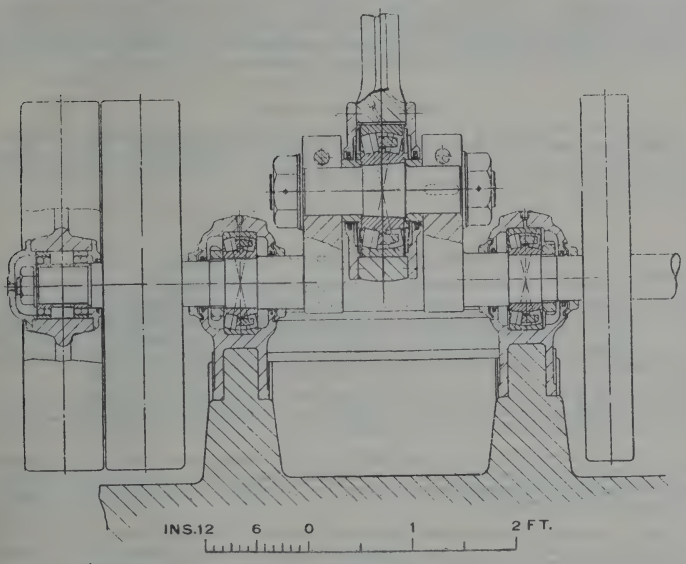

FIG 22.

successfully used for heavy duty such as railway axle-boxes, trams, crushers, calenders, etc. On account of its construction it is able to negotiate thrust load in either direction simultaneously with radial load. This bearing can deal with a radial load of about 100 per cent. greater than a ball bearing of equivalent dimensions, and has been applied to a large number of passenger coaches where the speeds attained have been between 60 and 70 m.p.h.

ANTI-FRICTION BEARINGS FOR LOG FRAME-SAWS.*

Log frame-saws of the modern type have several saw-blades in series, mounted in a suitable frame made to slide up and down within the main frame of the machine by means of a crank and connecting rod. The type which is of particular interest here is the single-crank type, and fig. 22 illustrates a bearing arrangement which has been found effective.

The size of the crank-pin bearing, which is of the spherical double-row roller type, is as follows:

Bore, tapering, 140 mm. diameter at the smallest end;
Outside diameter, 380 mm.;
Width, 120 mm.

The connecting-rod is of wrought nickel steel, and the thickness of the material of the big-end housing varies between 30 to 50 mm. The crank radius is 250 mm. (approximately 10 ins.). If the width of the saw-frame is between 500 and 600 mm., its weight, complete with blades and accessories will be about 615 lbs., and the weight of the connecting-rod complete, including the outer ring of the roller-bearing, will be about 485 lbs. When the frame is running at a speed of

* J. B. E. Dahlerus, *Proc. Inst. Mech. Eng.*, 1925.

350 r.p.m., this being the highest speed attained so far, the maximum acceleration force on t crank-pin bearing will be about 37,600 lbs.. or approximately 16¾ tons.

In calculating the maximum load coming on the bearing, the force required for sawing shou also be added. This amounts normally to about 900 lbs. The calculated load is not, of cour constant, but varies intermittently throughout every revolution.

With a bearing of the dimensions given in this particular instance. the factor of safety approximately two over the published figures, and has been found to meet the conditions admirabl The service on these machines is practically continuous day and night, so that the requiremer in respect of durability and safety in operation are very severe.

General Applications.

Other machines where these bearings have been successfully applied include: ball mill tube mills; pulp beaters for paper making; pulverizers; disintegrators; chocolate refini rolls; an alternator of 2,500 kw. at 1,000 r.p.m.; 3-bearing rotary converters; road wheels motor buses; cross rolls in steel plant.

Mounting Ball and Roller Bearings.

The revolving race of a ball or roller journal bearing must be made an interference fit on t seating to prevent creep or slow rotation of the race relative to the shaft or housing, and it advisable to clamp this race firmly endways. The stationary race should be allowed just sufficie clearance on its seat to permit it to take up its correct position endways relative to the revolvi race, and sufficient end clearance should be arranged for to prevent the stationary race comi in contact with a shoulder and thus putting a permanent side-thrust on the bearing.

The writer of this article considers that the stationary race should be mounted with a so backing such as linoleum, a hard wood ring, or hard fibre in order to reduce noise and to allow of small movement if the housing gets out of alignment.

In obtaining the necessary fits it is essential that the seatings and abutments of the housi and shaft be perfectly round and true. The hardened steel races have a comparatively thi section, and should be regarded purely as tracks for the balls, as they will conform readily t inaccuracies of their seatings.

The use of set screws, keys, or similar devices for fixing the races and preventing creep canno be too strongly deprecated, as they readily distort the races, causing overloading of the bearing In any case, it will be found these are of very little use as they shear or fret away rapidly.

Where there is no definite end-thrust the shaft may be located endways by clamping th stationary race of one bearing only in a solidly connected length of shaft. The most lightl loaded bearing should be selected for this purpose.

The revolving race of a ball thrust bearing should be made a push fit on the shaft, and it i essential that the shoulder against which it abuts is perfectly smooth and square. It should be o such diameter as to extend at least half-way across the track of the race to adequately suppor this and prevent deflection under load. The stationary race must be held concentric, and wher it is not possible to ensure a perfectly square seating, a self-aligning bearing should be used.

It is essential that a ball thrust bearing be not called on to take any journal load whatsoeve and a journal bearing of some kind must be mounted immediately alongside to ensure that th two ball races are held concentric. A ball or roller bearing is, of course, to be recommended fo this, as it will not wear slack and allow the shaft to drop out of concentricity with the housing

For high speeds it is important to keep the pitch diameter of the races and the size of the balls as low as possible, and where thrust bearings are required for speeds above those listed by manu facturers, it is advisable to consult the makers.

Split housings should as a general rule be avoided, and it is generally found an advantage t make the housings in the form of plain, eye-bored castings, and fit loose end covers for protectio and retention of lubricant.

Perhaps the most frequent cause of failure of a ball bearing is lack of protection against dir and water. The highly polished surfaces of the balls and races render them peculiarly liable t corrosion and rust. Grit or dirt in a bearing is crushed between the balls and tracks, forming a abrasive compound which causes rapid wear.

For ordinary conditions it is sufficient to make the protecting end cover as wide as possibl where it meets the shaft, and to bore it out with a diametric clearance of about 0·010 in. A serie of annular grooves should be turned in the bore, which will become filled with grease and form grease seals.

For special conditions, where there is excessive dust or moisture present, extra protection is necessary, and throwers should be fitted on the shaft overhanging the end covers so that the rotation of the thrower will tend to throw off the dirt or water and prevent its having direct access to the aperture between the end cover and the shaft.

Where it is not possible to obtain accurate alignment between two housings, self-aligning bearings should be used, but it should be noted that these can only swivel about one centre, and will not accommodate actual lateral displacement errors, so that where there are more than two bearings per shaft the self-aligning feature is of use only to accommodate want of squareness of the housing. For self-alignment of two or more bearings mounted in a rigid housing it is essential that all the bearings swivel about one point.

Manufacture of Ball and Roller Bearings.

The success of ball and roller bearings depends upon extreme accuracy of manufacture and fitting; also on the quality of the material. All must be of the very best. The manufacture of such bearings requires great skill and special plant, hence it is the height of folly for firms not equipped for such work to attempt to make their own bearings.

Some makers favour special low-carbon steel, deeply carburised on the tracks only; others prefer high-carbon chrome alloy steel. Since highly satisfactory bearings are turned out from both kinds of steel, it is impossible to say which is the better.

For special purposes, such as to resist corrosion or chemical action, stainless steel is sometimes used, but as regards load-carrying capacity it is not equal to the standard materials.

After rough finishing, both balls and races are carefully heat treated and then finished by grinding and polishing to a very high degree of accuracy. Balls are produced to guaranteed limits, both as to diameter and sphericity, of + or − 0·0001 in. The ball tracks also have to be finished to the same degree of accuracy. The bores and outside diameters of the races of best quality bearings have a tolerance of only 0·0005 in., from which it will be evident that the bearings are to a very large extent interchangeable.

The reason why extreme degrees of accuracy in workmanship are necessary for ball and roller bearings will be apparent when it is remembered that the approach of two surfaces when separated by a ball is extremely small for safe loads, hence if there be only very small hills on either the balls or tracks the increase of load as the ball passes is very severe. Articles dealing with this question will be found in *Engineering*, Aug. 3 and 24, 1923, also June 19, 1925.

When under load the balls and tracks are deformed until there is a measurable but very small area of contact, the stresses on this area are consequently very high, which are repeated many millions of times during the life of the bearing.

Lubrication of Ball and Roller Bearings.

In a ball or roller bearing the intensity of pressure between the rolling elements and the track is such as to entirely squeeze out every trace of lubricant, and actual metal-to-metal contact occurs. This does not mean that a ball or roller bearing will run satisfactorily without any lubricant, which is necessary to lubricate the cage containing the balls or rollers, and to protect the tracks and rolling elements from corrosion. In a high-class bearing the greatest care is taken in obtaining a surface as free from imperfections and scratches as it is possible to produce commercially. This extreme care is necessary to obtain durability, a low coefficient of friction, and silence in running. Unfortunately, surfaces of this character are particularly susceptible to corrosion, and it is essential, therefore, that the lubricant be free from all solid impurities or free acid, and the free alkali should not exceed 0·1 per cent. Lubricants with an animal or vegetable base are all liable to develop free acid over a period and are therefore unsuitable.

For normal conditions a pure mineral grease, perfectly neutral, and of a consistency rather greater than that of vaseline, is the most suitable lubricant for ball and roller bearings. It must not readily absorb moisture, nor contain solidifying matter such as French chalk, graphite, etc., which would act as a lapping compound and cause rapid wear and deterioration of the bearing. At high speeds the lubricant used in a bearing is subjected to severe churning action, and unless a good quality grease be used, it will be found there is a tendency for the grease to disintegrate, the oil running out of the bearing, leaving a hard, gummy residue which clogs and finally breaks up the cage and thus destroys the bearing.

In exceptional cases where the bearing is exposed to an abnormally high temperature, grease with a high melting-point should be used. This is obtainable suitable for use up to a temperature of 300° F. Its consistency, however, is very stiff at normal temperatures, and it should therefore not be used where there is no external heat.

If arrangements can be made to prevent leakage, oil may be used for lubrication, and, indeed, at high speeds is preferable to grease. It has, however, the disadvantage that where the bearing is likely to remain stationary for any length of time the oil will drain away from the upper surfaces, leaving them exposed to the corrosive action of the atmosphere.

Provision must be made for replenishing the lubricant. This, however, is only necessary at long intervals, which vary according to the conditions under which the bearing is running. The grease may be inserted by a Stauffer or other lubricator, or by means of a grease pump, but it is of the utmost importance that the grease used, and the hole through which the grease is inserted, are perfectly clean; the latter should be kept plugged. It cannot be over-emphasised that the best of bearings can be ruined in a few days by the action of dirt or water.

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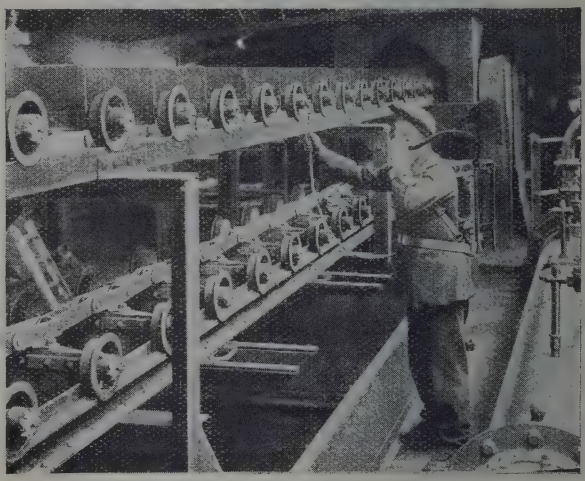

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SECTION XX

PART II

LUBRICATING OILS, LUBRICATION, AND LUBRICATORS.

LUBRICATING OILS.

(Contributed by Harold Moore, M.Sc.Tech., M.Inst. Pet. Tech., F.C.S., A.I.M.E.)

At the present time most machinery is lubricated either by means of mineral oils or by mixtures containing a large proportion of mineral oil with a small amount of either animal or vegetable oil added. The mineral oils used are almost entirely derived from petroleum, but a certain amount of low-viscosity oils, such as spindle oils, are prepared from shale oil, and certain tar and lignite products are used for grease manufacturing. Where coal tar and lignite are available in quantity, coal tar and lignite products are used as substitutes for petroleum products. As a general rule the petroleum product is the superior article, and it is only for exceptional purposes that coal tar or lignite products are found to possess equal values with the petroleum oils. For grease-making, however, anthracene oil, a heavy distillate of coal tar, is used to a considerable extent in this country.

Lubricating oils may be divided into three classes: (1) the straight run mineral oils, which are certain fractions obtained by the distillation of petroleum; (2) certain blended oils, which are mineral oils prepared by the mixture of two or more different varieties of mineral oil; and (3) compounded oils, which contain mixtures of mineral oil, together with either animal or vegetable oil.

Lubricating oils of very high viscosity are prepared by distilling off a large portion of the oil, and then utilising the residue as lubricant. The residues are usually dark, and are known as 'dark steam refined cylinder stock.' For very high-class oils of high viscosity it is necessary to remove a certain amount of the bituminous content of these residues, and this is effected by filtering the cylinder stock through fuller's earth, bauxite, or adsorbent clays, when the bituminous bodies are absorbed and the black, opaque cylinder stock is converted into 'filtered cylinder stock,' usually of a greenish colour and semi-transparent. Such cylinder stocks are generally mixed with the distillate to give blended oils of any desired viscosity.

The distillates used for lubrication are generally refined, either by treatment with sulphuric acid or by filtration through fuller's earth, bauxite, or clay. The characters of the lubricants obtained from the crude oil, though to some extent affected by the treatment to which the oils have been subjected, is mainly dependent upon the nature of the oil which is used in the first place for the preparation of the lubricant.

The most important properties by the estimation of which the valuation of lubricating oils is effected, are the 'specific gravity,' 'flash point,' and 'viscosity,' and in special cases it is also necessary to determine the coke content, demulsification properties, acidity, content of saponifiable oil, and a large number of minor tests. The main importance of the specific gravity is its value as denoting the base of an oil. The 'open flash-point' is determined by heating the oil in an open cup, observing the temperature, whilst a small flame is periodically brought to bear upon the surface of the oil, the open flash-point being that temperature at which a small sheet of flame flickers over the surface of the oil and immediately goes out. If the oil is heated to a higher temperature after the observation of the open flash-point, it will eventually reach a temperature at which sufficient inflammable vapour is generated to maintain a flame on the surface of the oil. This temperature is known as the 'burning-point' or 'fire-test.' Special instruments have been devised for the determination of flash-points, in which the oil is enclosed in a small cylindrical vessel, so that the vapour is not liable to be affected by currents of air. The results given by such instruments are called 'closed flash-point' tests. The Abel instrument consists of a vessel surrounded by a water-jacket to ensure gradual increase in temperature, and is designed for the testing of kerosene (lamp oil), the flash-point of which is required by governmental regulation to be above 73° F. by the Abel test. As the water-jacketed instrument is

unsuitable for testing flash-points at high temperatures, it is usual to employ either the Gray or the Pensky-Marten instrument for the testing of lubricants. Both of these instruments are very similar to the Abel apparatus, except in that a cast-iron jacket is employed in place of the water jacket, and that stirring arrangements are provided to allow of the agitation of the oil whilst heat is being applied. In the Gray instrument a bevel-driven paddle is used, whilst the Pensky-Marten has a paddle driven by a flexible shaft.

The property of viscosity is the resistance to motion, or, in common terms, the 'thickness' of the oil. As the viscosity varies according to temperature, it is necessary that a viscosity should be determined at some fixed temperature, in this country usually at 70°, 100°, 140°, 200°, or 212° F. As the rate of change in viscosity with increase of temperature varies with different types of oil, it is often necessary to plot a curve obtained by the viscosity of oils at various temperatures. The instruments usually used for measuring this property are the Redwood, Engler, Saybolt, and Barbet viscometers. The results of determinations made on these instruments are quite different, but the principle on which they work is very much the same in each case. It consists in allowing a quantity of oil to fall through a jet or tube, and in measuring either the time taken for a fixed quantity to pass through the instrument, or in measuring the quantity passed in a fixed time. The Redwood instrument is used in this country; the Engler is very extensively used on the Continent; the Saybolt is the standard American instrument; whilst the Barbet is generally used in France.

During recent years it has been frequently suggested that measurements of viscosity should be made in absolute units instead of in arbitrary units obtained in the various commercial testing appliances. The absolute unit of viscosity is the amount of force in dynes required to move a unit area of plane surface with unit speed relative to another plane surface, from which it is separated by a layer of lubricant of unit thickness. It is usual to employ C.G.S. units, and the result is obtained in dynes per square centimetre per second. This unit has been named the 'poise.' As the absolute unit is a comparatively large unit of measurement, and would be inconvenient for commercial use, it is probable that, if absolute viscosity measurements came into general use, the unit taken would be the 'centipoise,' or one-hundredth part of the absolute unit.

Mineral oils possessing similar viscosities at any particular temperature may not possess similar viscosities at a higher or at a lower temperature, the rate of fall in viscosity with increase in temperature being dependent upon the chemical nature of the base oil. For example, a paraffin base oil does not show nearly such a rapid fall in viscosity with increase in temperature as do the asphaltic and naphthenic base oils, and to compare the viscosity of oils it is really necessary to prepare a curve by plotting the viscosity against the temperature.

Though these three tests are the ones most commonly used in commerce, it is necessary to employ a large number of other tests for various particular purposes. For example, oils required for service on internal combustion engines should be tested by the coke test, to measure their liability to produce carbon in the engine. Oils required for use in turbines should be tested to ensure that they will readily separate from water without forming an emulsion. It is also necessary to ensure that the oils are free from mineral acids, and that they do not contain excessive quantities of organic acids. When compounded oils are under examination, it is necessary to determine how much of the saponifiable oil is present. It may also be necessary to test for inorganic matter by the determination of the ash content, or for water, or for mechanical impurities.

In addition to the properties mentioned above, there is the property of 'oiliness,' on which subject a great deal of research has been conducted during the last few years. This is undoubtedly a surface tension effect, and is the property of maintaining a film when subjected to pressure between two plane surfaces. This is a property which cannot be readily measured, but its influence is well known. Certain of the saponifiable oils, that is to say, animal and vegetable oils, are much more satisfactory as regards this property than are mineral oils, and it is frequently observed that when a saponifiable oil or a compounded oil is employed for any particular purpose it is possible to use a product of lower viscosity than if a straight mineral oil were being used for the same purpose. The asphaltic and naphthenic oils are slightly superior to the paraffin base oils as regards this property.

In drafting specifications for the supply of lubricants for any particular purpose, it is essential that note should be taken of the nature of the mineral oil employed as a base. It is quite insufficient to simply specify the usual properties of gravity, flash-point, and viscosity.

The colour of a lubricant, which denotes the degree to which it has been refined, is a matter of the greatest importance. Clear oils are preferable to turbid oils, and, as a general rule, oils of light colour are more valuable than darker oils.

Owing to the use of different standard instruments for the determination of the viscosities of oils, it is sometimes necessary to be able to convert values given in one standard into the corresponding values in another standard. The three tables, p. 1057, serve for the conversion of values between the Redwood, Engler, and Saybolt systems.

Viscosity in C.G.S. units $= 0{\cdot}00353 \left(3{\cdot}6 \text{ Red.} - \frac{\delta^2}{\text{Red.}}\right)$, approximately, where 'Red.' is the Redwood value, and δ is the density. (*H. R. K.*)

MULTIPLYING FACTORS FOR THE CONVERSION OF ENGLER NUMBERS TO SAYBOLT OR REDWOOD SECONDS.

Engler Number.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Redwood Seconds.	Engler Number.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Redwood Seconds.	Engler Number.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Redwood Seconds.
1·00	28·1	26·7	1·70	32·5	29·0	2·90	36·1	30·4
1·05	28·4	27·0	1·80	33·0	29·2	3·00	36·2	30·5
1·10	28·8	27·2	1·90	33·5	29·4	3·50	36·7	30·7
1·15	29·1	27·5	2·00	33·9	29·6	4·00	37·1	30·9
1·20	29·5	27·6	2·10	34·2	29·7	4·50	37·3	31·1
1·25	29·8	27·8	2·20	34·5	29·9	5·00	37·4	31·2
1·30	30·2	28·0	2·30	34·8	30·0	6·00	37·5	31·3
1·35	30·5	28·2	2·40	35·1	30·1	8·00	—	31·3
1·40	30·8	28·3	2·50	35·3	30·2			
1·45	31·1	28·5	2·60	35·5	30·3	50·00	37·5	31·3
1·50	31·4	28·6	2·70	35·7	30·3			
1·60	32·0	28·8	2·80	35·9	30·4			

MULTIPLYING FACTORS FOR THE CONVERSION OF SAYBOLT SECONDS TO ENGLER NUMBERS OR TO REDWOOD SECONDS.

Saybolt Seconds.	Factor for Conversion to Engler Number.	Factor for Conversion to Redwood Seconds.	Saybolt Seconds.	Factor for Conversion to Engler Number.	Factor for Conversion to Redwood Seconds.	Saybolt Seconds.	Factor for Conversion to Engler Number.	Factor for Conversion to Redwood Seconds.
28	0·0357	0·95	50	0·0314	0·91	110	0·0276	0·84
30	0·0352	0·95	55	0·0308	0·90	120	0·0274	0·84
32	0·0346	0·95	60	0·0302	0·89	130	0·0272	0·84
34	0·0342	0·94	65	0·0297	0·88	140	0·0271	0·84
36	0·0337	0·94	70	0·0293	0·87	160	0·0269	0·84
38	0·0333	0·93	75	0·0289	0·86	180	0·0268	0·84
40	0·0330	0·93	80	0·0286	0·86	200	0·0267	0·84
42	0·0327	0·92	85	0·0284	0·86	250	0·0267	0·84
44	0·0323	0·92	90	0·0282	0·85	300	0·0267	0·84
46	0·0320	0·92	95	0·0280	0·85			
48	0·0317	0·91	100	0·0279	0·85	1,800	0·0267	0·84

MULTIPLYING FACTORS FOR THE CONVERSION OF REDWOOD SECONDS TO SAYBOLT SECONDS OR TO ENGLER NUMBERS.

Redwood Seconds.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Engler Numbers.	Redwood Seconds.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Engler Numbers.	Redwood Seconds.	Factor for Conversion to Saybolt Seconds.	Factor for Conversion to Engler Numbers.
28	1·05	0·0377	50	1·13	0·0344	120	1·20	0·0324
29	1·05	0·0372	55	1·14	0·0340	130	1·20	0·0323
30	1·06	0·0368	60	1·15	0·0337	140	1·20	0·0322
32	1·06	0·0364	65	1·16	0·0335	160	1·20	0·0321
34	1·07	0·0361	70	1·16	0·0333	180	1·20	0·0320
36	1·07	0·0358	75	1·17	0·0331	200	1·20	0·0320
38	1·08	0·0355	80	1·18	0·0330	250	1·20	0·0320
40	1·09	0·0353	85	1·18	0·0329	300	1·20	0·0320
42	1·09	0·0351	90	1·19	0·0328			
44	1·10	0·0349	95	1·19	0·0327	1,500	1·20	0·0320
46	1·11	0·0347	100	1·19	0·0326			
48	1·12	0·0345	110	1·19	0·0325			

PROPERTIES OF LUBRICATING OILS.

Oil.	Sp. Gr.	Flash Pt. F°.		Viscosity Redwood seconds at F°.				Cold test. F°.
		Clsd.	Open.	70	100	140	200	250	
Pennsylvanian 200 neutral	0·872	415	425	374	158	74	43	—	30
Russian No. 2	0·900	355	—	405	162	69	41	—	below 0°
Polish spindle oil	0·884	305	325	110	63	44	—	—	35
Polish red Oil	0·910	385	402	525	200	82	45	—	35
Californian red oil	0·932	336	342	713	228	82	43	—	below 0°
Paraffin base red oil	0·908	408	420	655	240	99	47	—	35
Californian red oil	0·935	387	399	1390	392	121	50	—	below 0°
Russian No. 1 engine oil	0·911	380	395	1200	405	130	54	—	below 0°
Roumanian red oil	0·923	380	—	980	272	95	46	—	10
Roumanian red oil	0·935	395	—	2220	550	160	56	—	—
Polish red	0·921	430	445	1260	427	142	56	—	32
Pennsylvanian 550E filtered cylinder oil	0·894	480	—	—	—	382	115	62	55
Pennsylvanian cylinder oil	0·895	515	—	—	—	530	141	72	40
Pennsylvanian bright stock	0·891	485	—	—	2085	612	168	78	14
Pennsylvanian bright stock	0·891	510	—	—	1860	550	153	73	32
Western bright stock	0·915	540	—	—	4550	1093	234	102	30
Pennsylvanian long residuum	0·882	420	440	1740	640	225	75	—	25
Pennsylvanian 600 S.R. cylinder	0·900	505	535	—	2730	622	155	—	—
Western 600 S.R. cylinder	0·933	505	—	—	—	904	193	86	32
Russian O.O.	0·912	417	—	2610	760	220	72	—	—
Roumanian cylinder	0·952	485	—	—	—	845	150	—	10

ACTION OF OIL ON METALS.

From experiments with common metals immersed in various oils for twelve months at normal atmospheric temperatures, the following results were obtained :—

Class of Oil.	Not affected.	Slightly affected.	Moderately affected.	Much affected.
Mineral lubricating	Copper, Zinc	Brass	—	Lead
Olive	—	Tin	Lead	Copper, Brass
Rape	Brass, Tin	Iron	—	Copper
Tallow	—	Tin	Iron	Copper
Lard	—	Zinc	Lead	Copper
Cottonseed	—	Lead	—	Tin
Sperm	—	Brass, Copper	Lead	Zinc
Whale	Tin	Brass	—	Lead
Seal	—	Brass	Iron	Copper

As fatty oils have a destructive effect upon metals at high temperatures in the presence of moisture, lubricants compounded of such oils and of hydro-carbon mineral oils, although serviceable for internal combustion engines, are not desirable for the internal lubrication of steam engines. (*Mechanical World Year Book.*)

TABLE SHOWING THE PHYSICAL AND FRICTIONAL PROPERTIES OF VARIOUS STANDARD OILS COMMONLY USED FOR LUBRICATION.

(*T. J. Pullin and J. Veitch Wilson.*)

Lubricant.	Description.	Specific Grav. at 60° Fah.	Flash Point Fah.	Average Viscosity at *				Normal Working.		Viscosity at Working Temp.
				60° F.	70° F.	120° F.	212° F.	Drag.	Temp. Fah.	
		1.	2.	3.	4.	5.	6.	7.	8.	9.
Water (distilled)	—	1,000	—	21	21	20½	boils	—	—	—
Sperm (refined)	Southern	881	482	51	44½	30	24	18	189	25
„ „	Arctic	878	490	52	45	31	24½	18·5	194	25
Olive	Gallipoli	916	457	97	79	38	262	26·5	202	26½
„	Smyrna	917	418	107	84	39	26	25	198	25½
„	Saffi	915	430	89½	72	37	25½	26	202	26
Neatsfoot	British	916	458	108	83	40	26	27	208	26½
Lard Oil	Prime American	916	525	100	80	39	26	27·5	210	26½
Tallow Oil	British	914	456	109	87	40	26	27	204	26½
Refined Rape Oil	'Special'	916	535	116	93½	43	27	32	214	27
„ „	German	914	498	114	88½	42	27	32	213	27
„ „	English	918	506	100	82	40	27	28	207	27
Castor Oil	French First	964	526	—	974	143	33	41	232	31½
Tallow (solid)	British	—	502	solid	solid	43	27	—	—	—

NOTE.—The viscosities given in this table were determined by Coleman's Viscosimeter.

Simple Tests for Lubricating Oil.

Colour.—A good oil, before use, will appear of a clear colour, and will not separate into layers of different shades, or deposit sediment after being allowed to stand for a few days. It will not rust or corrode in any way any pieces of ordinary polished tool steel suspended in it.

Emulsion.—When mixed with warm water and shaken in a bottle the oil will soon separate entirely from the water and show no soapy emulsion. The test does not apply to marine engine oil nor to black cylinder stock oils which are blended, for obvious reasons, to produce this very emulsion.

Wax Content.—At ordinary temperatures it is a difficult matter to decide whether wax, either in the form of solid paraffin or some other substance, is or is not present. The readiest test is to cool the oil with ice, when the wax will have a tendency to separate out, and so cause the oil to appear cloudy.

Filtration of Oil.

When oil is properly filtered it can be used indefinitely without losing any of its lubricating qualities.

RECOVERY OF LUBRICATING OIL.*

Settlement and Filtration Method.

Fig. 1, p. 1060, shows a waste oil filter made by Messrs. A. C. Wells & Co.; these filters consist of three compartments, any of which can be readily removed from the other to facilitate cleaning.

* Abstract of paper by Alfred J. Wilson, A.M.I.Mech.E., A.M.I.Pet.Tech., read before the Diesel Engine Users Association, 21st October 1920.

The top chamber receives the dirty oil, which after admission is allowed to settle for about a day, the time varying with the degree of foulness attained by the oil. The top chamber is provided with a floating syphon which when set in operation delivers the settled oil drop by drop into the second compartment, whence it passes by gravity through a special filter pad into the lowest compartment. The descending oil is collected off the underside of the filter pad in the

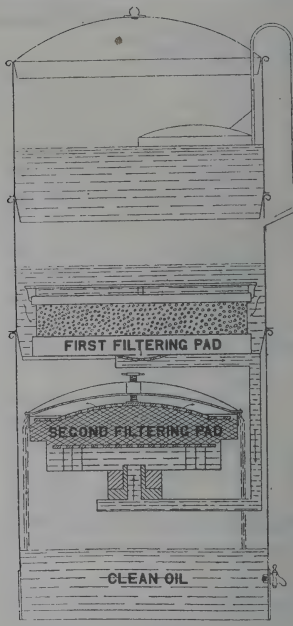

FIG. 1.

second stage and led into a tube which terminates in a further filter pad. This cleans the oil by upward filtration, the recovered oil falling into the bottom of the third, or lowest, compartment, whence it is drawn off for re-use as required. By heating the oil with steam coils or electric heaters the capacity of the filter can be practically doubled:

Messrs. A. C. Wells & Co. also specialize on a machine for continuous feed in connection with marine work.

Boiling Water Method.

Compound oils can be cleaned by passing them over boiling water.

One of the most satisfactory examples of this system is that installed at the Generating Station of the Chelsea Electricity Supply Company. The waste oil from the engines, excluding that drained from the compressors, is collected into a common tank, whence it is pumped into a larger tank placed at a height of about 8 ft. above floor level. A pipe from this elevated tank is led to a cylindrical open-top tank of about 50 gallons capacity which stands on the floor beneath. This latter tank (fig. 2, p. 1061) is the one used for the boiling treatment, and is filled with water to a height of 12 ins. or thereabouts. The water is raised to boiling-point by means of a steam coil immersed therein. The dirty oil is then slowly fed into the tank by gravity and the flow is regulated by a valve, so that the mixture of oil and water is maintained at a temperature which causes a yellow froth to appear on the surface. When about 30 gallons of dirty oil have been so introduced the supply is shut off and also the steam heater. Settling then takes place and is allowed to continue for some hours, the treated oil being drawn off through cocks at different levels and put into a filter, leaving a deposit of carbon particles on the top of the water. The filter to which the oil is transferred is divided into an upper and a lower compartment, the

treated oil when cooled being drawn off by a floating suction pipe and passed into the lower compartment. This arrangement ensures that oil from the upper surface only of the cooled oil shall be passed into the lower compartment, from whence it is drawn off for re-use. No filtering medium is used, the carbon, etc., which has escaped removal in the boiling tank settling out in the first compartment of the filter.

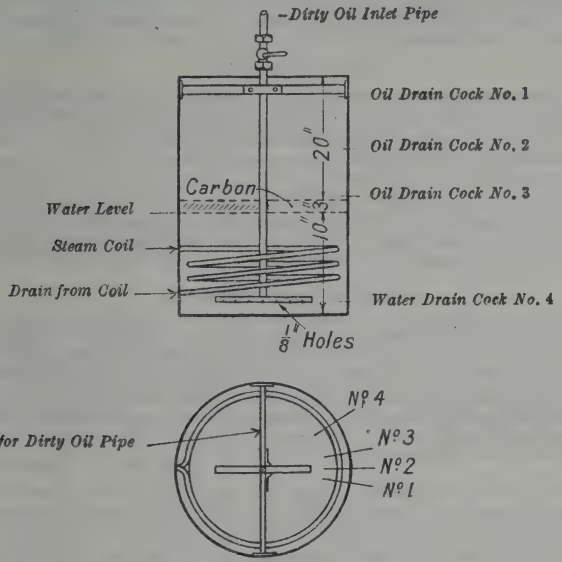

FIG. 2.

Other methods are those in which :—

(1) The oil is allowed to settle either with or without warming. Objections to this method are the length of time and the large number of settling tanks required.

(2) The oil is warmed and then cleaned by chemical means.

(3) The oil is passed through a centrifugal cleaner.

LUBRICATION.

Crank Chambers.

In engines of the Willans type, in which lubrication is effected by a bath of water with a thin layer of oil on the top, it is generally safer to use a pure hydrocarbon of good body, preferably of the charcoal refined class, which represents the highest lubricative efficiency obtainable in mineral oil. It is important that the oil selected, especially if it is to be used in conjunction with hard water, should be free from tendency to emulsify, as, should this occur in the crank case, lubrication will be much impaired.

For engines lubricated by force, as in the Belliss and some others, an oil of moderate body is required, as, assuming that the bearings are in good condition, the pressure of the pump ought to provide a continual film of oil on each journal. It is also important that this oil should separate freely from water, as the formation of an emulsified magma would interfere with the circulation of the oil.

Crankshaft Bearings.

It is impossible to lay down definite rules in regard to the oil to be used on these bearings, which vary greatly in size, in speed, and in the method of applying the oil. Speaking generally, for large engines lubricated by syphons or by pipes, an oil of good body containing a percentage of fatty oil, ought to be used. It is important to note, in comparing a fatty oil with a mineral oil, that their respective efficiency cannot be determined by body or viscosity alone, as, on account of some hidden virtue in fatty oils, it will be found that a fatty oil of moderate body will reduce friction to a greater extent and will last longer than a mineral oil of much superior body, showing that body by itself as not the final criterion.

Ring Lubrication

introduces another condition apart from the direct question of the immediate efficiency of the oil. In ordinary lubrication the oil is slowly fed to the bearing at a rate calculated to make good the loss by waste or use. The oil, therefore, practically serves only once, but in the case of ring lubrication the oil may remain in use for months with only occasional slight additions to replace waste; but during all the time that the oil is in use it is being taken up by the rings and spread over the journal and bearing in a thin film continually exposed to the action of the atmosphere. Under these conditions an animal or vegetable oil would, by the absorption of oxygen from the atmosphere, be slowly thickened and become gummy and unsuitable. Therefore, in this case, it is advisable to forgo the advantages offered by fatty oils and to select a pure hydrocarbon oil of suitable body and high boiling point which will not too readily lose bulk by evaporation or be chemically affected by the action of the atmosphere.

NOTES ON RING LUBRICATION.

Sluggish action of the oil-rings of motors in a large New Jersey factory, leading to improper lubrication of the bearings, was cured by bevelling the sides of the rings. On testing the motors it was noticed that the rings would creep along at a very slow speed, two or three revolutions a minute on a machine of several horse-power, instead of the regular speed of about thirty to fifty revolutions. It was finally discovered that under certain conditions a ring would start with the machine and perhaps come up to normal speed, but would soon work itself towards one side of the slot and slow down, hugging closer and closer until there was only a very thin film of oil between the ring and the flat part of the journal. Three rings were removed and their sides were slightly bevelled, when the trouble entirely disappeared.

(P. G. Bernholz, 'Electrical World.')

Regular inspection of the oil-rings on generators, converters, or motors should be made by the operator to determine if they are turning properly. This is especially necessary when a machine is started up, as the rings are apt to stick at this time. The fact that the oil need be changed only once or twice in a year does not necessarily imply that the bearings are fool-proof and need no attention on the part of the operator. If the rings stick and fail to revolve, the bearing will get no oil. This frequently happens, resulting in an overheated bearing, and sometimes in enforced shutdown of the machine. Consequently, it is an important duty of the operator to make regular inspection of these rings to see that they are turning. If they are not, they should be started with a small hardwood stick, which should be kept on hand for this purpose. At the same time, the operator should see that the gauge glasses on bearings are at least half-full of oil, and that there is no leakage around the glasses. In case of any apparent leakage, lack of oil, or chronic sticking of any particular oil-ring, the matter should be reported to the foreman. When inspecting oil-rings on a running rotary, operators should wear goggles to protect their eyes from possible flashovers.

The rings should be turned and bored truly from extra thick commercial brass tube, and made approximately twice the diameter of the journal it is required to lubricate, and the width about one-half of the shaft diameter. As regards thickness, it has been proved by experiment that the thicker the ring, with its consequently increased weight, the more dependable is the rotation with the shaft, the oil allowing the greater surface of the heavier ring to pass through it with less increase of friction compared with the frictional drive of the heavy ring by the shaft.

Steam Turbines.

The only parts calling for lubrication in turbines are the glands and the external bearings. In the larger sizes both the glands and the bearings are provided with jackets through which water may be circulated, when this is necessary, to keep the bearings cool. In the earlier types of turbines, the glands were packed in the ordinary manner and called for the use of oil of a cylinder character to reduce friction. In modern practice the glands do not call for lubrication, as they are fitted with special metallic ring packing which does not make metallic contact with the shaft. A little water is injected and serves to condense any escaping steam at the high pressure end and the admission of air at the low pressure, or vacuum, end and also in a measure acts as a lubricant.

The lubrication of turbine bearings is usually effected by the circulation of oil by a pump which forces the oil from a tank in the base of the engine through a system of pipes to the bearings,

from which it returns by other pipes to the tank through which cold water circulates in pipes to reduce the temperature of the oil.

The conditions calling for consideration in the lubrication of turbines seem to be the abnormally high temperature of the bearings, due to the transmission of heat by the shaft from the turbine, the probability that, despite most careful precautions, water may find its way into the oil, and the fact that the oil may remain in use for many months without change and with comparatively little addition of fresh oil. These conditions call for oil of considerable body, which should not be liable to emulsify in contact with water, and which should not be injuriously affected by long use and contact with air. (See also Section XXX, Part IV, p. 1853.)

Dynamos,

which are generally provided with ring bearings, should be dealt with on the lines indicated in 'Ring Lubrication,' p. 1062.

Air Compressor Lubrication.

See p. 1263.

Shafting

requires oil of moderate body, which may be either a compound oil, if the best results are required or a pure mineral oil if the strain on the bearings is not too great and the system of lubrication ensures a constant and regular supply of oil.

Abrasive Wheels.

See p. 1178.

Automatic Tools.

The high speeds adopted in tools of the turret lathe type, and the great pressure and high temperature developed at the cutting point in large automatic lathes, call for oils of superior quality to save the edge of the tool and the surface of the metal on which it operates; but although the old-fashioned soap-suds are unsuitable, from their rusting action on the tools and on the metal of the job, it has been found that, in many cases, satisfactory results are, and may be, obtained by the use of a soluble oil, or soluble paste dissolved in water, which keeps the cutters cool and in good condition, and does not rust the job.

Automobiles.

See p. 2012.

Cutting Lubricants.

See p. 1152.

Drills.

See p. 1113.

Graphite Lubrication.

Graphite, plumbago, and blacklead are mineralogically similar, but whereas blacklead often consists of a large proportion of clay and very little pure blacklead, on the other hand graphite (especially those grades prepared for very special lubricative purposes) may consist of as much as, and even more than, 99 per cent. of pure graphitic carbon.

The selection and preparation of graphite for lubrication requires the observance of two principal considerations, viz., the structure of the graphite itself and the character and amount of other matter incorporated with it. For instance, a flake graphite, comprising 95 per cent. of pure graphitic carbon having the necessary unctuousness, but mixed with 5 per cent. of hard siliceous rock or quartz, would not be satisfactory for any form of lubrication. Unfortunately, many purchases of such deleterious admixtures are made because the price is lower than, for example, a flake graphite, consisting also of 95 per cent. unctuous graphite with 5 per cent. smooth foliated micaceous matter. The latter, for many purposes, is every bit as good as a 99·8 per cent. or 99·9 per cent. pure flake graphite, and is comparatively much cheaper than grades of such high purity, but its cash value is many times that of the one containing rock or quartz (though the difference in actual cost between the 'quartz' grade and the 'soft mica' grade may only be a few pence per lb.). The damage which such an abrasive mixture will undoubtedly do to any kind of machinery is serious. Engineers should therefore exercise very particular supervision over these purchases.

As already stated the important points are :—

(1) The structure of the graphite, and (2) the character and amount of the impurities in it.

Flake graphite is necessarily the best for lubrication, when consideration is given to the manner in which its lubricative duties are performed. It is required to associate itself and become attached

to, and form part of, one or both of the rubbing surfaces, and impart an even and smooth finish to these surfaces, by filling up any tiny depressions. The way confetti clings to the floor is a good illustration in this connection of the advantage of a flat or flake structure.

In the well-known 'Foliac' brand of flake graphite (of *Graphite Products, Ltd.*), the flake structure is combined with foliations which act similarly to a pack of cards under pressure, by slithering apart and presenting a much larger smooth and slippery surface. This foliated or laminated structure is a distinct feature of these products, and it is claimed that a much lower coefficient of friction is obtained with them than with, e.g., the amorphous varieties of graphite or plumbago, whether carried to the surface in colloidal form or not. In connection with colloidal or deflocculated graphites it must be remembered that acidity, alkalinity, or other disturbing cause is necessary in order that the colloid may flocculate into particles large enough to attach themselves to bearing surfaces.

Recent examinations of representative samples of 'Foliac' flake graphites showed the following results :—

Foliac No. 1,	assayed,	96·00	per cent. carbon.
Foliac No. 2,	,,	95·50	,, ,,
Foliac No. B1371,	,,	96·13	,, ,,
Foliac No. 100,	,,	99·85	,, ,,
Foliac No. 101,	,,	99·75	,, ,,

Because graphite has a higher specific gravity than oils (about 2·2 to, say, ·9 or so for oil) it is impossible to permanently suspend it in ordinary lubricating oils, at any rate without special and complicated treatment; therefore, in order to convey flake lubricating graphites to bearing surfaces with certainty and regularity, suitable greases with the graphite in intimate admixture are best. Many instances are recorded where suitable flake graphite greases have outlasted other kinds (without flake graphite) five or six times and with less friction.

The Use of Graphite.

The right kind should be selected for a specific purpose. As examples, the large flake is best suited to large areas of surface, whether bearings, cylinders or valve faces; and the small flake is best for smaller areas of surface. At the same time, for intricate, fine or fast moving motions, it is well to select a specially prepared fine flake graphite for these purposes.

All surfaces in frictional contact should be well rubbed with the selected flake graphite for any particular class of machinery, before assembly. This rubbing is best done by dipping a clean oily pad in the graphite, and rubbing it well into the surfaces. The smoothness and consequent reduction of friction is most noticeable, and it is a very long time before this 'graphite skin' or polish is lost.

The removal of the flake graphite after this rubbing in can only be done by filing or grinding—in other words, to remove it, the surface or the metal itself has to be removed.

For regular use after assembly of parts, as already stated, one of the flake graphite greases is best, but occasional doses of flake graphite can be fed with the ordinary lubricating oil with most satisfactory results. It will be obvious that the large flake graphite mixed with a thin spindle oil will settle much faster than a very fine flake graphite in a bodied engine or heavy machine oil.

Too much should never be used, especially when mixed with oils—from 2 per cent. to 5 per cent. according to the service required, is usually ample. With greases, the proportion may be larger.

Graphite, particularly the flake variety (if free from abrasive matter), is an exceedingly useful and beneficial product—but it should not be used to excess, as too much is likely to give trouble.

Feeding Graphite.

In the first place, when erecting or repairing engines, or whenever the cylinders and valves are opened, the working surfaces should be freely covered with a thick mixture of graphite and cylinder oil. Flake graphite cannot satisfactorily be fed through the usual sight-feed displacement lubricators for the reason that its high specific gravity causes it to settle in the oil and to clog up the connecting pipe. A reasonable doubt might be entertained as to whether graphite can readily become attached to the frictional surface if it is so fine that it passes through the pores of filter paper, as is claimed by some, which would indicate that the particles of graphite are surrounded by an unbreakable oil film. But if these particles could become attached to the frictional surface, efficient but not lasting aid to lubrication would certainly result. Experience seems to show that there is a limit to a desirable subdivision of graphite, and if this is so the settling of graphite in cylinder lubricators must be overcome by mechanical means, since even the smallest particles of graphite which can be seen will settle in oil. There are, however, cylinder lubricators on the market for feeding graphite, the best known of which relies on continuous stirring to secure suspension of the graphite, even in the delivery pipe, by means of a spiral wire which is constantly turning.

Graphite as a Lubricant for Cylinders.

As a cylinder lubricant, flake graphite has come to be widely used, as it is quite unaffected, either chemically or physically, by any temperature encountered in a cylinder and retains its high lubricating value even when at a red heat.

Wells and Scott-Taggart, in their book 'Cylinder Oil and Cylinder Lubrication,' write concerning the oil polish as follows: 'In order to satisfy themselves as to the working of an oil, most engineers open the cylinders at intervals and note the condition of the surfaces. Satisfaction is generally felt if they find the inside of the cylinder polished like silver, or if it has a bright, smooth surface, "like a mirror," as some express it. Now, this is not by any means the condition the cylinder ought to be in, if it is lubricated with oil alone. Suppose an engineer found, on opening the cylinders of his engine, that bright streaks existed, he would conclude at once that the bright spots were the result of friction . . . Strange to say, if he found the whole surface of his cylinder polished, he would not think it was friction. A well-lubricated cylinder ought to present a rather dark-looking surface, smooth, but with no signs of bright polish, even if coated with oil. The slightest rubbing with a polishing rag would produce a bright surface on such a cylinder, thereby proving that the lack of a polish is due to the absence of friction.'

In addition to the 'oil polish' referred to above, there is the smoothing and polishing effect produced in ammonia cylinders of refrigerating machinery, the 'water polish' frequently observed in marine engines and in pump cylinders, and the 'graphite polish.' This last is different from the others, which are really friction polishes, obtained by rubbing off the roughness of the grain of the metal. Graphite polishes by filling in the grain of the metal, just as wood filler and varnish polish a surface of wood, and cannot therefore be construed as an evidence of friction.

The question of the best manner of separating graphite from exhaust steam is frequently raised by those not familiar with its use. In answer it may be said that any separator, grease extractor, or settling tank that will remove even a fair percentage of cylinder oil will remove all the graphite that goes out with the exhaust. Graphite passing into a separator is apt to adhere to the baffle plates, and it is good practice to remove and clean them from time to time.

Where measures are not taken to separate or otherwise eliminate such graphite as may leave the cylinder with the exhaust steam, certain small amounts may pass into the boiler with the feed water. Graphite in a boiler is an advantage rather than a detriment. If the feed water contains scale-forming salts, the graphite will combine with the scale to make it softer and more easily crumbled. The heat transfer will not be affected, for graphite is a very good conductor of heat. (See also 'Foliac Boiler Graphite,' p. 1688.)

Graphite as a Lubricant for Gas Engines.

An authority on gas-engine cylinder lubrication has stated that the perfect lubricant for this work should either be consumed entirely or else not at all. Flake graphite meets this last requirement fully, since the intense heat encountered in a gas-engine cylinder has no effect whatever on graphite. There are many ways of feeding graphite for gas-engine cylinders, as there are many types of gas engines, but space does not admit of a full description of the different methods. Inhalation of dry graphite from a closed container or cup attached to the inlet pipe into the gas and air mixing chamber has been successful, the pulsations due to alternate compression and reduction of pressure allowing a little graphite to feed through the hole (say $\frac{1}{32}$ in. diameter) in the bottom of the container.

Difficulty has sometimes been encountered with graphite by its short-circuiting sparking points in jump-spark ignition. This usually means that too much graphite has been used, and reducing the quantity removes the trouble.

Lubrication Troubles from Uncleaned Castings.

When a new engine or turbine is first set to work, there is certain to be trouble with bearings in perhaps a majority of cases. This is because so many constructors neglect the proper cleansing of castings. Castings are never properly cleaned of sand even externally by the still common methods of steel brushing and coke rubbing, and in steam ports and passages it is hopeless to expect cleanliness from such antiquated methods. 'Sandblasting' with chilled-steel pellets will clean a casting externally, but cannot be relied on for the internal cleansing of ports or oil receptacles. Thus it is that lubrication troubles are so usual when starting up new sets. Some engineers strongly favour the pickling of castings as the most effective way of removing sand. The castings are first roughly cleansed and fettled, and then hosed with weak hydrochloric acid. Where sand is present this spreads the acid by capillary action, and the result of a few hours of acid action is to remove all sand and leave the iron surfaces clean and free also from the hard siliceous scale which is so destructive of turning tools and other tools, especially millers, and is also most injurious to lathe-bed surfaces and other working surfaces of all machine tools. When the acid treatment has done its work, the castings are washed by warm water, and this may be dosed with soda to neutralise any unspent acid.

Note on Lubrication.

Special attention should be given to all internal parts such as box beds, which act as oil receptacles, as well as to steam and exhaust passages. The oil of any circulating system becomes dirty with use. Dirt comes over from the boilers with the steam and finds its way into turbine bearings in spite of all the constructive care to guard against this. The atmospheric dust gets in somewhere, and there may be leakage at oil coolers. There is also the microscopic metallic waste from bearings. All these sources of dirt are quite enough to call for filtration, apart from the gross carelessness which is shown by the presence of foundry sand. Oil may sometimes be at fault if it has been chosen wrongly, but more usually sand, which ought never to have found itself so far from the foundry, is to blame. Organic oils deteriorate with age owing to their property of absorbing oxygen: this causes them to become gummy or resinous, and thus to lose their lubricating quality. Mineral oils, which are not, chemically speaking, oils, do not absorb oxygen, and are free from this deterioration.

LUBRICATORS.

The V.S.M. Automatic Forced Lubrication System.

In the V.S.M. System of Lubrication (*Messrs. Vickers, Ltd.*) the oil is forced in between the shaft and its bearings at the point of maximum pressure. This is done by means of a pump, which is only about $\frac{3}{8}$-in. diameter, with a stroke of about $\frac{1}{8}$ of an inch. Preferably one such pump is provided for each bearing. The pump works in a closed circuit of oil, and the same oil used over and over again. *Whenever the pressure per square inch between the shaft and its bearing increases, due to the weight of the shaft or to external stresses, the pump automatically raises the pressure of oil to meet and overcome this resistance, and forces it through to form a positive and unfailing film between the two surfaces exposed to maximum pressure.*

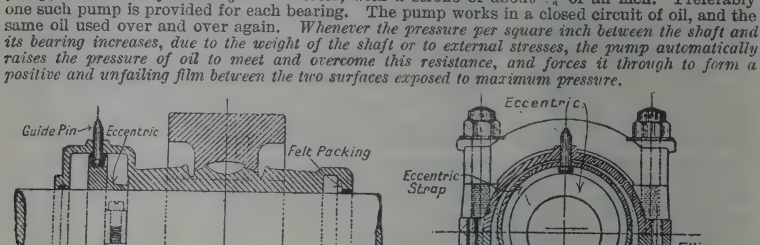

Fig. 3.

Fig. 3 shows the forced lubrication system applied to a 2½-in. swivel bearing. The pump is surrounded by a reservoir of oil, which has the effect of flooding the inlet openings in the pump body. In this way a suction valve is dispensed with, and the pump plunger is, in effect, its own valve.

The action of the pump is as follows: When the plunger rises to the top of its stroke the inlet openings in the pump body are fully exposed, and oil from the reservoir flows in through these openings, filling the available space in the pump chamber. In making the return stroke the pump plunger gradually passes the inlet openings and finally cuts off the connection between the pump chamber and the external reservoir. The remainder of the downward stroke forces the oil imprisoned in the pump chamber past the non-return delivery valve into the delivery channel, and thence into the bearing on the surface exposed to maximum pressure. This action is repeated with every revolution of the shaft, and in large slow-running shafts the eccentric can be replaced by a cam giving two or more pump strokes per revolution as required.

Each stroke of the pump delivers a definite volume of oil to the bearing, and at the same time displaces an equal volume from the bearing. The displaced oil falls into the chambers provided at each end of the bearing, and flows back, by simple gravity only, into the reservoir surrounding the pump.

In cases where the V.S.M. System of Lubrication has to be applied to bearings and structures already in existence, and where it is impossible to incorporate the V.S.M. apparatus in the design and structure of each bearing, a multiple pump arrangement is adopted consisting of a number of units up to twelve in number. The principle of the arrangement is exactly the same as that shown in fig. 3. To ensure that each bearing gets its proper supply of oil, a separate pump is provided for it, with delivery pipe.

The multiple pump can be driven by a belt or chain, or it can be coupled up to another shaft. The eccentrics operate the pumps exactly as described. The oil flows by gravity from the reservoir past the stop valve through channels to the regulating valves. The oil drops by gravity into the suction side of the pump, and is then forced past the delivery valve on the way to the bearing to be lubricated. Glass tubes are provided for convenience to exclude dust and yet at the same time to enable one to watch the amount of oil passing to each bearing.

In the application of the V.S.M. system to an axle-box for railway rolling-stock the eccentric pump and accessories are substantially the same as those used for ordinary fixed bearings. With fixed bearings, however, the pressure on the bearing itself is usually on the under side, but in railway axle-bearings the pressure is on the top side, and in addition the bearing on the under side is entirely cut away. In consequence it is necessary to provide a short pipe, preferably of copper, to convey the oil from the pressure side of the pump to the top of the bearing at the point of maximum pressure. This arrangement permits the oil pump to be fixed at or near the bottom of the oil reservoir, ensuring an ample supply on the inlet side of the pump. The copper pipe leading from the pressure side of the pump to the top of the bearing is made long with bends, so that any relative movement between the top bearing and the pump may take place in the bends without stressing the unions at both ends of the pipe. Preferably the pump itself is designed as a separate piece from the axle-box for the purpose of manufacture, inspection, and more convenient application to the axle-box.

With a railway axle-bearing having an oil reservoir the great difficulty is to prevent the surplus oil escaping along the axle through the inner end of the axle-box, and so rapidly emptying the reservoir. Another difficulty is to prevent the dust entering through the same space and acting as an abrasive on the axle and its bearings, and causing the rapid wear of both. To overcome these difficulties a special ring has been provided to act as a dust excluder and oil retainer.

The Hulburd Valveless Force-Feed Mechanical Lubricator.

(Hulburd Patents Ltd., 26, Park Road North, Acton, London, W. 3.)

The Hulburd Valveless Force-Feed Mechanical Lubricator (for locomotive cylinders, steam chests, axle-boxes, etc.), fig. 4, is a thoroughly reliable instrument of robust construction and extreme simplicity; it thus affords adequate guarantees as to durability and low-working costs. It is entirely without valves, either suction or delivery, and, being positive in action, it makes air locks impossible, and will start to work automatically without the preliminary hand manipulation necessary in the case of previously existing types.

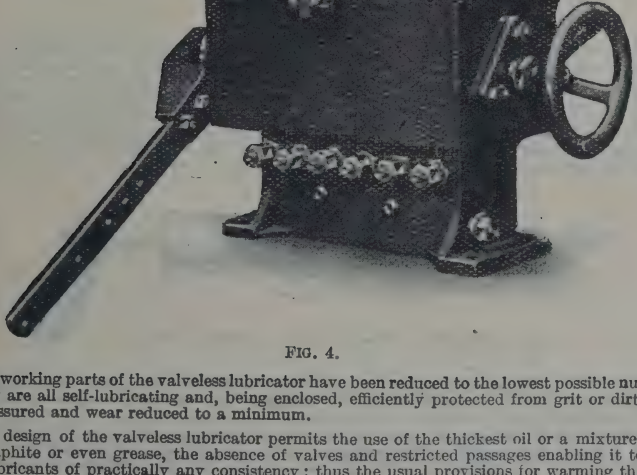

Fig. 4.

The working parts of the valveless lubricator have been reduced to the lowest possible number. As they are all self-lubricating and, being enclosed, efficiently protected from grit or dirt, long life is assured and wear reduced to a minimum.

The design of the valveless lubricator permits the use of the thickest oil or a mixture of oil and graphite or even grease, the absence of valves and restricted passages enabling it to deal with lubricants of practically any consistency; thus the usual provisions for warming the container, being unnecessary, are entirely dispensed with.

The principle of action of the valveless lubricator is that of two opposed plungers working in a common cylinder. Of these plungers one has a continuous reciprocating motion imparted to it, and the other, normally carried with the first and partaking of its movement, is arrested and held stationary at suitable intervals so that they mutually separate from and approach each other, thereby in turn closing the inlet and outlet ports and producing the suction and discharge strokes which are thus rendered effective without valves of any description.

There being no delicate springs or valves to be put out of action by every small obstruction, and no narrow and intricate passages to become blocked, the lubricator is rendered unchokeable, and all working parts, being within the oil container, are not only effectively protected from dust and dirt, but are also continuously lubricated without extraneous attention, so that neglect under that head has not to be reckoned with, the whole being entirely automatic.

The valveless lubricator is positive in its action, and ensures a uniform rate of feed against all pressures and under all conditions; it delivers, as regulated, a definite charge of lubricant at every stroke which is forced in its entirety to the desired point.

One of these lubricators, after running the equivalent of some 40,000 miles at the rate of 60 miles per hour, and forcing oil against an average pressure of 175 lbs. per sq. in., was dismantled, and it was impossible to detect any wear on any of the working parts; the pump plungers after being measured on a micrometer were found to be exactly as they were before the test started; also during the test the amount of oil delivered was carefully measured at intervals and found to be absolutely constant throughout.

The 'Tecalemit' High-Pressure Lubrication System.

(*Tecalemit Ltd.*, 10 *Little Portland Street, London, W.* 1.)

This system consists of lubricating plugs (fig. 5) fitted with a non-return valve, which takes the place of the Stauffer type or drop-feed lubricator. These plugs can be supplied with any required male or female thread, or can be supplied for fitting to plain bored holes.

Fig. 5.—Hook-on plugs.

A 'Gun,' which is operated by hand, is used to supply the lubricant to these plugs. This consists of a lubricant receptacle (fig. 6) of 2½, 5, 10, or 17 ozs. capacity, fitted with a handle which forces the lubricant into a small high-pressure cylinder. When the gun is applied to the plug or lubricating point, either by sliding it on in the case of the 'Automatic' type, or by simply pressing it on in the case of the 'Tecalemit Z' type, a leak-proof connection between the gun and the plug is automatically made, and, by applying further pressure, the high-pressure cylinder telescopes into a small piston fitted inside the nosepiece, and forces the lubricant under a pressure of 5,000 lbs. to the square inch through the plug and on to the bearing.

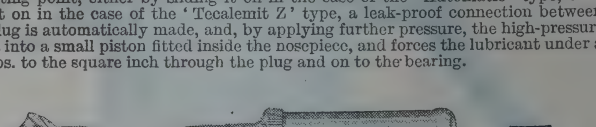

Fig. 6.
Type, Automatic. Capacity, 5 ozs. Length, 17 ins.

If there are sufficient lubricating points to justify the outlay, there is the Tecalemit transportable workshop pump, capacity 17 lbs. of lubricant, on four small wheels, or the 11 lbs. capacity knapsack pump, arranged to be strapped on the operator's back. The former type is only suitable for the Tecalemit slide-on nozzle, whilst the latter can be used with either the slide-on or the push-on nozzles. The pressure obtainable is 5,000 lbs. per square inch.

A special pattern of portable lubricating tank, capacity 100 lbs., is made, which is suitable for any type connection. With this tank a high output of lubricant under low pressure can be

obtained, or, by screwing on one of the nosepieces delivered with the apparatus, a large number of points can be lubricated under 5,000 lbs. pressure with two turns of the handle. This machine is in considerable demand for large workshops, tramway depots, etc.

Notes on Lubricators.

In general, leaky connections on a lubricator will cause irregular feeding of the oil. Should the sight-feed glass become clogged, it may be due to setting up too tightly on the bottom nut when the glass was installed. This often causes the rubber gasket to be squeezed out of place and perhaps into the glass. If the oil-feed cone should become displaced or off centre, it may cause the globules of oil to move up the sides of the glass, and perhaps to stick there, causing the glass to fill with oil. The glass should then be removed and the cone filed down, or it will be found effective to solder a fine copper wire to the side of the cone, leading it upward through the centre of the glass, nearly to the top. The oil drop will then follow the wire, and the glass will remain clean. It is not advisable to allow a hydrostatic lubricator to run empty of oil, owing to the danger of the sight-feed and gauge glasses becoming hot, thus causing oil to stick to the sides of the glass.

SECTION XX

PART III

VISCOSITY AND VISCOUS FLOW OF OILS.

VISCOSITY OF OILS.

(*The Petroleum World, June and July*, 1913.)

Oils of a particular description may vary largely in kind; 'shale' oil, for example, may vary from petrol to heavy oil, and other descriptions may also vary; the names of the oils referred to in the following table cannot therefore be taken as being characteristic of their viscosity.

TABLE I.—VISCOSITY TESTS OF VARIOUS OILS.

(Referred to in Tables II, III, and IV.)

No.	Description.	Origin.	Colour.	Density (δ) at 20° C.	Redwood Viscosity Number at 20° C.
1	Shale	—	Dark brown	0·8530	8·25
2	Fuel	Burma	Dark brown	0·8890	14·8
3	Refined machine	—	Pale yellow	0·8630	21·8
4	Olive	—	Yellow	0·9130	69·3
5	Refined spindle	Russia	Pale brown	0·8955	76·3
6	Fuel	Texas	Black	0·9310	126·0
7	Engine	Russia	Brown	0·9055	255·0
8	Fuel	Roumania	Black	0·9495	579·0

TABLE II.—CHANGE OF VISCOSITY BY CHANGE OF TEMPERATURE.

No.	Percentage rate of change of viscosity per 1° C.*									
	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°
1	3·2	3·0	2·8	2·6	2·5	2·4	2·4	2·4	2·5	2·6
2	4·7	4·1	3·8	3·5	3·1	2·9	2·7	2·6	2·5	2·6
3	—	4·5	3·8	3·4	3·2	3·3	3·4	3·6	3·9	4·4
4	4·7	4·4	4·2	4·0	3·7	3·4	3·2	3·2	3·5	4·1
5	7·0	5·7	5·3	5·5	5·7	—	—	—	—	—
6	—	—	6·1	5·1	4·8	4·6	4·4	4·4	4·4	4·4
7	—	—	5·6	5·4	5·9	—	—	—	—	—
8	—	—	6·5	6·1	6·2	6·7	—	—	—	—

* The values given in the table must be divided by 1·8 to obtain the percentage rate of increase of viscosity per 1° F.

TABLE III.—DENSITY (δ).

No.	Temperature °C.						
	10°	20°	30°	40°	50°	60°	70°
1	0·8595	0·8530	0·8465	0·8395	0·8330	0·8265	0·8200
2	0·8955	0·8890	0·8825	0·8760	0·8690	0·8625	0·8560
3	0·8695	0·8630	0·8565	0·8500	0·8440	0·8375	0·8315
4	0·9195	0·9130	0·9065	0·9000	0·8935	0·8865	0·8800
5	0·9015	0·8955	0·8890	0·8825	0·8760	0·8700	0·8635
6	0·9375	0·9310	0·9245	0·9180	0·9115	0·9050	0·8985
7	0·9115	0·9055	0·8990	0·8930	0·8870	0·8810	0·8845
8	0·9560	0·9495	0·9430	0·9365	0·9300	0·9235	0·9170

TABLE IV.—VISCOSITY IN C.G.S. UNITS.*

No.	Temperature °C.												
	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°
1	0·1075	0·0905	0·077	0·066	0·057	0·0498	0·0438	0·0387	0·0343	0·0304	0·0270	0·0238	0·0208
2	—	0·216	0·168	0·135	0·111	0·0925	0·0785	0·0675	0·0590	0·0515	0·0453	0·0400	0·0350
3	—	—	0·257	0·200	0·163	0·1365	0·116	0·0985	0·0835	0·070	0·0585	0·0475	0·0375
4	1·38	1·075	0·840	0·670	0·540	0·440	0·363	0·304	0·258	0·221	0·187	0·155	0·124
5	—	1·375	0·920	0·680	0·520	0·400	0·300	0·224	—	—	—	—	—
6	—	—	—	1·100	0·795	0·610	0·478	0·378	0·302	0·244	0·195	0·157	0·126
7	—	—	—	2·050	1·515	1·160	0·880	0·640	—	—	—	—	—
8	—	—	—	5·150	3·650	2·680	1·970	7·440	1·000	—	—	—	—

VISCOUS FLOW.

Although there are two kinds of flow, viz. 'stream line' or 'viscous' flow, and 'turbulent' flow, for all practical conditions, heavy oils, Mexican oils, and others, follow the law governing viscous flow.

The frictional loss due to purely viscous flow is given by the equation

$$H = 0{\cdot}0066875 \frac{TVP}{d^2}$$

where,

H = loss of head per 100 ft. of piping;
T = viscosity measured in secs. by Redwood No. 2 Viscometer;
V = velocity in ft. per sec.;
P = weight in lbs. per cub. ft.;
d = diameter of pipe in ins.

(*Weir Marine Auxiliary Machinery, G. & J. Weir, Ltd., Cathcart, Glasgow.*)

If

Red. = Redwood viscosity number;
W = weight in tons per hour of oil passing through pipe;
δ = oil density;

then,

$$T = 4{\cdot}895 \frac{\text{Red.}}{\delta}; \quad V = 1{\cdot}83 \frac{W}{d^2 \delta} \text{ ft. per sec.};$$

* See p. 1056. The 'viscosity' of a substance is measured by the tangential force on unit area of either of two horizontal planes at unit distance apart, one of the planes moving with unit velocity relatively to the other.

$$H = 2{\cdot}09\ \frac{\text{Red. V.}}{d^2} = 3{\cdot}73\ \frac{\text{Red. W.}}{d^4\,\delta} \qquad (H.\ R.\ K.)$$

Example.—124 tons (W) per hour of No. 8 oil, Table I. p. 1071, is to be pumped through a straight length of 9-in. diameter (d) pipe, 50 ft. long. What is the frictional loss (H)?

From Table I., Red. = 579, $\delta = 0{\cdot}9495$, therefore,

$$H = 3{\cdot}73\ \frac{579 \times 124}{9^4 \times 0{\cdot}9495} = 3{\cdot}73\ \frac{579 \times 124}{6561 \times 0{\cdot}9495} = 43 \text{ ft.};$$

or,

$$43 \times \frac{50}{100} = 21{\cdot}5 \text{ ft. for 50 ft.}$$

See also 'The Design of Oil Fuel Pipe Lines,' by W. G. Watkins, *Engineering*, December 19 and 26, 1924.

PUMPS FOR VISCOUS LIQUIDS.

See Section XXV, Part II.

SECTION XX

PART IV

SHAFTING AND SHAFTS.

Horse-power of Shafting.

Wrought-Iron Shafting.

Wrought-iron shafting is now but seldom used. The diameter required to transmit any horse-power may be calculated from the formula :—

$$\text{Diameter of a wrought-iron shaft, in inches, at bearings} = 5\sqrt[3]{\frac{\text{Horse-power}}{\text{Number of revolutions per minute}}}$$

Steel Shafting.

If D = shafting diameter ; R = revs. per min. ; H.P. = horse-power transmitted, then,

$$\text{H.P.} = D^3 \times R \times 0{\cdot}02.$$

Power that Steel Shafting will Transmit at Various Speeds.

Revolutions per Minute.	Diameter in Inches.									
	1¼	1½	2	2¼	2½	2¾	3	3½	4	4½
	Horse-power Transmitted.									
50	3·3	5·3	8·0	10·9	15·6	20·8	27	43	64	91
60	4·0	6·4	9·6	13·1	18·8	25·0	32	51	77	109
70	4·7	7·5	11·2	15·2	21·9	29·1	38	60	89	128
80	5·4	8·5	12·8	17·4	25·0	33·3	43	69	102	146
90	6·0	9·6	14·4	19·6	28·1	37·4	49	77	115	164
100	6·7	10·7	16·0	21·8	31·2	41·6	54	86	128	182
110	7·4	11·8	17·6	23·9	34·4	45·8	59	94	141	200
120	8·1	12·9	19·2	26·1	37·5	49·9	65	103	154	219
130	8·7	13·9	20·8	28·3	40·6	54·1	70	111	166	237
140	9·4	15·0	22·4	30·5	43·8	58·2	76	120	179	255
150	10·1	16·1	24·0	32·6	46·9	62·4	81	129	192	273
160	10·8	17·1	25·6	34·8	50·0	66·5	86	137	205	292
170	11·5	18·2	27·2	37·0	53·1	70·7	92	146	218	310
180	12·2	19·3	28·8	39·2	56·3	74·9	97	154	230	328
190	12·8	20·4	30·4	41·3	59·4	79·0	103	163	243	346
200	13·5	21·4	32·0	43·5	62·5	83·2	108	172	256	365
225	15·2	24·1	36·0	49·0	70·3	93·6	122	193	288	410
250	16·9	26·8	40·0	54·4	78·1	104·0	135	214	320	456
275	18·6	29·5	44·0	59·8	85·9	114·4	149	236	352	501
300	20·3	32·2	48·0	65·3	93·7	124·8	162	257	384	547
325	21·9	34·8	52·8	70·7	101·6	135·2	176	279	416	592
350	23·6	37·5	56·0	76·2	109·4	145·6	189	300	448	638
375	25·3	40·2	60·0	81·6	117·2	156·0	203	322	480	683
400	27·0	42·9	64·0	87·0	125·0	166·4	216	343	512	729
425	28·7	45·6	68·0	92·5	132·8	176·8	230	364	544	775
450	30·4	48·2	72·0	97·9	140·6	187·2	243	386	576	820
475	32·1	50·9	76·0	103·4	148·4	197·6	257	407	603	866
500	33·7	53·6	80·0	108·8	156·2	208·0	270	429	640	911

POWER THAT STEEL SHAFTING WILL TRANSMIT AT VARIOUS SPEEDS—*continued.*

Revolutions per Minute.	Diameter in Inches.									
	5	5½	6	6½	7	7½	8	9	10	12
	Horse-power Transmitted.									
50	125	166	216	275	343	422	512	729	1,000	1,728
60	150	200	259	330	412	506	614	875	1,200	2,074
70	175	233	302	385	480	591	717	1,021	1,400	2,419
80	200	266	346	439	549	675	819	1,166	1,600	2,765
90	225	299	389	494	617	759	922	1,312	1,800	3,110
100	250	333	432	549	686	844	1,024	1,458	2,000	3,456
110	275	366	475	604	755	928	1,126	1,604	2,200	3,802
120	300	399	518	659	823	1,012	1,229	1,750	2,400	4,147
130	325	433	562	714	892	1,097	1,331	1,895	2,600	4,493
140	350	466	605	769	960	1,181	1,434	2,041	2,800	4,838
150	375	499	648	824	1,029	1,265	1,536	2,187	3,000	5,184
160	400	532	691	879	1,097	1,350	1,638	2,333	3,200	5,530
170	425	566	734	934	1,166	1,434	1,741	2,479	3,400	5,875
180	450	599	778	989	1,235	1,519	1,843	2,624	3,600	6,221
190	475	632	821	1,044	1,303	1,603	1,945	2,770	3,800	6,566
200	500	665	864	1,099	1,372	1,687	2,048	2,916	4,000	6,912
225	563	749	972	1,236	1,543	1,898	2,304	3,280	4,500	7,760
250	625	832	1,080	1,373	1,715	2,109	2,560	3,645	5,000	8,640
275	688	915	1,188	1,510	1,886	2,320	2,816	4,009	5,500	9,504
300	750	998	1,296	1,648	2,058	2,531	3,072	4,374	6,000	10,368
325	813	1,081	1,404	1,785	2,229	2,742	3,328	4,739	6,500	11,232
350	875	1,165	1,512	1,922	2,401	2,953	3,584	5,103	7,000	12,096
375	938	1,248	1,620	2,060	2,572	3,164	3,840	5,468	7,500	12,960
400	1,000	1,331	1,728	2,197	2,741	3,374	4,096	5,832	8,000	13,824
425	1,063	1,414	1,836	2,334	2,915	3,585	4,352	6,197	8,500	14,688
450	1,125	1,497	1,944	2,472	3,087	3,796	4,608	6,562	9,000	15,552
475	1,188	1,580	2,052	2,609	3,258	4,007	4,864	6,926	9,500	16,416
500	1,250	1,664	2,160	2,746	3,430	4,218	5,120	7,290	10,000	17,280

NOTE.

The faster a shaft revolves under the same horse-power, the less is the torsional strain upon it.

Hollow Shafts.

Hollow shafts resist torsion better than solid ones of the same area of metal.

If D = outer diameter;

d = inner diameter,

then,

$$\text{Breaking torsion force, in lbs.} = \frac{(D^4 - d^4) \times \text{Constant}}{\text{Leverage in feet} \times D}.$$

Distance between Supports in Ordinary Shafts.

If d = diameter of shaft, in inches;

l = distance between supports, in feet,

then,

$$l = 5\sqrt[3]{d^2},$$

where no power is taken off between the supports.

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NUTS,
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F. 1077

FRANCIS'S TABLE, WHERE POWER IS TAKEN OFF BETWEEN SUPPORTS.

Diameter of Shaft, in Inches.	Distance between Bearings, in Feet.	
	Wrought-iron Shafts.	Steel Shafts.
2	15·46	15·89
3	17·70	18·19
4	19·48	20·02
5	20·99	21·57
6	22·30	22·92
7	23·48	24·13
8	24·55	25·23
9	25·53	26·24

Where power is taken off by rigger between supports, each case should be separately considered; 7 to 12 feet is usual.

Speed of Shafting.

Shafting for metal-cutting machines . . . 200 revolutions per minute.
„ for wood-working . . . . . 250 „ „
„ for cotton and woollen mills . . . . 300 „ „

Hollow shafting has been run at 600 revolutions per minute.

DIAMETER OF AXLE, CRANK-PIN, AND SHAFT.

Diameter of Axle.

d = diameter in inches, in the bearing; and the length of the bearing, $1{\cdot}5d$.
W = weight in pounds, acting in the bearing.

Waterwheels.	*Common Machinery in good order.*
$d = \frac{\sqrt{W}}{18}$, for cast iron.	$d = \frac{\sqrt{W}}{24}$, for cast iron.
$d = \frac{\sqrt{W}}{21}$, for wrought iron.	$d = \frac{\sqrt{W}}{28}$, for wrought iron.
$d = \frac{\sqrt{W}}{26}$, for steel.	$d = \frac{\sqrt{W}}{34}$, for steel.

EXAMPLE.—A waterwheel weighs 58,680 lbs., and is supported in two bearings. Required the diameter of the wheel axles. The weight acting in each bearing will be $\frac{58680}{2} = 29{,}340$ lbs., and diameter $d = \frac{\sqrt{29340}}{21} = 8{\cdot}15$ inches of wrought iron.

Diameter of Crank-pin.

$d = \sqrt{\frac{F}{1200}}$, for wrought iron. $d = \sqrt{\frac{F}{1570}}$, for steel.

Length of pin $= \frac{3d}{2}$.

EXAMPLE.—The pressure on pin = 27,000 lbs. Required the diameter and length of pin of wrought iron.

$$d = \sqrt{\frac{27000}{1200}} = 4\tfrac{3}{4} \text{ inches.}$$

Length of pin $= 4\frac{3}{4} \times \frac{3}{2} = 7$ inches.

Diameter of Shaft.

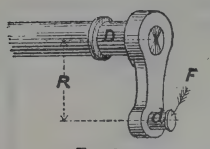


FIG. 1.

D = diameter of shaft, in inches. R = Radius of crank, in feet.
F = force from the steam piston, in pounds.

$$D = \sqrt[3]{\frac{FR}{80}}, \qquad F = \frac{D^3 \times 80}{R}, \qquad \text{for wrought iron.}$$

$$D = \sqrt[3]{\frac{FR}{120}}, \qquad F = \frac{D^3 \times 120}{R}, \qquad \text{for steel.}$$

EXAMPLE.—The force on the piston in a steam-engine is F=45,600 lbs., applied direct on a crank of R = 3 feet radius. Required the diameter of the shaft, the latter being of wrought iron.

$$D = \sqrt[3]{\frac{45600 \times 3}{80}} = 11{\cdot}96 \text{ inches.}$$

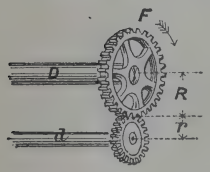


FIG. 2.

$$D = \sqrt[3]{\frac{H}{n} \times 125}, \qquad \text{for wrought iron.}$$

$$D = \sqrt[3]{\frac{H}{n} \times 83{\cdot}3}, \qquad \text{for steel.}$$

H = the horse-power transmitted. n = the number of revolutions per minute.

$$D : d :: \sqrt[3]{R} : \sqrt[3]{r}, \quad \text{or,} \quad d = D\sqrt[3]{\frac{r}{R}}.$$

EXAMPLE.—A cog-wheel of R = 6·5 feet radius is to gear with a pinion of r = 1·25 feet radius, and to transmit an effect of 231 horses (H) with 42 revolutions per minute (n). Required the diameter of the wheel and pinion shafts. The force F is acting uniformly at the periphery.

$$\text{Diameter of wheel-shaft } D = \sqrt[3]{\frac{231}{42} \times 125} = 8{\cdot}8 \text{ inches.}$$

$$\text{Diameter of pinion-shaft } d = 8{\cdot}8\sqrt[3]{\frac{1{\cdot}25}{6{\cdot}5}} = 5{\cdot}1 \text{ inches.}$$

TO DETERMINE WHAT DIAMETER OF STEEL SHAFT WILL MAINTAIN THE TWISTING MOMENT BELOW A REQUIRED LIMIT.

δ = twist or deflection in degrees; F = twisting force in lbs., applied at pin d (Fig. 1) at right angles to crank; R = radius of twisting force in inches; L = length between arms of twist in inches; D = diameter of shaft in inches, then

$$D = 0{\cdot}08347\sqrt[4]{\frac{FRL}{\delta}} = K\sqrt[4]{FRL}$$

TABLE OF VALUES OF δ AND K.

$$\left(K = \frac{0{\cdot}08347}{\sqrt[4]{\delta}}\right)$$

δ	K.	δ	K.	δ	K.
0·10	0·1484	1·50	0·0755	5·00	0·0553
0·15	0·1341	2·00	0·0703	5·50	0·0545
0·20	0·1248	2·50	0·0665	6·00	0·0534
0·25	0·1180	3·00	0·0635	7·00	0·0514
0·50	0·0991	3·50	0·0612	8·00	0·0497
0·75	0·0896	4·00	0·0591	9·00	0·0482
1·00	0·0835	4·50	0·0574	10·00	0·0470

Example—

What diameter, D, of steel shaft would be required to bring the twisting moment below 0·25 degree (δ), the values of D, F, R, and L being

$$\delta = 0{\cdot}25\ ;\ F = 4{,}000 \text{ lbs.}\ ;\ R = 6 \text{ ins.}\ ;\ L = 48 \text{ ins.}$$

From table, K (corresponding to $\delta = 0{\cdot}25$) = 0·1180, therefore

$$D = 0{\cdot}1180 \sqrt[4]{4{,}000 \times 6 \times 48} = 3{\cdot}87 \text{ ins.}$$

Twisting angle of Steel Shafts.

To find the angle of twist or deflection, δ, of a given shaft, the value of K is found from

$$K = \frac{D}{\sqrt[4]{FRL}}$$

and the corresponding value of δ in the table gives the required result.

Standard Conditions and Rules for the Shafts of Marine Steam Engines.

(Issued by the Board of Trade* and published by His Majesty's Stationery Office, Imperial House, Kingsway. Price 1*d*. net.)

(*Abstract.*)

MATERIALS FOR SHAFTING.

Ingot steel for shafts shall be generally of 28 to 32 tons per sq. n. standard quality and be such that after forging or rolling the sum of its tensile strength, in tons per sq. in., and percentage of elongation, measured on the British Engineering Standards Association test-pieces C, D, or E, shall be not less than 57.

The webs of built crank shafts may be forged or rolled from ingot steel, wrought iron, or scrap mild steel, or they may be steel castings.

The material of cast steel webs generally must be such that the tensile strength does not exceed 32 tons per sq. in., and the sum of the tensile strength in tons per sq. in. and the percentage of elongation measured on the British Engineering Standards Association test-pieces C, D, or E, shall be not less than 50.

RULES FOR THE DIAMETERS OF SHAFTS.

Turbine-driven Shafting.

1. Turbine-driven installations shall have shafts the diameters of which are not less than is given by the following rule:—

$$d = \sqrt[3]{\frac{\text{S.H.P.}}{R}} \times F.$$

Where *d* is the diameter of the intermediate shaft in inches;

S.H.P. is the maximum designed shaft horse-power;

R is the number of revolutions per minute at that power;

F is (1) 64 for ocean-going and home-trade ships, such as would require a No. 1 or No. 2 Certificate of the Board of Trade if carrying passengers. (2) 58 for ships making short coasting voyages or working on estuaries, rivers, lochs or lakes, such as would require a No. 3, No. 4, or No. 5 Certificate of the Board of Trade if carrying passengers.

* Accepted by Board of Trade, Lloyd's Register, British Corporation, and Bureau Véritas, at Conference for the Unification of Rules for the Construction and Dimensions of Shafting for Marine Steam Engines, April 16, 1923.

Shafting of Reciprocating Engines.

2. Reciprocating steam-engine installations shall have shafts the diameters of which are not less than are given by the following rules :—

$$d = \sqrt[3]{\frac{D^2 \times S \times p}{f(r+2)}},$$

Where d is the diameter of the intermediate shaft in inches ;

D is the diameter in inches of the low-pressure cylinder, or the equivalent diameter where two or more low-pressure cylinders are used ;

S is the stroke of the piston in inches ;

p is the working pressure in the boiler in lbs. per sq. in. ;

r is the ratio of the swept volume of the low-pressure cylinder or cylinders to that of the high-pressure cylinder or cylinders ;

f is a coefficient from the following table, and has two values for each type of engine depending upon the nature of the service as defined in the foregoing paragraph.

Type of compound, triple or quadruple reciprocating engine.	Service of Ship.	
	No. 1 (1).	No. 1 (2).
(*a*) 2 cranks at 90°	1900	2100
(*b*) 2 cranks at 180°	1350	1500
(*c*) 3 cranks at 120°	2150	2400
(*d*) 4 cranks balanced	2150	2400
(*e*) 4 cranks at 90°	2100	2300

(2) Crank shafts shall be in diameter not less than $1{\cdot}05 \times d$.

(3) Thrust shafts transmitting torque shall be at the collars not less in diameter than $1{\cdot}05 \times d$. Thrust shafts may be tapered down outside the collars to the diameter d required for the intermediate shaft.

(4) Tube shafts shall be in diameter not less than $1{\cdot}05 \times d$, and any part of a tube shaft within the tube which may be exposed to sea-water shall be in diameter not less than $1{\cdot}075 \times d$.

(5) Wheel shafts of geared turbine-driven installations shall be in diameter not less than $1{\cdot}05 \times d$, but where there is only one pinion gearing into the wheel, or where there are two pinions which are set to subtend an angle at the centre of the shaft of less than 120° the diameter of the wheel shaft at the wheel and the adjacent journals shall be not less than $1{\cdot}1 \times d$. Abaft the journals the shaft may be tapered to $1{\cdot}05 \times d$.

Tail Shafts.

3. Tail shafts shall be not less in diameter than is given in the following rule :—

$$d_t = d + \frac{P}{K},$$

where,

d_t = diameter of tail shaft in inches ;

d = diameter of intermediate shaft required ;

P = diameter of screw propeller in inches ;

K = 144 where a continuous liner is fitted ;

K = 100 where a continuous liner is not fitted.

Tail shafts which run in stern tubes may have the end forward of the stern gland tapered down to a diameter at the coupling flange equal to $1{\cdot}05 \times d$.

Crank Webs of Built Shafts.

1. Crank webs of built shafts should have dimensions not less than the following :—

$$h = 0{\cdot}625 \times d$$

$$t = \sqrt{\frac{0{\cdot}12 \times d^3 c}{h}}$$

where,

d_c = diameter of crank shaft in inches ;
h = thickness of web measured parallel to the axis ;
t = thickness of metal around the eye-holes measured radially.

The Rules also relate to ' Bronze Liners on Shafts ' and ' Coupling Flanges and Bolts.'

British Standard Specification for Shafting for Marine Purposes.

See No. 3021—1922.

Flexible Couplings.

Flexible couplings are now being used in all cases where it is not possible to ensure shafting being exactly in line.

Experiments over a large number of factories and works have shown that the power absorbed by shafting forms quite a large percentage of that generated. This loss is chiefly due to malalignment, and can be saved by introducing suitable flexible couplings ; the same remark also applies in the case of two machines whose shafts are coupled together, and apart, of course, from the actual loss of power sustained, trouble and expense is entailed due to the unnecessary stresses in shafting and bearings.

The flexible shaft coupling shown by fig. 3 is designed generally to absorb shocks and stresses, and for taking up malalignment and wear in bearings.

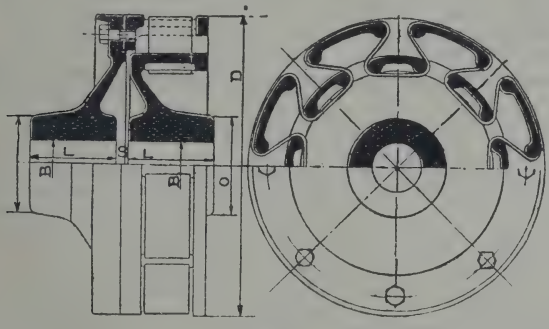


FIG. 3.

The coupling, fig. 3, consists of four parts :

(*a*) The outer disc, which has a suitable boss to take the shaft of the driving member.

(*b*) The belt ring, which is secured to the outer disc.

(*c*) The inner half, which has a suitable boss for taking the shaft of the driven member.

(*d*) A special cotton belt, which passes alternately around the lugs on the inner half and on the belt ring, securing together the two halves of the coupling.

The outer disc can be taken apart without removing the belt. A special advantage of the arrangement is that one shaft is electrically insulated from the other. The coupling, however, is not suitable for reversing drives.

Among the many applications of this type of coupling may be mentioned the following:

For generators driven by steam, gas, oil, and petrol engines, or motors; for motor-driven centrifugal fans; for direct connected motor-driven shafting in textile and other mills; for motor-driven rolling mills; for direct connection between motors and machine tools, and for connecting one length of shafting with another.

TABLE OF PARTICULARS OF FLEXIBLE SHAFT COUPLINGS.

Outside Dia.	Capacity B.H.P. R.P.M.	Max. Safe Speed in R.P.M.	Bore Diameter.		Boss Diameter.		Boss Length.	Clearance.	Overall Length.
			Max.	Min.	Max.	Min.			
D.			B.	B.	O.	O.	I.	S.	
Inches.			Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
8	0·01	1700	2	1	3½	3	2	3/4	4½
10	0·02	1350	2¼	1⅛	4	3	2½	1/4	5¾
11⅜	0·03	1160	2½	1¼	4½	3½	3	1/4	6¾
13¾	0·05	1000	2¾	1⅜	5¼	4	3½	1/4	7¾
15¾	0·075	870	3	1½	5½	4¼	4	1/4	8¾
17¾	0·10	770	3¼	1⅝	6	5	4½	1/4	9½
19¾	0·15	700	3½	2	6¾	5½	5	1/4	10½
21¾	0·27	630	4¼	2⅛	7¼	6	5½	1/4	11⅝
23⅛	0·46	580	4¾	2⅜	9	7¼	6	1¼	13¼
25½	0·60	540	5	3	9	7½	6½	1¼	14¼
27½	0·75	500	5¼	3¼	9½	8	7	1¼	15¼
31½	1·12	435	6	3½	10	8½	8¼	1¼	17¾
35	1·60	390	6¾	4¼	11	9½	9½	1¼	20¼
39	2·13	350	7¼	5¼	12	10	10¾	1½	23
43	2·70	320	8	5½	14	11	11¼	1½	24
47	3·80	290	8¼	6	14½	12	12	1½	25½
55	5·25	250	9⅛	7	17½	16½	13	2	28
63	8·0	220	10⅝	8	21½	19	14	2	30
71	10·0	190	12	9	23	20½	15	2	32

SECTION XX

PART V

SPRINGS.

HELICAL.

If r = mean radius of spring, in inches, measured from axis to centre of wire; d = diameter, in inches, of wire, if *round* in section; h and b = depth and breadth respectively, in inches, of wire, if *rectangular*; b = breadth and depth, if *square*; n = number of coils of which spring consists; c = coefficient or modulus of transverse elasticity of wire, in lbs. per square inch; W = any load, in lbs., not exceeding the greatest safe load; Δ = corresponding extension or compression, in inches; W_s = greatest safe *steady* load, in lbs.; Δ_s = greatest safe corresponding extension or compression, in inches; f = greatest safe shearing stress per square inch, in lbs.; then

$$\Delta = \frac{Wnr^3}{cd^4}64, \quad \text{or,} \quad W = \frac{\Delta cd^4}{64nr^3}, \quad \text{for } \textit{round} \text{ wire}$$

$$\Delta = \frac{Wnr^3}{c\frac{b^3h^3}{b^2+h^2}}6\pi, \quad \text{or,} \quad W = \frac{\Delta c\frac{b^3h^3}{b^2+h^2}}{6\pi nr^3} \quad \text{for } \textit{rectangular} \text{ wire;}$$

$$\Delta = \frac{Wnr^3}{cb^4}12\pi, \quad \text{or,} \quad W = \frac{\Delta cb^4}{12\pi nr^3}, \quad \text{for } \textit{square} \text{ wire;}$$

$$\Delta_s = \frac{fnr^2}{cd}4\pi, \quad \text{and,} \quad W_s = \frac{fd^3\pi}{r16}, \quad \text{for } \textit{round} \text{ wire;}$$

$$\Delta_s = \frac{fnr^2}{c\frac{bh}{\sqrt{b^2+h^2}}}\left(\frac{\pi}{2}\right)^3\frac{3}{\sqrt{2}}, \text{ and,} \quad W_s = f\frac{\frac{b^3h^3}{\sqrt{b^2+h^2}}\left(\frac{\pi}{4}\right)^2\frac{1}{\sqrt{2}}}{r}, \quad \text{for } \textit{rectangular} \text{ wire}$$

$$\Delta_s = \frac{fnr^2}{cb}\left(\frac{\pi}{2}\right)^3 3, \quad \text{and,} \quad W_s = \frac{fb^3}{r}\left(\frac{\pi}{4}\right)^2\frac{1}{2}, \quad \text{for } \textit{square} \text{ wire.}$$

$$\text{Greatest safe sudden load} = \frac{W_s}{2}; \qquad \text{Resilience} = \frac{W_s\Delta_s}{2}$$

$$\frac{1}{64} = \cdot0156; \quad 6\pi = 18\cdot85; \quad \frac{1}{6\pi} = \cdot0531; \quad 12\pi = 37\cdot70; \quad \frac{1}{12\pi} = \cdot0265; \quad 4\pi = 12\cdot57;$$

$$\frac{\pi}{16} = \cdot196; \quad \left(\frac{\pi}{2}\right)^3\frac{3}{\sqrt{2}} = 8\cdot22; \quad \left(\frac{\pi}{4}\right)^2\frac{1}{\sqrt{2}} = \cdot436; \quad \left(\frac{\pi}{2}\right)^3 = 11\cdot63; \quad \left(\frac{\pi}{4}\right)^2\frac{1}{2} = \cdot308.$$

The value of c for steel in lbs. per square inch may be taken as 16,000,000. The greatest safe value (f) which is certain not to impair the elasticity of the spring by frequent repetition may be taken at 50,000.

From the formula $W_s = \frac{\cdot196fd^3}{r}$, if $f = 50{,}000$, we get,

$$d = \sqrt[3]{\frac{W_s r}{\cdot196f}} = \sqrt[3]{\frac{W_s 2r}{\cdot392f}} = \sqrt[3]{\frac{W_s 2r}{19{,}600}}; \text{ Board of Trade rule, } d = \sqrt[3]{\frac{W_s 2r}{8{,}000}}$$

A spring with its mean diameter small as compared with the size of the bar will allow a higher stress with less set than one of larger mean diameter; size of bar being the same, a spring of small diameter may safely stand higher stress than one of large diameter; springs of too small diameter compared with size of bar are so injured in coiling as to weaken the steel; the ratio of mean diameter of spring to diameter of bar should never be less than 3. For a good grade of steel the following values have been found safe:

Ratio of Mean Diameter to Diameter of Bar.	Safe Torsional Stress.	
3 .	112,000	Bars less than $\frac{3}{4}$ in.
8 .	85,000	in diameter.
3 .	110,000	Bars $\frac{7}{16}$ in. to $\frac{3}{4}$ in
8 .	80,000	in diameter.

Ratio of Mean Diameter to Diameter of Bar.	Safe Torsional Stress.	
3 .	105,000	Bars $\frac{13}{16}$ in. to $1\frac{1}{4}$ in.
8 .	75,000	in diameter.

For extension springs the value of stress is only two-thirds these values.

(*C. H. Benjamin and R. A. French.*)

Steel Helical Springs—Round Wire.

(Contributed by R. A. Sturgeon, A.M.Inst.C.E.)

Table of Safe Loads and Scales.

The stresses from which the safe loads are calculated are given for each size of wire. The scale—i.e. the ratio of load to deflection produced—is based on a single coil spring. By dividing the figure given in the table by the number of coils in the spring, the load required to extend or compress the spring 1 in. is obtained. The value of G is assumed to be 12,000,000 lbs. per sq. in.

Mean Diam. of Coil. Ins.	Safe Load. Lbs.	Scale. Lbs. per In.
16 Gauge—0·064 in. (=$\frac{1}{16}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{8}$	19·2	477
$\frac{7}{16}$	16·5	301
$\frac{1}{2}$	14·4	201
$\frac{9}{16}$	12·8	141
$\frac{5}{8}$	11·5	103
$\frac{3}{4}$	9·6	59·6
$\frac{7}{8}$	8·2	37·6
1	7·2	25·2
$1\frac{1}{8}$	6·4	17·7
$1\frac{1}{4}$	5·8	12·9
$1\frac{3}{8}$	5·2	9·7
$1\frac{1}{2}$	4·8	7·5
$1\frac{3}{4}$	4·1	4·7
2	3·6	3·1
15 Gauge—0·072 in. (=$\frac{5}{64}$ in.−) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{8}$	27·4	764
$\frac{7}{16}$	23·5	481
$\frac{1}{2}$	20·5	322
$\frac{9}{16}$	18·2	226
$\frac{5}{8}$	16·4	165
$\frac{3}{4}$	13·7	95·6
$\frac{7}{8}$	11·7	60·1
1	10·3	40·3
$1\frac{1}{8}$	9·1	28·3
$1\frac{1}{4}$	8·2	20·6
$1\frac{3}{8}$	7·5	15·5
$1\frac{1}{2}$	6·8	11·9
$1\frac{3}{4}$	5·9	7·5
2	5·1	5·0
14 Gauge—0·08 in. (=$\frac{5}{64}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{8}$	37·5	1,165
$\frac{7}{16}$	32·2	734
$\frac{1}{2}$	28·2	491
$\frac{9}{16}$	25·0	345
$\frac{5}{8}$	22·5	252
$\frac{3}{4}$	18·8	146
$\frac{7}{8}$	16·1	91·7
1	14·1	61·4
$1\frac{1}{8}$	12·5	43·1
$1\frac{1}{4}$	11·2	31·5
$1\frac{3}{8}$	10·2	23·6
$1\frac{1}{2}$	9·4	18·2
$1\frac{3}{4}$	8·0	11·5
2	7·0	7·7
$2\frac{1}{4}$	6·2	5·4
$2\frac{1}{2}$	5·6	3·9
13 Gauge—0·092 in. (=$\frac{3}{32}$ in.) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{8}$	57	2,038
$\frac{7}{16}$	49·0	1,283
$\frac{1}{2}$	42·8	860
$\frac{9}{16}$	38·1	603
$\frac{5}{8}$	34·3	440
$\frac{3}{4}$	28·5	255
$\frac{7}{8}$	24·5	160
1	21·4	107
$1\frac{1}{8}$	19·0	75·5
$1\frac{1}{4}$	17·1	55·0
$1\frac{3}{8}$	15·6	41·3
$1\frac{1}{2}$	14·3	31·8
$1\frac{3}{4}$	12·2	20·1
2	10·7	13·4
$2\frac{1}{4}$	9·5	9·4
$2\frac{1}{2}$	8·6	6·9
12 Gauge—0·104 in. (=$\frac{7}{64}$ in.−) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{8}$	82	3,327
$\frac{7}{16}$	71	2,096
$\frac{1}{2}$	62	1,404
$\frac{9}{16}$	55	986
$\frac{5}{8}$	49·5	719
$\frac{3}{4}$	41·2	416
$\frac{7}{8}$	35·3	262
1	30·9	175
$1\frac{1}{8}$	27·5	123
$1\frac{1}{4}$	24·7	89·8
$1\frac{3}{8}$	22·5	67·5
$1\frac{1}{2}$	20·6	52·0
$1\frac{3}{4}$	17·7	32·7
2	15·5	21·9
$2\frac{1}{4}$	13·7	15·4
$2\frac{1}{2}$	12·4	11·2
11 Gauge—0·116 in. (=$\frac{7}{64}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{1}{2}$	86	2,173
$\frac{9}{16}$	76	1,526
$\frac{5}{8}$	69	1,113
$\frac{3}{4}$	57	644
$\frac{7}{8}$	49·1	405
1	42·9	272
$1\frac{1}{8}$	38·2	191
$1\frac{1}{4}$	34·3	139
$1\frac{3}{8}$	31·2	104
$1\frac{1}{2}$	28·6	80·5
$1\frac{3}{4}$	24·5	50·7
2	21·5	33·9
$2\frac{1}{4}$	19·1	23·8
$2\frac{1}{2}$	17·2	17·4
3	14·3	10·1
10 Gauge—0·128 in. (=$\frac{1}{8}$ in.) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{1}{2}$	115	3,221
$\frac{9}{16}$	102	2,262
$\frac{5}{8}$	92	1,649
$\frac{3}{4}$	77	954
$\frac{7}{8}$	66	601
1	58	403
$1\frac{1}{8}$	51	283
$1\frac{1}{4}$	46·1	206
$1\frac{3}{8}$	41·9	155
$1\frac{1}{2}$	38·4	119
$1\frac{3}{4}$	32·9	75·1
2	28·8	50·3
$2\frac{1}{4}$	25·6	35·3
$2\frac{1}{2}$	23·1	25·8
3	19·1	14·9
9 Gauge—0·144 in. (=$\frac{9}{64}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{1}{2}$	164	5,160
$\frac{9}{16}$	146	3,623
$\frac{5}{8}$	131	2,642
$\frac{3}{4}$	109	1,529
$\frac{7}{8}$	94	963
1	82	645
$1\frac{1}{8}$	73	453
$1\frac{1}{4}$	66	330
$1\frac{3}{8}$	60	248
$1\frac{1}{2}$	55	191
$1\frac{3}{4}$	47·0	120
2	41·0	80·6
$2\frac{1}{4}$	36·5	56·6
$2\frac{1}{2}$	32·8	41·3
3	27·3	23·9

STEEL HELICAL SPRINGS—ROUND WIRE—*continued.*

Mean Diam. of Coil. Ins.	Safe Load. Lbs.	Scale. Lbs. per In.
8 Gauge—0·16 in. (=$\frac{5}{32}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{1}{2}$	225	7,863
$\frac{9}{16}$	200	5,521
$\frac{5}{8}$	180	4,027
$\frac{3}{4}$	150	2,330
$\frac{7}{8}$	129	1,467
1	113	983
$1\frac{1}{8}$	100	690
$1\frac{1}{4}$	90	503
$1\frac{3}{8}$	82	378
$1\frac{1}{2}$	75	291
$1\frac{3}{4}$	64	183
2	56	123
$2\frac{1}{2}$	50	86·2
$2\frac{1}{2}$	45	62·9
3	37·5	36·4
7 Gauge—0·176 in. (=$\frac{11}{64}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{5}{8}$	240	5,896
$\frac{9}{16}$	200	3,412
$\frac{7}{8}$	171	2,148
1	150	1,439
$1\frac{1}{8}$	133	1,011
$1\frac{1}{4}$	120	737
$1\frac{3}{8}$	109	554
$1\frac{1}{2}$	100	426
$1\frac{3}{4}$	86	268
2	75	180
$2\frac{1}{4}$	66	126
$2\frac{1}{2}$	60	92·1
3	50	53·3
$3\frac{1}{2}$	42·8	33·6
4	37·5	22·5
6 Gauge—0·192 in. (=$\frac{3}{16}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{5}{8}$	311	8,351
$\frac{11}{16}$	259	4,833
$\frac{7}{8}$	222	3,043
1	195	2,038
$1\frac{1}{8}$	173	1,432
$1\frac{1}{4}$	156	1,044
$1\frac{3}{8}$	142	784
$1\frac{1}{2}$	130	604
$1\frac{3}{4}$	111	380
2	97	255
$2\frac{1}{4}$	86	179
$2\frac{1}{2}$	78	130
3	65	75·5
$3\frac{1}{2}$	56	47·5
4	48·6	31·8
5 Gauge—0·212 in. ($\frac{7}{32}$ in.+) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{5}{8}$	419	12,413
$\frac{11}{16}$	349	7,183
$\frac{7}{8}$	300	4,523
1	262	3,030
$1\frac{1}{8}$	233	2,128
$1\frac{1}{4}$	210	1,551
$1\frac{3}{8}$	191	1,165
$1\frac{1}{2}$	175	898
$1\frac{3}{4}$	150	565
2	131	379
$2\frac{1}{4}$	116	266
$2\frac{1}{2}$	105	194
3	87	112
$3\frac{1}{2}$	75	70·7
4	65	47·3
4 Gauge—0·232 in. (=$\frac{15}{64}$ in.) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{5}{8}$	549	17,801
$\frac{3}{4}$	458	10,302
$\frac{7}{8}$	392	6,487
1	343	4,345
$1\frac{1}{8}$	305	3,052
$1\frac{1}{4}$	275	2,225
$1\frac{3}{8}$	250	1,675
$1\frac{1}{2}$	229	1,287
$1\frac{3}{4}$	196	813
2	172	543
$2\frac{1}{4}$	152	381
$2\frac{1}{2}$	137	278
3	114	161
$3\frac{1}{2}$	98	101
3 Gauge—0·252 in. (=$\frac{1}{4}$ in.) diam. Safe Stress—70,000 lbs. per sq. in.		
$\frac{3}{4}$	587	14,341
$\frac{7}{8}$	503	9,030
1	440	6,049
$1\frac{1}{8}$	391	4,249
$1\frac{1}{4}$	352	3,097
$1\frac{3}{8}$	320	2,327
$1\frac{1}{2}$	293	1,792
$1\frac{3}{4}$	251	1,129
2	220	756
$2\frac{1}{4}$	195	531
$2\frac{1}{2}$	176	387
3	147	224
$3\frac{1}{2}$	126	141
4	110	94·5
2 Gauge—0·276 in. (=$\frac{9}{32}$ in.−) diam. Safe Stress—67,900 lbs. per sq. in.		
$\frac{3}{4}$	746	20,636
$\frac{7}{8}$	639	12,993
1	559	8,704
$1\frac{1}{8}$	497	6,113
$1\frac{1}{4}$	447	4,457
$1\frac{3}{8}$	407	3,343
$1\frac{1}{2}$	373	2,579
$1\frac{3}{4}$	319	1,624
2	279	1,088
$2\frac{1}{4}$	248	764
$2\frac{1}{2}$	223	557
3	186	322
$3\frac{1}{2}$	160	203
4	140	136
1 Gauge—0·3 in. (=$\frac{19}{64}$ in.+) diam. Safe Stress—66,000 lbs. per sq. in.		
$\frac{7}{8}$	799	18,137
1	699	12,150
$1\frac{1}{8}$	622	8,534
$1\frac{1}{4}$	559	6,221
$1\frac{3}{8}$	509	4,674
$1\frac{1}{2}$	466	3,600
$1\frac{3}{4}$	400	2,267
2	349	1,519
$2\frac{1}{4}$	310	1,067
$2\frac{1}{2}$	279	778
3	233	450
$3\frac{1}{2}$	200	283
4	175	190
$4\frac{1}{2}$	155	133
0 Gauge—0·324 in. (=$\frac{21}{64}$ in.−) diam. Safe Stress—64,100 lbs. per sq. in.		
1	860	16,530
$1\frac{1}{4}$	765	11,610
$1\frac{1}{4}$	688	8,463
$1\frac{3}{8}$	626	6,359
$1\frac{1}{2}$	574	4,898
$1\frac{3}{4}$	492	3,084
2	430	2,063
$2\frac{1}{4}$	382	1,451
$2\frac{1}{2}$	344	1,058
3	287	612
$3\frac{1}{2}$	246	386
4	215	258
$4\frac{1}{2}$	191	181
5	172	132
$5\frac{1}{2}$	156	99
00 Gauge—0·348 in. (=$\frac{11}{32}$ in.+) diam. Safe Stress—62,200 lbs. per sq. in.		
1	1,033	22,000
$1\frac{1}{8}$	918	15,451
$1\frac{1}{4}$	826	11,264
$1\frac{3}{8}$	751	8,462
$1\frac{1}{2}$	688	6,518
$1\frac{3}{4}$	590	4,105
2	516	2,750
$2\frac{1}{4}$	459	1,931
$2\frac{1}{2}$	413	1,408
3	344	815
$3\frac{1}{2}$	295	513
4	258	344
$4\frac{1}{2}$	229	241
5	206	176
$5\frac{1}{2}$	188	132
000 Gauge—0·372 in. (=$\frac{3}{8}$ in.) diam. Safe Stress—60,000 lbs. per sq. in.		
1	1,215	28,725
$1\frac{1}{8}$	1,080	20,175
$1\frac{1}{4}$	972	14,721
$1\frac{3}{8}$	883	11,050
$1\frac{1}{2}$	810	8,511
$1\frac{3}{4}$	694	5,360
2	607	3,591
$2\frac{1}{4}$	540	2,522
$2\frac{1}{2}$	486	1,839
3	405	1,064
$3\frac{1}{2}$	347	670
4	304	449
$4\frac{1}{2}$	270	315
5	243	230
$5\frac{1}{2}$	221	173
0000 Gauge—0·4 in. (=$\frac{13}{32}$ in.−) diam. Safe Stress—58,000 lbs. per sq. in.		
$1\frac{1}{8}$	1,297	26,970
$1\frac{1}{4}$	1,167	19,661
$1\frac{3}{8}$	1,061	14,772
$1\frac{1}{2}$	973	11,378
$1\frac{3}{4}$	834	7,165
2	730	4,800
$2\frac{1}{4}$	648	3,371
$2\frac{1}{2}$	584	2,458
3	486	1,422
$3\frac{1}{2}$	417	896
4	365	600
$4\frac{1}{2}$	324	421
5	292	307
$5\frac{1}{2}$	265	231
6	243	178

STEEL HELICAL SPRINGS—ROUND WIRE—*continued.*

Mean Diam. of Coil. Ins.	Safe Load. Lbs.	Scale. Lbs. per In.	Mean Diam. of Coil. Ins.	Safe Load. Lbs.	Scale. Lbs. per In.	Mean Diam. of Coil. Ins.	Safe Load. Lbs.	Scale. Lbs. per In.
00000 Gauge—0·432 in. (= $\frac{7}{16}$ in.—) diam. Safe Stress—55,400 lbs. per sq. in.			000000 Gauge—0·464 in. (= $\frac{15}{32}$ in.—) diam. Safe Stress—53,700 lbs. per sq. in.			0000000 Gauge—0·5 in. (= $\frac{1}{2}$ in.) diam. Safe Stress—50,000 lbs. per sq. in.		
$1\frac{1}{8}$	1,559	36,692	$1\frac{1}{8}$	1,686	35,599	$1\frac{1}{8}$	1,782	36,063
$1\frac{1}{4}$	1,403	26,749	$1\frac{1}{4}$	1,533	26,746	$1\frac{1}{4}$	1,634	27,784
$1\frac{3}{8}$	1,275	20,096	$1\frac{3}{8}$	1,405	20,601	$1\frac{3}{8}$	1,400	17,493
$1\frac{1}{2}$	1,169	15,479	$1\frac{1}{2}$	1,204	12,973	2	1,225	11,179
$1\frac{5}{8}$	1,002	9,748	2	1,054	8,691	$2\frac{1}{4}$	1,089	8,230
2	877	6,530	$2\frac{1}{4}$	937	6,104	$2\frac{1}{2}$	980	6,000
$2\frac{1}{4}$	779	4,586	$2\frac{1}{2}$	843	4,450	3	817	3,472
$2\frac{1}{2}$	701	3,344	3	703	2,575	$3\frac{1}{2}$	700	2,187
3	584	1,935	$3\frac{1}{2}$	602	1,622	4	612	1,465
$3\frac{1}{2}$	501	1,218	4	527	1,086	$4\frac{1}{2}$	545	1,029
4	438	816	$4\frac{1}{2}$	468	763	5	490	750
$4\frac{1}{2}$	390	573	5	422	556	$5\frac{1}{2}$	445	564
5	351	418	$5\frac{1}{2}$	383	418	6	408	434
$5\frac{1}{2}$	319	314	6	351	322	7	350	273
6	290	242	7	301	203	8	306	183
			8	263	136	9	272	129

Multiplying Constants.

1. For compression springs with little variation of load multiply *Safe Loads* by 1·25.

2. For Springs, especially tension springs subjected to considerable variation of load suddenly applied, multiply *Safe Loads* by 0·67.

3. For Square Wire Springs where the Side equals the diameter given in the table—multiply

Safe Load by 1·06
Scale by 1·5

4. For Brass Wire Springs (round) multiply the Scale by 0·42. (Only for *Hard* Brass.)

Note.—In getting out Compression Springs allow for the fact that one coil at each end is idle. These two coils do not affect the Scale, but do affect the closed length.

PHOSPHOR-BRONZE SPRINGS.

The formulæ adapted for phosphor-bronze wire such as is manufactured by the Phosphor-Bronze Smelting Company, of Philadelphia, are as follows :—

$$W = \frac{7{,}000\ d^3}{D - d};\quad F = \frac{8\ P\ (D-d)^3}{6{,}200{,}000\ d^4}.$$

When P = W, then

$$F = \frac{7\ (D-d)^2}{775\ d}$$

W = carrying capacity, in lbs. ; d = diameter of wire, in ins. ; D = outside diameter of coil in ins. ; F = deflection in one coil, in ins. ; P = load, in lbs.

These formulæ for springs of all diameters, ranging from d = No. 10 B. & S. gauge to $d = \frac{5}{8}$ in., are accurate within 10 per cent. They apply equally well to tension springs wound closely without initial tension.

(*H. R. Gilson.*)

Clock Type Springs.

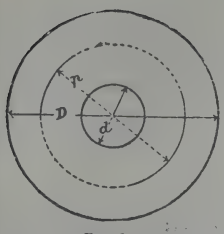


Fig. 1.

(1)

Let
d = diameter of innmost coil = spindle + t; D = diameter of outer coil = barrel − t; b = breadth of spring steel; t = thickness of spring steel; L = total length; I = moment of inertia of section; n = number of coils when unwound; n' = number of coils when wound; s = turns from unstrained state; E = coefficient of elasticity; a = total angle of wind; p = diameter of inner coil unwound, or of outer coil wound; M = moment of spring in inch pounds.

For D = 3d the following obtains :—

$$tn = \cdot1273\,D; \qquad d = 0{\cdot}33\,D;$$

$$t = \frac{\cdot0787\,D}{n'-n}; \qquad n = \frac{\cdot1273\,D}{t}; \qquad n' = \frac{\cdot206\,D}{t};$$

$$I = \frac{bt^3}{12}; \qquad L = \frac{\cdot3491\,D^2}{t}; \qquad \text{or} \quad L = n \times 2{\cdot}7416\,D; \qquad a = 2\pi s;$$

$$M = \frac{Ebt^3a}{12L}; \qquad D = \sqrt{\frac{\cdot000859\ M\ (n'-n)^4}{b\,s}}; \qquad p = \sqrt{\tfrac{1}{2}(D^2+d^2)}.$$

d = usually $30t$. For any spiral, $L = \frac{N}{2}(C+c)$, C and c being the circumferences of extreme coils. Maximum practicable, D = $160t$.

(2)

If l = length of spring; b = breadth of spring; t = thickness of spring: each in inches. E = Young's modulus of elasticity in lbs. per sq. in.; F = safe tensile strength of material in lbs. per sq. in.; N = number of turns spring is capable of taking. R = radius of box containing spring; r = radius of arbor: each in inches. T = maximum torque of spring.

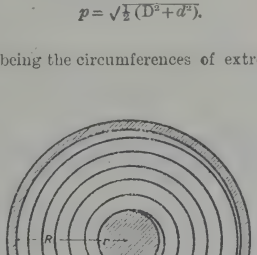


Fig. 2.

$$= \frac{F}{E} \cdot \frac{(R+r)(R+3r)}{R-r}; \qquad b = \frac{6E^2}{F^3} \cdot \frac{T(R-r)^2}{(R+r)^2(R+3r)^2};$$

$$l = \frac{\pi E}{4F} \cdot \frac{(R-r)^2}{R+r}; \qquad N = \frac{E}{4F} \cdot \frac{(R-r)^2}{(R+r)^2(R+3r)}.$$

For steel, E = 32,000,000; F = 224,000;

therefore

$$t = \cdot007\,\frac{(R+r)(R+3r)}{R-r}, \qquad b = \cdot547\,\frac{T(R-r)^2}{(R+r)^2(R+3r)^2};$$

$$= 112{\cdot}2\,\frac{(R-r)^2}{R+r}. \qquad N = 35{\cdot}7\,\frac{(R-r)^2}{(R+r)^2(R+3r)}.$$

(*J. St. Vincent Fletts*: '*The Engineer*', *July* 18, 1913).

VOLUTE FLAT SPRINGS.

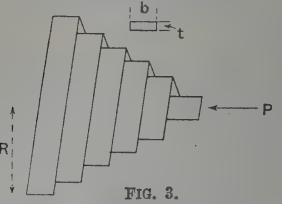


FIG. 3.

If P = carrying capacity of spring in lbs. = greatest safe *steady* load; S = safe stres sin bending, in lbs. per sq. in.; b = breadth of spring metal; t = thickness of spring metal; R = radius of spring at base; L = length of spring; G = torsional modulus of elasticity; S_s = safe shearing stress in lbs. per sq. in.; Δ = deflection of spring in ins.; C for various ratios of $\frac{b}{t}$ is as follows:

$\frac{b}{t}$	1	2	4	8
C	3·56	3·50	3·35	3·21

then,

$$P = \frac{2Sbt^2}{9R}; \quad \Delta = \tfrac{1}{2}CR^2L\frac{(b^2+t^2)P}{Gb^3t^3} = \tfrac{1}{2}CRL\frac{(b^2+t^2)S_s}{Gb^2h},$$

the torsional modulus of elasticity for steel being 12,600,000.*

See also 'Kent's Mechanical Engineers' Handbook.' (New York: John Wiley & Sons, Inc.; London: Chapman and Hall, Ltd.)

CONICAL ROUND WIRE SPRINGS.

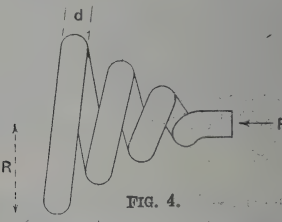


FIG. 4.

If d = diameter of wire; H = solid height of spring, assumed to equal $d \times$ number of coils, then,

$$P = \frac{\pi Sd^3}{16R} = \cdot 196\frac{S_s d^3}{R};$$

$$\Delta = \frac{16PLR^2}{\pi Gd^4} = \frac{RLS_s}{Gd};$$

$$L = 1\cdot 571\frac{H}{d}(D_1 + D_2).$$

If D_1 = mean diameter of largest coil; D_2 = mean diameter of smallest coil; p = average horizontal pitch of coils; d = diameter of wire,

then,

$$\Delta = 0\cdot 00332\frac{D_1^3 - D_2^3}{pd}; \quad P = 31{,}400\frac{d^3}{D_2},$$

the torsional modulus of elasticity for steel being 12,600,000.*

See also 'Machinery Handbook.' (New York: The Industrial Press; London: The Machinery Publishing Co., Ltd.)

* See Semi-Steel, p. 294.

Heat Treatment of Springs.

Experiments made by the Automatic and Electric Furnaces, Limited, show that springs heated to 800 degrees and afterwards tempered to 350 degrees give the best results. Overheating is shown to be detrimental; springs which are heated to 900 degrees and quenched, then reheated to 800 degrees and tempered at 350 degrees, show that the bad effects of overheating are not neutralised by reheating to 800 degrees and requenching. These effects can be neutralised by thoroughly annealing after the first overheating and then by reheating to the correct temperature and quenching.

A spring that has not been overheated, and that has been correctly tempered, can be loaded up to within 5 per cent. of its breaking point without showing any set after the first loading.

Handy Kink for Making Spiral Springs.

Take a piece of fibre about 2 by 6 ins. and bore four or five holes in one end, ranging in size from $\frac{1}{8}$ to $\frac{3}{4}$ in., as in fig. 5. Near the large holes bore several small ones, say $\frac{1}{16}$ in. in diameter. By using nails or pieces of small rod, any size spring can be made, according to the size of the holes.

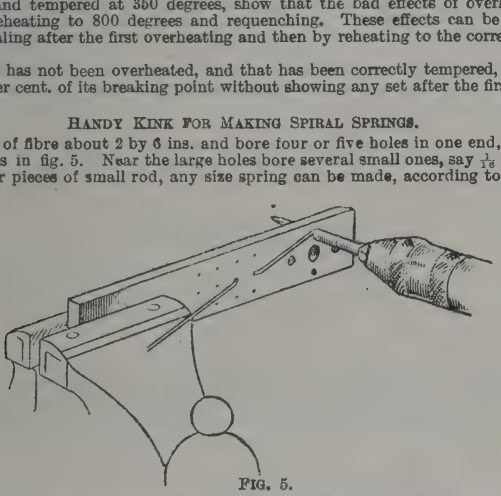


Fig. 5.

Put the block in a vice and thread the spring wire through the holes to give it tension. Take a nail the size of the spring you want to make, cut the head off, and put it into the hole where it fits best. Wrap a few turns of the wire around the nail, and grip the wire and nail in an ordinary brace, as in the figure. Then simply wind the wire around the nail until the desired length of spring is obtained. (*J. W. Fager*, '*Power*.')

Winding a Compression Spring.

Small music wire compression springs can be easily made by the following method. Having selected a mandrel A, fig. 6, the exact diameter of the interior of the desired spring, and wire B, obtain a piece of hard wood C and bore a hole in it in which the mandrel will fit, as shown in the illustration. Within $\frac{1}{32}$ inch from this hole bore another hole, the size of the wire to be used for the spring. Place the mandrel in the chuck of the lathe, slip the piece of wood over the mandrel, and insert the wire in the smaller hole, pushing it through until its end catches in the jaws of the chuck. Now press the piece of wood against the jaws of the chuck and commence winding the spring, first by pulling on the lathe belt, and then by throwing on the power when the coiling operation is well started. During the winding operation, the piece of wood should be pressed firmly against the coils so that the spring will have the appearance of being close wound. When the completed spring is removed from the mandrel, it will elongate or expand, thus forming a compression spring that is the size of the mandrel on which it is wound.

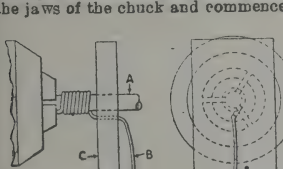


Fig. 6.

If, instead of leading the wire through a small hole as described, a notch is cut in the hole which fits over the mandrel, and the wire fed through this, the inside diameter of the spring will be smaller than the outside diameter of the mandrel. To make the spring a loose fit on the mandrel, the wire should be led through a small hole located at a greater distance from the large hole. If the spring is straightened out by pulling it off from the mandrel, the wire will be badly kinked, but if re-wound by the methods described, a good spring will be produced. To remove the strains in the wire spring that result from the winding operation, it should be heated carefully, if made from steel, until it is a uniform blue colour. If the spring is made of phosphor-bronze or brass wire, it should be covered with tallow or beeswax and heated until it smokes; this will remove the strains, so that it will maintain its form. (*J. H. B.*, '*Machinery*.')

SECTION XXI

(Contributed and revised by Professor Dempster Smith, M.B.E., M.Sc.Tech., M.I.Mech.E.)

PART I

MACHINE TOOLS – BROACHING – DRILLING – MAGNETIC CHUCKS – POWER REQUIRED BY MACHINE TOOLS – TOOL STEEL—TOOLS—HARDNESS OF MATERIALS—SAVING WORN PARTS (pp. 1093-1173)

PART II

GRINDING, ABRASIVES, AND POLISHING APPLIANCES (pp. 1175-1192)

(Revised and amplified by Alfred B. Searle)

PART III

STEAM AND POWER HAMMERS (pp. 1193-1202)

SECTION XXI

PART I

MACHINE TOOLS — BROACHING — DRILLING — MAGNETIC CHUCKS—POWER REQUIRED BY MACHINE TOOLS—TOOL STEEL — TOOLS — HARDNESS OF MATERIALS — SAVING WORN PARTS.

(Revised and amplified by Professor Dempster Smith, M.B.E., M.Sc.Tech., M.I.Mech.E.)

METAL CUTTING MACHINES.

LATHES.

With a cutting angle of 80° for cast iron (tool angle 75°) and of 70° for soft steel (the best cutting angles in practice), the horse-power needed at the point of the tool is about 2 h.p. per pound of chips per minute. To this must, of course, be added the power needed to drive the tool light, which, in the case of light cuts, is a large proportion of the whole, and is the main reason why a heavy cut and a slow speed are more economical of power than a light cut at a higher one. Where the chips come off in the same shape and fashion, and the tools are equally sharp, the net horse-power expended in the actual cutting operation is practically the same per pound of metal removed whether a light or a heavy cut is taken. The power to be provided will, of course, depend upon the heaviest cut which the tool is to take. This will generally be heavier in a turret lathe than in a common lathe operating on work of the same diameter.

For the common lathe the heaviest cut is $\frac{1}{40}$th of the height of the centres in depth, and the traverse is $\frac{1}{150}$th of the same height. The area cut is then $\frac{h^2}{6{,}400}$, where h is the height of the centres. The speed of cutting may be in feet per minute,

$$\text{For soft steel, } v = \frac{10}{\sqrt[3]{a}}. \qquad \text{For cast iron, } v = \frac{3{\cdot}5}{\sqrt[3]{a}}.$$

where v is the cutting speed in feet per minute, and a is the area of cut in square inches.

Keener tools should be used on a material like copper than on steel, and keener on steel than on cast-iron.

In regard to the proper proportioning of the step-pulley and change-gears, the highest speed should be that enabling the tool to give its maximum possible output on the smallest diameter which it is profitable to turn in the lathe, and this may be a diameter of one-eighth the height of centres. The lowest speed should be such that the maximum output is also attained on the maximum diameter which can be swung on the lathe. The geometric ratio between successive speeds should be 1·08 in the case of a 6-inch lathe and 1·24 in the case of a 72-inch lathe. That is to say, if R be the maximum of revolutions per minute provided for and r the smallest, then, in the case of a 6-inch lathe, $R = r\,(1{\cdot}08)^n$, where $n + 1$ is the total number of speed changes.

The highest and lowest Spindle Speeds and their ratio.—These data are fundamental to the design of the fast headstock, and the following figures, rationally deduced, have been confirmed by practice: —

Height of centres . . .		6 ins.		12 ins.		18 ins.		36 ins.		60 ins.		
Spindle speeds for carbon steel lathes	Greatest .	300	50	150	50	102	60	50	100	30	180	Ratio
	Least .	6		3		1·7		0·5		0·16		
Spindle speeds for high-heat steel lathes	Greatest .	600	10	300	30	200	50	100	100	60	120	Ratio
	Least .	80		10		4		1		0·5		

The Belt drive.—To enable them to transmit the great powers now required, much higher belt speeds have become necessary. Speeds through the air of 2,000 ft. or 3,000 ft. per min. are now used, and unduly wide belts avoided. The efficiency of the belt drive is also improved by using large pulleys running at moderate speeds, rather than small pulleys running at very high rates of revolution.

A simple rational formula for the power required for actual cutting when operating with ordinary high-speed steel on mild steel is :—

$$\text{Cutting HP} = \frac{\text{Force} \times \text{speed of cutting}}{33{,}000}.$$

The force for mild steel is 90 tons per square inch and the standard cutting speed is $\frac{10}{\sqrt{a}}$ where a is the area of cut (cut × traverse) in square inches.

$$\text{Thus C.HP} = \frac{2240 \times 90 \times a}{33{,}000} \times \frac{10}{\sqrt{a}} = 60\sqrt{a}.$$

For standard lathes the test cut in terms of the height of centres is

$$\frac{h}{40}, \text{ and the traverse is } \frac{h}{160}, \text{ or } a = \frac{h^2}{6{,}400}.$$

$$\text{Then C.HP} = 60\sqrt{a} = 60\sqrt{\frac{h^2}{6{,}400}} = 0{\cdot}75\,h.$$

Adding 10 per cent. say for friction in the journals, gears, etc., then gross HP = 0·83 h.

(*Nicolson & Smith.*)

High-Speed Lathe Centres.

Owing to trouble experienced with carbon steel centres on repetition work, an experiment was made by the Ready Tool Co., of U.S.A., with the use of high-speed steel centres. These centres were used on the same machines and for the same work as carbon-steel centres, they showed no signs of either burning or wearing after five weeks of hard usage, and as a result it was definitely decided to put them on the market.

Experiments have shown that on lathe work at both high and low speeds the life of high-speed centres is easily ten times that of carbon-steel centres. In grinding machines, high-speed centres also seem to stand the wear of the abrasive which gets into the cutting compound and deteriorates the carbon-steel centres very rapidly.

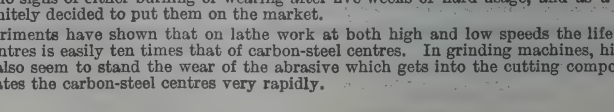


Fig. 1.

The centres, being made from solid high-speed steel, were, of course, expensive, but by welding the front or wearing end of the high-speed steel centre to a chrome-nickel steel shank, a satisfactory centre can be made at a comparatively low cost. These centres are shown by fig. 1 ; the object in designing the centres was to reduce the first cost, especially in large sizes, and still retain all the advantages of a high-speed steel centre.

The centre consists of a chrome-nickel steel shank having a high-speed steel point. This point is welded to a machine-steel extension piece to provide an unusually deep seat in the shank and ensure holding the point securely. The hole in the shank is reamed slightly tapering, and the point or plug is ground, after hardening, to the same taper as this hole. In assembling the plug and shank, the latter is first heated to about 1100° or 1200° F., and then the plug is forced into the hole under a heavy pressure, after which the shank is cooled by plunging it into cold water. As a result of this combination shrinkage and force fit, the plug or centre is gripped very tightly by the shank.

Lathe Tool Holders.

It is rarely possible to hold a tool or cutter securely by a plain parallel shank or stem fitting alone, without any sort of screw or binding clamp. Fig. 1A shows a tool holder made by Sir W. G. Armstrong, Whitworth & Co., Ltd., Manchester, for their railway wheel lathes. The tool has a head *A*, about 1½ inches in diameter, which is tapered slightly to provide for front clearance.

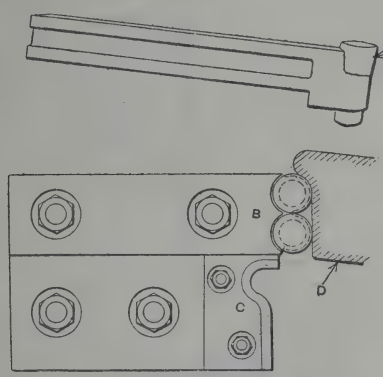


Fig. 1A.

The stem is cylindrical and a tight fit in the holder. The top of the head is dished slightly to give the required rake. In machining, the holder the end is countersunk to fit the head, after which the front portion is cut away; this leaves a close-fitting supporting wall at the back of the cutter. When the cutting edge is dulled, the tool *A* is simply loosened and turned around far enough to bring a new cutting edge into position. When the entire edge has become dull, the tool is re-ground.

PLANING MACHINES.

Vickers' Patent Automatic Reversing Drive.

In this system, fig. 1B, as applied to a planer, the motor itself reverses and is directly geared to the driving screw or rack-wheel of the machine. There are no driving pulleys to reverse, and the inertia of the driving system is much reduced, permitting quick reversal without the excessive waste of energy shown by a power diagram of the usual type of belt machines. There are no belts to wear. The cost of belts averages 30*l.* to 40*l.* per annum on belt-driven planers of large size. The speed of cutting can be instantly varied between the limits of the slowest cut and of the quick return. Thus, in a planer having slowest cutting speed 15 ft. per min., and (constant) quick return 60 ft. per min., the cut can be varied from 15 ft. to 60 ft. per min. by small intervals, and without altering the quick return speed, by simply turning the handle of the speed controlling switch to the proper position. The speed of the return stroke can be varied in a similar manner. The cutting speed can be instantly suited to the material from the hardest steel to softest steel and wrought iron, thus increasing the general output of the machine. The tool will plane accurately up to a line.

VICKERS' PATENT AUTOMATIC REVERSING DRIVE.

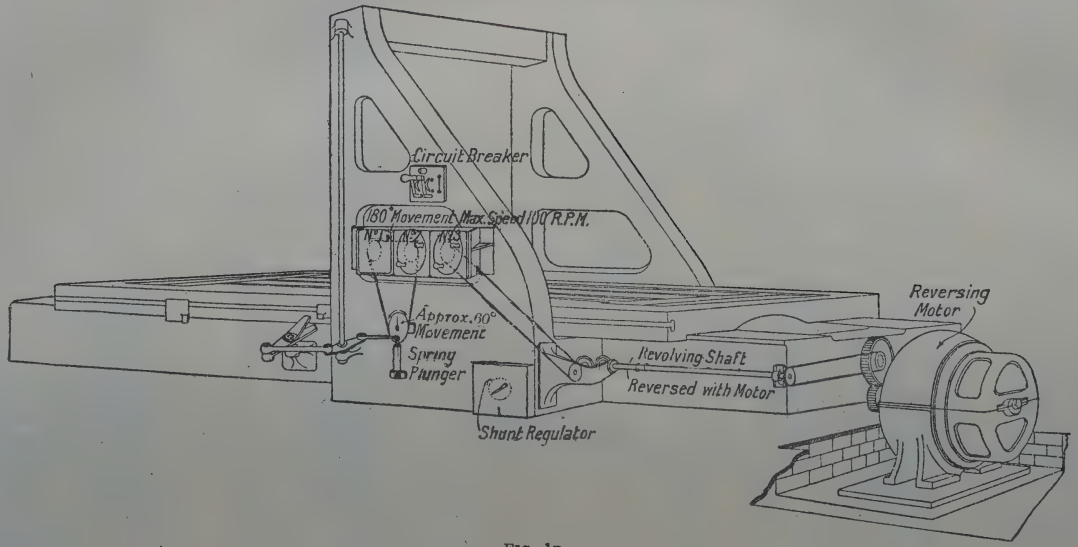


FIG. 1B.

The following is a list of speeds of cutting and return stroke in use with planers which have been converted to this system of drive :—

Size of Planer.	Cutting Speeds.	Return Speeds.	No. of Tools.	Horse-power of Motor.
Feet.	Ft. per Min.	Ft. per Min.		
3 × 3 × 20	30/120	120/30	3	10
4 × 4 × 12	30/120	120/30	3 or 4	15
5 × 5 × 12	30/120	120/30	4	20
6 × 6 × 14	25/100	100/25	4	25
7 × 7 × 18	25/100	100/25	4	30
8 × 8 × 16	20/80	80/20	4	40
9 × 9 × 20	15/60	60/15	4	45
10 × 10 × 20	15/60	60/15	4	45
*12 × 12 × 24	10/40	40/10	Up to 8	50

* Armour-plate planing machines.

PLANING MACHINE TESTS.

Material.	Cutting Speed. Feet per Minute.	Depth of Cut.	Feed.	Authority.
		In.	In.	
Steel slabs	25	$\frac{1}{8}$	$\frac{1}{8}$	Armstrong-Whitworth, using A.W. Steel.
Steel horn blocks	35	$\frac{1}{8}$	$\frac{1}{8}$	Armstrong-Whitworth, using A.W. Steel.
Hard cast iron	40	$\frac{1}{4}$	$\frac{1}{8}$	Richard Hornsby & Sons, Ltd.
Cast iron	36	$1\frac{1}{4}$	$\frac{1}{8}$	Armstrong-Whitworth.
Cast iron	55	$\frac{1}{8}$	$\frac{3}{16}$	Armstrong-Whitworth.

PLANING SPEEDS AND FEEDS.

Material.	Cutting Speed. Ft. per Min.	Feed Ins. per Stroke.	Depth of Cut. Ins.
Roughing Cuts.			
Cast iron	37–48	$\frac{3}{16}$	$\frac{7}{16}$
Cast steel	28–48	$\frac{5}{32}$	$\frac{1}{4}$
Machine steel	28–48	$\frac{5}{32}$	$\frac{1}{4}$
NOTE.—Leave $\frac{1}{32}$ in. of metal for removal by subsequent cuts. When so set, the tools tend to dig in and actually leave about 0·026 in. of surplus stock.			
Straightening Cuts.			
Cast iron	45	$\frac{3}{16}$ to $\frac{1}{4}$	0·018
Cast steel	45	$\frac{1}{8}$	0·018 to 0·021
Machine steel	45	$\frac{1}{8}$	0·018 to 0·021
Finishing Cuts.			
Cast iron	28–35	$\frac{1}{4}$ to $1\frac{1}{2}$	0·003 and 0·001
Cast steel	45	$\frac{1}{32}$	0·004
Machine steel	45	$\frac{1}{32}$	0·004
NOTE.—For cast iron, it is good practice to divide the work up into two operations, taking off 0·003 in. with the first cut and 0·001 in. with the second cut. This prevents a tendency for the tool to dig in at the high spots.			

SPEED TABLE FOR PLANING MACHINES.

(Bateman's Machine Tool Co. Ltd.)

Size of Planer.	Length of Stroke taken.	Time of 10 Cycles.	No. of Feet in 10 Cycles.	Average Speed.	Maximum Speeds. Ft. per min	
	Ft. Ins.	Min. Secs.		Ft. per Min.	Cut.	Re-turn.
24 ins. by 24 ins. by 6 ft.	6 3½	1 8	126	111	80	225
30 ins. by 30 ins. by 8 ft.	8 0	4 20	160	37	22	218
(With three-speed gear-box)	8 0	2 21	160	68	45	218
	8 0	1 41	160	96	65	218
36 ins. by 36 ins. by 12 ft.	12 0	6 0	240	40	20	175
(With three-speed gear-box)	12 0	3 34	240	67	40	175
	12 0	2 46	240	87	62	175
36 ins. by 36 ins. by 20 ft.	20 3	10 12	405	40	24	163
(With three-speed gear-box)	20 3	6 14	405	65	42	163
	20 3	4 46	405	85	61	163
42 ins. by 42 ins. by 20 ft.	22 6	6 39	450	68	45	145
42 ins. by 42 ins. by 14 ft.	14 0	3 56	280	71	50	155
42 ins. by 42 ins. by 12 ft.	11 0	2 36	220	84	58	175
48 ins. by 48 ins. by 8 ft.	8 0	2 4	160	77	52	160
60 ins. by 60 ins. by 12 ft.	12 0	6 0	240	40	25	150
(With three-speed gear-box)	12 0	3 50	240	62½	42	150
	12 0	2 50	240	85	60	150
72 ins. by 72 ins. by 16 ft.	16 0	7 40	320	41	25	110
(With three-speed gear-box)	16 0	5 40	320	56	39	110
	16 0	4 50	320	66	50	110

For taking the roughing and straightening cuts it is usually found that high-speed steel is the most satisfactory material, owing to its greater productive capacity ; but where considerable accuracy and perfection of finish is required in performing the final planing operations, far more satisfactory results will usually be obtained by making the cutting tools of carbon steel, because this material can be ground to a keener edge, and experience has shown that the tools retain this edge longer and are thus able to produce a smoother and more accurate finish on the work.

MILLING MACHINES.*

One of the chief points is to make the cutters of such shape that all the fitting surfaces and cutting edges can be easily and accurately ground. In fig. 2 an ordinary grooving cutter is shown so designed. It will be noticed that the hole is chambered out so that the cutter fits the spindle at the two narrow surfaces, A and A′, only. These surfaces can be more easily ground to standard size than could a bearing the full width of the cutter. After the hole has been accurately finished it is an easy matter to mount the cutter on a mandrel and grind the surfaces BB and B′B′, and also the cutting edges, CC, C′C′, and DD all at the same setting, as indicated in fig. 2. Nothing now remains to be done but to back off the teeth in the way indicated in figs. 3 and 4. Such a cutter, when mounted on a true spindle, provided with a solid collar, against which the cutter is held, is self-setting and accurate.

In determining the correct angle for the face of the teeth, the diameter and shape of the cutter should be taken into account. For small-sized cutters it will, in order to obtain a strong shape, generally be found best to make the faces truly radial, as shown in figs. 2, 3, and 4. This also is more convenient when the cutter is to have teeth both on the sides and periphery. Cutters with the teeth so formed have worked upon both wrought and cast iron perfectly well, and at the same time they are not so liable to seize hold and bite into the work as cutters which have the faces of their teeth undercut. The pitch of the teeth is, again, partly determined by the diameter and class of cutter. In those cutters which are cut at the sides, the pitch at the circumference has often to be made wider than is advisable, in order to give clearance room for the emery wheel

* Abstract of a paper read before the Manchester Association of Engineers.

when grinding the converging side teeth (see fig. 4). A pitch of from $\frac{5}{16}$ inch to $\frac{3}{8}$ inch will usually be found to give good results. In all except very narrow cutters it is advisable to cut the teeth on the periphery spirally. This ensures a smoother action of the machine and produces better work. In deciding whether to make the cutters right- or left-hand spirals, attention should be paid to the direction in which they are to revolve. For example, in a vertical machine whose spindle revolves to the right hand, as in an ordinary drilling machine, the cutters should be cut

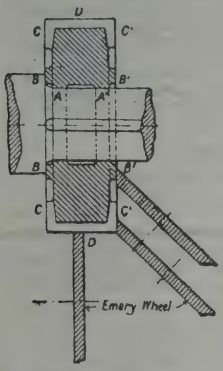


FIG. 2.

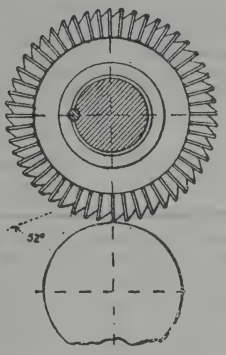


FIG. 3.

with a left-hand spiral. This has the effect of forcing the work down on to the table and the spindle up against its end bearings, as the cutter and the work act as a screw and a nut. In cutters of small size high-class tool steel is most suitable, although great care is required in heating it gradually and evenly. The bottom of the spaces between the teeth should be slightly rounded, and the keyways made semicircular, in order to avoid starting-places for fracture.

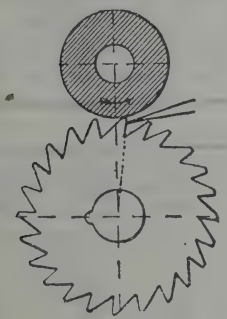


FIG. 4.

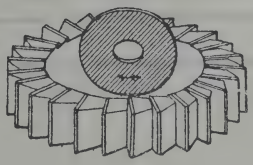


FIG. 5.

For cutters of larger sizes and strong sections Howell's case-hardening steel may be used with great advantage.

Too great stress cannot be laid upon the necessity of keeping milling cutters sharp, and both machines and cutters in such a condition that the cutters shall run true. In grinding milling cutters it is essential that the spindle and emery wheel of the grinding machine should run true and be accurately balanced, as, owing to the high speeds at which they are run, it is clear that any inaccuracy in these respects is highly detrimental. In order to prevent the emery wheel from

glazing, it is necessary to keep it perfectly free from oil or perspiration, and care should be taken not unduly to force the emery wheel against the work, as excessive pressure rapidly generates heat, which not only softens and glazes the emery wheel, but also draws the temper of the thin edges of the cutter, often without showing any discoloration on the edge just ground. For general cutter grinding the emery wheels should be fairly coarse and free-cutting, otherwise they are apt to soften the cutter, which may be known by a fine blue burr, to be seen on the faces of the teeth, the metal along this line being softened. For ordinary-sized cutters an emery wheel $2\frac{1}{2}$ inches in diameter by $\frac{5}{16}$ inch or $\frac{1}{4}$ inch wide will be found most suitable, the speed of which may vary from 3,000 to 4,500 revolutions per minute, but either too fast or too slow a speed will cause the wheel to burn and soften the cutter. The finishing cut should be very small in amount, especially in cutters of large diameter, otherwise the wear in the diameter of the emery wheel will materially affect the height of the cutter teeth, those last ground being the highest.

For general work, in which ordinary cylindrical cutters can be used, cutters of small or medium size, say up to $3\frac{1}{2}$ inches in diameter, will be found to possess important advantages.

The plain cylindrical cutter is the cheapest and most effective wherever it can be used.

Speed of Milling Cutters.

Table I. shows examples taken from everyday practice, working on wrought-iron forgings.

TABLE I.

Diameter of Cutter.	Depth of Cut.	Width of Cut.	Revolutions of Cutter per Minute.	Cutting Speed in Feet per Minute.	Feed in Inches per Minute.
Inches.	Inch.	Inches.			
2	$\frac{1}{4}$	$\frac{3}{4}$	150	78	$2\frac{1}{2}$
$3\frac{1}{2}$	$\frac{1}{4}$	$3\frac{1}{2}$	70	64	2
$7\frac{1}{2}$	$\frac{1}{4}$	5	35	68	$1\frac{1}{2}$

The following particulars of milling work which is being done at the North London Railway shops have been furnished by Mr. J. C. Park, the locomotive superintendent.

TABLE II.

CUTTERS 3 INCHES IN DIAMETER.

Speed and Feed.	Brass.	Wrought Iron.	Tool Steel.	Cast Iron.	Mild Steel.
Speed of cutters in feet per minute	112	60	33	18	33 to 60
Feed in inches per minute	1 in. and upwards	$\frac{3}{4}$ in. to 1 in.	$\frac{1}{2}$ inch	$\frac{1}{2}$ in. to $\frac{5}{8}$ in.	$\frac{3}{4}$ in. to 1 in.

TABLE III.

Class of Work.	Diameter of Cutter.	Depth of Cut.	Width of Cut.	Revolutions per Minute.	Cutting Speed in Feet per Minute.	Feed in Inches per Minute.
	Inches.	Inches.	Inches.			
Mild steel coupling rods, roughing cut	..	$\frac{1}{2}$	5	..	50	$\frac{3}{4}$
Finishing cut	..	$\frac{1}{32}$	5	..	60	1
Steel rails	7	1	2	15	32	$\frac{1}{7}$
Wrought-iron spring buckles	12	$1\frac{1}{2}$	2	15	47	$\frac{1}{7}$
Cast-steel horn-blocks	6	$\frac{1}{4}$	$2\frac{5}{8}$	14	22	$\frac{1}{4}$
Wrought-iron nuts (with two side cutters)	6	$\frac{1}{16}$ to $\frac{1}{8}$	..	30	47	$\frac{1}{2}$
Brass flanges	3	..	..	80	62	$1\frac{1}{4}$
Soft brass window frames	$1\frac{1}{2}$	$\frac{1}{8}$	..	90	35	$2\frac{3}{4}$
Cast-iron steam-chest covers	3	..	..	25	20	$\frac{1}{2}$

Tables IV., V., and VI., furnished by Messrs. John Musgrave & Sons, Bolton, are the results of an extended experience in milling.

TABLE IV.

AVERAGE SPEED AND FEEDS OF CYLINDRICAL MILLING CUTTERS FOR MACHINE STEEL.

Diameter of Mill in Inches.	Depth of Cut in Fractions of an Inch.	Cut $\frac{1}{4}$ Inch Wide.		Cut $\frac{1}{2}$ Inch Wide.		Cut 1 Inch Wide.		Cut 2 Inches Wide.		Cut 4 Inches Wide.	
		Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.
$\frac{1}{2}$	Full diameter	360	110	330	150						
	$\frac{1}{8}$	400	110	365	110	335	110				
	$\frac{1}{16}$	440	110	400	110	365	110				
	Finishing	480	85	440	85	400	85				
$\frac{3}{4}$	Full diameter	240	100	220	120						
	$\frac{1}{8}$	280	100	255	100	230	100				
	$\frac{1}{16}$	300	100	275	100	250	100				
	Finishing	320	75	290	75	265	75				
1	Full diameter	180	90	165	100						
	$\frac{1}{8}$	200	90	185	90	170	90	150	90		
	$\frac{1}{16}$	220	90	200	90	185	90	165	90		
	Finishing	240	68	220	68	200	68	180	68		
$1\frac{1}{4}$	Full diameter	144	80	130	90	120	90				
	$\frac{3}{16}$	160	80	150	80	130	80	120	86		
	$\frac{1}{16}$	175	80	160	80	145	80	132	80		
	Finishing	190	60	175	60	160	60	145	60		
$1\frac{1}{2}$	Full diameter	120	70	112	80	100	80	92	80		
	$\frac{1}{8}$	130	70	120	70	108	70	96	70		
	$\frac{1}{4}$	140	70	130	70	116	70	106	70		
	Finishing	160	53	150	53	130	53	120	53		
2	$\frac{1}{8}$	95	60	88	60	80	60	72	60	58	60
	$\frac{1}{4}$	100	60	92	60	84	60	75	60	60	60
	$\frac{1}{2}$	105	60	96	60	87	60	80	60	64	60
	Finishing	120	45	108	45	100	45	90	45	72	45
$2\frac{1}{2}$	$\frac{1}{8}$	75	50	70	50	64	50	58	50	47	50
	$\frac{1}{4}$	80	50	74	50	68	50	60	50	49	50
	$\frac{1}{2}$	85	50	77	50	71	50	64	50	51	50
	Finishing	95	37	88	37	80	37	72	37	58	37
3	$\frac{1}{8}$	65	40	60	40	54	40	48	40	38	40
	$\frac{1}{4}$	68	40	63	40	57	40	51	40	41	40
	$\frac{1}{2}$	72	40	66	40	60	40	54	40	43	40
	Finishing	80	30	74	30	67	30	60	30	48	30
4	$\frac{1}{8}$	48	35	44	35	40	35	36	35	29	35
	$\frac{1}{4}$	50	35	47	35	43	35	38	35	30	35
	$\frac{1}{2}$	53	35	49	35	47	35	40	35	32	35
	Finishing	60	26	55	26	50	26	45	26	36	26
5	$\frac{1}{8}$	38	30	35	30	32	30	29	30	23	30
	$\frac{1}{4}$	41	30	37	30	34	30	30	30	24	30
	$\frac{1}{2}$	43	30	39	30	36	30	32	30	26	30
	Finishing	48	23	44	23	40	23	36	23	29	23
6	$\frac{1}{8}$	32	25	30	25	26	25	24	25	19	25
	$\frac{1}{4}$	34	25	31	25	28	25	26	25	21	25
	$\frac{1}{2}$	36	25	33	25	30	25	27	25	22	25
	Finishing	40	19	37	19	33	19	30	19	24	19
7	$\frac{1}{8}$	28	22	25	22	23	22	21	22	17	22
	$\frac{1}{4}$	30	22	27	22	25	22	22	22	18	22
	$\frac{1}{2}$	31	22	28	22	26	22	23	22	19	22
	Finishing	34	17	31	17	29	17	26	17	21	17
8	$\frac{1}{8}$	24	20	22	20	20	20	18	20	14	20
	$\frac{1}{4}$	26	20	23	20	22	20	19	20	15	20
	$\frac{1}{2}$	27	20	25	20	23	20	20	20	16	20
	Finishing	30	15	27	15	25	15	22	15	18	15

TABLE V.

AVERAGE SPEEDS AND FEEDS FOR CYLINDRICAL MILLING CUTTERS FOR CAST IRON.

Diameter of Mill in Inches.	Depth of Cut in Fractions of an Inch.	Cut ½ Inch Wide.		Cut ½ Inch Wide.		Cut 1 Inch Wide.		Cut 2 Inches Wide.		Cut 4 Inches Wide.	
		Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.
½	Full diameter	450	110	410	110	375	110				
	⅛	500	110	455	110	415	110	375	110		
	1/16	550	110	500	110	455	110	410	110		
	Finishing	600	85	550	85	500	85	450	85		
¾	Full diameter	300	100	275	100	250	100				
	⅛	350	100	320	100	290	100	265	100		
	1/16	375	100	340	100	310	100	280	100		
	Finishing	400	75	365	75	330	75	300	75		
1	Full diameter	225	90	205	90	190	90	170	90		
	⅛	250	90	330	90	210	90	190	90		
	1/16	275	90	250	90	230	90	205	90		
	Finishing	300	68	275	68	250	68	225	68		
1¼	Full diameter	180	80	165	80	150	80	135	80		
	3/16	200	80	185	80	165	70	150	70		
	1/16	220	80	200	80	180	70	165	70		
	Finishing	240	60	220	60	200	60	180	60		
1½	Full diameter	150	70	140	67	125	67	115	67		
	¼	160	70	150	67	135	50	120	50		
	⅛	175	70	160	67	145	50	133	50		
	Finishing	200	53	185	50	165	40	150	40		
2	½	120	60	110	45	100	40	90	40	72	40
	¼	125	60	115	45	105	40	94	40	75	40
	⅛	130	60	120	45	108	40	100	40	80	40
	Finishing	150	45	135	34	125	30	112	30	90	30
2½	½	95	50	88	36	80	32	72	32	58	32
	¼	100	50	92	36	84	32	75	32	61	32
	⅛	105	50	96	36	88	32	80	32	64	32
	Finishing	120	37	110	27	100	24	90	24	72	24
3	½	80	40	74	30	67	26	60	26	48	26
	¼	85	40	78	30	71	26	64	26	51	26
	⅛	90	40	82	30	75	26	67	26	54	26
	Finishing	100	30	92	22	83	20	75	20	60	20
4	½	60	35	55	22	50	19	45	19	36	19
	¼	63	35	58	22	53	19	47	19	38	19
	⅛	66	35	61	22	55	19	50	19	40	19
	Finishing	75	26	69	17	62	15	56	15	45	15
5	½	48	30	44	17	40	16	36	16	29	16
	¼	51	30	47	17	43	16	38	16	30	16
	⅛	54	30	49	17	45	16	40	16	32	16
	Finishing	60	23	55	13	50	12	45	12	36	12
6	½	40	25	37	14	33	13	30	13	24	13
	¼	43	25	39	14	35	13	32	13	26	13
	⅛	45	25	41	14	37	13	34	13	27	13
	Finishing	50	19	46	11	41	10	37	10	30	10
7	½	35	22	31	12	29	11	26	11	21	11
	¼	37	22	33	12	31	11	28	11	22	11
	⅛	39	22	35	12	33	11	29	11	23	11
	Finishing	43	17	39	9	36	8	32	8	26	8
8	½	30	20	27	10	25	9	22	9	18	9
	¼	32	20	29	10	27	9	24	9	19	9
	⅛	34	20	31	10	28	9	26	9	20	9
	Finishing	38	15	34	7	31	6	28	6	22	6

TABLE VI.

AVERAGE SPEEDS AND FEEDS OF FACE MILLING CUTTERS.

Depth of Mill in Ins.	Depth of Cut in Fractions of an Inch.	Cast Iron.		Machine Steel.		Cast Steel.	
		Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.	Revolutions per Minute.	Revolutions per Inch of Feed.
4	Scale	36	16	29	32	24	32
	$\frac{1}{16}$	40	12	32	24	27	24
	Finishing	45	8	36	12	30	12
5	Scale	29	13	23	26	19	26
	$\frac{1}{16}$	32	10	26	20	21	20
	Finishing	36	7	29	10	24	10
6	Scale	24	11	19	22	16	22
	$\frac{1}{16}$	27	8	21	16	18	16
	Finishing	30	6	24	8	20	8
7	Scale	21	9	17	18	14	18
	$\frac{1}{16}$	23	7	19	14	15	14
	Finishing	26	5	21	7	17	7
8	Scale	18	8	14	16	12	16
	$\frac{1}{16}$	20	6	16	12	13	12
	Finishing	22	4	18	6	15	6
10	Scale	14	7	11	14	9	14
	$\frac{1}{16}$	16	5	12	10	10	10
	Finishing	18	3	14	5	12	5
12	Scale	12	6	9	12	8	12
	$\frac{1}{16}$	13	4	10	8	9	8
	Finishing	15	$2\frac{1}{2}$	12	4	10	4
16	Scale	9	5	7	10	6	10
	$\frac{1}{16}$	10	3	8	6	7	6
	Finishing	11	2	9	3	8	3
20	Scale	7	4	5	8	5	8
	$\frac{1}{16}$	8	$2\frac{1}{2}$	6	5	5	5
	Finishing	9	$1\frac{1}{2}$	7	$2\frac{1}{2}$	6	$2\frac{1}{2}$
24	Scale	6	3	4	6	4	6
	$\frac{1}{16}$	7	2	5	4	4	4
	Finishing	8	$1\frac{1}{4}$	6	2	5	2

Generally speaking, the speed of milling cutters of 6 inches diameter and upwards, provided there is no great depth of material to be cut away, may be as follows :—

Material.	Speed in Feet per Minute.	Depth of Cut in Inches.
Steel	36	$\frac{1}{2}$
Iron	48	1
Cast iron	60	$1\frac{2}{3}$
Brass	120	$2\frac{2}{3}$

CUTTER DIMENSIONS.

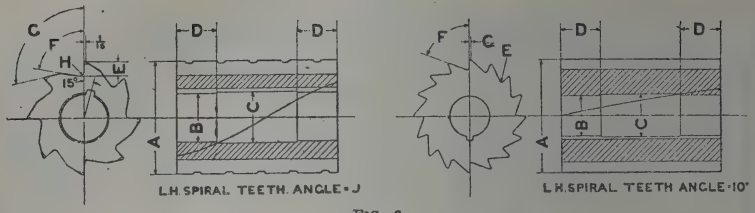


FIG. 6.

Coarse Pitch.
Dimensions in Inches.

Diam. of Cutter. A	B	C	D	E	F	G	H	J	Key-way.	No. of Teeth.
2½	1	1 1/16	1¼	3/8	80°	103°	1/8 R	26½°	5/32 × 3/32	8
3	1¼	1 5/16	1¼	3/8	80°	103°	3/16 R	26½°	3/16 × 1/8	8
3½	1½	1 9/16	1¼	7/16	80°	103°	1/4 R	26°	1/4 × 5/32	8
4	1¾	1 13/16	1¼	7/16	71°	94°	3/16 R	25½°	1/4 × 3/32	10
4½	2	2 1/16	1¼	1/2	71°	94°	3/16 R	26½°	5/16 × 5/16	10

Fine Pitch.
Dimensions in Inches.

Diam. of Cutter. A	B	C	D	E	F	G	Key-way.	No. of Teeth.
2½	1	1 1/16	1¼	3/64 R	70°	3/64	5/32 × 3/32	14
3	1¼	1 5/16	1¼	3/64 R	70°	3/64	3/16 × 1/8	14
3½	1½	1 9/16	1¼	1/16 R	70°	3/64	3/16 × 1/8	16
4	1½	1 9/16	1¼	1/16 R	65°	1/16	1/4 × 5/32	18
4½	1½	1 9/16	1¼	1/16 R	65°	1/16	1/4 × 5/32	20

The above table gives particulars of a range of cutters suitable for heavy roughing work, and also corresponding fine pitch cutters used for light milling.

(*P. V. Vernon (Alfred Herbert & Co.)*)
(*Paper read before the Manchester Association of Engineers*, 1912.)

Experiments to determine the effect of cutting speed on the life of a milling cutter were mentioned by E. Buckingham in a discussion on a paper on milling that was read recently before the American Society of Engineers. Tests were made at speeds of 70 and 80 feet per minute with high-speed steel cutters on small nickel-steel forgings. Very consistent results showed definitely that at 70 feet per minute the cutters would mill twice as many pieces as when running at 80 feet per minute. Therefore two cutters exactly similar, except that one has 21 and the other 24 teeth, would show a great difference in their life between grindings if each were set to remove the same amount of material in the same time. Under the conditions mentioned above the 24-tooth cutter would mill twice as many pieces before regrinding were necessary. The author of the original paper referred to experiments conducted with spiral milling cutters. One of the cutters experimented with was of double spiral type, in which successive teeth are of opposite spiral hand. The results when compared with those obtained from a spiral cutter with teeth all of one hand, showed that with the double spiral there was a saving of from 20 to 30 per cent. in the power required. (*'Power,' February* 16, 1922.)

The cutting speed will, when tapping and screwing with carbon steel tools and copious streams of lubricant, be about 10 ft. per minute.

A Milling Cutter for Copper.

The diameter of the cutter (fig. 6A) should be of such proportions as will allow the placing of eighteen teeth of 1-in. pitch upon a 6-in. diameter circle. This will give excellent results, and is the result of a series of exhaustive tests.

Each tooth should be hacked off slightly on either side, as shown shaded at A, and have a rake angle of about 10°.

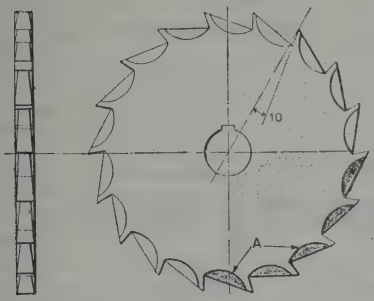


FIG. 6A.

Should a cutting lubricant be found to be necessary, a quantity of lard oil, thinned with turpentine, is recommended. (*Mechanical World*, *April* 3, 1925.)

BROACHING.

Recently the finishing of holes, oil gutters, keyways, etc., by broaching has received considerable attention. Any class of material appears to lend itself to this process provided the broach is of suitable design. Broaches under 1½ ins. diameter are frequently made of high-speed steel containing from 14 per cent. to 18 per cent. tungsten. Such steel, however, is hard throughout and likely to fail under shock. For this reason, some firms make their broaches entirely of vanadium steel, which contains neither tungsten nor chromium. This steel is hardened at 750° C. and quenched in oil and tempered at 420° C. For general work a mild steel containing about 0·15 per cent. carbon, carburised at 900° C., reheated to 800° C. and dipped in water has given very satisfactory results. The reheating before quenching gives a tough core. For broaching hard steel, a mild steel containing from 2 per cent. to 3 per cent. nickel and about 0·14 per cent. carbon, carefully case-hardened, reheated to 770° C. and quenched in whale oil, has proved suitable. In making a broach, choose a bar with at least ¼ in. excess in diameter of the finished broach, so as to avoid small surface cracks and skin stresses. Broaches above 2 ins. diameter are frequently built up, in which case the teeth are formed on hardened steel rings, and these are securely mounted on a mild steel core. The teeth of the broach should be periodically examined when in use. Should any of these be chipped or dulled, these must have the cutting edge restored. Should a tooth break it must be ground down and the cut distributed amongst the next four teeth or so.

In the case of white metal an accurate hole and fair finish may be obtained with a broach having fine pitched teeth (say, from ⅜ in. to 1 in. in broaches from 1½ ins. to 6 ins. diameter), and each cutting tooth increasing by 0·0005 in. The cutting teeth are preceded by a plain part (to act as a pilot) about 2 in. long and 0·002 in. below the diameter of the first cutting tooth and diameter of the hole. From 6 to 12 teeth at the end of the broach are parallel and about 0·002 in. larger than the finished hole, to allow for creep. This dimension will vary with the springiness of the member. The teeth should have a parallel land of 0·02 in. and a top-take of about 10°.

Design of Broach.

The broach may be secured to the cross-head of the machine by means of a screw or a flat key, or a buttress-thread and pad, a plain cylindrical stem with cotter. An example of the latter is shown in fig. 7. This method is extensively used, on account of the ease with which the pin can be withdrawn and the security it affords, in that the pin is sheared before any damage is done to the broach or machine.

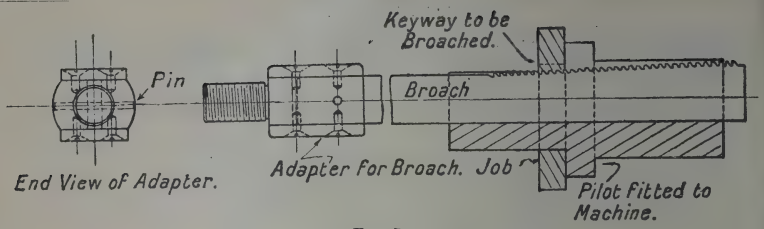


FIG. 7.

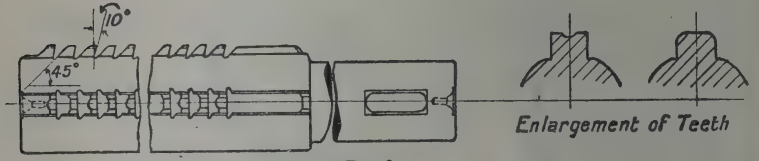


FIG. 8.

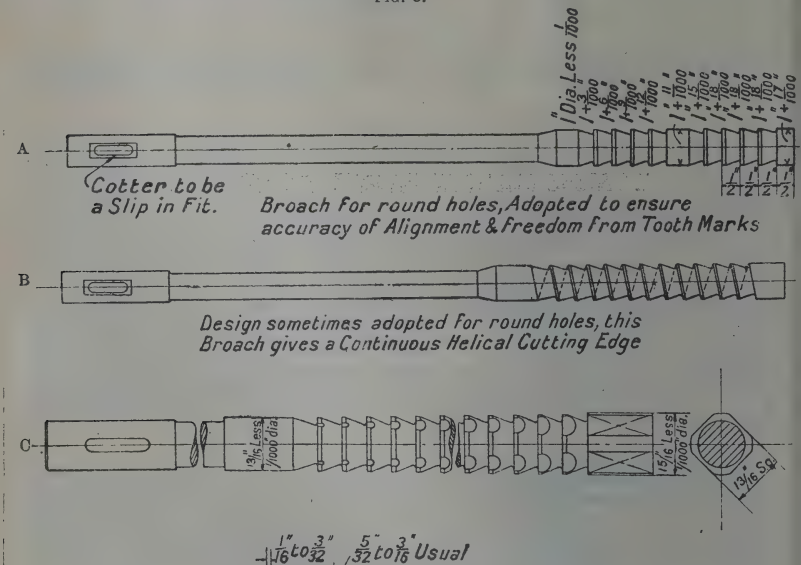


FIG. 9.—Types of Broaches.

All broaches should be provided with a pilot. The pilot is made a sliding fit in the hole or slot, and leads the cutting edges centrally to their work. It is a very important factor, as it not only helps to produce accurate work, but prevents damage to the broach. In the case of very long broaches, pilots or steadies are provided at intervals along the broach itself, as shown at A, fig. 9. It is advisable that the broach should have four or five teeth at the end for sizing only. These may be of a smaller pitch than the normal, as the cut removed per tooth is exceedingly fine. C, fig. 9, shows a square broach with progressive increasing cut per tooth which in this design is permissible.

Pitch of Teeth.

The pitch of the teeth is regulated by the number of teeth engaged, the cut taken per tooth, the material operated upon, and the material of which the broach is made. It is clear that the cutting force should not exceed the tensile strength of the broach or strength of the teeth. In the case of broaching, a circular, square or hexagonal hole in mild steel, it is usual to allow of three teeth being in action, each tooth taking $\frac{3}{1000}$ in. cut, that is, 9 teeth thousandths. This is suitable, say, for a broach 1 in. dia., but for a broach $\frac{1}{2}$ in. dia. only 5 teeth thousandths should be allowed, whilst for a 2 in. broach 18 teeth thousandths can be allowed, and a proportionately larger amount as the diameter of the broach increases. With softer material more teeth can, of course, be engaged. It is desirable that the teeth should have a top rake of about 10°, a land of about $\frac{1}{32}$ in., and a side clearance of about 3°, as shown in fig. 8. Proportions of teeth in common use are shown at D, fig. 9.

It is difficult to obtain uniformity of cutting per tooth on the first trial, and the broach may be pulled through a sample piece, the amount removed per tooth being noted, and the teeth honed down where necessary. On rectangular and circular work the teeth are sometimes spiral as shown at B in fig. 9. This design has the advantage of giving a side rake to the cutting edges, and it is claimed that it tends to neutralise any lateral thrust. Occasionally the teeth are staggered, and where the material to be cut is very hard the teeth may be fluted or nicked. An example of the latter is shown in fig. 8, where the alternate teeth are arranged to remove the corner and body of the groove. This arrangement breaks up the chip and materially reduces the stress on the broach.

In fig. 7 is shown the design of a broach adopted for cutting single keyway in a member, and the pilot which is fitted to the machine to guide the broach. Where more than one key is required, arrangements are made to turn the member round, but the spacing obtained under such conditions is rarely accurate, and a better method is to provide for a double spline broach as shown in fig. 8. It is always desirable, where there is more than one gutter, to have a broach with the necessary number of splines.

Speed of Cutting.

The speed of cutting varies with the material operated upon, and for soft brass may be as high as 20 ft. per minute, and for medium hard steel about 5 ft. per minute. The cutting speed is relatively of little importance, and it is generally advisable to adopt about half the above speeds.

Lubrication.

When a highly-polished finish is required on ductile materials it is desirable to use a cutting compound, and on such materials one pint of oil mixed with 4 ozs. of flowers of sulphur has given good results. The J. N. Lapointe Co. recommend the following mixture when broaching mild steel :—

Mineral lard oil, 3 gallons ; water, 50 gallons ; and soda ash, $2\frac{1}{2}$ lbs. The whole of the lard oil and soda ash should be mixed with 10 gallons of water and the remaining proportion of water added before putting into use.

For heavy duty use castor oil.

DRILLS AND DRILLING.

Cutting Edges of Drills.

The cutting edges of drills are formed by grinding the end facets at an angle as shown by A, C, B, fig. 10, and this angle varies from 5° for drilling hard metal, such as steel, to 20° for

soft metal, such as brass or copper. The angle of one cutting edge to the other varies from 45° for steel to about 35° or 40° for soft metals.

Drills for work of ordinary hardness are tempered to an orange purple; but if the metal to be

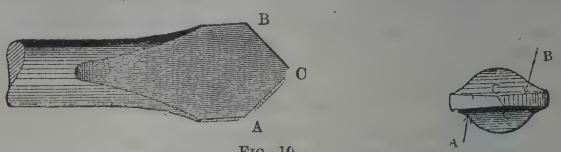


FIG. 10.

cut is very hard a straw colour is preferable, or the drill may be left as hard as it leaves the water; that is to say, hardened, but not tempered. In these cases great care must be exercised and the speed of the drill reduced.

Twist Drills.

A twist drill possesses three cutting edges, A, B, and C, as shown in fig. 11.

The point A, being the least effective, since it cannot be made anything like as keen as the other two, B and C, is a hindrance to clean and rapid cutting and is one of the most important factors to be considered when arriving at the amount of feed progression per inch of travel.

In order to obtain the greatest possible duty from a twist drill, it is imperative that it should be

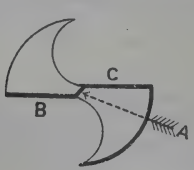


FIG. 11.

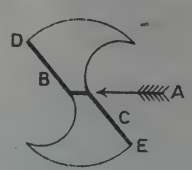


FIG. 12.

ground perfectly true, so that the point of the drill shall be central and in line with the axis on which it revolves. The cutting edges must be of equal length and at the same angle to the axis of the drill. If the point of the drill is not central to the axis, the two cutting edges are not at the same angle, the result being that all the duty falls on one cutting edge, and the hole made will still be larger in diameter than the drill, there being a tendency for the cutting edge B to push, or crowd, the drill over to the opposite side of the hole.

From the foregoing it will be obvious that the more correctly a drill is ground, the longer it will last without re-grinding: the greater its amount of feed may be to take an equal depth of cut, and the nearer the diameter of the hole bored will be to that of the drill.

Another important point when the maximum duty is expected from a twist drill is the relationship between the speed and feed, which varies more or less with different materials and with different grades of hardness of like materials.

When a drill has been in operation for a short time it should be withdrawn from the machine and examined as to its cutting edges, fig. 12. Should the cutting edges B C show more wear towards their extreme diameters D E, this would show the speed is too great as compared with the feed.

The grooves of a twist drill make either a constant angle with the axis or an angle that increases gradually from point to shank. The latter form is supposed to facilitate the escape of the cuttings, though opinions differ, but it has the serious effect of rendering the cutting angle more obtuse as the drill becomes ground back. When the angle is constant it ranges from 24° to 32° with the axis, measured at the periphery, 26° being an average. In the increase-twist drills it ranges roughly between 30° and 25°, the angle lessening by that amount from point to shank. The thickness of the web is increased from point to shank to enable it to resist torsional stresses. The diminished area for the escape of chips consequent on this thickening is counteracted by increasing the twist.

'FIRTH'S SPEEDICUT' HIGH-SPEED TWIST DRILLS.

(Thos. Firth & Sons, Ltd., Sheffield.)

The chart (fig. 13) indicates speeds and feeds suitable for drilling mild steel; for cast iron use the same feed per minute but decrease the speed 20 per cent. Both speeds and feeds may be modified to suit variation of material.

The feeds and speeds given on the chart are approximate, and represent ordinary working speeds for average depths of holes.

The chart shows that a 1-in. drill should run under the following conditions.

Mild Steel.	*Cast Iron.*
Speed, 280 revs. per min.	Speed, 224 revs. per min.
Feed, 4⅞ ins. per min.	Feed, 4⅞ ins. per min.
Feed per rev., ·0175.	Feed per rev., ·022.

If the material is thin, as in the case of boiler plate, both feed and speed can be increased. If the material is hard, decrease both the feed and speed. Always run with lubricant if possible except in the case of cast iron. If no lubricant is used, decrease both feed and speed about 25 per cent. When possible, always keep the feed per rev. the same as given on the chart for the

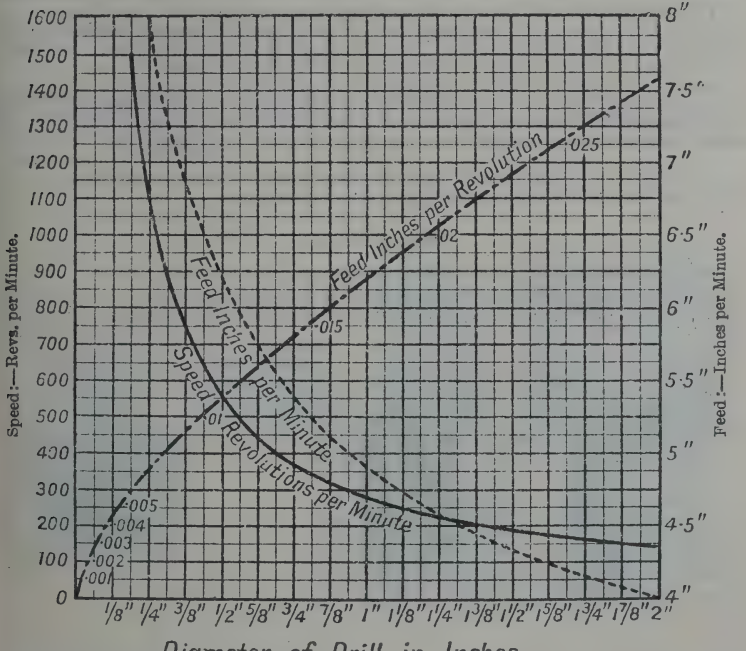


FIG. 13.

two different classes of material, i.e. steel and cast iron. Never decrease the feed below a minimum of, say, 3 ins. per min. for a 1-in. drill, the others in like proportion.

SPEEDS FOR ORDINARY CARBON STEEL DRILLS.

Diameter of Drill in Inches.	Revolutions per Minute.			Diameter of Drill in Inches.	Revolutions per Minute.		
	Soft Steel and Wrought Iron.	Cast Iron.	Brass.		Soft Steel and Wrought Iron.	Cast Iron.	Brass.
1/8	768	610	1,536	1	96	76	192
5/16	512	405	1,024	1 1/8	85	66	170
1/4	384	304	768	1 1/4	77	61	154
5/16	307	243	614	1 3/8	70	55	140
3/8	256	203	512	1 1/2	64	50	128
7/16	219	174	438	1 5/8	59	47	118
1/2	192	152	384	1 3/4	55	43	110
9/16	170	135	340	1 7/8	51	41	100
5/8	154	122	308	2	48	38	96
11/16	139	111	278	2 1/4	42	34	84
3/4	128	102	256	2 1/2	38	30	76
13/16	118	93	236	2 3/4	35	27	70
7/8	109	87	218	3	31	25	62
15/16	102	81	204				

Feed revolutions for the above speeds, on wrought iron and steel: up to and including 1/4 in. diameter, 1/150 in.; from 1/4 in. up to 7/16 in. inclusive, 1/130 in.; from 7/16 in. up to 5/8 in. inclusive, 1/110 in.; from 5/8 in. up to 1 in. inclusive, 1/90 in.; from 1 in. up to 1 1/2 in. inclusive, 1/80 in.; from 1 1/2 in. upwards, 1/75 in. For cast iron these feeds may be increased 20 per cent.

For small holes in brass the feed should be from 0·0015 in. to 0·003 in. per revolution; 1/8 in. to 1/4 in. diameter, 0·003 in. to 0·006 in. per revolution; 1/4 in. to 1/2 in. diameter and upwards 0·006 in. to 0·020 in. per revolution. When drilling mild steel the feed should be approximately one-third the above, and harder metals slower in proportion.

Should the drill be running too fast the outer edge of the lip becomes quickly dulled; should the central stem become dull, or the lips chip, the feed is too great.

GRINDING DRILLS.

When grinding the drill points, the following rules should be observed:—

I. Both cutting lips, fig. 14, should be inclined at the same angle with the axis of the drill, and must be of equal length. The point angle of 59° has been universally adopted as best suited for average conditions.

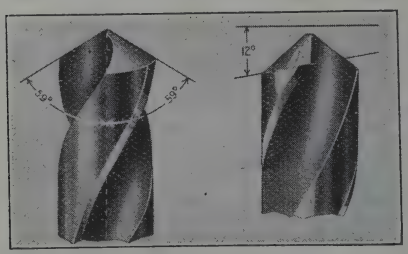


FIG. 14. FIG. 15.

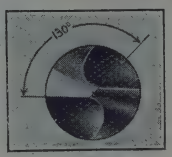


FIG. 16.

II. The drill point must have the proper clearance or contour of surface back of the cutting edges, and this clearance must be identical on both sides. Approximately a 12° clearance angle, fig. 15, combined with the centre angle of 130°, which will give a constantly increasing clearance toward the centre, fig. 16, has proved best for average conditions.

Some of the undesirable conditions resulting from drill points improperly ground are as follows :—

(1) If both lips are not ground at the same angle with the axis, fig. 17, one lip will fail to counteract the tendency of the other to spring away from the cut; consequently, one lip will do more work than the other, which will result in its becoming dull more rapidly than if both lips were cutting equally, and it will be subjected to an abnormal torsional strain.

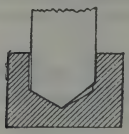


FIG. 17.

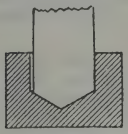


FIG. 18.

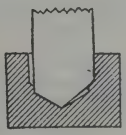


FIG. 19.

(2) When the cutting lips of a drill have the same point angle but are of different lengths, fig. 18, the point of the drill will be off centre, or eccentric. As a result, the hole will be oversize to an extent equal to double the amount of this eccentricity.

(3) If the drill point is ground both with lips at different angles and of different lengths, fig. 19, there will be a combination of the undesirable results described in the two preceding paragraphs.

(4) Fig. 20 shows a side and end view of a drill with the proper angle of point (59°) and the proper angle of clearance at the periphery (12°), but with insufficient clearance at the point or centre.

(5) Fig. 21 shows a drill with insufficient clearance both at the periphery and at the centre. The line ABC is at an angle of 12°, but there is no clearance immediately back of the cutting edges (BC), and the excess of clearance at the heel (AB) is of no benefit.

(6) Fig. 22 shows what is liable to happen to a drill ground with insufficient clearance, or as described in paragraphs Nos. 1 to 5, especially if an attempt is made to obtain maximum production.

FIG. 21. FIG. 22. FIG. 23.

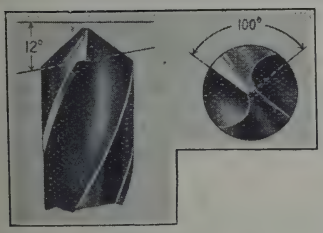


FIG. 20.

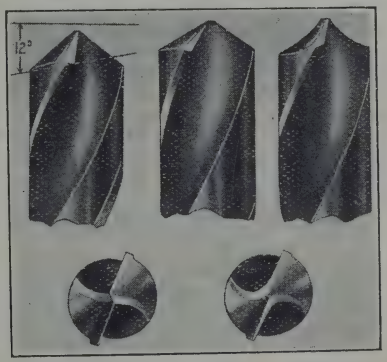


FIG. 24. FIG. 25.

(7) Fig. 23 shows a drill with a clearance angle of about 12°, but it does not have the proper contour back of the cutting edges. This manner of grinding leaves the cutting edges thin and weak, causing them to crumble away under heavy feeds.

Most twist drills are made with a gradual increase in the thickness of the web or centre of the drill toward the shank. As the drill becomes shorter and the web thicker, greater force

is required to drive it. To overcome this, it is good practice to thin the web by grinding away the excess thickness, reducing it to its original dimensions. This grinding must not extend too far up the flute of the drill, and care must be exercised that the cutting lips are not injured and the same amount is ground out of each groove. Fig. 24 shows a drill with the web properly thinned. In fig. 25 the grinding is excessive, leaving the web entirely too thin and liable to crumble. When this happens a split drill is practically inevitable.

Paragraphs 1 to 5 and the preceding paragraph show the cause of drills splitting up the centre, and no manufacturer should be called upon to replace a split drill unless a flaw is evident in the steel.

Twist drills are made with a slight taper from point to shank, so that the largest diameter is always across the corners of the cutting lips. This prevents the drills from binding in the work when they are sharp. If the outer corners are allowed to become badly worn, the drills will bind and cannot perform satisfactorily. Whenever the outer corners of the cutting lips show wear, the drills should be reground and every particle of worn surface removed, or the drill will continue to bind and very quickly be damaged beyond repair.

In grinding high-speed drills care should be taken not to overheat them, and when heated they should never be plunged into cold water. Doing so is likely to cause small surface cracks, which reduce the efficiency of the drill and may result in serious damage to it. Forcing the grinding on a wet grinder may also bring about the same condition.

It is hardly possible to do grinding as accurately by hand as by using a good twist-drill grinding machine.

Broken or damaged tangs of drills are generally the result of an imperfect fit of the drill shank in its socket, which may be caused by a worn-out socket, dirt or chips accumulating in the socket, or bruises on the shank of the drill.

In any case, the driving power of the taper is reduced or destroyed, resulting in an abnormal strain being put upon the tang.

A drill of either carbon or high-speed steel that can be filed is not necessarily too soft for service; in fact, if drills were tempered so that a good file would make no impression, they would be entirely too hard for general use. If there is any doubt regarding the temper, try the drills in actual service.

Assuming the drill is properly ground, when the corners of the cutting lips wear away rapidly it is an indication that the speed is too great. If the cutting edges roughen or break out in minute particles it indicates that the feed is too great.

It is seldom that very small drills can be run at more than a fraction of the speed necessary to obtain the best results, and excessive breakage is inevitable. They should be run true and the cutting edges kept sharp; a fine-grade emery stone is best suited for this latter purpose.

MORSE TAPER MEASURES FOR TWIST DRILLS.

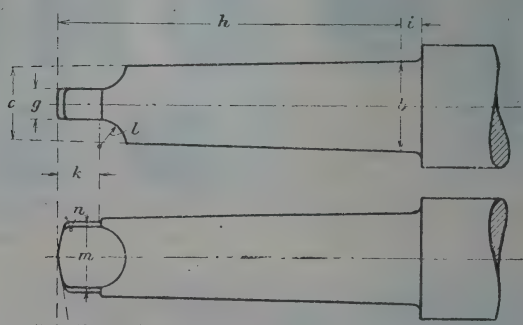


FIG. 26.

Morse Taper No.	*b*		*c*		*g*		*h*		*i*		*k*	*l*	*m*	*n*	Taper.	
	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	mm.	mm.	mm.	per 100 mm.	in 12-In.
1	12,05	·475	9,03	·356	5,1	$\frac{13}{64}$	60,5	$2\frac{3}{8}$	5	$\frac{3}{16}$	8	5	8,4	1,3	5	·600
2	17,75	·700	14,09	·556	6,3	$\frac{1}{4}$	73	$2\frac{7}{8}$	5	$\frac{3}{16}$	9,5	6,5	13,4	1,6	5,017	·602
3	23,8	·938	19,26	·759	7,9	$\frac{5}{16}$	90,5	$3\frac{9}{16}$	5	$\frac{3}{16}$	11	7	18,5	2	5,017	·602
4	31,25	1·231	25,31	·997	11,9	$\frac{15}{32}$	114,5	$4\frac{1}{2}$	6,5	$\frac{1}{4}$	13	8	24,5	2,5	5,191	·623
5	44,4	1·748	36,74	1·446	15,9	$\frac{5}{8}$	146	$5\frac{3}{4}$	6,5	$\frac{1}{4}$	16	9,5	35,7	3	5,25	·630
6	63,35	2·494	52,76	2·077	19	$\frac{3}{4}$	203	8	8	$\frac{5}{16}$	22	12,5	50,8	3,8	5,216	·626

Notes on Drilling.

The power for a given diameter of drill and feed is proportional to the cutting speed.

The horse-power is proportional to the torque, and for a given drill and speed does not increase as fast as the feed.

Since the torque is practically proportional to the diameter of the drill squared, the horse-power, for a given feed and cutting speed, is directly proportional to the diameter of the drill.

The horse-power per cubic inch of metal removed is inversely proportional to the feed and independent of the drill and cutting speed.

The work required to drill a given hole, when one drill is used, is greater than that required to drill the same hole in two operations with drills of different diameters. The greater the difference in the drill diameters, the greater the saving in work; speed and feed remaining the same throughout. This is due to the fact that the mean cutting angle of the single drill is greater than the average angle in use for the two drills and that the stress is proportional to the angle.

With twist drills of the usual proportions, the cutting angle is not sufficiently keen to drag the drill into the work when enlarging a hole in cast iron or steel.

The horse-power when operating on soft cast iron or medium steel varies as $t^{0·7}$ (t = feed per rev.) for a given drill and speed.

The horse-power for a given feed and speed does not increase as fast as the diameter but varies as $d^{1·8}$.

The torque and horse-power when drilling medium steel is about 2·1 times that required to drill soft cast iron with the same drill speed and feed.

The end thrust when operating on cast iron or steel does not increase in proportion to the feed for a given diameter of drill or in proportion to the diameter for a given feed.

While the chisel point scarcely affects the torque it is accountable for about 20 per cent. of the end thrust.

Lubricated trials on steel when compared with the dry tests show a diminution in the torque and horse-power, varying from 28 per cent. with the $\frac{1}{100}$ feed to 8 per cent. with the $\frac{1}{5\cdot5}$ feed. This may be due to the lubricant washing away the small metal chips which tend to jam between the walls of the hole and the drill, and to the preserved cutting edge. The diminished frictional resistance of the shaving across the lip together with above reduces the end thrust by about 25 per cent. for all feeds.

As the result of a series of experiments on twist drills, recently undertaken at the engineering experiment station of the Illinois University, the following lubricants are recommended:—For tool steel—lard oil, machine oil, turpentine, soda-water, kerosene; for soft steel—lard oil, machine oil, soda-water; for cast iron—dry or compressed air; for brass—dry or paraffin oil; for aluminium—kerosene, soda-water, and aqualine and soda-water.

The drill most commonly adopted in practice has an included angle, at the point, of 120°. If this angle is increased, the torque diminishes but the end thrust increases, while if this angle is decreased, the reverse is the result. So far as economy in power is concerned the torque is the factor to consider, as the feeding horse-power is only about 1 per cent. of the whole, in small drills, and very much less for the larger sizes. From this point of view the drill with the larger point angle is to be preferred. The accompanying increased end thrust, however, strains the machine parts in proportion. When the point of the drill breaks through the metal at the bottom of the hole, a considerable portion of the end load is removed. The strain due to that load is released, thereby causing the drill to advance more than its rated feed, and possibly to break.

The drill with the greater included angle will be most likely to give trouble in this direction, both on account of the increased strain and torque, and conversely.

By decreasing the spiral of the drill a keener cutting angle with a decreased end thrust and torque can be obtained without altering the point angle above the accepted standard, 120°. This, however, would in turn affect the durability of the drill.

With a small included point angle there is little metal to support the cutting edge at the chisel point, and trouble due to blunting of this part is to be expected.

The endurance of a drill may be increased by from 300 per cent. to 1,000 per cent. by rounding the sharp corners at the periphery.

In estimating the time required to drill a hole of given depth, the length of the drill point must be taken into account. The length of the point for different included point angles is :

$$90° = 0{\cdot}5d\,; \quad 120° = 0{\cdot}29d\,; \quad 150° = 0{\cdot}134d.$$

In the course of a paper read before the Institution of Production Engineers, Mr. L. C. Keen gave the following advice :—Do not attempt, on drills below $\frac{3}{8}$-in. diameter, to drill a depth more than three times the diameter of the drill, without drawing out to clear the chips ; if the drill as well as the work is revolved, however, it can be easily fed in to a depth of five times the diameter, at one traverse.

True drilling is usually dependent upon good centering, and it may be advisable to draw attention to the well-known but often ignored rule, namely, that the centering tool must have a lesser cutting angle than the drill point, otherwise the drill will strike on the point, wobble, start out of centre, and sometimes break.

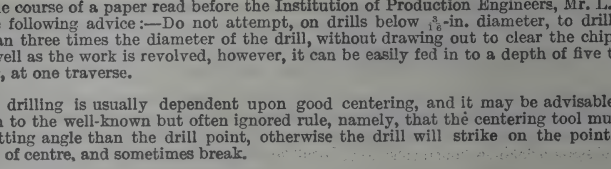


FIG. 27.

Good centering. Bad centering.

Fig. 27 shows good centering at *A* and bad at *B*. As a general rule the centering drill should have an included angle of 100° against the standard angle for the drill point of 119°.

(*Machinery.*)

(See also '*Smith & Poliakoff : Proc. Inst. of Mech. Engrs.* 1909.')

A high efficiency can be obtained by fitting all running bearings of drilling machines (including the spindle bearings) with annular ball bearings, which never require adjustment. The fact that the spindles themselves have no sleeve or rubbing bearing whatever enables even the smallest sizes of high-speed drills to be run at their proper speeds. At the same time the saving in friction all over the machine permits the feed to be quicker, and enables larger holes to be drilled than has been hitherto possible with ordinary sensitive machines.

Vulcanised fibre is being applied to the thrust bearings of light, sensitive, drilling machines. Ball bearings cause considerable trouble if one of the balls fractures or chips, and it has been found that a fibre disc answers the purpose admirably. The permeability of the fibre to oil renders it self-lubricating, and its life under these conditions is remarkable. (*Machinery.*)

SMALL DRILL PROTECTOR.

The function of this protector is to stiffen the shank of the drill, leaving exposed a length of the drill sufficient only for the depth of the hole to be drilled. The protector, fig. 28, consists of a length of hard brass, drilled from one end to the other, and with about three-quarters of its length slotted on one side, the internal diameter being equal to the diameter of the drill to which it is to be applied. To use the protector, the drill is inserted therein with the cutting point projecting from the chamfered end, the exposed length being equal to the required depth of the hole to be drilled. The split end of the protector is inserted into the drill chuck so that it is secured for about half an inch of its length, the chuck then being tightened up in the usual manner.

If it is required to drill a hole of greater depth than usual all that is necessary is to release the chuck and slide the protector farther up the drill for the extra length required and then tighten up the chuck again.

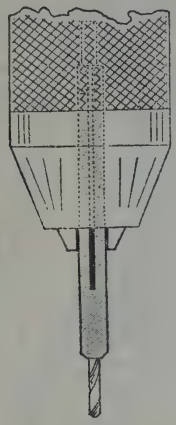


FIG. 28.

The protectors are supplied suitable for short or long length drills in sizes varying from $\frac{1}{32}$ up to $\frac{1}{8}$ in., from 20 to 66 wire gauge sizes and from 1 to 2 mm.

Portable Electric Drills.

THE WESTOOL ELECTRIC DRILL.

This modern heavy duty side spindle drill, fig. 29 (*The Westminster Tool and Electric Co., Ltd., Westool Works, Putney, London, S.W.* 15), has been designed to withstand the hard usage and continuous heavy work met with in shipyards, boiler works, railway shops, and general engineering works. Its special features are great mechanical strength, maximum length of feed, and high efficiency secured by the use of ball bearings throughout.

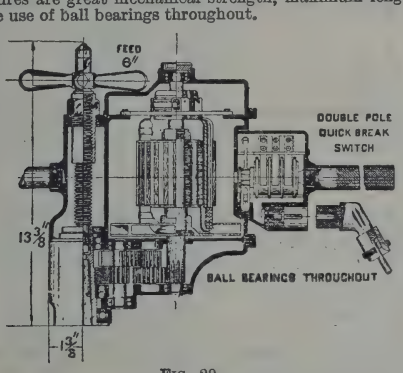


FIG 29.

All electrical conditions have been carefully considered—the armature and commutator being ventilated by a shrouded fan fitted to the lower end of the windings which produces a strong draught, not only round the windings but also through the ventilating holes provided in the core stampings.

The reversible switch is of exceptionally strong design with double pole quick make and break action.

The firm have a complete range of electric portable drilling machines, meeting all normal conditions. The fourteen sizes are shown in the following table :—

Size.	Type.	Fitted with	Capacity M. Steel.	Speed r.p.m.	Weight lbs.
No. 00	Grip handle	$\frac{1}{4}$-in. chuck	$\frac{1}{4}$	800	$7\frac{1}{2}$
No. 0	Spade handle	$\frac{3}{8}$-in. chuck	$\frac{3}{8}$	660	$13\frac{1}{2}$
No. 0A	Breast plate	$\frac{1}{2}$-in. chuck	$\frac{1}{2}$	550	14
No. 1 St'd.	Feed screw	No. 1 Morse taper	$\frac{9}{16}$	400	24
No. 1 S.S.	do.	No. 1 Morse taper	$\frac{9}{16}$	200	35
No. 1A	do.	No. 2 Morse taper	$\frac{3}{4}$	200	26
No. 2 St'd.	do.	No. 2 Morse taper	$\frac{7}{8}$	250	34
No. 2 S.S.	do.	No. 2 Morse taper	$\frac{7}{8}$	180	36
No. 2A	do.	No. 3 Morse taper	$1\frac{1}{8}$	160	36
No. 3 St'd.	do.	No. 3 Morse taper	$1\frac{1}{4}$	160	65
No. 3 S.S.	do.	No. 3 Morse taper	$1\frac{1}{4}$	100	68
No. 4	do.	No. 4 Morse taper	$1\frac{1}{2}$	120	70
No. 5 St'd.	do.	No. 4 Morse taper	2	75	62
No. 5 S.S.	do.	No. 4 Morse taper	2	40	64

This firm have recently introduced a series of portable flexible shaft electric grinders for 6-in., 8-in. and 10-in. diameter grinding wheels in which the troubles arising from broken shafts at the junction of the shaft and the handle are eliminated by the employment of their patented Westool handle.

The Van Dorn Drill.

These tools, fig. 30, are made by the Van Dorn & Dutton Co., Cleveland, Ohio. They are designed so as to be easy to handle, and are light and compact. The machines designed to take drills up to $\frac{5}{8}$-in. diameter may be operated by either direct or alternating current. Another advantage of the design lies in the fact that the drill spindle is offset, so that holes may be drilled close to a flange or similar projection.

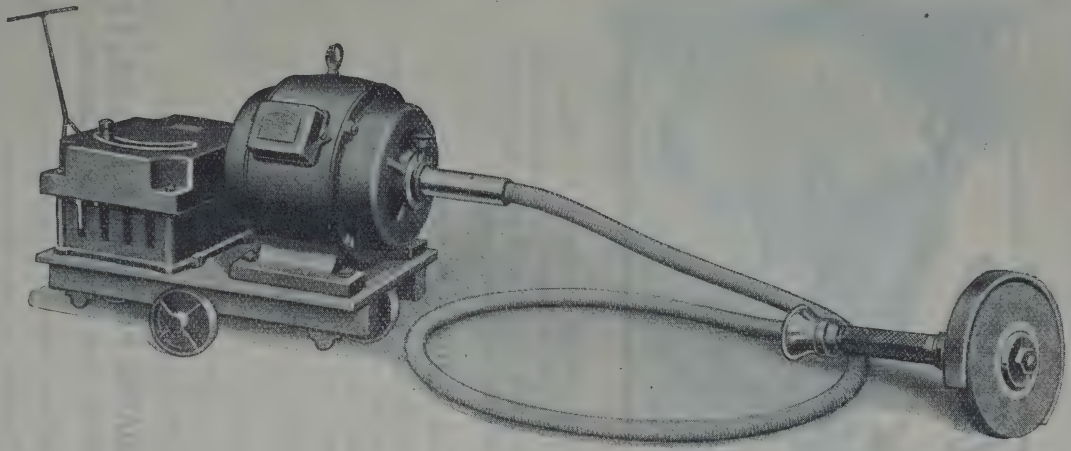
The Gear Case is a light aluminium casting reinforced with ribs to resist distortion. This case is not only an efficient housing for the gears, but forms a grease chamber from which the gears and main spindle bearing receive ample lubrication. Each end of armature shaft runs in a ball journal bearing fitted in a steel housing, and the thrust is also taken on a ball thrust washer. The gear spindles run in high-grade phosphor bearings.

The Gears, accurately generated, are made of special heat-treated steel, hardened and ground.

The Motor is series wound. The adoption of this type of winding renders the speed automatic, the pressure used to force the drill into the work governing the speed of the drill. The armature and field coils are form wound and thoroughly insulated.

The Armature is of the slotted drum type built up of soft steel laminations, these being made from special steel adapted to the purpose and uniformly insulated. On the DC.2 and larger machines the armature is built on a hollow shaft to preserve lightness.

WESTOOL FLEXIBLE SHAFT ELECTRIC GRINDERS



These Grinders are fitted with the Westool Patent Self-aligning Handle which eliminates risk of breakage at the junction of flexible shaft and handle. Three standard sizes for 6″, 8″ and 10″ diameter wheels to suit all circuits.

THE WESTMINSTER TOOL AND ELECTRIC CO. LTD.

Westool Works—Putney Bridge Road, LONDON S.W.15.

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F. 1116

FOR drilling holes in metal or wood, the LITTLE GIANT meets the demand for Portable Electric Drills that give rapid work in comparatively unskilled hands.

OUTSTANDING FEATURES:

Ease of Manipulation	High Drilling Speed
Conveniently placed Trigger Switch	Ball Bearings throughout
Light Weight	Air-Cooled Motor

Portable Electric Grinders also supplied.

Write for Catalogue No. 14, *with full particulars of our Little Giant Drills and Grinders.*

(*See Editorial pages* 1117-1120 and 1153-1157.)

THE CONSOLIDATED PNEUMATIC TOOL CO., LTD.

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F. 1117

Ventilation.—One of the distinctive features of the Van Dorn drills is the system adopted for thoroughly cooling the motor. It consists of a large aluminium fan of special design, screwed on the armature shaft. It is so constructed and placed in such a position as to draw out the hot air at one end of the machine, to be replaced by cool from the other. A constant draught is therefore maintained, ensuring a low temperature.

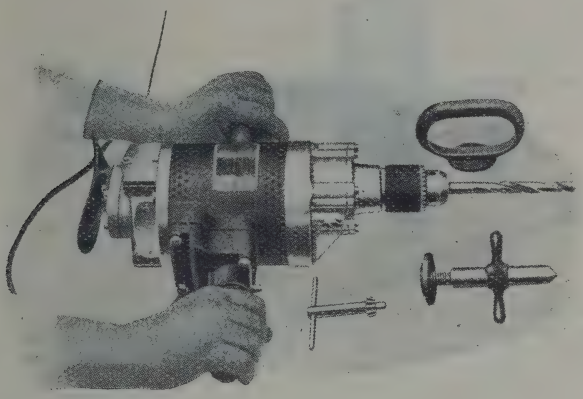


FIG. 30.

The Switch is of the quick-break type with a capacity of 5 per cent. above the duty required. By the use of release attachments the switch has the same rapidity in breaking as in the making contact. The larger sizes are provided with a quick-acting self-releasing attachment.

A Safety Fuse, consisting of a small piece of fuse wire held by screwed terminals, is fitted to machines up to and including ½-in. capacity, and may be quickly replaced if necessary; this prevents the possibility of damage to the machine from overloading or from a short circuit, which is generally caused by the operator omitting to clean the commutator.

MINIMUM DRILLING PERFORMANCE OF UNIVERSAL PORTABLE ELECTRIC DRILLS.

Carbon-steel drills in 0·20 per cent. to 0·30 per cent. carbon steel

Capacity of Tool and Size Drill. In.	Speed.	Rate of Feed. In. per Min.	H.P. at 1 H.P. per Cub. In. Metal Removed per Min.*
¼	800	1½	0·08
5/16	650	1⅜	0·10
⅜	525	1¼	0·13
½	375	1	0·19
⅝	300	¾	0·23

THE LITTLE GIANT ELECTRIC DRILL.

(*The Consolidated Pneumatic Tool Co., Ltd.*)

This drill, fig. 31, is made in many sizes and in A.C., D.C., and universal types. The armature is built up on a one-piece shaft and pinion, hardened and ground, ensuring perfect alignment of pinion at all times. On large sizes, the armature core and commutator are mounted on sleeves, and may be removed from the shaft. Forced ventilation is obtained by means of a fan mounted

* Extensive tests have shown this to be a reliable basis for determining power requirements

on the armature shaft. The coils of the armature are former wound, heavily insulated, and carried in insulated slots in the armature core. Other important features are: The use of ball

FIG. 31.

bearings, long feed screw (entering into the body of supporting bracket), thus giving the same rigidity as a telescopic feed; also a quick-acting control switch, making slow break impossible and preventing destructive burning of contacts, and a removable, and therefore easily replaced, tool socket in the spindle.

THE LITTLE GIANT AIR DRILL.

(The Consolidated Pneumatic Tool Co.)

Fig. 31A shows a Little Giant Air Drill in section. This particular machine, which is representative of the majority of air drills on the market, has four cylinders arranged in pairs diagonal to a two-throw crankshaft, thus two cylinders diagonally opposed operate on one crank,

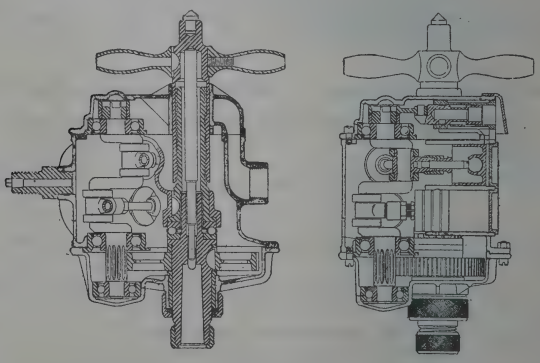


FIG. 31A.

giving the maximum power for the minimum weight and overall dimensions; such an arrangement also gives best mechanical balance and freedom from vibration.

One end of the case carries a feed screw, breast plate or grip handle, the other the drill chuck. On each side (usually carried from stout bosses on the drill case) are two handles, usually of steel pipe for lightness, one handle acting as air inlet and having a cock or throttle incorporated therein. See fig. 31B.

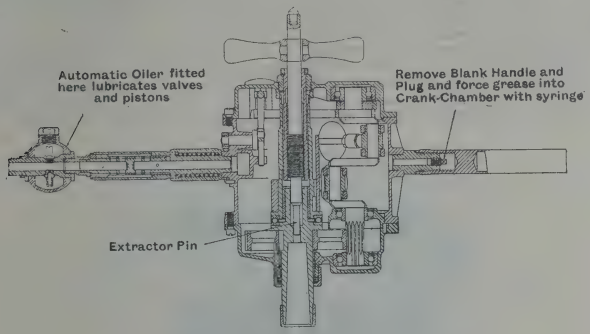


FIG. 31B.

Bearings are usually of the ball or roller type, as these suit the high speeds and powers which are developed in such relatively small frames. Sometimes even the big ends of the connecting rods are fitted with balls or rollers, though this is exceptional.

As these machines develop very considerable power (from 1 to 5 h.p.) for their size and weight, it is necessary to use high-grade materials, consequently special steels are used, and all parts are specially heat treated and ground to a finish.

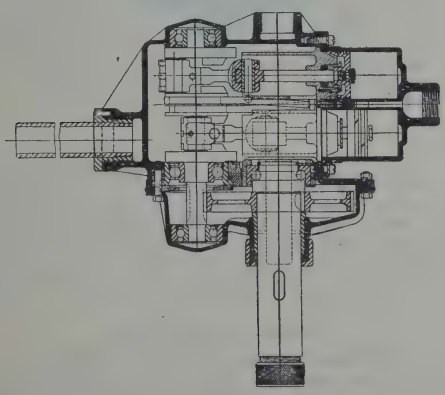


FIG. 31C.

Generally, piston or corliss type valves are used, operated by eccentrics of the usual type. Occasionally, a flat plate type of valve is employed, and sometimes a rotary valve has been used with success, the latter being driven by a spur wheel from the main shaft.

A type of tool made by the Consolidated Pneumatic Tool Company is the 'Red Giant,' fig. 31c, which contains a twin cylinder double-acting engine. This engine develops equal power to a four-cylinder type, and has crosshead guides, piston valves, and a two-throw balanced crankshaft.

One problem with these small high-speed air engines is the lubrication of the parts, as the drill has to operate in any position that the user may find convenient. Sometimes it operates with the crankshaft horizontal, sometimes vertical, and often at any intermediate position which is necessary on the job, and the difficulties are still further complicated by the necessity of providing the crank case with a 'breather.'

Fig. 32 shows the arrangement introduced by the Consolidated Pneumatic Tool Company. By this arrangement the atmosphere is admitted automatically at the top end of the crank case only, *i.e.* at the end where there is no oil. A tube, which is open to the atmosphere through a **T**-piece in the middle and may be closed at either end by a double cone-shaped plug, which is free to move inside the tube, is fitted approximately parallel to the crankshaft. When the

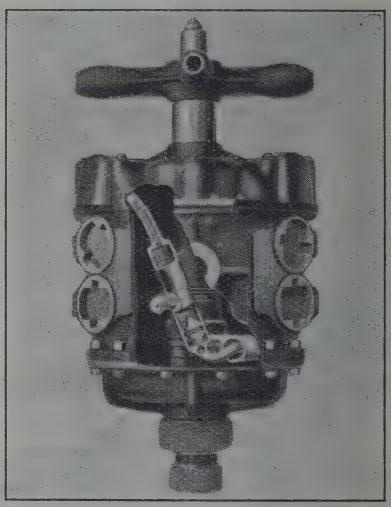


FIG 32.

machine stands with the drill point downwards, the oil is obviously at the lower end of the crank case, and the lower end of this tube is submerged in oil. The cone plug also falls to this end and closes the tube, so that no oil can be blown into it, and at the same time leaves the top end free to breathe to the atmosphere through the **T**-connection, to the outer air.

If the tool is turned upside down, the oil flows to the other end of the crank case; the cone plug drops to the other end also and now closes that end.

If the machine is operated with the crankshaft horizontal, the cone plug takes no definite position, and the crank case may breathe through either end, and no oil gets blown out.

Drilling Appliances.

THE 'SELSON' GRAVITY DRILLING MACHINE VICE.

In this arrangement, fig. 33, the jaws are opened by sliding them up the angle guides, the maximum opening of the upper jaws being 8 ins., the lower 2½ ins. When the work is set, gravity, supplemented by the pressure of the drill, forces the jaws downwards in the guides, ensuring an absolutely firm hold of the work and making the vice practically an automatic tool.

A slight turn of the handle prevents the work from becoming slack when the pressure on the drill is decreased at the bottom of the hole.

The vice can be used loose on the machine table, except in extreme cases. Slots are, however, provided for bolting it down.

The vice will securely hold all round work from ½ in. to 8 ins. diameter. Work is ensured against turning, even with slight pressure on the drill. Special shapes are held as firmly as regular ones.

There are but five main parts in the vice, which adds to its simplicity.

Size of base, 12 ins. × 6½ ins. Approximate weight, 45 lbs.

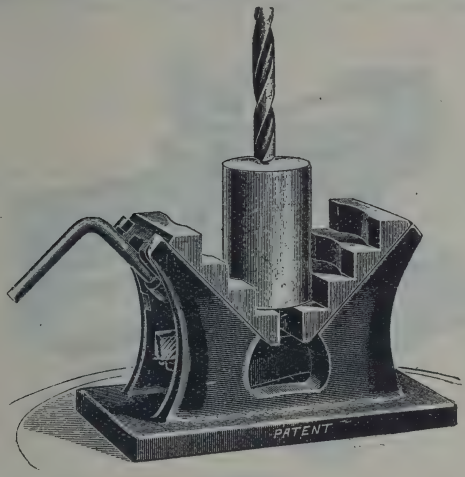


FIG. 33.

V-BLOCK WITH ADJUSTABLE CLAMP.

A compact method of fitting a clamp to grip work in a V-block for marking or for drilling purposes, is to make the block with uprights composed of two plates attached to the ends of the block (fig. 34). Three pinholes are drilled through the uprights, into which an ordinary headed pin is slid to sustain the cranked clamp seen. This is tightened down upon the work by setting up the screw. ('*Machinery*.')

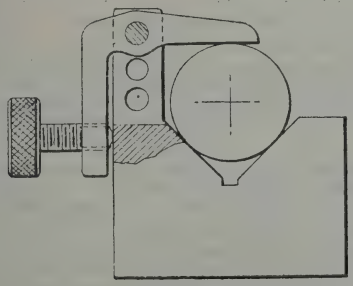


FIG. 34.

THE 'BROOKE' QUICK-CHANGE UNIVERSAL DRILL JIG.

This arrangement (fig. 35) is for the purpose of drilling pin holes in bolts, studs, pins, etc., for split pins, etc. It consists of a baseplate, on which are mounted two pillars carrying, at the top, a steel cross beam, which serves as a clamp for holding the work and also as a guide to the drill by means of suitable bushes. The jig can either be used on a table with a plain surface or bolted down, as required. For plain service tables, a locating pin is supplied to fit the base-

plate and hole in the centre of drilling machine table, keeping the guide bush in the cross beam always in line with the drill spindle.

The work is held in a V-block, provided with a groove on each side, fitting the square portions of the pillars, which thus act as guides, enabling the block to be rapidly adjusted to the required position indicated by pointer and rule, and afterwards locked in place by a small lever instead of the hexagon nut shown in the fig. This block admits bolts from $1\frac{1}{2}$ in. to $\frac{3}{4}$ in. diameter,

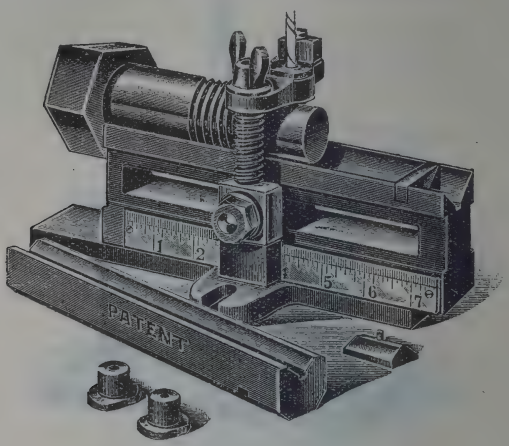


FIG. 35.

and for smaller work an additional V-block is supplied, which fits into the larger one, and can be used for objects down to $\frac{1}{4}$ in. diameter. For studs and other parallel work, steps are provided on the right of both V-blocks, against which the end of the stud rests.

MAGNETIC CHUCKS.

The Magnetic Chuck is now largely used for holding machine parts of iron and steel for grinding, turning, and planing operations. Many pieces, such as milling cutters, thin saws, air-compressor valve discs, chain links, etc., can be more effectively held by this method than by any other. Not only is there a great saving in the time ordinarily required for setting up, but the likelihood of distorting the job due to unequal straining of the holding down bolts is eliminated.

It must be understood that the holding power of a magnetic chuck depends as much on the shape and section of the piece to be held as on the magnetic chuck itself. If the piece is small in section the hold will be very light, no matter what the section or intensity of the chuck magnets may be. The hold is entirely dependent upon the number of magnetic lines that can be passed through the section of the piece, and not on the total magnetism that the chuck can produce. Some makers claim a holding power of 100 lbs. per sq. in., this having been attained on a perfectly surfaced cube of Swedish iron applied between the chuck poles. This affords no useful measure of the holding value of a magnetic chuck, as theoretically a small magnet either of steel, wrought iron or even cast iron, if perfect at the joints, would give (on such a cube) 100 lbs. per in. On the other hand, if two such cubes were placed together the pull would not be proportionately increased, as the magnet being small the section of the first cube would absorb all the magnetism it could supply. Thus a chuck, say 30 ins. by 8 ins., which would pull 100 lbs. on any sq. in. of its surface could not, under any circumstances, pull 30 ins. by 8 ins. by 100 lbs., or nearly 11 tons, on its entire surface. The pitch of the poles should be arranged to suit the class of work to be held; if the pieces are of heavy section, the magnet must be of heavy section to get the best results.

Fine Grinding.—For fine grinding it is well to reduce the magnetic pull of a chuck face, either by inserting resistances in the coil circuit, or by the interposition of non-magnetic material

FIG. 36.

between the work and the chuck face. The lighter the pull the more accurate the resultant work. Specially constructed chucks of a very light but even pull are necessary for thin saws, light piston rings, etc. Grinding with water, soda and other liquids makes it absolutely essential that the magnetic chucking apparatus must be impervious to water. In the Humphreys chucks

FIG. 37

FIG. 38

FIG. 39

FIG. 40.

FIG. 41

one of the leading features is the insulating method employed. The wire itself, before winding, is insulated with a special liquid having very high insulating properties and capable of withstanding weak acids, alkalies, saline solutions, or alcohol. After winding and coating with a special fabric for mechanical protection, the coils are heated to 200° F., and placed in a heated

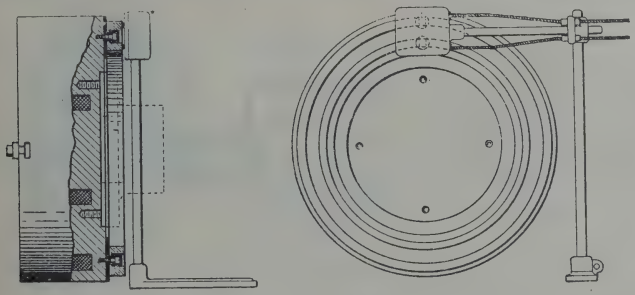


FIG. 42.

tank from which all air and moisture is then extracted. After being subjected to this high vacuum for some time, the tank, without breaking the seal, is filled with a liquid asphaltum compound at high pressure, rendering the coils absolutely proof against moisture, etc. The coils are then placed in position over the cores of the magnets, and the whole chuck body filled and made solid with the asphaltum compound.

Fig. 36 shows the face of a Humphreys (Pat.) circular chuck suitable for piston rings, saws, milling cutters, and general work. These chucks are constructed in sizes ranging from 6½ ins. diameter to 72 ins. diameter. Other designs of chuck faces for special work are shown in figs. 37,

38, 39, 40 and 41; the finer pole designs being used for very small pieces, and the simpler 8-pole design for larger section pieces.

The method of current supply is shown in fig. 42; this is used for dry grinding only. The chuck is fitted to a lathe or grinding machine spindle exactly as an ordinary mechanical chuck.

The brass slip-ring running with the chuck itself collects the current from a contact box, which is held by a tubular support from the lathe or machine bed. The contact box contains a pair of carbon brushes actuated by springs; these brushes are totally enclosed. The method is simple and effective, especially in cases where the chuck is only used occasionally and the apparatus has to be removed and set up each time. Fig. 43 shows an arrangement adopted by the above makers for both horizontal and vertical machine spindles. A hollow spindle machine

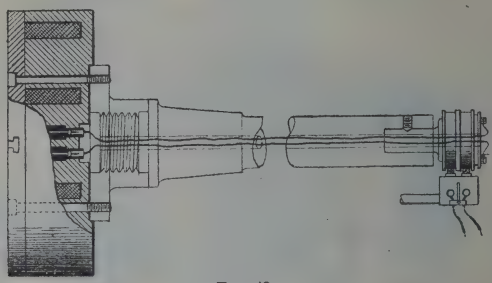


FIG. 43.

is necessary in this case, and the advantage is that all water suds or soda mixture is kept entirely away from the running contacts. The current is carried from the contact rings through the spindle, and is conveyed to the chuck windings by means of a pair of plugs fitting directly into the back of the chuck.

Magnetic chucks are not adaptable to alternating current, and must be used on the voltage for which they are designed. If a higher voltage be applied there is a likelihood of burning out the coils, and with a lower voltage the full power of the chuck is not developed. Fig. 44 shows

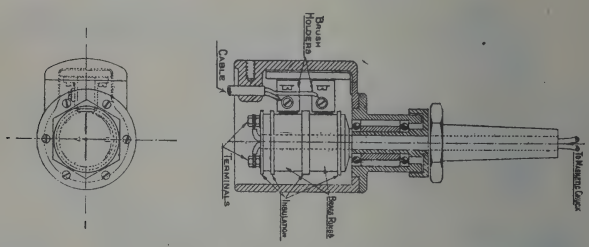
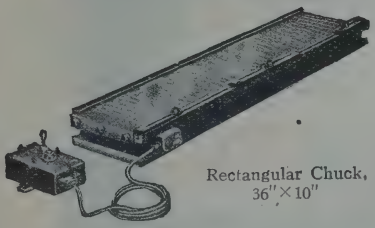


FIG. 44.

the contact arrangement when used with a vertical spindle; it is totally enclosed, the shank is tapered and fitted with a nut to facilitate removal. An oil throw or guard is provided to keep off the bearing oil.

Flat Chucks.—In fig. 45 is shown the details of the 'Humphreys' standard flat chucks, suitable for grinding, planing, and milling machines. These are constructed in sizes up to 72 ins. by 10 ins.; they are fitted complete with a rise and fall parallel strip and an adjustable end-stop. Movable fingers or clamps may be set to support work set on edge; these fingers are secured by set screws in a T-slotted bar, which may be fixed conveniently at any height. The end-stop is necessary to take the thrust of a milling or planing cut; in most grinding operations it is not necessary to use it.

MAGNETIC CHUCKS OF ALL TYPES



Rectangular Chuck, 36″×10″

RECTANGULAR Chucks from 9″ to any length (sectional), including standard sizes for almost all makes of grinding machines.

DEMAGNETIZING apparatus for treating hardened steel.

Demagnetizing Plate with Transformer and Starter.

Circular Chuck, 42″ dia.

CIRCULAR Chucks from 6″ dia. to 42″ dia., in standard sizes. Also Chucks may be specially built for horizontal or vertical Grinding Machines, and for light or heavy work.

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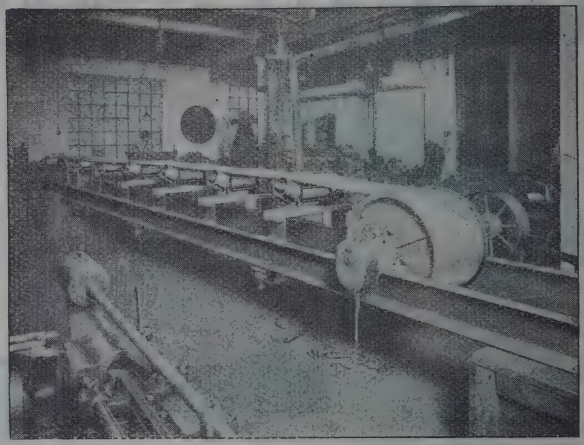

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FOR the removal of iron from every kind of raw material, either as an impurity or to protect crushing and grinding machinery from damage.

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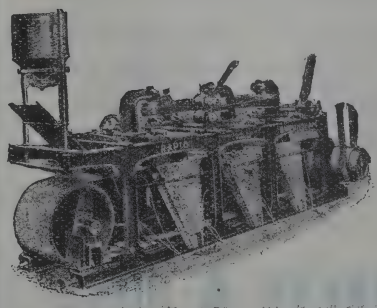

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Separators for feebly magnetic ores.

Electro-Magnetic Chucks for Grinding Purposes.

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THE RAPID MAGNETTING MACHINE Co. Ltd.

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F. 1125

Fig. 46 shows a variation of this form of chuck for machining taper pieces. This chuck is carried on a sub-base hinged at one end, and has a fine knurled screw adjustment at the other. The index graduation is in inches per foot. When the setting is at zero the chuck can be used for ordinary flat work.

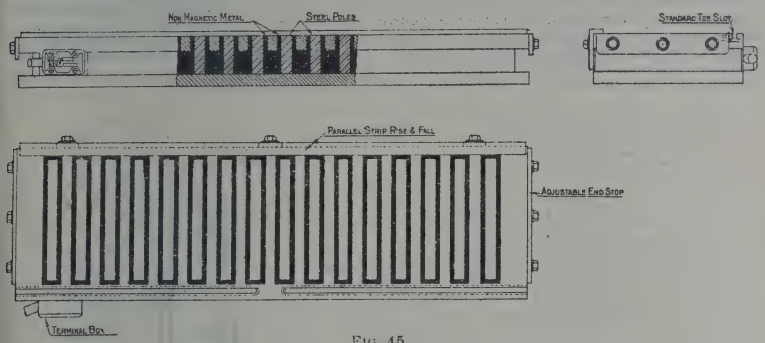

Fig. 45.

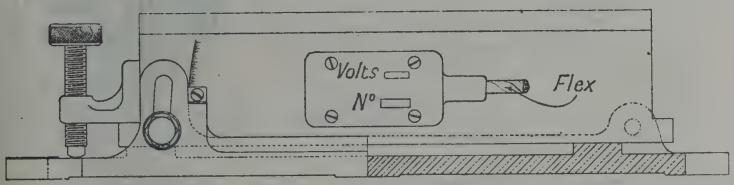

Fig. 46.

To facilitate the grinding of square sections on the chucks shown in figs. 45 and 46, an attachment has been recently devised. This consists of a rectangular block made up of steel plates of very high magnetic permeability interspaced with non-magnetic material. Placed on the chuck face without any connections, either mechanical or electrical, it brings into operation a vertical magnetic face by means of which work can be set up and ground square.

To grind a rectangular piece, grind two opposite faces on the magnetic chuck in the ordinary manner, then by holding the piece by one of the ground surfaces against the side of the attachment and supported underneath to the requisite height, a perfect square can be obtained.

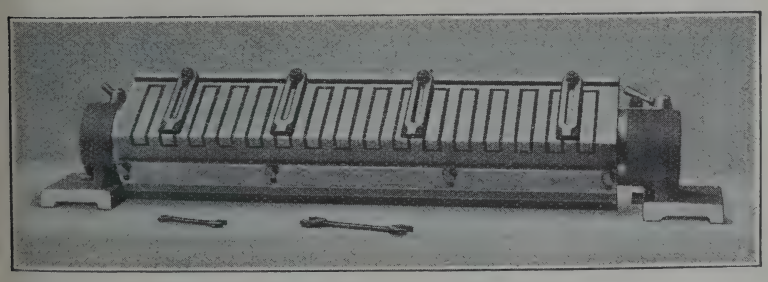

Fig. 47.

A new Humphrey Swivelling Chuck is shown in fig. 47. A graduated ring enables the operator to set the chuck at any desired angle.

The poles on this chuck are carried right up to the edge, thus permitting narrow pieces to be held on the side as well as on the top face of the chuck.

Switches.—One of the most important pieces of apparatus in connection with the magnetic chucks are the switches used for operating. When the current from a magnetic chuck is cut off, a back current is induced in the chuck coils. This induced current is of a very high voltage, and if the switch gear is not perfectly designed to deal with it, the insulation of the chuck, however well designed and carried out, will inevitably break down. The switch must be double-pole, that is, it must operate on both the positive and negative supply wires at the same time, also it must be capable of admitting current to the chuck in either direction, and in order to deal with the induced back current when switching the chuck off, it must be provided with a non-inductive resistance which must automatically be put in circuit with the chuck prior to breaking the circuit. Fig. 48 shows the 'Humphreys' No. 7 Demagnetising Switch. To operate it the

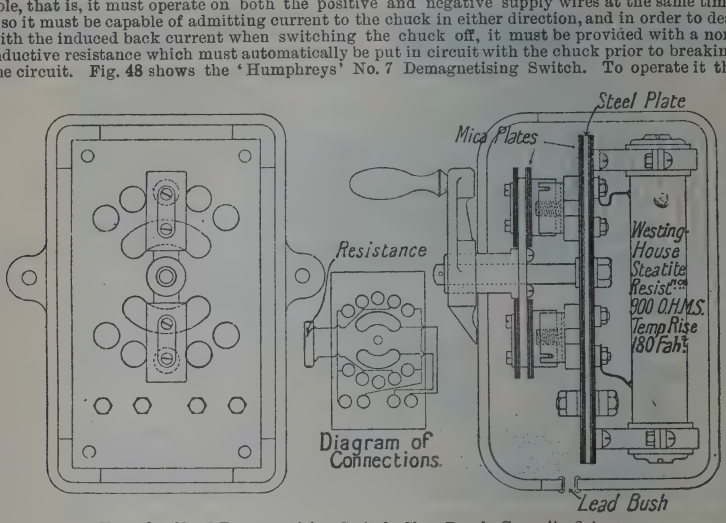

FIG. 48. - No. 7 Demagnetising Switch, Slow Break, Capacity 2 Amps.

switch handle must be moved past the 'Off' position and held momentarily on the 'Reverse,' going back quickly to the 'Off' position; this is for the purpose of demagnetising the chuck sufficiently to allow of the work to be easily removed. The view on the left of the figure shows the arrangement of contacts. For very large chucks a special oil-break switch is furnished; the method of operation is similar to that of the No. 7 switch, but the contacts are immersed in oil and the non-inductive resistances are carried in a separate iron case forming the base of the switch.

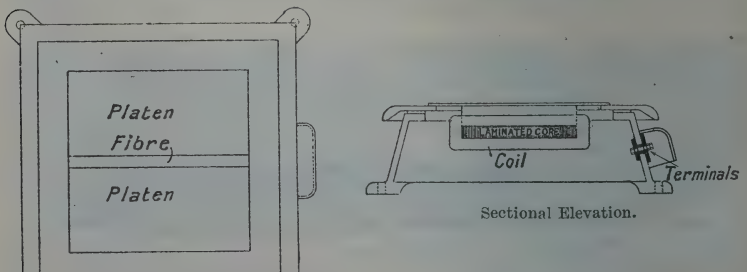

FIG. 49.

The sectional view on the right-hand side of the figure shows the non-inductive resistance The main plate is mica insulated; in several sizes of switches this main plate consists of a slab of slate.

The arrangement of the connections, etc., is shown in the central view of fig. 48.

Demagnetisers.—Consequent on the use of magnetic chucks is the permanent magnetic condition imparted to the finished work, which with milling cutters and similar articles would prove a decided objection. A magnetised milling cutter would collect to itself the cuttings as produced, and though this might not impair its efficiency as a cutter, it would be a source of annoyance to the operator. Fig. 49 shows a sectional elevation and plan of a demagnetiser by J. H. Humphreys & Sons. There are two working platens, and all that is necessary is to pass the work over these platens, when it will be instantly demagnetised. As shown in the section drawing, immediately under the working platens is a powerful laminated magnet, which takes from the transformer a low period, low voltage, alternating current. The transformer carries

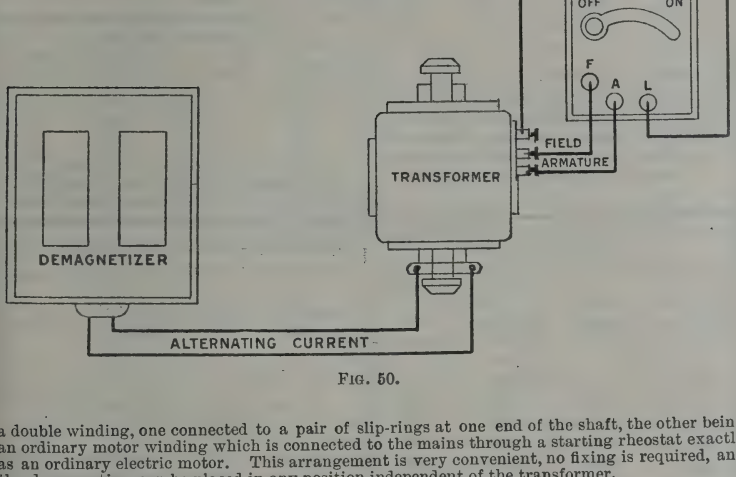

FIG. 50.

a double winding, one connected to a pair of slip-rings at one end of the shaft, the other being an ordinary motor winding which is connected to the mains through a starting rheostat exactly as an ordinary electric motor. This arrangement is very convenient, no fixing is required, and the demagnetiser can be placed in any position independent of the transformer.

The whole apparatus, fig. 50, includes demagnetiser, rotary transformer, and starting rheostat.

Electro-Lifting Magnets.

An electro-magnet attachment to overhead yard cranes facilitates the picking up of scrap and pig iron and is also useful for charging boxes with these in steel works. The attachment when provided with a skull cracker is used for breaking up scrap and pig. The ease with which the cracker can be picked up and dropped without the help of other labour than the crane man himself, also the speed of hoisting and freedom from accidents are factors which have contributed to the development of this gear.

A 5-ton crane to lift at 20 feet per minute takes about a 10 h.p. motor.

(See also page 921.)

POWER REQUIRED FOR MACHINE TOOLS.

LATHES.

Heavy Crank-shaft Lathes with Twin Saddles and Duplex Rests.				
Height of centres in inches	42	48	60	66
H.P.—Main drive	40	45	50	60
H.P.—Auxiliary	15	15	20	20

LATHES (*continued*).

Wheel Lathes for Locomotive Wheels (High Speed).

Diam. of Faceplate.	H.P. required for Two Tools.	Diam. of Faceplate.	H.P. required for Two Tools.
Ft. Ins.		Ft. Ins.	
3 0	10	5 0	18
3 6	12	6 0	21
4 0	14	7 0	23
4 6	16	8 0	25

The largest diameter swung may be taken as 4 ins. above the faceplate diameter. For lathes fitted with duplex rests and 4 tools in operation, increase the power given above by 50 per cent., while with 6 tools in operation double the power given is required.

Tyre Boring Lathes suitable for use with High Speed Steel.

Diam. of Faceplate.	H.P.	Diam. of Faceplate.	H.P.
Ft. Ins.		Ft. Ins.	
3 6	20	6 0	35
4 0	25	7 0	35
5 0	30		

Axle Lathes (High Speed).

Height of Centres.	H.P.	Height of Centres.	H.P.
Ins.		Ins.	
8½	15	12	25
10	20	15	30

The machine is provided with a compound rest on each side of the central driving head.

Standard Lathes suitable for use with High Speed Steel.

Height of Centres.	H.P. required.	Twin Duplex Rests. Height of Centres.	Twin Duplex Rests. H.P. required.
Ins.		Ins.	
6	5	36	30
9	7½	42	35
12	12	48	40
15	15	60	50
18	20	84	75
24	30	96	100

Surfacing and Boring Lathes (High Speed).

Diam. of Faceplate.	H.P.	Diam. of Faceplate.	H.P.
Ft.		Ft.	
2	7	5	20
2½	9	6	25
3	12	7	30
3½	15	8	30
4	17½	10	35

DRILLING AND BORING, SCREWING AND TAPPING MACHINES.

Drilling and Boring Machines.

Class of Machine.	Diam. of Spindle in ins.	H.P.
Sensitive	$\frac{13}{16}$	1
,,	$\frac{13}{16}$	1½
,,	1	2
Vertical	1¼	3
,,	2	4
Vertical and Radial	2¼	7½
Radial and Horizontal	2¾	9
,, ,,	3	10
,, ,,	3½	12
,, ,,	3½	15

Bolt Screwing and Nut Tapping Machines.

Size of Machine in ins.	H.P.
½ to 1½	1½
½ to 2	2½
½ to 3	4

Tube Screwing Machines.

Size of Tube.	H.P.
Up to 2 ins. diam.	1
Up to 3 ins. diam.	2
Up to 4½ ins. diam.	3
Up to 10 ins. diam.	4
Up to 12 ins. diam.	5

Shaping and Slotting Machines, Boring and Turning Mills.

Shaping Machines.		Slotting Machines.		Vertical Boring and Turning Mills with two Cutter Bars on Cross-side.	
Stroke.	H.P. per head.	Stroke.	H.P.	Diameter Admitted.	H.P.
Ins.		Ins.		Ft.	
6	$1\frac{1}{2}$	6	$1\frac{1}{2}$	3	$7\frac{1}{2}$
8	2	8	$3\frac{1}{2}$	4	10
10	3	10	5	5	$12\frac{1}{2}$
12	5	12	$7\frac{1}{2}$	6	15
15	5	18	10	8	20
18 (Double Head.)	$7\frac{1}{2}$	24	15	10	25
24	10	30	20	15	35
30	$12\frac{1}{2}$	36	25	20	50
		54	30		
		72	35		
		Locomotive Frame Plate Slotting Machine 10 h.p. per head.			

Planing Machines.

Planing Machines (High Speed).							Vertical and Horizontal Planing Machines (High Speed).	
Size in Ft. and Ins. Width × Height.						H.P. required.	Size in Ft. and Ins. Vertically × Horizontally.	H.P. required.
Ft.	Ins.	×	Ft.	Ins.			Ft. × Ft.	Ins.
1	9	×	1	9		$2\frac{1}{2}$		
2	0	×	2	0		$3\frac{1}{2}$		
2	6	×	2	6		6	7 × 10	6 18
3	0	×	3	0		8	9 × 12	20
3	6	×	3	6		10	12 × 15	25
4	0	×	4	0		20	15 × 20	30
5	0	×	5	0		25	18 × 24	35
6	0	×	6	0		30	20 × 25	45
7	0	×	7	0		35		
9	0	×	9	0		45		

Two tool boxes on cross-slide.

Two tool boxes on cross-slide and one on the front upright.

Punching Machines.

Diameter of hole in inches	$\frac{3}{4}$	1	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$
Plate thickness in inches	$\frac{3}{8}$	$\frac{5}{8}$	1	$1\frac{1}{4}$	$1\frac{3}{8}$
H.P. required	1	$2\frac{1}{2}$	5	$7\frac{1}{2}$	10

Punching, Shearing, and Cropping Machines.

Hole Punched.		Flat Bar Sheared at one Stroke.	Diameter Cropped.	H.P. required.
Diameter.	Plate Thickness.			
Ins.	Ins.	Ins. Ins.	Ins	
1	$\frac{5}{8}$	$3\frac{1}{4} \times \frac{3}{4}$	$1\frac{1}{2}$	6
$1\frac{3}{16}$	$\frac{13}{16}$	4×1	$1\frac{7}{8}$	8
$1\frac{5}{16}$	$\frac{7}{8}$	$4\frac{3}{8} \times 1$	$2\frac{3}{8}$	10
$1\frac{3}{8}$	1	$4\frac{3}{4} \times 1\frac{1}{4}$	$2\frac{1}{2}$	12
$1\frac{1}{2}$	$1\frac{1}{4}$	$5\frac{3}{8} \times 1\frac{1}{4}$	3	16

The above is suitable for 20 strokes per minute.

Grinding Machines.

Plain Grinding Machines. (Heavy duty.)		Universal Grinding Machines.		Crank-shaft Grinding Machines.	
Maximum Swing.	H.P. required.	Maximum Swing.	H.P. required.	Maximum Swing.	H.P. required.
Ins.		Ins.		Ins.	
$7\frac{1}{2}$	5	8	3	12	12
10	$7\frac{1}{2}$	10	5	15	15
12	10	12	5	18	20
15	15	15	5–$7\frac{1}{2}$	24	25
20	20	20	$7\frac{1}{2}$–10		
24	25				
30	30				

Internal Cylinder Grinding Machines.		Vertical Spindle Surface Grinding Machines.	
Normal Capacity. (Diameter × length.)	H.P. required.	Diameter of Wheel.	H.P. required.
Ins.		Ins.	
6×15	3	12	15
9×18	5	14	20
18×42	$7\frac{1}{2}$	18	25

Milling Speeds and Feeds.

With regard to milling speeds and feeds, the amount of reliable experimental data available is very meagre and the machinist must for the present content himself with compiling data for himself. The subject is very complicated, and he will require to make the fullest possible observations at least at the commencement. For this purpose, he will note the following: dia. and width of cutter, revs. per min., depth and width of cut, feed in inches per min., number of teeth in the cutter, type of cutter, feed per tooth, material and nature of the work. To measure the capacity of the machine by the feed per tooth alone may give misleading results.

TESTS MADE ON A NO. 22 'SINGLE PULLEY' HORIZONTAL MILLING MACHINE MADE BY MESSRS. ALFRED HERBERT LTD., COVENTRY.*

4½-in. High-speed Cutter, 10 Teeth, 2-in. Hole.
Block (Cast Iron and Mild Steel) 8 ins. wide at 60 turns = 70 ft. per minute.
(Power required to run motor and machine light, ·7 net H.P., has been deducted from the recorded H.P.s to give the figures in the table.)

Depth of Cut.	(Cast Iron) Metal Removed.			(Mild Steel) Metal Removed.			
	Feed Measured	Net H.P.	Cubic Ins. per Min.	Cubic Ins. per H.P. Min.	Feed Measured	Net H.P.	Cubic Ins. per Min.	Cubic Ins. per H.P. Min.
Ins.	Ins.		Ins.	Ins.	Ins.		Ins.	Ins.
·24	17⅝	20·3	33·80	1·66	11⅜	30·8	21·84	·71
·25	17½	23·0	35·00	1·52	10⅞	29·6	21·75	·73
·26	17⅜	26·1	36·15	1·38	11½	39·8	23·14	·58
·28	17 3/16	34·6	38·52	1·11	9¾	28·6	20·44	·71
·30	13⅞	23·7	33·30	1·40	9 3/16	29·6	21·67	·73
·32	13¼	29·6	33·92	1·15	8⅞	30·8	22·72	·74
·34	11⅝	24·9	31·55	1·27	8 5/16	42·1	24·31	·58
·36	11½	27·3	33·12	1·21	7 7/16	30·8	21·06	·68
·375	13½	22·8	40·50	1·77	7½	28·6	21·37	·74
·40	11 3/16	27·3	35·84	1·32	6 7/16	27·3	19·40	·71
·42	11⅛	26·1	38·22	1·46	6	29·6	20·16	·68
·44	9⅛	23·7	32·12	1·35	5	24·9	17·60	·71
·46	9 1/16	24·9	33·34	1·32	5	27·3	18·40	·67
·48	9 1/16	27·3	35·33	1·29	4 15/16	28·6	18·96	·66
·50	9¼	30·8	37·00	1·20	4 5/16	30·1	19·75	·66
·55	7½	28·6	33·00	1·15	4¼	30·8	21·45	·69
·60	6 3/16	23·7	29·76	1·25	4 3/16	37·1	23·10	·62
·625	9 1/16	24·9	45·93	1·84	3 15/16	29·0	19·68	·68
·70	7 7/16	35·1	41·60	1·19	3 5/16	30·8	22·05	·71
·75	6 1/16	28·6	38·80	1·35	3¼	28·6	19·50	·68
·80	6 1/16	29·6	38·79	1·31	3¼	32·0	20·80	·65
·85	4¾	27·3	33·15	1·21	2⅝	26·1	17·85	·68
·90	4 5/16	29·6	35·54	1·20	2 9/16	30·8	18·45	·60
·95	4⅛	35·1	36·10	1·03	2½	24·9	16·15	·65
1	4	27·3	32·00	1·17	2⅜	29·6	17·00	·57
1·05	3⅞	37·1	32·54	·86	2 1/16	24·9	17·32	·69
1·1	3 5/16	28·6	29·04	1·02	2 1/16	28·6	18·15	·64

EXAMPLES OF COLD SAWING. A.W. HIGH SPEED STEEL.

Inserted-Tooth Saw.	Material.	Cutting Speed.	Time to Cut Through.
Diam. in Ins.		Ft. per Min.	Mins.
36	Steel (joist, 20 ins. deep by 7½ ins. wide; ¾ in. web)	122	17
36	Steel (rail, 100 lbs. per yard)	90	2
36	Forged steel (bar 3 ins. diam.)	90	2½
36	Forged steel (bar 10 ins. diam.)	90	11
36	Forged steel (bar 7½ ins. by 9 ins.)	84	9

METAL HAND SAWING.

Experiments undertaken in France to determine the best method of sawing metal by hand indicate that it takes less time to saw off a rectangular bar of steel when the saw is moved parallel to the shorter side of the rectangle than when it moves parallel to the longer side. It was also found that the shorter the stroke of the saw, the quicker would the bar be sawed off.

* P. V. Vernon (Alfred Herbert & Co.) before the Manchester Assoc. of Engrs., 1912.

In sawing off a rail by a hack saw, it required nearly three times as long when the stroke was 4 ins. in length, as compared with when it was somewhat less than ½ in. in length. The work performed per minute decreases regularly for each ½-in. increase in the length of the stroke. It is also stated that by holding down the end of the saw farthest away from the workman—not by hand but by a weight—the time required for sawing through a bar is shortened, a thinner blade can be used, and a better surface on the ends of the sawed-off bar is obtained.

Miscellaneous.

	H.P.
Double punch, running light	2·0
Punching both ends 1 in. hole, ⅝ in. plate, 28 punches per minute at each end	5·0
Punch and shear, running light	2·0
Punching hole as above, and shearing ⅞ in. plate, 5½ in. cut, 28 strokes per minute	6·5
Large plate-bending rolls, running light	5·5
Rolling plate $\frac{5}{16}$ in. thick, 4 ft. 4 ins. wide, and 16 ft. 6 ins. long, endways on (4 ft. 4 ins.)	6·9
Sideways on (16 ft. 6 ins.)	12·2
Plate $\frac{11}{16}$ in. by 4 ft. 8½ ins. by 21 ft. long, sideways on	19·3
Same rolls lifting and lowering top roll: Lifting	8·5
Lowering	7·0
Forcing $\frac{1}{2}\frac{3}{2}$ in. plate down	10·0
Forge fan, for 24 fires	10·5
Angle squeezer, running light	0·8
Squeezing	2·5
Riveting machine, running light	1·6
Riveting	3·0
Plate planing machine, running light	1
Reversing light	2
Cutting	5
Stern frame, boring, cutting	1·75
Angle-cutting machine, running light	1·6
Cutting angle 6 ins. by 3½ ins. by ⅜ in.	3·5
Winch, lifting 28 cwt. single purchase, 50 ft. per minute	6·5
Ending machine, running light	1·9
Cutting girder 18 ins. by 7 ins.	4 to 4·8
Cold saw, running light 24 in. saw	2·0
Cutting 4 in. by 4 in. angle	4 to 4·5
Air compressor, 10 ins. by 14 ins. cylinder, 50 lbs. pressure	15 to 23·5
Hydraulic pumps, three pumps, 3¾ ins. diameter; 4½ ins. stroke, 60 strokes per minute; pressure, 870 lbs.	38·0
Electric winch, running light	1·2
Lifting 24 cwt. 16 ft. per minute	5·6
Vertical cylinder boring machine (marine), 14 ins. diam. bar	15·0
" " " 18 " "	20·0
Broaching machine (screw 2½ ins. diam.)	7·5
Bevel gear planer to take wheels up to 12 ins. diam.	2·0
" " " 24 "	4·0
" " " 36 "	5·0
Sunderland gear planers to cut up to 3 D.P. (No. 6)	7·0
" " " 1½ D.P. (No. 9)	10·0
" " " 1¼ D.P. (No. 11)	15·0

Wood-working Machinery.

The following allows for the motors being capable of giving 25 per cent. overload for not less than 1½ hour, without any undue heating. The figures are based upon the average work found in the particular shops where the machines are generally used. The type of motor chosen has a certain influence upon the amount of marginal power, and this point requires careful attention.

Machine type and size.	Power of motor required for average work. H.P.	Motor belted to the machine or counter, or direct coupled.	Remarks.
24 in. and 30 in. Horiz. Log Frame Saw, 1 blade in use	10	Belted to machine	—
36 in. " " "	12	" "	This machine takes between 10 and 11 h.p. to start

MACHINE TYPE AND SIZE.	POWER OF MOTOR REQUIRED FOR AVERAGE WORK. H.P.	MOTOR BELTED TO THE MACHINE OR COUNTER, OR DIRECT COUPLED.	REMARKS.
42 in. Horiz. Log Frame Saw, 1 blade in use	15	Belted to machine	—
48 in. „ „	18 to 20	„ „	—
24 in. Circular Saw Bench (hand feed)	10	„ „	—
30 in. Circular Saw Bench (hand feed)	12	„ „	—
36 in. Circular Saw Bench (hand feed)	15	„ „	—
42 in. Circular Saw Bench (hand feed)	20	„ „	—
24 in. Band Saw (hand feed)	1½	Belted or direct coupled	—
30 in. Band Saw (hand feed)	2	„ „	—
36 in. Band Saw (hand feed)	3	„ „	—
42 in. Band Saw (hand feed)	5	„ „	These machines are used on heavier work than the 30 in. and 36 in. sizes
48 in. Band Saw (hand feed)	6 to 7	„ „	
36 in. Band Saw (power feed)	8 to 9	„ „	—
42 in. Band Saw (power feed)	11 to 12	„ „	—
16 in. Double Dimension Saw (hand feed)	5	Belted to machine	—
18 in. diam. Cross-cut Machine (hand feed)	3	„ „	—
24 in. diam. Cross-cut Machine (hand feed)	5	„ „	—
30 in. diam. Cross-cut Machine (hand feed)	7	„ „	—
7 in. by 3 in. Four-Cutter Planer (power feed)	10 to 12	Belted to counter or direct coupled to counter	—
16 in. Plain Surfacing Machine (hand feed)	3	Belted to machine	—
20 in. Plain Surfacing Machine (hand feed)	4	„ „	—
24 in. Plain Surfacing Machine (hand feed)	5	„ „	Machines above 20 ins. wide do not often plane the full width
Vertical Spindle Molder (light) 2½ ins. deep	2	Belted to counter or direct coupled to counter	—
Vertical Spindle Molder (heavy) 4 ins. deep	3 to 4	„ „	—
Vertical Double Spindle Molder (heavy) 4 ins. deep	6 to 7½	„ „	—
Vertical Double Spindle Molder (heavy) 6 ins. deep	10	„ „	—
Medium type Tenoner (1 scribing spindle)	5	„ „	—
20 in. Combined Surfacing and Thicknessing Machine	8	for ordinary seasoned timber	Surfacing is hand feed, Thicknessing is power feed
24 in. Combined Surfacing and Thicknessing Machine	10	„ „	

When motors are direct coupled it is advisable to use a flexible coupling in order to avoid shock on the motor due to fluctuating loads.

The foregoing powers assume that the cutters or saws are running at about standard speeds, and are in good working condition; also it is assumed that the rate of feeding is about the standard, and not speeded up above the makers' speeds. It is, of course, understood that any machine, particularly saw benches, can be fed until they take an abnormal amount of power, but the intelligent workman can so humour the feed without losing time that he gets almost the maximum amount of cutting done with the minimum amount of power expended.

R R

The power absorbed per sq. ft. surface sawn per minute varies very much in some instances and it is impossible to get anything like an accurate figure, as there are so many variable factors; thus, the amount of power absorbed by the saw increases or decreases according to the amount of set given to the teeth, and the set requires to be varied considerably according to the class of timber to be sawn: even in the same class of timber the grain in one part of the cut might be such that it closes in on the saw more than in another part of the cut.

SPEED.

The speed of the cutting edge and the angle, in knife tools, and the shape of saw tooth, speed, angle, and thickness of saw, in saws, has a great influence on the amount of power a machine will absorb when doing certain classes of work.

The following list gives the various speeds, etc., of certain machines, the information being the latest practice.

Circular Saws for ripping, soft wood	9,600 to 11,000 ft. per min. (peripheral)	
" " hard "	9,600 to 11,000 " "	
" " ordinary cross-cutting, soft	10,000 " "	
" " " " hard	8,000 to 10,000 " "	
" " (Hollow ground)	10,000 to 11,000 " "	
Ordinary plain Band Saws, soft wood	4,300 to 5,000 " "	
" " hard wood	4,300 to 5,000 " "	
Deal cutting Band Saws, hard or soft	6,500 to 7,000 "	Specially designed machines
Log Band Saws	6,500 to 8,000 "	

Reciprocating Mortising Machines:

Mortising up to $\frac{7}{8}$ in. wide, $4\frac{1}{2}$ ins.	stroke	(not graduated),	crankshaft speed	400	r.p.m.
" " 1 " "	"	"	"	350	"
" " $1\frac{1}{4}$ " 6	"	(graduated)	"	270	"
" " $2\frac{1}{2}$ " $6\frac{3}{4}$	"	"	"	255	"
" " 3 " 7	"	(not graduated)	"	160	"

Vertical Deal Frames (Single):

To take timber 12 ins. by 6 ins.	Continuous Feed	"	300	"
" " 18 ins. by 6 ins.	"	"	250	"
" " 28 ins. by 5 ins.	"	"	200	"

Vertical Deal Frames (Double):

To take timber 20 ins. by 6 ins.	"	"	225	"
" " 24 ins. by 6 ins.	"	"	200	"

Horizontal Saw Frame (Single blade):

To take timber 24 ins. square	2 ft. 6 ins. stroke (balanced)		"	320	"
" " 30 "	"	"	"	300	"
" " 36 "	"	"	"	280	"
" " 42 "	"	"	"	260	"
" " 48 "	"	"	"	230	"

Double Equilibrium Deal Sawing Frames (balance swing frames):

To cut 2 deals up to 14 inches × 5 inches, 350 revs. per min. (of crankshaft).

" "	18 "	× 6 "	300	"	"	"
" "	24 "	× 7 "	250	"	"	"

Bandsaws, blades running on wheels up to 3 feet diameter:

For sawing very hard ivory, etc., traverse of saw blade per minute, 750 feet.

" iron " " " " " 250 "

Vertical Spindle Moulding Machines:

Single Spindle (light type)	5,000 to 6,000 revs. per minute.
Double " (")	5,000 to 6,000 " "
Single " (medium type)	4,000 to 4,500 " "
Double " (")	4,000 to 4,500 " "
" " (heavy type)	3,500 to 4,000 " "

High speed Four Cutter Moulders:

Bottom spindle	4,000 revs. per minute,	6 ins. dia.	cutting circle app.
(2) Side spindles	4,000 " "	6 " "	"
Top spindle	5,000 " "	6 " "	"

The above represents the average machine up to 12 ins. by 4 ins., and gives approximate peripheral cutting speeds of :—bottom spindle, 6,300 ft. per min.; side spindle, 6,300 ft. per min.; top spindle, 7,800 ft. per min.

The extra speed given to top cutter spindle is because this cutter spindle has the heaviest work to do, having to reduce the timber to an even thickness and a given size.

Surface planing machines . . . 5,000 to 5,500 ft. per. min. of cutting circle.
Surfacing and thicknessing machines (combined) 5,000 to 5,500 " " "

The above instances are for average cases, and may be accepted as good standard practice at the present time.

Tenoning Machine (light) 4,500 to 5,500 ft. per min. of cutting circle.
" " (heavy) 3,500 to 4,500 " " "
Fret Saws . . . . . 1,200 revs. per min. 1½ in. stroke.
Carving Machines (light) . . 8,000 revs. per min. of spindle.
Single Spindle Dovetailing Machines 5,000 to 6,000 revs. per min. of spindle.

Boring Augers (ordinary):

Up to 1 in. diam., 1,800 to 2,000 r.p.m. Up to 2 ins. diam., 1,000 r.p.m. Up to 3 ins. diam., 750 r.p.m.

Emery Wheels, for saw-sharpening, etc., 4,500 to 6,000 feet periphery velocity.

Force Required to Punch Holes and Cut Plates.

If W = maximum force in lbs. required to punch hole,

t = thickness of plate in ins.,

then

$$W = 190{,}000dt$$

for structural steel, soft iron, boiler and steel plate.

As W varies as dt, the same machine and power would punch a ¾-in. hole in a ¾-in. plate, as would punch a 2¼-in. hole in a ¼-in. plate, since $\frac{3}{4} \times \frac{3}{4} = 2\frac{1}{4} \times \frac{1}{4}$.

If F = force required to shear plates with straight knives inclined at an angle $\alpha°$ with each ther, then

$$F = 30{,}000\, t^2 \cot \alpha°.$$

An approximate rule for finding the force required to cut metal by punching or shearing is

> Force = 80 per cent. of the tensile strength of a bar having a cross-sectional area equal to the area of the metal cut.

The side thrust on a shearing blade when it is dull and the plate is tipped may be taken as equal to 1·5 W, when W is the force acting normal to the plate.

Flat punches should always be used when the thickness of the plate is greater than two-thirds the diameter of the hole. If the thickness is less than half the hole diameter, much less force is required when a shearing punch is used. Shearing punches are also recommended for cases where a large number of holes are to be punched close together, because they do not distort the plate as much as flat-ended punches.

The diameter of a punched hole is equal to the diameter of the punch, but if there is an appreciable clearance between the punch and the die, the hole will be conical.

(*Lewis Jenkins, University of Cincinnati.*)

Hack-Saws.

Insufficient attention is given to the lubrication of hack-saws while cutting. It is as necessary to apply ample lubricant to hack-saws as to any other cutting tool, and many power hack-saw blades merely rub their way through stock because the first few strokes have destroyed the hardness of the teeth, owing to the temperature attained in the absence of lubricant.

Hand hack-saw blades generally suffer the same careless treatment accorded to files. The proper use of these hand tools is not impressed upon the semi-skilled labour of to-day, and the hack-saw bills of many firms could be reduced considerably if more attention were given to this matter.

Power Losses in the Machine Shop.

Engine friction, 10 per cent.; line shafting, 15 per cent.; belts and pulleys, 15 per cent.; empty machines, 15 per cent.; cutting metal, 45 per cent.; total, 100 per cent.

Even this efficiency is probably only realised when everything is working at full capacity. Of all metals cut in the machine shop, cast-iron is said to absorb least power per unit of weight removed, while the harder steels require the maximum. Thus, to remove 1 lb. of cast-iron per hour requires the continuous expenditure of from 0·15 to 0·30 h.p., or, say, an average of $\frac{1}{10}$ h.p., where steel calls for $\frac{1}{2\frac{1}{2}}$ h.p. An average lathe will cut 10 to 20 lbs. of cast-iron per hour and absorb ¼ to ½ h.p. in useful work, and similarly steel will be removed at a rate of 5 to 10 lbs. and demand ⅕ to ⅖ h.p. Much also depends on the condition of the machine itself, which may increase its demand for power from 0·36 to 2·3 h.p. very quickly, simply from a dry main spindle. A lathe run without cut may absorb 0·04 to 0·16 h.p., and this will amount up to 0·3 or 0·4 simply by tightening the work in the centres. A large 84-inch wheel lathe has been found to absorb 1·75 h.p. and when cutting, 5·8 h.p. on heavy work.

Planers use ·035 h.p. per pound of cast-iron removed per hour, and 0·065 h.p. per pound of steel, and it may remove 20 lbs. of soft steel or 30 lbs. of cast-iron per hour. Ordinarily, however, the machine would not consume 1 to 1·3 h.p., as these figures would indicate, but only about ½ h.p. Adding for the machine will probably show an average power of 1·0 h.p. in ordinary work.

Felt Wipers on Slides.

To prevent grit working under the slides of machine tools owing to rounded corners, felt wipers may be fitted as shown in fig. 51. The felt is held in place by 1-in. angle iron secured to

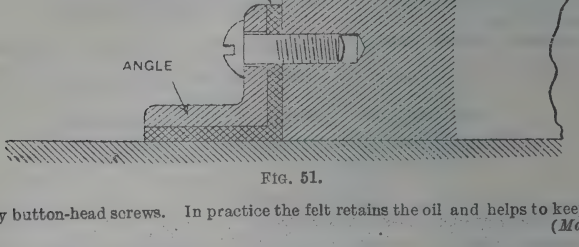

Fig. 51.

the slide by button-head screws. In practice the felt retains the oil and helps to keep the slide lubricated. (*Machinery.*)

TOOL STEEL AND TOOLS.*

Treatment of Carbon and High-Speed Steel Tools.

Carbon Steel.

The term carbon steel has been generally applied to 'straight carbon' and 'carbon-alloy' steel. The former is obtained directly from blister steel, which is melted in crucibles, poured into a cast-iron mould and cooled. Subsequently the ingots are retreated, hammered and rolled to the desired shape and size. The carbon-alloy is obtained by adding small quantities of tungsten, chromium, silicon, etc. The latter steel has distinct advantages over the former in that it is easier to forge, is less liable to failure in hardening, and has a greater cutting capacity. The chemical composition of a representative tool of the latter class is given below.

Chemical Composition of Ordinary Carbon Tool Steel.

Carbon, 1·1 per cent.; manganese, 0·35 per cent.; silicon, 0·17 per cent.; phosphorus, 0·018 per cent.; sulphur, 0·015 per cent. The sulphur and phosphorus are undesirable quantities, the former producing brittleness when hot or 'hot shortness,' and the latter 'cold shortness.' The silicon and manganese facilitate melting and forging, and improve the quality of the finished steel. The hardness of the steel chiefly depends upon the carbon contained in it. The various tools contain different percentages of carbon to suit the work they have to do. Thus, tools subject to sharp blows should contain a low percentage of carbon, and keen-edged tools a high percentage. The carbon contents for different classes of tools are as follows:—

Tools such as snaps, hammers, drifts, stamping dies, contain about 0·65 per cent. carbon. Smiths' tools, hot and cold sets, swages, punches, shearing blades, cold chisels, miners' drills, minting dies, contain about 0·7 to 0·8 per cent. carbon.

Large milling and other circular cutters, very heavy lathe tools, drills, taps, screwing dies, reamers, contain about 1 per cent. carbon, whilst the smaller and lighter varieties of cutters, turning and similar tools, drills, and reamers, contain from 1·1 per cent. to 1·3 per cent. carbon.

Hardening.

Hardening is effected by heating the tool to a colour between a dull and cherry-red; that is, between a temperature of 1,365° F. (740° C.) and 1,400° F. (760° C.), and immediately quenching it in water, or in a suitable bath so that the temperature is at least lowered to 390° F. (200° C.), but preferably to a normal temperature of about 60° F. Some tools, depending on their composition, will harden a few degrees below 1,365° F. and some require a slightly higher temperature. The upper limit must not be exceeded, otherwise the steel becomes coarse and weak, but providing the temperature is kept within the range the steel is apparently uninjured. The lower hardening temperature, or what is called the 'critical point,' must be reached, otherwise the steel after quenching will be too soft for cutting metal.

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* See also METALLURGY, Section XL.

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High Speed Twist Drills

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HOW do these figures compare with your own performance. These tests are typical of Firth 'Speedicut' endurance :—

Dia. of 'Speedicut' Drill.	Revolutions per Minute.	Cut per inch.	Penetration Inches per minute.
$\frac{13}{16}$″	385	35	11
$\frac{15}{16}$″	325	35	9·3
1″	315	35	9
$1\frac{1}{4}$″	245	35	7
$1\frac{1}{2}$″	200	35	5·7
2″	160	35	4·57

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Tempering.

This is done by heating to a temperature between 390° F. (200° C.) and 600° F. (315° C.) and cooling slowly. The higher the tool is heated within this range the softer it becomes. It is of the utmost importance that the tool should be uniformly heated, and quenched, otherwise some parts will be harder than others and internal stresses set up which will produce warping and cracking. To minimise any irregularity in heating formed cutters, modern practice is to heat these in a bath of molten metallic salts which is maintained at a constant temperature by gas or oil jets.

Annealing.

Irregular annealing is responsible for much warping and cracking, and it is advisable that formed cutters should be carefully annealed before forging, and even again before being hardened, so as to remove any initial strains and strains produced in machining. These precautions as to annealing should be observed with all classes of steels.

Self-Hardening or Mushet Steel.

This class contains on the average about 5·5 per cent. tungsten, 2 per cent. carbon, 1·5 per cent. manganese, 1 per cent. silicon, and 0·4 per cent. chromium. As in the case of high-speed steels the proportions of the various elements have a most pronounced effect on the quality.

The self-hardening property of this steel principally depends upon a high percentage of manganese or chromium in combination with tungsten or molybdenum. Such steel is hardened by heating it to a bright red colour (about 1,500°F.) and allowing it to cool. If heated much above this temperature it will crumble in forging, and its cutting capacity is permanently impaired. When cold it is very hard, and retains its cutting edge much better than carbon steel tools.

High-Speed Steels.

High-speed steels are also self-hardening, but are usually forced in cooling by an air blast or by quenching in oil or other medium. The elements of this steel are very similar to some of the older types of self-hardening steels, but they contain much more tungsten and chromium and about one-third the quantity of carbon. Several old self-hardening steels had all the desirable elements and proportions of a high-speed steel, and it was due to the supposed 'overheating' of such steel that its latent cutting capacity was revealed, and not to any new properties or proportions.

Broadly speaking, there are two classes of this steel, viz., *ordinary* and *new* high-speed steel, and for these Mr. F. W. Taylor gives the following chemical composition :—

Chemical Composition of Ordinary and New High-Speed Steels.

Class of Steel.	Tungsten. Per cent.	Chromium. Per cent.	Carbon. Per cent.	Manganese. Per cent.	Vanadium. Per cent.	Silicon. Per cent.
Ordinary .	8·0	3·8	1·85	0·30	—	0·15
New or modern	18·91	5·47	0·67	1·1	0·29	0·043

The carbon contents in the ordinary high-speed steel is high, and the principal difference between the ordinary and new high-speed steels is that the latter contains a quantity of vanadium. The addition of vanadium raises the 'critical point' and enables the tool to withstand a higher temperature due to an increased speed of cutting. Tools of this steel are harder and retain their cutting edges longer than ordinary high-speed steel tools. They are therefore particularly suitable for cutting very hard metals, such as railway and car tyres, which have become very hard with usage, manganese steel castings, chilled rolls, etc. A tool containing 0·25 per cent. of vanadium lasted twice the time of a similar tool containing no vanadium, whilst Mr. J. M. Gledhill points out that by substituting 2 per cent. vanadium for chromium in a steel, good results were obtained when tried on medium steel, but were no better than the steel containing the much cheaper element chromium.

A steel may therefore be made of the best quality of material, but unless the elements are properly proportioned and care and skill be exercised during melting to ensure a proper mixing and avoid 'dryness' (a brittleness produced by retaining the steel in its melted state for an undue length of time), it may fall short of a first-class steel. As the percentage of the vital elements decrease, the difficulties in successful melting and mixing increase, and the most satisfactory steel to suit the various conditions prevailing in practice can only be obtained by prolonged experimenting.

To Identify High-Speed Steel Scrap.

The spark from high-speed steel ground on an emery wheel is a dark-red spark that is inclined to scatter, while the spark from ordinary carbon steel is much whiter and is not inclined to scatter. The sparks from high-speed steel are about the same colour as from cast iron, but are much finer.

Annealing.

This process is best accomplished by placing the tools in a sealed oven, furnace, or muffle, where they are uniformly heated by radiation. By excluding the air, and preventing the flame impinging on the steel, scaling is avoided and the fine cutting edges preserved. The furnace should be heated in such a manner that in about two hours' time it attains a temperature of

1,544°F. (840°C.), or very slightly higher, and should be steadily maintained at this temperature for about two hours. The heat is then cut off and both furnace and tools are allowed to cool slowly.

To release the furnace during the cooling process some smiths bury the articles in lime, powdered charcoal, soot, or coarse sawdust of some particularly hard wood. The bed in the latter case should be about 24 inches deep and contained in a box having an airtight lid. The articles when dropped on the top of the sawdust and covered with the lid work their way slowly down.

Should such a furnace not be available the tools may be placed in an iron pot or pipe and packed tight with steel cuttings or lime. The pot is then sealed with fireclay and raised to the above temperature at which it is retained for about eight hours before it is placed in charcoal ashes to cool. Good results are obtained from this process, but it is exceedingly slow, and it is doubtful if any advantage is obtained by prolonging the treatment after the annealing temperature has been attained throughout.

Forging.

If a piece has to be cut from the cold bar, this should be done before nicking the bar all round, otherwise small cracks are likely to be started. Preferably the bar should be cut through at a forging heat. In forging, heat the tool slowly and uniformly (without the blast) to a dull red, then raise quickly to a bright red or yellow heat (1,800° to 1,900° F.), when it can be easily and rapidly manipulated. To prevent cracks, hammering should cease as soon as the heat has fallen to a medium red (about 1,400° F.). The steel may be rapidly reheated from this temperature for subsequent forging without any ill-effects. On account of ease and economy in forging, together with general utility and efficiency in cutting, a roughing tool is recommended. This form of tool can be quickly forged by first cutting the required length from the bar and afterwards forming the front, side and top angles by simply jumping the nose. This shape gives the minimum of waste material.

Hardening.

A temperature of 2,000° F., which is ruinous to other steels, gives this steel the property of resisting abrasion at a higher temperature. It is therefore capable of retaining its cutting edge at the high temperatures accompanying high speeds of cutting. This quality, which has been termed 'red hardness,' is not possessed by other steels. In hardening high-speed steel it is slowly pre-heated (in order to obtain a uniform heat throughout) to a medium red (about 1,550° F. then quickly raised to the following temperatures:—Ordinary high-speed and molybdenum steel from 2,000° F. to 2,200° F. (yellow or lemon heat), vanadium steel from 2,200° F. to 2,350° F. The lower figure is recommended for oil hardening and the higher for air hardening. When the heating is done in the smith's fire, obtain a good, deep bed of small coke or soft coal and pre-heat the tool by laying it in the fuel at some distance from the hottest part till the fire is thoroughly blown up. To ensure uniformity the tool during both stages of heating should be frequently turned round. Some smiths prefer to obtain final heat by placing the tool within a piece of scrap piping which is maintained at the required temperature by the surrounding fuel on the hearth. Except for the simplest form of tools such as those of the lathe type, the smith's hearth is unsuitable. Formed tools such as milling cutters, hobs, reamers, etc., are best heated in gas, oil or coke-fired muffle furnaces. Modern furnaces for this work usually have two chambers, i.e., an upper in which the cutter is pre-heated, and a lower chamber in which the cutter is raised to the final temperature. Another method of raising the cutter to its final heat is to immerse it in a mixture of molten metallic salts (barium chloride, etc.). The bath is heated and maintained at any desired temperature by passing an electric current through it. As the heat generated varies as the current passes through the circuit the arrangement is ideal for obtaining uniform conditions. The first cost, however, is large, and attempts have been made to obtain similar results from gas-heated salts in graphite crucibles. Trouble arises in the latter device through oxidisation: particles of iron oxide floating on the surface are inclined to adhere to the tool and produce soft spots.

Many have an idea that it is impossible to injure high-speed steel by overheating. This is certainly not the case. If an ordinary high-speed steel tool be heated to 2,400° F. and cooled in an air blast, its fracture will show a very coarse grain.

Once the final temperature has been attained the tool should be immediately withdrawn, as prolonging the treatment, even without raising the temperature injures the steel and reduces its cutting capacity.

'Pack' Hardening.

It requires a man with considerable experience to harden successfully large high-speed steel milling cutters or hobs, and also a first-class furnace designed for this purpose. The disaster attending repeated attempts to do this has caused some hardeners to resort to 'pack hardening,' and possibly the desire to get away from scaling effects has also had something to do with this innovation. In this process about a 1-in. layer of charcoal (¼-in. lumps) is made in the bottom of a cast steel box. Over the charcoal is placed a perforated plate which supports the cutters, but there is no charcoal against the cutters, etc. When several cutters are packed in the box these are separated by asbestos. When charged a lid is placed on the top of the box and sealed with clay. The box is then placed in a suitable furnace and the temperature raised to 1,250° C., and held at that for an hour or two, depending on the time required to thoroughly heat the contents. The cutters are cooled in hot oil or metallic salts in the usual way.

The object of the charcoal is to consume the free oxygen in the box before the steel gets sufficiently hot to scale. Scale is oxide of iron, and will not form if there is no free oxygen, so that however hot the steel may get, it cannot scale.

Tools or cutters which have to be rehardened after having been in use should be annealed prior to this operation, and thereby relieve the internal strains.

Before attempting to harden steel, it is advisable to remove by grinding or machining the black scale (oxide of iron) on the bar or forging, as immediately adjoining it is a thin film of decarburised material, which cannot be altogether avoided in the manufacture, and which will not be hardened.

Quenching.

Uniform cooling is just as essential to the successful treatment of steel as uniform heating, providing this is done it does not matter whether the medium is an air blast, oil, or water. To quench high-speed steel in water, however, is liable to produce cracks, and this is particularly the case in formed cutters where it is impossible to obtain uniform cooling by such a rapid process. Tools of the lathe type are usually cooled in a strong air blast, whereas formed cutters are generally quenched in a bath of salts about 500° F. or in rape or whale oil at a temperature of 250° F. and afterwards cooled in cold oil. The oil cooling gives a clean smooth surface to the cutter.

Quenching Medium.

After heating, it is usual to quench this steel in water, brine, oil, metallic salts, molten lead, etc., depending on the size of the tool or purpose for which it is intended. The function of the medium is to abstract rapidly the heat from the steel, as it passes through the critical range, and nothing more than this. Water therefore, on account of its mobility, makes an excellent cooling medium. The colder the water, and the more rapidly it is circulated, the greater the hardness will be. Cold water which has not had the chill taken off is very liable to produce cracks, whilst with boiling water it is impossible to harden at all. In the latter case a jacket of steam forms between the tool and the water, and cooling is retarded. It follows, therefore, that different degrees of hardness can be obtained by having the water at different temperatures. To raise the boiling-point, salt (as much as the water will carry) is frequently added, and for general purposes such a mixture at 40° C. (104° F.) is quite good. Keep the liquid clean and free from grease or oil. A great deal of nonsense has been spoken and written on the relative merits of quenching mediums, and to Mr. S. N. Brayshaw, M.I.Mech.E., especial credit is due for exploding many of the fantastical theories on this subject. According to Mr. Brayshaw, the ability of a liquid to bring a body immersed in it to its own temperature depends upon the following properties: (1) Specific Gravity, (2) Specific Heat, (3) Boiling-point, (4) Thermal Conductivity, and (5) Fluidity.

Specific Gravity.—The specific gravity determines the weight of liquid in contact with the tool being quenched.

Specific Heat.—The heat required to raise the temperature by a given amount, of a pound of different liquids varies enormously. If a red-hot tool weighing 1 lb. be immersed in a gallon of water weighing 10 lbs., the water quenches the tool, and its own temperature is raised about 12° C. in so doing, but if immersed in 10 lbs. of mercury, which has a very low specific heat, the temperature of the mercury rushes up more than 200° C.

Boiling-point.—When a tool is quenched in water or oil, a jacket of steam or vapour may be instantly formed, and this retards the cooling very greatly. Liquids, like solids, vary in their ability to conduct heat, but a deficiency in this respect may be compensated for by motion in the liquid.

Fluidity.—The ability of a liquid to circulate freely is one of the most important factors as regards quenching. The agitation may be caused by moving the tools about rapidly in the liquid, or by directing jets upon them.

Water.—The fact that its thermal conductivity is very low is counterbalanced by its fluidity. The higher the temperature of the quenching water, the more nearly does its effect approach that of oil, and if boiling water is used it will be even more gentle in its action than oil.

The Boiling-point of Water in relation to its Quenching Capacity.

If ordinary tool steel could be very rapidly quenched by any means to a temperature of 100° C. it would harden perfectly; but water at 100° C. (that is, boiling water) is incapable of quenching steel rapidly, and the nearer the boiling-point is approached, the worse it becomes for quenching purposes. When a red-hot tool is immersed in water, steam is generated around the tool, keeping the water away from it and interfering with the quenching. If the water is boiling, the tool is completely jacketed.

The Effect of Stirring during Quenching.—The tools cool much more quickly if they are stirred, or, what amounts to the same thing, if the water is projected in a stream upon the tools.

The Addition of Acid or Salt to the Quenching Bath.—The addition of sulphuric acid increases the conductivity of the water, but the gain from this cause is small in comparison with rapid circulation of water.

It is sometimes stated that sulphuric acid is added to prevent hardening cracks, but this is inconsistent with the other idea that it is used to obtain a greater degree of hardness. If the liability to crack is reduced, it is because the acid has made the quenching bath more gentle in its action, and thereby reduced the hardness.

Seasoned Water for Quenching.

Water ordinarily contains air dissolved in it, and this air is expelled when heat is applied. For this reason water which has recently been boiled and allowed to cool again, may be expected to quench the steel with greater rapidity and uniformity.

Quenching in Oil.—It is necessary in some cases to quench in oil, although it should be avoided wherever possible. Oil to one specification is not always the same, and even if it were, considerable changes are brought about with use, and its quenching power soon becomes different to that of new oil.

Quenching in Fusible Salts.—The ideal quenching liquid would be one which, at a temperature of say 100° C., had sufficient quenching power to cool steel so rapidly that it would harden thoroughly.

Experiments have been made by Mr. Brayshaw with chlorides, fluorides, carbonates, and other compounds, in order to find a 'melt' for quenching.

Such a 'melt' or mixture of salts differs from that used in the salt bath as ordinarily understood, in the fact that the salt bath commonly consists of a mixture of chlorides which are liquid at a red heat, and in which tools are immersed in order that they may be raised to the temperature necessary for hardening. The 'melt' now under consideration is primarily not for heating, but for cooling the tools, although it may be remarked incidentally that such a 'melt' may usefully be applied for the tempering of tools after they have been hardened.

The endeavour was to find a mixture, free from water, which would be liquid at a temperature as low as possible, have a high specific heat, and should be obtainable at reasonable prices.

A mixture known as 'Quenchite' resulted. It is liquid at 135° C. (275° F.), and at this temperature it is almost as fluid as water. It quenches steel very rapidly, has a very high boiling-point, and consequently the liquid is in direct contact with the steel almost from the moment of immersion.

The temperature of 135° C. is, however, so high that 'Quenchite' is only suitable for hardening small or thin articles. Small cutters and long reamers or taps can be quenched in it to give a glasshard surface, and with practically no warping or change of shape, but it is not sufficiently severe in its action to give the necessary hardness to a sufficient depth in the case of large tools in which there is a considerable body of steel behind the cutting edge.

Manner of Quenching.

In order to secure uniform cooling and absence of warping, all sorts of dodges are resorted to by hardeners. In the case of small articles, these are dipped bodily into the medium, so that the whole is cooled at the same instant.

Twist drills, taps, reamers, etc., are dipped vertically, and to move these sideways in the bath would distort them. To avoid this, the medium is stirred with a stick so as to give it a rotary motion, and the drill or tap is dipped in the centre of the swirling liquid, and moved vertically upwards and downwards. Blades for lawn mowers, shear blades, and similar things should be gripped in the centre with the tongs, dipped edgewise in the liquid, and moved edgewise through it, or the liquid itself may be agitated. Sometimes the blade is held between two pieces of iron slightly larger than the blade, and the whole dipped together. A hammer face, if dipped in the liquid, would cool at the edges before it did at the centre, and for this reason a sprayer or jet of water directed on the centre of the face is preferred.

Tempering.

May be accomplished by placing the cutter in a gas stove and raising the temperature to about 500° F., when the gas is shut off and the whole allowed to cool slowly.

Some prefer to first reduce the temperature of formed cutters to about 800° F. in the air blast, then to plunge the same in tallow at 200° F., when the temperature is again raised to about 500° F. and the whole allowed to cool.

Grinding.

The tool should be ground by *hand* pressure on a *wet* sandstone wheel. If it is necessary to use the emery wheel, the tool should be roughly ground to shape after forging, and finished on the wet sandstone after hardening.

Hardening High-Speed Steel Tools *

(1.)

The heat treatment usually prescribed for hardening high-speed steel tools consists in heating the nose of the tool slowly and uniformly to a red heat, then rapidly to a white or welding heat, at which the steel commences to fuse and blister, and then cooling either rapidly or slowly in air or quenching in oil.

The Department of Scientific and Industrial Research desires to direct the attention of users of high-speed steel tools to the fact that uniform and improved results may be obtained by carrying out the hardening process in two stages in accordance with the instructions given below. This treatment is the outcome of the researches of F. W. Taylor in America, and of Carpenter, Edwards, Dempster Smith, and others, in this country. It may be stated that the adoption of this process for the hardening of special tools required for a most important purpose in connection with the war has yielded consistently uniform results, which are immensely better than the best results previously attained. The procedure given below is that adopted by Mr. Dempster Smith in the researches on tool steel carried out in the Manchester School of Technology for the Manchester Association of Engineers, with the aid of a grant from the Research Department.

First or High Heat Treatment.—Thoroughly preheat the tool to about 800° C. (1,472° F.), and transfer immediately to a high temperature furnace at a temperature of not less than 1,350° C. (2,462° F.) for ordinary high-speed tools, and about 1,320° C. (2,408° F.) for super high-speed steel. Retain it in the furnace until the surface of the tool nose is covered with small blisters slightly larger in size than a pin's head, in the case of ordinary high-speed steel, or until the entire surface of the nose is in a state of incipient fusion, or in the case of super high-speed steel presents a greasy appearance. The steel in the first case will have attained a temperature of about 1,320° C. (2,408° F.), and in the second a temperature of 1,290° C. (2,354° F.). Remove the tool and cool in an air blast of large volume.

Second or Low Heat Treatment.—Reheat the tool hardened as above to 570° C. (1,058° F.), for half an hour for tools with sections of half an inch square, or longer in the case of larger sections, and cool in an air blast or in still air. If carefully handled a higher temperature of about 610° C. (1,130° F.) may be adopted if the treatment is limited to ten minutes for tools of the smaller section, and slightly lower for those of larger section. All temperatures for the first and second heat treatment should be measured by means of a pyrometer, and care should be taken to ensure that the portion of the tool under treatment is uniformly heated throughout to the required temperature.

(2.)

The prevailing method of heating tools in ordinary gas furnaces, even when the utmost care is exercised, does not yield uniform results as regards cutting efficiency. The following procedure will be found to yield uniform results :—

First or High Heating.—The preliminary heating to about 800° C. (1,472° F.) may be carried out in a gas-fired muffle or semi-muffle. Care should be taken at this stage to ensure that the whole of the nose of the tool or the part to be heated subsequently to a high temperature is brought uniformly to the required temperature. The high heating to 1,350° C. (2,462° F.) should be carried out in a gas-fired furnace with a reducing flame so disposed that the heating of the tool is effected more by radiation from the heated surfaces of the furnace than by contact with the gases. It is important that the tool shall not be brought directly in contact with the burning gases. Detailed drawings of a furnace to fulfil the above conditions will be furnished on application to the Department.

Second or Low Heating.—This may be carried out at 570° C. (1,058° F.) in a gas-fired muffle or in a lead bath.

Tool Steels.

The treatment given above may be applied to steels containing tungsten, chromium, or vanadium, and generally to ordinary brands of high-speed tool steel. It may be found that certain special steels require a modification of the above treatment, particularly of the temperature required for the second heating; in such cases users are advised to refer to the makers of the steel, or, if possible, to investigate the matter for themselves.

Results.

When the heat treatment described above is carefully carried out, it will be found that the cutting efficiency of the tools is high and is maintained throughout the entire length of the nose, and that no further heat treatment is necessary after grinding (see page 1145). The second heat treatment toughens the steel, and its advantage is very pronounced when working tools at high speeds.

* Communicated by the Department of Scientific and Industrial Research to the *Ministry of Munitions Journal*, and reproduced by permission of the Editor of that Journal.

Furnace.

A type of gas muffle recommended is shown by fig. 52.

Oil Fuel Heating Systems.

(Abstract of paper read before the Royal Society of Arts by Mr. A. F. Baillie.)

Billet-heating furnaces using the air-jet system, with air and oil preheated by the exhaust gases showed a consumption of 9 lbs. of oil per 100 lbs. of metal heated for drop stamping. In heating furnaces for nut-making, the consumption was found to be about 4 lbs. of oil per 100 lbs. of metal heated, and for bolt-making about 4½ lbs. A test on a bolt-making furnace 9 ins. by 12 ins. by 20 ins. resulted in 400 to 500 gross of bolts of from ¾ in. to 1 in. per week on a consumption of 300 gallons of oil. Rivet-heating tests show for some furnaces on this work a consumption of 10·3 lbs. of oil per 100 lbs. of metal heated. For pot furnace work a tilting crucible furnace takes about 10 lbs. of oil per 100 lbs. of gunmetal melted, an open-hearth furnace about 11·3 lbs., and a lift-out furnace about 12·5 lbs. of oil. Stock converter furnaces for melting cast iron and steel-making take about 15 lbs. of oil per 100 lbs. of metal for melting only, but the total, including lighting and heating up, runs to about 40 lbs. In glass works the tank type of furnace takes about 37 lbs. per 100 lbs. of finished glass. An Italian plant of open-hearth Siemens basic furnaces of 55 tons capacity, with an output of 150 tons of steel per 24 hours per furnace, the oil consumption ranges from 16·5 tons to 18·75 tons, or from 11 lbs. to 12·5 lbs. per 100 lbs. metal. The air pressure for atomisation was 4 kilos. per sq. centimetre.

The Burdon Oil-Gas System.

In this system the oil fuel, first very finely atomised and intimately mixed with a large volume of air at *low pressure*, is converted into gas in a small retort, and from the retort the gas is delivered into the furnace (through pipes of varying diameters), where, by the regulation of the air supply, any desired flame can be obtained. The intimate mixture of gas and air produces very high heating results, the full calorific value of the fuel being obtained.

The temperature is regulated by adjusting the valves which control the oil and air supplies. By proper regulation of the air the fuel burns with a non-luminous Bunsen flame, and complete combustion with entire absence of smoke is easily secured.

The air and fuel can be supplied in any proportion desired, so that the flame in the furnace may be either reducing, oxidising, or neutral as desired.

A furnace 10 feet by 6 feet can be brought from cold to approximately 3,000° F. in less than three hours.

The Burdon system can be used for billet heating, slab and bloom heating, chain making, all kinds of welding and forging, case-hardening, tube heating, rivet and bolt making and heating, tin smelting, tool heating, horseshoe making, etc., also for steam raising, superheating, glass melting, metal melting, assaying, insulator making, etc.

Later developments effected in this system enable any quality of liquid fuel, either heavy crude fuel oil, or such as a mixture of 50 per cent. pitch and 50 per cent. of a tar-oil, or, alternatively, any of the lighter fuel oils, such as creosote and gas oils, etc., to be used with results giving high heating efficiency and economy in oil fuel.

The furnaces, which are made in various sizes, from small portable rivet heaters up to large forging types, consist of a combined generator and heating chamber. The oil is contained in the tank, from which it flows, without pressure, to the atomiser and the hot carburettor, where it is vaporised and intimately mixed with the air supply, forming a combustible gas, which passes to the actual heating chamber. The waste gases from this chamber pass through flues to the upper chamber to maintain a sufficient heat in the carburettor, to gasify the oil fuel.

Among the advantages claimed for this system are:

Cleanliness of installation and economy of space.

The producers can be applied to existing furnaces with a minimum of alteration or reconstruction.

Remarkably small fuel consumption, and no coal or coke trimming, stoking, or removal of clinker or ashes.

The cost and time of working is less than for coal or coal gas-fired furnaces.

Compressed Gas System.

There is an optimum pressure for the various applications of gas, and in order to meet this the gas can first be compressed to (say) 280 inches head of water (about 10 lbs. per sq. inch) which can be controlled at the various furnaces, etc., to the pressure required at each place. Pressures for typical work are as follows:—For melting tin or solder 65 inches; small hardening furnaces 65 inches; for blueing steel 65 to 80 inches; for the steel tempering lead pot 150 inches; while for melting metals at 2,000° F. to 2,600° F. 200 inches should be used.

Soldering irons can be heated at 65 inches pressure, which pressure is also convenient for the lighting.

With gas at 2*s.* per 1,000 and coal at 20*s.* per ton, there is little to choose between gas and coal firing as regards fuel costs. As regards cleanliness, uniformity, wear and tear of pots, and accuracy of control, the advantages are however in favour of gas, and in many cases with properly

GAS MUFFLE FURNACE FOR HEATING HIGH-SPEED TOOLS.

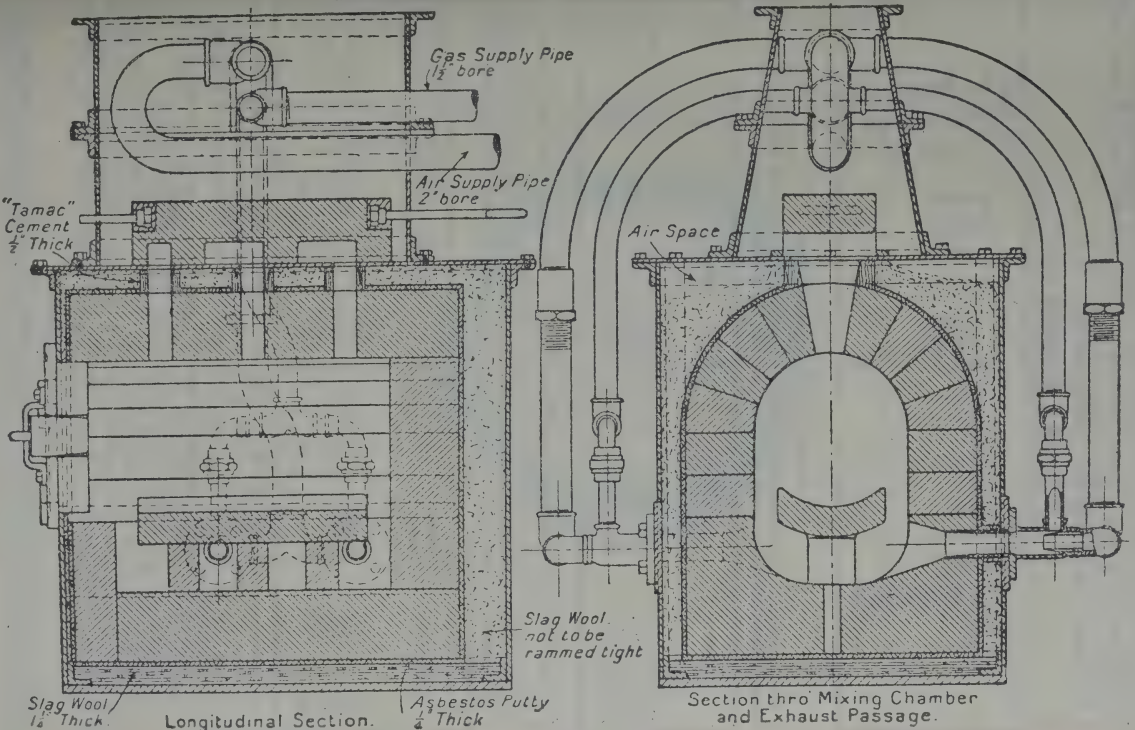

FIG. 52.

designed furnaces it is greatly superior to coal, not only from the point of view of cost, but from convenience, reliability, and ease of manipulation. There is also a large saving of time taken and space occupied by a gas furnace as compared with a coal furnace of similar power, factors of great importance when increased output is called for.

Low-pressure gas with air blast is largely adopted.

TABLE OF COMPRESSOR DATA.

Capacity of Compressor. Cub. ft.	H.P. required.	Floor Space. Ins.
100	·12	18 by 7½
200	·25	22 „ 9
500	·5	23 „ 12
1,000	1·0	27 „ 17
2,000	1·5	32 „ 19
4,000	2·5	40 „ 23
10,000	3·5	48 „ 29

Colours of Tempered Steel.

The *tempering* in this case relates to lowering the degree of hardness obtained by plunging the steel when heated to a cherry red (1,650° F., 899° C.) in cold water :—

Colour.	F.°	C.°	Colour.	F.°	C.°
Very pale yellow	430	221·1	Dark purple	550	287·8
Straw yellow	460	237·8	Clear blue	570	298·9
Brown yellow	500	260·0	Pale blue	610	321·1
Bright purple	530	276·7	Blue tinged with green	630	332·2

Composition of Quenching Baths for Tempering Cutting Tools.

Fused nitrates of potassium and of sodium are too high in temperature for certain cutting tools, as they do not permit of cooling below 328° F. (220° C.) Mixtures of nitrate of potassium and of nitrate of sodium can, however, be employed, and a series of mixtures, fusing at different temperatures, be obtained.

Temperature.		Nitrate of Potassium.	Nitrate of Sodium.	Temperatures.		Nitrate of Potassium.	Nitrate of Sodium.
F.°	C.°			F.°	C.°		
536	280	0 parts	100 parts	279	137	55 parts	45 parts
446	230	20 „	80 „	293	145	60 „	40 „
342	172	40 „	60 „	437	225	80 „	20 „
293	145	50 „	50 „	635	335	100 „	0 „

Higher temperatures than 752° F. (400° C.) cannot be obtained with these mixtures. In steels where without extreme hardness absolute absence of brittleness is necessary, 932° F. (500° C.) to 1,112° F (600° C.) are temperatures more suitable. The following bath gives, on fusion, a temperature of 932° F. (500° C.) :—

Sodium chloride, 1 part; potassium chloride, 1 part; fused calcium chloride, 2 parts; hydrated barium chloride, 1 part; hydrate strontium chloride, 3 parts.

For a bath fusing at 1,292° F. (700° C.) the following mixture may be used :—

Hydrated boric acid crystals, 1 part; silver sand, 1½ part; anhydrous potassium carbonate, 1 part; anhydrous sodium carbonate, 1 part.

When prolonged treatment is required, a little cyanide or charcoal may be added to prevent superficial decarburisation; but, in view of the strongly cementating action of cyanide, this salt must be used with caution.

QUENCHING LIQUIDS.

When hot steel is continually dumped into a tank of oil, the lighter and volatile oils are evaporated and finally only the heavier oils will be left. When the oil becomes thick, it will not take the heat away from the steel rapidly; consequently, the steel will be soft and will not

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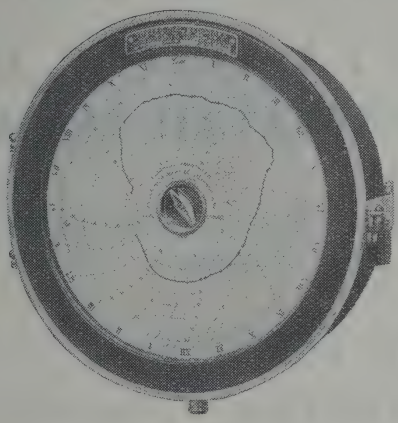

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show the maximum physical properties. To obtain good results, the quenching liquid should be of a constant specific gravity and maintained at a temperature of 70° to 90°, but the exact temperature at which the bath is maintained does not matter so much if it is always the same. To ensure the best results, the bath should always be maintained at a certain specific gravity and at some certain temperature. (*'Machinery,' New York.*)

In hardening and tempering a chisel, the best way, says the *English Mechanic*, is to heat it to a very dull red for a good inch up from the edge, holding the tongs in the left hand, and in the right a rub stone, a piece of broken grindstone or emery wheel, or, failing these, a piece of emery cloth wrapped round a small file. Dip the chisel for about half-an-inch until it just turns black, then withdraw it from the water and let it rest against the side of the pail, so as to steady it; rub it sharply with the stone, so as to brighten it, and watch the colour as it runs down from the part which is still hot, and when the edge is of a deep plum colour, verging on blue, dip it right out.

Grinding.

1. The tool should be forged roughly to shape and ground to the requisite contour by means of a composition wheel (preferably dry) without any lubricant being applied. The heating of the tool during grinding at this stage is not of any importance.
2. After shaping, the tool should be subjected to the two heat treatments indicated (page 1141).
3. It is advisable to finish-grind with a copious stream of water playing on the nose of the tool. If reasonable care to avoid heating be exercised, the tool may be ground on a composition wheel running in water.

Shape of Tool for Roughing Purposes.

The durability or length of time a tool will continue to cut under constant conditions as to feed, speed, etc., increases with the nose radius (fig. 53). The tendency to chatter, however, limits

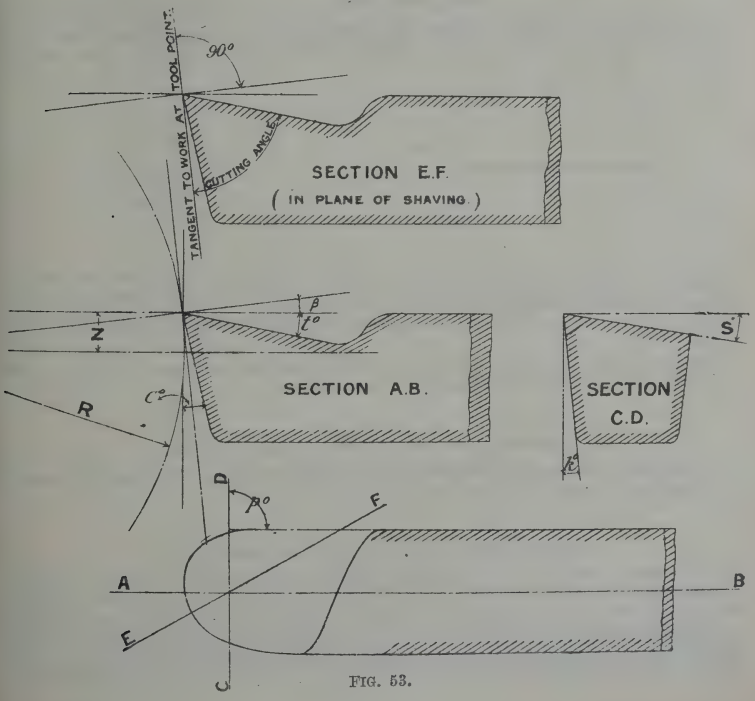

FIG. 53.

the extent to which the nose radius may be increased, and a round-nosed tool having a radius of $\frac{1}{4}$ in. to $\frac{5}{8}$ in. has been found to give the most satisfactory results for the general run of work. With work of a springy character a smaller nose radius may be required. The durability is also affected by the cutting angle, *i.e.*, the angle between the cutting face of the tool and the tangent to the work or 90° minus the top rake angle. The cutting angle is increased when the tool edge stands above the centre of the work, by an amount equal to the angle contained between the cutting edge of the tool and the axis of the bar.

The cutting angles which give the greatest durability to tools for roughing purposes are as follows:

Material.	Cutting Angle.	Material.	Cutting Angle.
Soft steel	65°	Soft cast iron	70°
Medium steel	70°	Medium cast iron	75°
Hard steel	80°	Hard Cast Iron	85°
Nickel steel	80°	Brass	85°
Manganese steel	85°	Hard gunmetal	85°

The above angles are measured in a plane at 45° to the length of the tool which is approximately the plane of the shaving. The side and front clearance angles for tools with cutting edges on the line of centres need not exceed 6°. The shape of the tool recommended is shown below.

Front top rake ($t°$); height above centre (Z); front top rake (reduced to centre) ($\beta + t°$); side top rake (S°); front clearance (C°); radius of work (R); angle (β); front clearance (reduced to centre) ($C°-\beta$); side clearance ($k°$).

Steel Tool Shanks.

By the ordinary method of welding, or securing by other means, high-speed steel tips to ordinary steel tool shanks, the shank is weakened considerably at the point where the high-

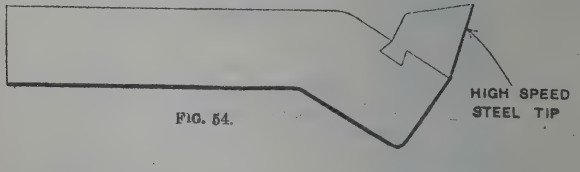

FIG. 54.

speed tip is applied, owing to the shank being cut away to accommodate the steel tip. In the J.B.R. system (the *J.B.R. Tool Co., Ltd., Longsight, Manchester*), fig. 54, the shank retains its original strength, the steel tip being held in a dovetail slot and brazed in position by a method which renders the two materials, when heat-treated, absolutely homogeneous at the joint.

The tools, which are stocked in a range of thirty-nine different shapes, each shape being manufactured in four sizes and two heights, are being largely used.

Sharpening-angles of Wood Machine Cutters.

Adzing soft wood across the grain, 30°; planing machines, ordinary soft wood, 30°; gouging and ploughing machines, 30° to 35°; hard-wood tool-cutters, 35° to 40°.

Cutting Speeds for Carbon Steel Lathe Tools.

The following table gives the appropriate cutting speeds for different depths of cuts and traverses when roughing out with carbon steel tools of the lathe type, having a nose radius $\frac{1}{8}$ in., on various metals. When finishing soft, medium, and hard steel the cutting speeds which may be used are 20 ft., 15·5 ft., and 11 ft. per minute, whilst for finishing soft, medium, and hard cast iron the cutting speeds are 24 ft., 19 ft., and 14 ft. per minute in the order given. When finishing brass and copper, speeds of 80 ft. and 150 ft. per minute respectively should be adopted. The finishing cut should not exceed $\frac{1}{32}$ in. in any case. (*Dempster Smith.*)

TABLE OF CUTTING SPEEDS IN FEET PER MINUTE FOR CARBON STEEL LATHE TOOLS.

Cut.	Transverse.	Soft Steel.	Med. Steel.	Hard Steel.	Soft C. I.	Med. C. I.	Hard C. I.	Med. gunmetal	Soft Brass.
1/64	1/64	40·0	32·0	24·0	32·0	27·0	20·0	50·0	100·0
1/32	"	38·0	31·4	22·5	30·5	25·0	18·0	46·0	90·0
3/64	1/16	36·0	30·0	21·0	28·3	22·6	17·0	40·3	79·2
1/16	"	34·0	28·5	20·0	25·6	20·4	15·3	35·2	71·5
3/32	1/8	33·0	27·0	19·0	23·8	19·0	14·3	32·0	66·6
1/8	"	32·0	26·0	18·6	22·5	18·0	13·5	29·7	63·0
5/32	3/16	31·5	24·5	17·5	21·5	17·2	12·9	28·0	60·2
3/16	"	30·0	23·2	16·6	20·7	16·5	12·4	26·6	57·9
7/32	1/4	28·6	22·2	15·9	20·0	16·0	12·0	25·4	56·0
1/4	"								
1/64	3/32	36·0	31·4	22·5	30·5	25·0	18·0	46·0	90·0
1/32	"	34·0	30·0	21·0	28·2	22·6	17·0	40·3	79·2
3/64	1/16	32·0	27·0	19·0	23·8	19·0	14·3	32·0	66·6
1/16	"	30·0	24·5	17·5	21·5	17·2	12·9	28·0	60·2
5/64	1/8	28·6	22·2	15·9	20·0	16·0	12·0	25·4	56·0
3/32	"	26·5	20·6	14·7	18·9	15·1	11·3	23·6	52·9
7/64	3/16	25·0	19·4	13·9	18·1	14·5	10·8	22·2	50·6
1/8	"	23·7	18·4	13·2	17·4	13·9	10·4	21·1	48·7
9/64	1/4	22·7	17·6	12·6	16·8	13·4	10·1	20·2	47·0
1/4	"								
1/32	1/16	32·0	26·0	19·0	23·8	19·0	14·3	32·0	66·6
1/16	"	28·6	22·2	15·9	20·0	16·0	12·0	25·4	56·0
3/32	"	25·0	19·4	13·9	18·1	14·5	10·8	22·2	50·6
1/8	"	22·7	17·6	12·6	16·8	13·4	10·1	20·2	47·0
5/32	"	21·1	16·4	11·7	15·9	12·7	9·5	18·7	44·5
3/16	"	19·8	15·4	11·0	15·2	12·2	9·1	17·6	42·6
7/32	"	18·8	14·6	10·5	14·6	11·7	8·8	16·7	40·9
1/4	"	18·0	14·0	10·0	14·1	11·3	8·5	16·0	39·5
1/32	3/32	30·0	24·0	17·5	21·5	17·2	12·9	28·0	60·2
1/16	"	25·0	19·4	13·9	18·1	14·5	10·8	22·2	50·6
3/64	"	21·8	17·0	12·1	16·3	13·1	9·8	19·4	45·7
1/8	"	19·8	15·4	11·0	15·2	12·2	9·1	17·6	42·6
5/64	"	18·4	14·3	10·2	14·4	11·5	8·6	16·4	40·2
3/16	"	17·3	13·5	9·6	13·7	11·0	8·2	15·4	38·4
7/64	"	16·4	12·8	9·1	13·2	10·6	7·9	14·6	37·0
1/8	"	15·7	12·2	8·7	12·8	10·2	7·7	14·0	35·8
1/16	1/8	22·7	17·6	12·6	16·8	13·4	10·1		
3/32	"	19·8	15·4	11·0	15·2	12·2	9·1		
1/8	"	18·0	14·0	10·0	14·1	11·3	8·5		
5/64	"	16·7	13·0	9·3	13·4	10·7	8·0		
3/32	"	15·7	12·2	8·7	12·8	10·2	7·7		
7/64	"	14·3	11·1	7·9	11·9	9·5	7·1		
1/16	"	12·5	9·7	6·9	10·8	8·6	6·5		
1/4	"	11·3	8·8	6·3	10·0	8·0	6·0		
1/8	1/4	14·3	11·1	7·9	11·9	9·5	7·1		
1/16	"	12·5	9·7	6·9	10·8	8·6	6·5		
1/32	"	11·3	8·8	6·3	10·0	8·0	6·0		
1/16	"	10·5	8·2	5·8	9·5	7·6	5·7		
3/64	"	9·9	7·7	5·5	9·0	7·2	5·4		
1/32	"	9·0	7·0	5·0	8·4	6·7	5·0		
1/16	"	8·4	6·5	4·6	8·0	6·4	4·8		
3/64	"	7·9	6·1	4·4	7·6	6·1	4·6		

For ordinary Mushet steel the above speeds may be increased from 33 per cent. in the case of the lighter cuts to 50 per cent. for the heavy cuts.

The following table gives the revolutions per minute for different cutting speeds and diameters of work or cutters:—

RELATION BETWEEN REVOLUTIONS, CUTTING SPEEDS AND DIAMETERS OF WORK.

Cutting Speed in Ft. per Min.	Diameter of Work or Cutter, in Inches.																	
	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	2	2½	3	3½	4	5	6
10	152	102	76	61	51	44	38	34	30	25	22	19	15	13	11	10	8	6·3
15	229	153	115	92	76	65	57	51	46	38	33	29	23	19	16	14	12	10
20	305	204	153	122	102	87	76	68	61	51	44	38	31	25	22	19	15	13
25	382	255	191	153	127	109	95	85	76	64	55	48	38	32	27	24	19	16
30	458	306	230	184	153	131	114	102	92	76	65	57	46	38	33	29	23	19
35	535	357	268	214	178	153	133	119	107	89	76	67	53	45	38	33	27	22
40	611	407	306	245	204	175	153	136	122	102	87	76	61	51	44	38	31	25
45	686	458	344	275	229	197	172	153	138	115	98	86	69	57	49	43	34	29
50	764	509	382	306	255	218	191	170	153	128	109	95	76	64	55	48	38	32
60	917	611	459	367	305	262	229	204	183	153	131	115	92	76	66	57	46	38
70	—	713	535	428	356	306	267	238	214	178	153	134	107	89	76	67	54	45
80	—	815	611	489	407	349	306	272	244	204	175	153	122	102	87	76	61	51
90	—	917	688	550	458	393	344	305	275	229	196	172	138	115	98	86	69	57
100	—	—	764	611	509	437	382	339	305	255	218	191	153	128	109	96	76	64
110	—	—	841	672	560	480	420	373	336	280	240	210	168	140	120	105	84	70
120	—	—	917	734	611	524	458	407	367	306	262	229	183	153	131	115	92	76
130	—	—	994	795	662	568	497	441	397	331	284	248	199	166	142	124	99	83
140	—	—	—	856	713	611	535	476	428	356	306	268	214	178	153	134	107	89
150	—	—	—	917	764	655	573	509	458	382	327	287	229	191	164	143	115	95

Cutting Speed in Ft. per Min.	Diameter of Work or Cutter, in Inches.																	
	7	8	9	10	12	16	20	24	30	36	42	48	60	72	84	96	108	120
10	5·4	5	4	3·8	3·2	2·4	2	1·6	1·3	1	·9	·8	·6	·5	·5	·4	·4	3
15	8	7	6	5·7	4·8	4	3	2	1·9	1·6	1·4	1·2	1	·8	·7	·6	·5	·5
20	11	10	8	7·7	6	5	4	3	2·5	2·1	1·8	1·6	1·3	1·1	·9	·8	·7	·6
25	14	12	11	10	8	6	5	4	3·2	2·6	2·3	2	1·6	1·3	1·1	1	·9	·8
30	16	14	13	11	10	7	6	5	3·8	3·2	2·7	2·4	1·9	1·6	1·4	1·2	1	1
35	19	17	15	13	11	8	7	6	4·5	3·7	3·2	2·8	2·2	1·9	1·6	1·4	1·2	1·1
40	22	19	17	15	13	10	8	6·3	5·1	4·2	3·6	3·2	2·6	2·1	1·8	1·6	1·4	1·3
45	25	21	19	17	14	11	9	7	5·7	4·8	4·1	3·6	2·9	2·3	2	1·8	1·6	1·4
50	27	24	21	19	16	12	10	8	6·5	5·2	4·6	4	3·2	2·6	2·3	2	1·8	1·6
60	33	29	25	23	19	14	11	10	8	6·4	5	4·8	3·8	3·2	2·7	2·4	2·1	1·9
70	38	33	30	27	22	17	13	11	9	7·4	6	5·6	4·5	3·7	3·2	2·8	2·5	2·2
80	44	38	34	31	25	19	15	13	10	8·5	7	6	5·1	4·3	3·7	3	2·8	2·6
90	49	43	38	34	28	21	17	14	11	9·6	8	7	5·8	4·8	4·1	3·6	3·2	2·9
100	55	48	42	38	32	24	19	16	13	10	9	8	6·4	5·3	4·6	4	3·6	3·2
110	60	53	47	42	35	26	21	18	14	12	10	9	7	5·8	5	4·4	3·9	3·5
120	65	57	51	46	38	29	23	19	15	13	11	10	7·7	6·4	5·5	4·8	4·2	3·9
130	71	62	55	50	41	31	25	21	17	14	12	10·4	8	6·8	5·9	5	4·6	4·2
140	76	67	59	53	45	33	27	22	18	15	13	11	9	7·4	6·3	5·6	5	4·5
150	82	72	64	57	48	36	29	24	19	16	14	12	10	7·9	6·9	6	5·3	4·8

CUTTING WITH ORDINARY AND HIGH-SPEED STEEL.

Steel.

Trials showed that 20 ft. per minute with a cut of $\frac{1}{16}$ in. by $\frac{1}{16}$ in. is the superior limit of speed for ordinary water-hardened steel operating upon Whitworth fluid-compressed soft steel;

whilst an ordinary Mushet tool can run at over 30 ft. per minute, with a $\frac{3}{16}$ in. by $\frac{1}{16}$ in. cut upon the same material.

Cast Iron.

The trials on *medium cast iron* showed that 25 ft. per minute is too high a speed with $\frac{1}{16}$ in. by $\frac{1}{16}$ in. cuts; 17 ft. is too high with $\frac{3}{16}$ by $\frac{1}{16}$ in. cuts; and 15 ft. is too high with $\frac{3}{16}$ in. by $\frac{1}{8}$ in. cuts for ordinary water-hardened tool steels. An ordinary Mushet ran for over 20 minutes at 23·6 ft. per minute on a $\frac{1}{16}$ in. by $\frac{1}{16}$ in. cut; whilst it failed at 19 ft. per minute on a $\frac{3}{16}$ in. by $\frac{1}{16}$ in. cut, and at 15 ft. per minute on a $\frac{3}{16}$ in. by $\frac{1}{8}$ in. cut on this material.

In the case of *soft cast iron*, 22 ft. per minute was too high a speed for water-hardened steel taking a $\frac{3}{16}$ in. cut by $\frac{1}{8}$ in. traverse; whilst an ordinary Mushet lasted over half an hour at 31·6 ft. per minute with the same cut upon the same material.

Heavy cuts are much more economical in power, for the waste work is a much larger proportion of the whole work required at light cuts than at heavy cuts. It is probably this fact which has given rise to the commonly accepted opinion that the cutting stress increases with the speed (as instanced by the objections of workmen to increase cutting speeds on account of the anticipated springing of the work), contrary to the results of these trials, which rather show the reverse to be the case. In soft steel, for example, the average horse-power required for actual cutting at $\frac{3}{16}$ in. by $\frac{1}{16}$ in. was 3, while at $\frac{3}{8}$ in. by $\frac{1}{8}$ in. it was 15. The friction horse-power of lathe and counter-shaft was about $2\frac{1}{2}$ h.p. The weight removed was about 105 lbs. and 445 lbs. per hour at the light and heavy cuts respectively, so that the weight removed per gross h.p. hour was 19·1 lbs. for the light and 25·3 lbs. for the heavy cut. Neglecting frictional loss, these figures would have been 35 and 29 respectively.

In the case of cast iron, the gain in power at the heavier cuts is still more conspicuous. Here the effective h.p. was 1·7 and 5·5 at the $\frac{1}{16}$ by $\frac{1}{16}$ and $\frac{3}{8}$ by $\frac{1}{8}$ cuts respectively, the waste h.p. being about 2. The weights removed were 42 lbs. and 198 lbs. per hour, and the weights per h.p. hour were therefore: 11·35 lbs. at the light cut, and 26·5 lbs. at the heavy cut.

These results show that more material can be removed in a given time with a heavy cut at its proper speed than with a light cut at the highest speed which the new steels can take, and that this can be done at a smaller expenditure of gross power per ton of shavings removed.

VARIATION OF CUTTING FORCE WITH AREA OF CUT, AND OF CUTTING STRESS OBTAINED IN THE ABOVE TRIALS.

For steel the cutting force is simply proportional to the area of cut, and this force has the following approximate values in tons per sq. in.:—

For soft steel (fluid compressed)	. 115	For soft cast iron	. 51
„ medium steel „ „	. 108	„ medium iron	. 84
„ hard steel „ „	. 150	„ hard iron	. 82

Fine traverses take more power than coarse ones.

Cutting stress does not vary much with speed, but tends to diminish.

Special high-speed tool steels will cut twice as fast as ordinary Mushet steel, and more than four times as fast as ordinary water-hardened steel.

(*Proc. Manchester Assoc. of Engrs.* 1903.)

CUTTING SPEED FOR HIGH-SPEED STEEL TOOLS WHEN CUTTING STEEL.

An extensive series of experiments have been carried out by the Lathe Tool Research Committee of the Manchester Association of Engineers, when operating on steel under different conditions.* The Committee in many of its investigations selected cutting speeds which would give a twenty minutes life to the tool, but state that for practical purposes and economic considerations, a speed which will give a two hours run is desirable. A relation is, therefore, given between the cutting speed and durability of the tool, and this conforms to the expression:

$$VT^{\frac{1}{3}} = \text{constant},$$

where,

V = cutting speed in ft. per min., and T = duration in mins.

* See Report of Lathe Tool Research Committee, published by H.M. Stationery Office, 1922. Price 5*s*.

The value of the constant varies with the material operated upon and also with the dimensions of the cut. This relationship is of the utmost value, since for a given material, tool, and cut, if the cutting speed V and the life of the tool T be observed, the cutting speed V_o for the tool to last a time T_o can be obtained, thus:

$$V_o = V\left(\frac{T}{T_o}\right)^{\frac{1}{3}}.$$

The change in the cutting speed with time as given by the above law may be better appreciated from its graphical representation in fig. 55, where the appropriate cutting speed is plotted on a base of tool life.

As an example, assuming a tool under test lasts 40 minutes when cutting at 110 ft. per minute,

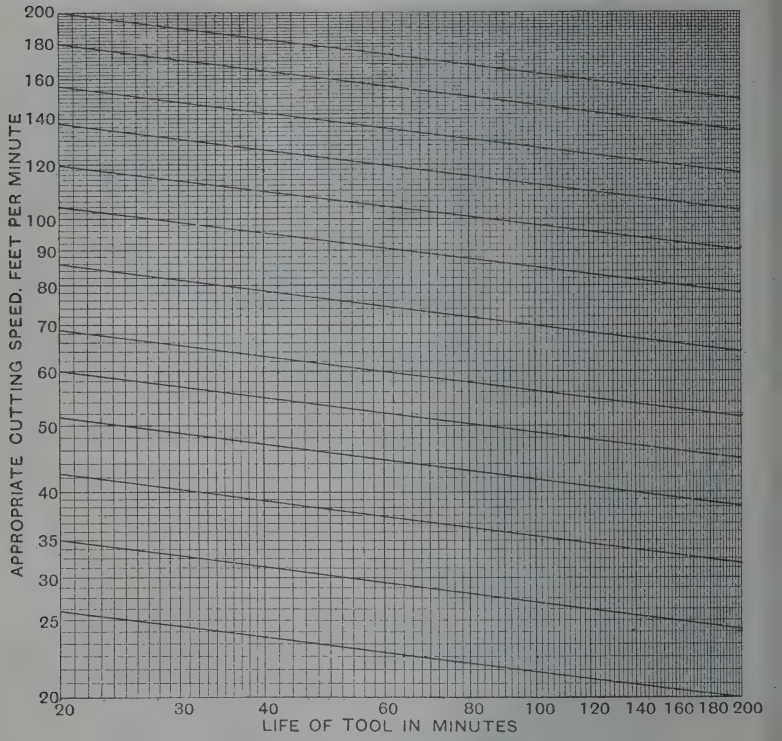

FIG. 55.—Relation between appropriate cutting speed and life of tool.

and it is required to find the speed at which the tool will last 120 minutes, other conditions remaining unaltered. Trace vertically above 40 minutes until the diagonal line, passing through the horizontal line of 110 ft. per minute, is reached. Follow this diagonal line until vertical over 120 minutes, when it intersects the horizontal line at 96 ft. per minute, which is the speed required.

CUTTING SPEED AND DIMENSIONS OF CUT (STEEL).

The value of the cutting speed varies with the dimensions of the depth of cut and traverse, shape and section of tool, as well as the material cut.

The cutting speeds for the various cuts and traverses given in fig. 56 correspond to a 2-hours' life of tool (which is considered to be the most economical life) when cutting a steel having an ultimate tensile stress of 38 tons per sq. in. and without any cooling medium.

The values were obtained when using a 1¼ in. square tool having a 60° plan angle, 70° cutting angle, and ⅛ in. nose radius.

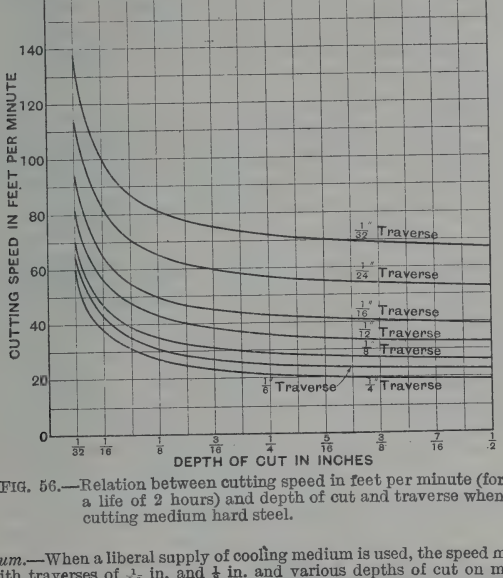

FIG. 56.—Relation between cutting speed in feet per minute (for a life of 2 hours) and depth of cut and traverse when cutting medium hard steel.

Cooling Medium.—When a liberal supply of cooling medium is used, the speed may be increased. For instance, with traverses of $\frac{1}{32}$ in. and ⅛ in. and various depths of cut on mild steel, it was found that the cutting speed might be increased by approximately 15 ft. per minute. The permissible increase will obviously depend upon the quality of cooling medium, dimensions of the cut, material cut, etc.

Tool Section.—Taking a 1¼-in. square tool as the standard, then for tools of smaller sections, say ½, ¾, and 1 in. square, the cutting speeds can be obtained by multiplying the value for the 1¼-in. square tool by the following factors: 0·815, 0·92, 0·97 for the sections in the order given, whilst for a 1½-in. square tool the permissible speed would only be about 2 per cent. greater than that of the 1¼-in. square tool.

Cutting Angle.—The results of the trials show that when the ratio of depth of cut to traverse is greater than unity, the 70° cutting angle tool gives the greatest durability for a given cutting speed, but when the ratio is equal to unity a cutting angle of about 80° is the most efficient and allows of an increase in the cutting speed of about 8 per cent. above that of the 70° tool. The relatively rough surface produced and the increased power consumption for the 80° cutting angle is likely to result in the 70° cutting angle being adopted for general workshop use. It may happen, however, that the power available is such as to demand a more acute cutting angle, in which case the permissible cutting speeds for tools having cutting angles of 50° and 60° are 71 per cent. and 82 per cent. respectively of that for the 70° angle tool, and these values are irrespective of the ratio of depth of cut to traverse.

Plan Angle.—Should the work and machine be sufficiently stiff or of a character such as would permit of a small plan angle tool, say 30° or 45° being used, then the cutting speed may respectively be taken as 1·55 or 1·21 times that given for the 60° plan angle tool. But should circumstances demand that a 75° or 90° plan angle tool be used then the permissible cutting speed is respectively 88 per cent. or 82 per cent. of that given for the 60° plan angle tool.

CUTTING SPEED AND DIMENSIONS OF CUT (CAST IRON).

The cutting speed when cutting soft cast iron, having a compressive strength of 29 tons per sq. in., with a 1¼ in. square tool, having a 75° cutting angle, ⅛ in. nose radius, and 60° plan angle (see fig. 53, p. 1145), are given in fig. 57. The speeds correspond to a 2-hours' life of tool (*i.e.* the length of time the tool will last before the cutting edge fails, and which is considered to give the most economical results) when cutting dry.

While the cutting speed decreases as the crushing strength of the material increases, a comparatively close relation between these cannot be given, as the cutting crumbles irregularly on the tool face.

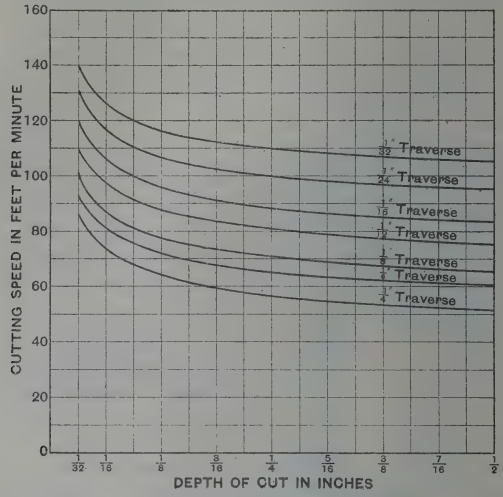

FIG. 57.—Relation between cutting speed in feet per minute (for a life of tool of 2 hours) and depth of cut and traverse when cutting cast iron.

The modification to be made in the cutting speed for other sections of tool, plan angle, etc., are for practical purposes similar to that given above for steel.

There is no close relation between the ultimate strength, or Brinell Hardness figure, of various metals and the cutting speed, but for ordinary straight steels (*i.e* containing little or no nickel, chromium, or tungsten), there is an approximation relationship which falls within ordinary workshop limits.

(*Proc. Manchester Assoc. of Engrs.* 1925.)

Cutting Lubricants.

The mineral oils best suited for use as cutting lubricants, either alone or mixed with animal or vegetable oil, are preferably of pale colour and low viscosity, ranging from 100 to 200 seconds Redwood at 100 deg. F., those of lower viscosity being used for high-speed conditions and those of higher viscosity for slow speeds. Tinged lard oil, containing as much as 10 or 15 per cent. of free fatty acids, is the animal oil most frequently used, either alone or in admixture : prime lard oil, which is almost free from acid, is more expensive, but is less inclined to gum under severe conditions of heavy cut and high speed. Wherever possible, a mixture of lard oil and low cold test mineral oil is to be preferred on account of greater fluidity in the cold. Cotton-seed oil oxidises more readily than rape oil, and should not be used for cutting lubricants that are to be employed in a circulation system.

Good cutting oils used straight will not cause rusting, but those containing fixed (animal or vegetable) oils, such as lard oil with a large percentage of free fatty acid, will give rise to verdigris on brass. Vegetable oils such as rape, with a small percentage of free acid, do not produce verdigris unless they are rancid. Cutting emulsions made up from cutting compounds or soluble oils and water cause rusting if they are used too weak or if they contain acid. Water containing sodium chloride is most destructive to emulsions and must not be used, nor must hard water on account of the precipitate caused by the calcium and magnesium salts in it. Emulsions of oil and water are not stable in the presence of even minute quantities of acid ; to a limited extent they can be reformed by neutralising the acids with ammonia, but excess of alkali may facilitate corrosion.

Factors in Selection.

Low speeds and shallow cuts require little cooling and lubrication. Low speeds and heavy cuts demand a lubricant of great oiliness, particularly if the material is tough. High speeds and shallow cuts demand a cutting medium with great cooling properties ; hence emulsions are

favoured and should be used if the speeds are particularly high. Turpentine substitute is a satisfactory lubricant for aluminium, but being inflammable must be used with care. A mixture of paraffin oil and lard or other cutting oil for high speed work on aluminium is also dangerous and has led to several fires. Cutting emulsions which possess the necessary cooling properties, and are not inflammable, are to be preferred. High speeds and heavy cuts demand a cutting lubricant with great cooling and lubricating properties; hence heavily compounded cutting lubricants of low viscosity must be used. For tough material and heavy cuts an emulsion containing 15 to 20 per cent. of a vegetable oil has been reported to be satisfactory.

Cutting emulsions are nearly always used for brittle material, and frequently for tough material if the speeds are high and the cuts light; when the material is tough and the cut heavy it is necessary to employ cutting lubricants used straight and containing 10 to 50 per cent. of animal or vegetable oils, or consisting entirely of such oils. Emulsions, in some cases, have been found to form a deposit on the working parts of automatic screw-cutting machines; this may be avoided by using straight oils, but emulsions should be adopted wherever possible in view of the present scarcity of oil. The amount of soluble oil or soluble compound used in preparing the cutting emulsion varies from 2½ to 20 per cent.; the richer mixtures are used for severe conditions, and the weaker for light duty or for materials like brass and aluminium, where there is no danger of rusting.

The cutting lubricant may be applied by hand by a drop-feed system, or by some system employing gravity or pumping. In large machine shops the cutting oil is sometimes circulated in pipes throughout the works, returning through other pipes to a central tank; group systems with central tanks are excellent where one mixture is used for all the machines on the circuit. The return pipes should be large and arranged for easy access for cleaning; isolating valves should be employed to sectionalise the system when large; efficient strainers should be fitted on all return pipes and pump sections, and should be cleaned daily. Tanks, as a rule, should be cleaned out every four weeks, and return pipes every four months. Any scum formed should be skimmed off the tanks daily. It must be remembered that the oil or emulsion, in any system in which it is circulated over and over again, is exposed to the admixture of dust and dirt from the machine shop and to the oxidising influence of air. The suction of any pumps that are employed should always be covered to prevent air from being drawn in, since aeration of the oil or emulsion has a strong oxidising effect upon it.

In machining aluminium (drilling, planing, etc.), use a lubricant of lard oil, kerosene, or a mixture of kerosene and gasolene or lard oil, for free cutting and a good finish.

Effects on Health.

Workers should be instructed not to wipe their hands on rags before washing, and to avoid washing their hands in the cutting compounds. Ether soap, which dissolves oil, has been found useful in preventing inflammation of the hair follicles, and dusting the arms with a powder containing equal parts of starch and zinc oxide before starting work prevents the action of the oil on the skin.

Workers whose hands have become the seat of septic infection should not be allowed to work on machines, as they are liable to infect the oil with germs and so infect others. As a general rule, frequent washing with soap and hot water is sufficient to bring about rapid cure of folliculitis produced by plugging of the glands. Subsequently the skin may be dusted with zinc oxide and starch powder, and where this has been insufficient a mild antiseptic applied on lint has relieved the irritation and given good results. Septic infection of the skin due to cuts should be treated on general principles with suitable antiseptic dressings.

(*Bulletin No.* 2, *the Department of Scientific and Industrial Research.*)

PORTABLE PNEUMATIC TOOLS.

The Boyer Long-Stroke Hammer.

(*The Consolidated Pneumatic Tool Co., Ltd.*)

This (fig. 58, p. 1154) is one of the best and most generally used of all pneumatic riveting hammers, at the present time. It has one distributing valve, which is placed at the rear end of the cylinder. The air-ports in the valve and cylinder of this hammer are so designed that the full air pressure is available to drive the piston forward on its working stroke, but the ports in valve and cylinder provided for effecting the return or idle stroke of the piston are of small area, so that the pressure used for this work is considerably reduced by wire-drawing, and the piston is returned practically without shock to the operator. The vibration of these hammers is thus reduced to a minimum.

For holding up against the riveting hammer, any of the present hand methods may be employed, and quite good work can be done either with the old-fashioned mawl, or a plain dolly bar

THE BOYER LONG-STROKE RIVETING HAMMER.
(*The Consolidated Pneumatic Tool Co. Ltd.*)
FIG. 58.

THE NEW GIANT DRILL.
(*The Consolidated Pneumatic Tool Co. Ltd.*)
FIG. 59.

Rivet your attention on

BOYER

Pneumatic Riveting Hammers

For all Classes of Riveting

TO reduce Costs and speed up output, you need the World's best Pneumatic Hammers, Drills and Grinders and in the BOYER LITTLE GIANT and RED GIANT you have them. Money cannot buy better.

(*See Editorial pages* 1117-1120 and 1153-1157.)

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F. 1154

FOR drilling holes in metal or wood, the LITTLE GIANT meets the demand for Portable Electric Drills that give rapid work in comparatively unskilled hands.

OUTSTANDING FEATURES:

Ease of Manipulation
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Light Weight
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Portable Electric Grinders also supplied.

Write for Catalogue No. 14, *with full particulars of our Little Giant Drills and Grinders.*

(*See Editorial pages* 1117-1120 and 1153-1157.)

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consisting of a piece of wrought iron weighing about 28 lbs. Where a suitable backing can be found for it, the pneumatic piston holder-on is most useful, and for boiler work and in certain classes of heavy shipyard riveting the hammer type of holder-on is frequently used. This gives a series of blows on the head of the rivet whilst it is being formed.

Pneumatic riveting hammers are now recognised as thoroughly practical and efficient tools for dealing with any class of work which was formerly done by hand, and rivets from $\frac{1}{4}$ in. up to $1\frac{1}{4}$ in. diameter can be closed by suitable tools. It takes from 7 to 10 seconds to close a $\frac{7}{8}$ in. snap-headed rivet.

The air consumption of these tools is generally 25 cubic feet of free air per minute, and the pressure may be from 80 to 100 lbs. per square inch, the latter figure being necessary for the heaviest class of riveting, and particularly for steam- or water-tight work.

Caulking Hammers.

The chipping or caulking hammer has now taken its place as an indispensable every-day tool, without which present rates of output could not be maintained. The average chipping hammer will remove mild steel at the rate of $3\frac{1}{2}$ to 4 oz. per minute, and the air consumption is from 17 to 20 cubic feet of free air per minute: pressure from 80 to 100 lbs. per square inch.

Drills.

A pneumatic drill of average size can be relied upon to drill in mild steel plate 1 in. diameter holes at the rate of 1 in. to $1\frac{1}{2}$ in. deep per minute, and larger and smaller holes in proportion, the air consumption varying from 30 cubic feet in the average drills to 50–60 in the larger tools. Usual air pressure 80 lbs. per square inch. Reamering and tapping are also among the varied uses to which these tools can profitably be put. Pneumatic drills are now available in a large range of sizes, from a tool weighing 8 lbs. for drilling $\frac{3}{16}$ in. holes up to a weight of 85 lbs. and a capacity for 3 in. drilling and tapping. (See fig. 59, page 1154.)

Pneumatic Tools for Salvage Work.

The chipping hammer and drill mentioned above can be fitted for use under water, for ship repairs, dock construction, and other similar work, and are already very largely used in this connection.

Air Mains and Receivers.

Air Mains for the distribution of compressed air are generally made of wrought-iron piping of steam quality, and should be so arranged that the rate of flow will not very much exceed 50 feet per second. At intervals along this main, or wherever tools are likely to be employed, a tee piece should be inserted which will take a connection for the flexible rubber hose which joins up to the tools. An important point to take care of is the provision of adequate means for draining any moisture from the air receiver or the pipe lines themselves, and it is advisable to arrange for the discharge of the compressor to deliver the air at the top of the receiver, and to connect the air main lower down. This assists in depositing any moisture which may be in the air as delivered from the compressor.

Air Receivers should be fitted with a manhole, in order that their interior condition may be examined from time to time, as it is possible for corrosion to take place, or on the other hand, if the lubrication of the compressor is not carefully attended to, a large deposit of oil will be formed, which may result in an explosive mixture being present in the receiver.

Air should not be throttled at connections. It is a good plan to introduce water traps in suitable places in a pipe system. Strainers should be carefully watched, they are liable to get choked; they may be cleaned by blowing air through them in the reverse direction.

Tubing and Tube Couplings.

To secure good, economical service, air hose must not kink. Kinking not only shuts off the supply of air at the time, but it creates a permanent injury in the wall of the hose, which later develops into a leak. To prevent accidents of this character, the thickness and number of plies must be proportioned to the size of the hose; the rubber must be of good quality; and the inner tube, fabric, and outer cover must be properly proportioned to each other.

Sometimes customers specify wire winding as a protection against outside wear. The practice is not recommended. It makes the hose heavy and hard to handle. Once bent, the hose is hard to reshape; and a wire covering is more costly than the thick rubber cover recommended as the best protection for the outside of the hose.

A moulded hose is advisable for any length over 50 ft. This type of hose eliminates extra couplings, which retard the flow of air and decreases the pressure at the tool. This is an important feature. It has been found that a 15-lb. increase in pressure can make a 37 per cent. difference in the amount of work accomplished by the tool.

The pressure which the hose will stand is inversely proportionate to its diameter. A 1-in. 6-ply hose may have a bursting pressure as high as 800 lbs., while a 2-in. 6-ply hose made of the same materials would burst at 650 lbs. Hence, care always should be taken to specify greater number of plies for the larger sizes.

Flexible Metallic Tubing (*The United Flexible Metallic Tubing Co. Ltd.*, 112 *Queen Victoria Street, London*) is being largely used for pneumatic tools. As the tubing withstands crushing and cannot kink, it is well adapted for conveying compressed air to pneumatic drillers and other machines.

TABLE GIVING THE THEORETICAL VOLUME OF EQUIVALENT FREE AIR, IN CUBIC FEET,

that will flow per minute at various pressures through straight pipes of different diameters, each 100 ft. long, without any reduction of pressure.

Initial and Terminal Gauge Pressure, Lbs.	Nominal Diameters of Pipes in Inches.																		Initial and Terminal Gauge Pressure, Lbs.
	1	1½	2	2½	3	3½	4	5	6	7	8	10	12	15	18	20	22	24	
10	24·05	75·67	153·0	244·7	433·3	636·4	883·8	1585	2542	3701	5134	9212	14530	22530	36280	48180	61870	77880	10
20	28·48	89·54	117·9	288·8	512·9	753·0	1045	1871	3006	4381	6076	10900	17210	26640	42940	57000	73220	92150	20
30	32·35	101·6	202·0	329·1	582·5	855·0	1187	2124	3415	4975	6900	12380	19540	30270	48750	64760	83160	104630	30
40	35·82	112·5	223·5	364·2	644·7	946·4	1314	2352	3779	5507	7635	13700	21620	33500	53960	71640	92010	115800	40
50	**38·96**	**122·4**	**243·4**	**396·3**	**701·5**	**1030**	**1430**	**2558**	**4114**	**5993**	**8312**	**14910**	**23520**	**36450**	**58730**	**74300**	**100150**	**126030**	**50**
60	41·83	131·4	261·1	425·4	752·9	1105	1535	2747	4416	6433	8920	16000	25260	39120	63040	83660	107470	135240	60
70	44·53	139·9	278·0	452·9	801·8	1176	1634	2925	4701	6848	9499	17030	26900	41660	67110	89100	114420	144000	70
80	47·08	147·9	294·0	478·8	847·6	1244	1728	3091	4971	7240	10040	18000	28430	44050	70960	94180	120970	152230	80
90	49·54	155·6	309·3	503·8	891·8	1307	1817	3253	5230	7619	10560	18940	29920	46340	74660	99100	127300	160190	90
100	**51·88**	**163·0**	**324·0**	**527·5**	**933·8**	**1370**	**1904**	**3407**	**5477**	**7979**	**11050**	**19850**	**31330**	**48530**	**78190**	**103770**	**133300**	**167720**	**100**
110	54·10	169·9	337·8	550·1	973·9	1429	1985	3552	5712	8320	11530	20690	32670	50610	81540	108220	139000	174920	110
125	57·15	179·5	356·8	581·3	1028	1510	2097	3754	6034	8789	12180	21860	34520	53470	86140	114430	146850	184800	125
150	62·10	195·1	387·8	631·7	1117	1641	2280	4080	6558	9553	13240	23760	37520	58120	93610	124280	159600	—	150
175	66·71	209·6	416·5	678·4	1201	1762	2448	4382	7044	10250	14220	25520	40300	62420	100520	133460	—	—	175
200	**70·93**	**222·9**	**443·0**	**721·4**	**1277**	**1874**	**2603**	**4659**	**7489**	**10900**	**15120**	**27140**	**42850**	**66370**	**106900**	**141910**	—	—	**200**
250	78·70	247·3	491·4	800·4	1416	2079	2889	5170	8309	12100	16780	30110	47550	73640	118620	—	—	—	250
300	85·85	269·9	536·3	873·4	1546	2269	3152	5642	9063	13210	18320	32870	51890	80380	—	—	—	—	300
400	98·55	309·9	615·7	1002	1775	2606	3619	6477	10400	15160	21020	37730	59580	92270	—	—	—	—	400
500	109·7	345·1	685·3	1116	1976	2902	4031	7215	11590	16890	23420	42020	66340	102750	—	—	—	—	500
600	**119·9**	**377·3**	**749·5**	**1220**	**2160**	**3172**	**4405**	**7882**	**12670**	**18460**	**25600**	**45940**	**72520**	—	—	—	—	—	**600**
700	129·3	406·6	807·6	1315	2328	3419	4748	8496	13650	19890	27590	49500	78150	—	—	—	—	—	700
800	138·1	434·1	862·0	1404	2486	3650	5070	9072	14580	21240	29450	52840	—	—	—	—	—	—	800
900	146·3	460·0	914·4	1489	2636	3871	5373	9618	15460	22520	31230	56040	—	—	—	—	—	—	900
1000	154·3	485·1	963·5	1569	2778	4079	5664	10130	16290	23730	32920	59060	—	—	—	—	—	—	1000
1100	**161·3**	**507·1**	**1008**	**1641**	**2906**	**4264**	**5924**	**10590**	**17040**	**24820**	**34430**	—	—	—	—	—	—	—	**1100**
1200	168·6	530·3	1053	1716	3037	4457	6193	11080	17810	25940	35980	—	—	—	—	—	—	—	1200
1300	175·7	552·2	1097	1787	3163	4643	6448	11540	18550	27030	—	—	—	—	—	—	—	—	1300
1400	182·2	572·4	1137	1853	3280	4814	6686	11970	19230	28020	—	—	—	—	—	—	—	—	1400
1500	188·2	591·5	1175	1914	3389	4973	6908	12360	19870	—	—	—	—	—	—	—	—	—	1500

(The Consolidated Pneumatic Tool Co.)

TABLE SHOWING LOSS IN AIR PRESSURE, IN POUNDS, DUE TO FRICTION IN PIPES 100 FT. IN LENGTH.

Gauge Pressure at Entrance to Pipe, 100 lbs.

Pipe Diameter. Ins.	Cubic Feet Free Air delivered per Minute.																											
	25	50	75	100	125	150	200	250	300	350	400	500	600	700	800	900	1000	1200	1500	1800	2000	2500	3000	3500	4000	5000	6000	7000	8000
1	0·3	1·18	2·66	4·75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1¼	0·08	0·33	0·73	1·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1½	—	0·13	0·29	0·6	0·8	1·15	2·04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	0·03	0·07	0·12	0·18	0·26	0·47	0·73	1·05	1·43	1·87	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2½	—	—	—	0·03	0·05	0·08	0·14	0·21	0·31	0·42	0·54	0·85	1·22	1·66	2·17	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	0·03	0·05	0·08	0·11	0·15	0·2	0·31	0·45	0·61	0·8	1·01	1·25	1·8	—	—	—	—	—	—	—	—	—	—	—
3½	—	—	—	—	—	—	—	—	0·05	0·07	0·09	0·14	0·21	0·28	0·37	0·46	0·57	0·82	1·28	—	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—	—	0·05	0·07	0·1	0·14	0·18	0·23	0·28	0·41	0·64	0·92	1·13	1·77	—	—	—	—	—	—	—
4½	—	—	—	—	—	—	—	—	—	—	—	0·04	0·06	0·08	0·1	0·13	0·16	0·23	0·35	0·51	0·63	0·98	1·41	—	—	—	—	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	0·03	0·04	0·06	0·07	0·09	0·13	0·2	0·29	0·36	0·56	0·81	—	—	—	—	—	—
6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·02	0·03	0·04	0·05	0·08	0·11	0·14	0·22	0·32	0·43	0·56	—	—	—	—
7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·02	0·02	0·04	0·05	0·06	0·1	0·14	0·2	0·25	0·4	0·57	—	—
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·02	0·03	0·03	0·05	0·07	0·1	0·13	0·2	0·29	0·39	0·51
10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·01	0·02	0·02	0·03	0·04	0·06	0·09	0·13	0·16
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·01	0·01	0·02	0·02	0·04	0·05	0·06

(The Consolidated Pneumatic Tool Co.)

Bellis & Morcom Pneumatic Hose Coupling.

(Belliss & Morcom, Ltd., Ledsam St. Works, Birmingham.)

This coupling (fig. 60), which is simple in construction and convenient in use, does not rely on springs to maintain its lock, being immediately sealed by the internal pressure, and cannot unlock of its own accord in or out of use. It is claimed to be absolutely air-tight; easily and quickly disconnected; practically unbreakable, being made from steel bar; dust-proof, and being gun-blacked, will not easily rust. Having no external projections, it can be easily drawn through close quarters or past work lying about the shop.

The rubber jointing, being held securely in place, cannot blow out, but can be easily removed by hand for replacement when required.

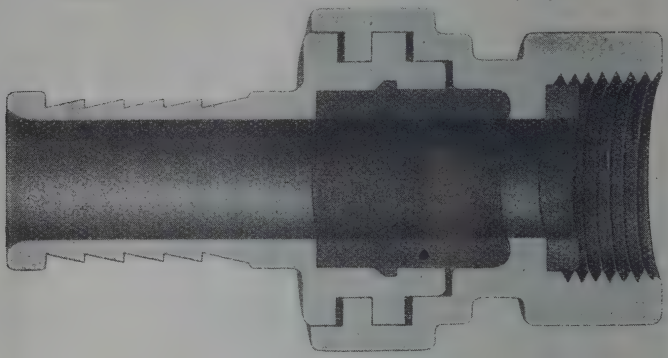


Fig. 60.

It is screwed on the shank and tapered to facilitate fitting on the hose. The ends of each hose pipe can be locked together, thus giving a neat appearance when coiled up. Additional hose for extensions can be connected up instantly. The coupling is supplied in the following sizes:—$\frac{1}{2}$ in. gas for chipping hammers, drills, riddles, etc.; $\frac{3}{4}$ in. gas for riveting hammers, etc.; 2 in. gas for coal-cutting tools and pressure mains.

The 'Flexstel' System of Ball and Socket Joints.

(Messrs. W. H. Dorman & Co. Ltd., Stafford.)

This system of Flexible Pipe Joints provides complete units (fig. 61), having standard flanged or screwed ends, and may be readily interposed between suitable lengths of piping to provide for movements up to an included angle of about 40°.

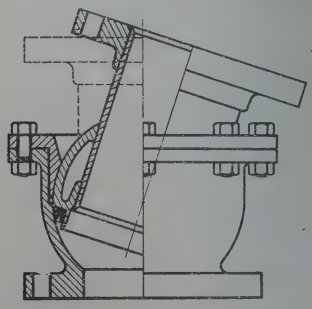


Fig. 61.

A special feature of the joint is the position of the packing ring, which is placed on a step on the leading end of the ball member, sealing the joint and insulating the spherical bearing surfaces

DORMAN PATENT

'FLEXSTEL' JOINTS

IMPROVED BALL AND SOCKET TYPES

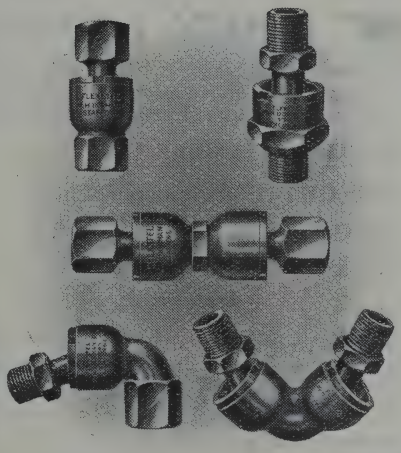
PATENT NO. 129812

Standardized & Interchangeable

2-inch to 12-inch Bore with flanged ends drilled to suit British Standard Table, No. 1 or No. 2.

LEAKPROOF *and* RELIABLE

¼-inch to 3-inch Bore with ends screwed, internally or externally, to suit British Standard Pipe Threads. For conveying Steam, Water, Oil, Compressed Air, Gas, etc., at high and intermittent pressures. Send for Illustrated Catalogue.



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Tight with equal pressure all round.

'JUBILEE' Worm-Drive (Pat.) CLIPS British Manufacture.

FOR AIR, WATER, AND OIL HOSE JOINTS

THE ENGINEER'S BEST FRIEND

BETTER AND CHEAPER THAN WIRE OR OTHER TYPES OF CLIPS.
EASY TO FIT.
WILL STAND HIGH PRESSURE.

THEY NEVER LEAK

Exclusively used by the L.M. & S., G.W., London Electric Railways, etc., G.P.O., 23 well-known Motor Car Manufacturers, R.A.S.C. and large Transport Cos., Paper Mills and Breweries, etc.

TRY A SAMPLE CLIP!

To fit OUTSIDE diameter of hose.

Size **0** fits $^{5}/_{8}$ inch to $^{7}/_{8}$ inch.
,, **1** ,, $^{7}/_{8}$ inch to $1\frac{1}{2}$ inch.
,, **2** ,, $1\frac{1}{2}$ inch to $2\frac{1}{8}$ inch.
,, **3** ,, **2** inch to $2\frac{3}{4}$ inch.
,, **4** ,, $2\frac{3}{4}$ inch to $3\frac{1}{4}$ inch.
(*We can make larger sizes*).

Approved by the BRITISH AIR MINISTRY for use in AIR-CRAFT.

Will even tighten this.

MANUFACTURERS:—

L. Robinson & Co.

14 London Chambers, Gillingham, Kent.

from contact with the fluent. The outer surface of the packing is so shaped to conform to the spherical surface of the cup, and being rather full in size provides for initial compression and ensures the joint being leak proof at low pressures. The joint is effectively sealed at higher pressures by the lip formation of the packing ring.

These joints are made in a range of sizes from ¼ in. to 12 ins. in bore, sizes up to 3 ins. being usually made with ends screwed to British Standard pipe threads, and sizes 2 ins. upwards have flanged ends faced and drilled to suit British Standard Tables No. 1 or No. 2. Joints with screwed ends can be had with external or internal standard screw threads and are of many types, the straight joints having both single and double ball connections, while the range of elbow joints includes 90° single and double, 135° single, and 40° double.

'Flexstel' joints are used for conveying compressed air, steam, water, oil, gas, acids, etc., a suitable packing ring being fitted for each use.

These joints can be fitted with obvious advantages to cater for the movement of machines or any moving bodies where it is desired to apply high or intermittent pressures of any of the fluents referred to above.

Jubilee Worm-Drive Hose Clips.

(Patent.)

(*L. Robinson & Co., Gillingham, Kent.*)

In these clips (fig. 62), a direct pull is exerted on a steel ribbon by a worm with heavy square-cut threads, which cannot be stripped. The arrangement gives an even and equal pressure round the hose, is easily fitted, and, when being removed, opens out automatically.

Open. Fig 62. Closed.

The clip adjusts accurately, even on hose too large or pipe not round; it is only necessary to push the free end under the screw and tighten up; the tightening up can be done again and again—a coin can be used if a screw-driver is not to hand.

The clip is smooth inside all round, and gives an even bearing; there are no sharp edges to cut, or spaces to permit leakage.

Being made of best quality steel, heavily galvanised, it is non-rustable and practically indestructible.

The whole arrangement is in one piece, so that there are no parts to lose and nothing to put together.

To fit from ⅝ in. to 3¼ in. outside diam., only five sizes are needed, viz.:—

Size.	Outside Diam. of Hose.	Size.	Outside Diam. of Hose.
No. 0	⅝ in. to ⅞ in.	No. 3	2 in. to 2⅝ in.
No. 1	⅞ in. to 1½ in.	No. 4	2⅝ in. to 3¼ in.
No. 2	1½ in. to 2⅛ in.		

The clip will stand up to practically any pressure, and is officially approved by the British Air Ministry for use on aircraft; also by the Metropolitan Railway and the London, Midland & Scottish Railway for the automatic brakes on their trains, and by a number of fire brigades.

Care of Pneumatic Tools.

Unless pneumatic tools are kept clean, well lubricated, and limited to the uses for which they are intended, they will not give the service for which they are designed. Wherever possible, the air supply should be drawn from some point outside the building where the air is most apt to be clean, cool and dry. In any event, a strainer should be placed over the exposed end of the inlet pipe. Such a strainer can be easily made by covering the opening with wire netting over

which one or two layers of muslin have been placed. A strainer should also be placed in the pipe lines leading directly to the pneumatic tools, and a strainer inserted between the pneumatic hammers and the hose nipple.

Lubrication.—Valves and pistons for both hammers and drills require a light machine oil, and as the compressed air which comes in direct contact with these parts has a tendency to drive the lubricant out through the exhaust, it is advisable to oil such parts freely and often, about once every hour while the tool is in constant use. Such portions of the tools as the gear and crank cases to which the compressed air does not have direct access are best lubricated with grease. This grease may be forced into the crank cases through the dead air handle by means of a squirt gun or syringe. A filling every 10 hours while the drills are in constant use gives the best results. It is a good plan to immerse pneumatic hammers in a bath of benzene or kerosene over-night and then blow them out under pressure the following morning, after which they should be thoroughly lubricated with a light machine oil.

Pneumatic Riveting.

According to information received from one of the leading East Coast shipyards, the best day's work on a shell with pneumatic riveting is 700 rivets of $\frac{7}{8}$ of an inch diameter, and for hand work, under the same conditions, 430. An average day's work, however, is considerably less than this, and may be taken as being 510 rivets with pneumatic rivets, against 264 with a hand squad, the figures being taken for work on all parts of one ship. According to the *Board of Trade Journal* the following may be taken as indicating the difference in the day's work of a hand and pneumatic riveting squad :—On the shell. with $\frac{7}{8}$ in. rivets, hand-riveting, 260 to 360 rivets ; with pneumatic riveting, 500 to 550 ; on the deck, with $\frac{5}{8}$ in. rivets, hand-riveting 450 pneumatic 700 ; on deck with $\frac{3}{4}$ in. and $\frac{7}{8}$ in. rivets, hand-riveting 350, pneumatic 550. Again, the pneumatic tool requires fewer men to work it. A hand riveting squad consists of three men and one or two boys. From two of these squads three pneumatic riveting squads can be formed, effecting a saving of 50 per cent. in labour alone. A third advantage of the pneumatic tool is that it gives both the other great advantages with less exertion and consequently less fatigue on the part of the men. (*'Machinery.'*)

Cost of Compressing Air.

In a large shipyard on the north-east coast the actual cost of compressing 100,000 cu. ft. of free air to 100 lbs. per sq. in. pressure with electric current at 1*d.* per unit worked out as follows :—

	s.	*d.*
Power	20	1
Circulating water	0	3
Labour	6	$0\frac{3}{4}$

(*R. W. Wilson. Paper read before Inst. of Mech. Engs., Feb.* 8, 1924.)

Mechanical Hammers.

The Kango Electro-Mechanical Hammer.

In this hammer (fig. 63) an entirely new principle is employed, centrifugal force is utilised for converting rotary motion into progressive kinetic energy, 3,000 blows per minute being delivered at the head of the tool in use, whether cold chisel, fettling tool, keyway cutter, stone driller, stone dresser, etc.

In the upper part of the casing of the arrangement is a motor which drives through a sliding and flexible coupling a spline shaft operating the striking element, which is housed in the lower part of the casing, a special oil-retaining device being fitted to prevent the oil in the lower part of the casing reaching the motor.

The striking element consists of a special steel structure carrying a bevel pinion and two crown wheels. The pinion is centrally placed and drives the two crown wheels, which are mounted on pins projecting from the sides of the striker, in opposite directions. On one side of each crown wheel is formed a heavy semi-circular weight, and the teeth are so engaged with those of the pinion that these weights are opposite each other when they are at the top and bottom of their revolution. The lower end of the striking element forms the hammer head, which conveys the blow to a specially formed transmitter secured in the lower end of the casing by a flexible diaphragm which renders oil-tight the lower part of the casing as the whole of the striking element works in a bath of oil. The striking element is kept towards the transmitter by a strong spiral spring which also serves to limit its oscillation.

The centrifugal force created by the weights on the crown wheels coming into juxtaposition at opposite points in their revolution, imparts a reciprocating motion to the whole striking element, the movement upwards being partially absorbed by the spring previously referred to, whilst

the downward movement is free to convey the full impact to the transmitter and through this to the tool being used.

All tools can be instantly extracted or replaced.

Hammers are at present constructed suitable for 110, 200, or 220 volts; A.C. or D.C. current; consumption about 300 watts only; the current supply can be taken from any lamp socket.

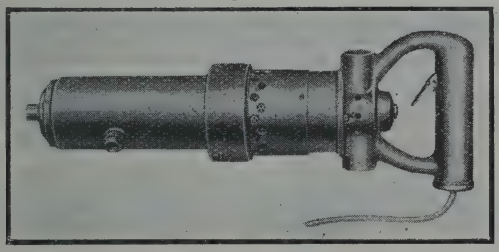

FIG. 63.

The weight complete of the hammer (which cannot be overloaded) is only 9 lbs.; no compressor is employed; all working parts of the striking mechanism work in an oil-bath and are easily accessible.

Diamond Turning Tools.

For turning materials, such as ebonite, galalith, bakelite, erinoid, and fibre, diamonds are greatly superior to any class of steel tool. More recently they have been applied to the turning of aluminium, aluminium alloys, and brass. On the Continent many of the largest makers of motor cars employ diamond turning for machining alloy pistons, and in this country the practice is gaining ground. On the Continent, also, diamonds are being used for boring gudgeon pin holes in aluminium pistons, and also as boring cutters held in bars for boring crankshaft bearing housings in aluminium crank-cases.

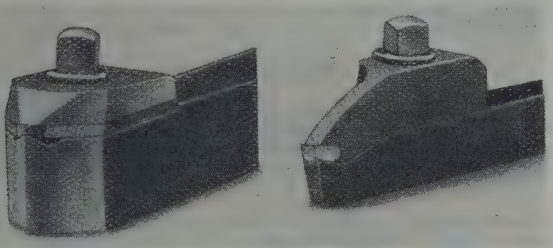

FIG. 64.

Fig. 64 shows two diamond tools specially designed for turning aluminium pistons. That on the left is for turning the cylindrical portions of the body of the piston, while that on the right is a square-nosed diamond for turning the piston ring grooves.

The diamond in the body turning tool is cut so as to give three small facets under 1 millimetre wide—a central facet and one on either side. When the tool is first used the central facet is set accurately so as to be parallel with the axis of the work.

With a feed of 0·1 millimetre the cuts taken by the diamond facet overlap, and providing the facet has been accurately set as described, the resulting finish is practically equivalent to a polished surface, free from tool marks. On an aluminium alloy piston, 3¼ ins. in diameter and

3½ ins. long, a spindle speed of 750 revolutions per minute is used, the best cutting speed being about 600 feet per minute, and the turning time about 60 seconds.

On such work each facet of the diamond lasts two months before any re-setting is required. As the remaining facets are still available, each diamond lasts about six months before it need be taken down and sent to the suppliers for re-cutting, after which it is useful for another long spell of work. It will be realised that with a very slow-wearing tool, such as a diamond, size is easily maintained, especially as little heat is developed during the cutting operation, the whole of the shaving being removed by a true cutting process without any sign of tearing.

A diamond tool appears to leave a finish greatly superior to grinding, and there is no risk of leaving abrasive particles embedded in the piston, it costs many hundreds per cent. more than a steel tool, but as its total life is about eighteen months, with very few resettings in the machine or redressings by the suppliers, it must be considered very economical, despite the apparently high first cost.

The diamond is of wedge shape, being deeper at the back than the front, while in plan the rear portion is dressed to V-form and fits a corresponding vee in the intermediate plate, seen under the upper clamp plate. The thickness of the intermediate plate is such that when the diamond is clamped in the holder the intermediate plate is gripped simultaneously, and the diamond relieved of any crushing pressure.

The diamond in the other tool is fitted without an intermediate plate, but is veed as shown on the under surface, to correspond with the lower portion of the holder. The diamond is the exact width of the slot required in the piston, but the extreme ends of the front cutting face are dressed to reduce the rake and remove the sharp corner. If these are left there is a risk of the diamond chipping at these points. These diamonds can be guaranteed to finish grooves in aluminium pistons within limits of 0·00025-in. in width.

The methods of holding these diamonds are the subjects of patents.

(*'Machinery,' August* 22, 1925.)

Files.

DESCRIPTION.

Single-cut.		*Double-cut.*		*Rasp.*	
Rough	Second-cut	Coarse	Smooth	Coarse	Second-cut
Coarse	Smooth	Bastard	Dead-smooth	Bastard	Smooth
Bastard		Second-cut			

The terms 'rough,' 'coarse,' 'bastard,' 'second-cut,' 'smooth,' and 'dead-smooth,' have reference only to the coarseness of the teeth, while the terms 'single-cut,' 'double-cut,' and 'rasp' have special reference to the character of the teeth.

There are more than 50 types of files recognised in the file manufacturing trade, and each type is supplied in 24 different lengths. Each length can generally be obtained in one of five cuts of varying coarseness.

RE-SHARPENING FILES.

(1)

The sand-blast process consists of injecting fine sand against the backs of the teeth by means of a steam jet, and is applicable to all files, from the rasp to the finest Groubet files. The action of the sand is to cut away the backs of the file teeth, thus forming a straight level on the teeth back, and giving a new cutting edge, and the process occupies from 3 to 5 minutes.

(2)

Another method is first to carefully cleanse the files with hot water and soda; they are then brought into connection with the positive pole of a battery, in a bath composed of 40 parts sulphuric acid and 1,000 parts of water. The negative (zinc) pole of the battery is connected to a copper spiral surrounding the files but not touching them. This arrangement is the result of practical experience. When the files have been in the bath for 10 minutes they are taken out, washed, and dried, when the whole of the hollows will be found to have been attacked in a sensible manner; but should the effect not be sufficient, the files are replaced in the bath for the same period as before. Sometimes two operations are necessary, but seldom more. The files thus treated are to all appearance like new ones, and are good for 60 hours' work.

(3)

The following is a formula for an etching or recutting solution without electric current :—

Nordhausen (fuming) sulphuric acid	1 part.
Nitric acid	1 ,,
Concentrated sulphuric acid	½ ,,

All the above parts are given by volume.

The process is carried out by first submerging the files for cleansing for a period of 15 minutes in a solution of caustic soda in boiling water, the proportions being about 150 grains of caustic soda to 2 gallons of boiling water. With ordinary files this will suffice for about 150. After cleansing, the files are placed in a tank which is acid proof, and 13 parts by volume of water are added. The files should not overlap and should be arranged so that the liquor can obtain access to all parts to be recut.

The above mixture is then added and the files allowed to stand for 5 to 10 minutes.

To Clean Files.

Files clogged with tin or lead can be cleaned in a few seconds by strong nitric acid. For iron filings, use blue vitriol; rinse in water, and dip in nitric. For copper or brass, use nitric several times; for zinc, dilute sulphuric acid. After any of these treatments, rinse the files in water, brush vigorously, and dry in sawdust, or by burning alcohol on the file.

When files become clogged with aluminium or aluminium alloys a strong solution of potash will dissolve the aluminium and leave the file teeth unaffected.

Auxiliary File Handle.

Figs. 65 and 66 show a form of auxiliary file handle, which was constructed for use in connection with an awkward filing job by Mr. H. Moore, of Hamilton, Ontario, and may be found convenient by other workers. The arrangement was devised to assist in filing out the ends of a number of channel pieces used on pump work. The position was such that only the tops of the fingers could rest on the file, and pressure could not be brought to bear on it in the usual way.

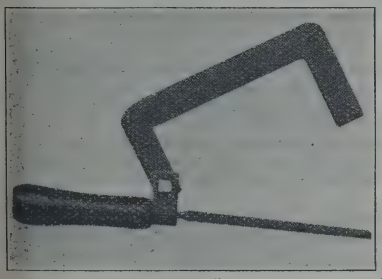

Fig. 65.

Fig. 66.

A clip of sheet metal was made to fit around the ferrule of the handle and a bridge piece, cut from No. 13 U.S. plate was pivoted to this on a bolt and nut. The bolt tightened the clip on the handle, and pressure could be brought to bear on the file tip by the bridge piece. As the bridge piece is jointed, any want of alignment between the file and handle can be accommodated. Fig. 65 shows the complete arrangement, and fig. 66 the auxiliary handle in use.

(*'Engineer.'*)

Tube Cutters.

The particular feature in these cutters (fig. 67) consists in widely separated duplex rollers, arranged in a block on the spindle end, making it practically impossible to set the tube cutter

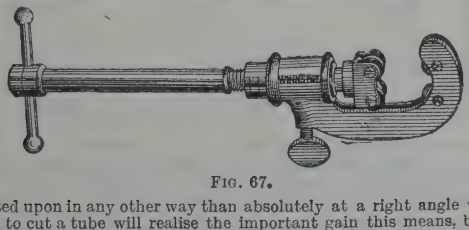

Fig. 67.

on the tube operated upon in any other way than absolutely at a right angle with it. All who have had occasion to cut a tube will realise the important gain this means, because no time is lost in cutting screw tracks on the tube, and there is no consequent breakage of cutters. The rollers save all friction on the tube, and two cutters are provided in the hook, so that the tubes can be cut off with great ease and speed. There is a further saving of time by the use of these tools, in the quick adjustment for different sizes ($\frac{1}{4}$ in. to $1\frac{1}{2}$ in. for one tool).

Using Woodworking Tools on Metal.

Aluminium, Duralumin (in the annealed state or just after heat treatment), and soft brass, can all be planed with an ordinary carpenter's block or jack-plane, the same as wood.

The blade of the plane used for these materials will require more frequent sharpening, however, and it is better to grind it to a sharper angle, which gives less clearance and a larger included angle, thus making the blade stronger and better able to resist wear on the cutting edge. The ordinary wood chisel may also be used on the metals mentioned, provided it is ground with a shorter bevel. The ease with which these soft metals can be worked with hand tools is surprising. They can be sawn with a coping saw or compass saw.

(*'Machinery.'*)

Cold Chisels.

A large number of the chisels now in use are not forged, shaped, and hardened in the best way to give long life and adequate service. Considering the making of a chisel from ⅝ in. octagon tool steel, the following method has been found to give good results :—

Forging.—Cut off a length of steel, depending on the length of chisel desired, and heat up the end for 2 ins. to a bright cherry-red. Trim off two opposite sides so as to form a blunt-nosed tool and eliminate the danger of lapping when drawing out. The horn of the anvil should be used in drawing out, inasmuch as this will have the least possible tendency to widen the piece, and therefore the minimum amount of 'edging-in' or hammering on the edge will be necessary. A chisel should not be hammered on the edge, because the grain of the steel will thereby be distorted or 'crumpled up,' and this always has a tendency to weaken any metal. If in the final forging operation the chisel gets a little too wide, it can be trimmed off on the emery-wheel during the grinding operation.

Draw the chisel out so that it will be about ⅛ in. thick at the end and about ⅜ in. thick and 1¼ in. back from the end. The forging should be finished with light blows until the steel has almost lost colour, but it absolutely must not be struck after the colour has disappeared. It is good practice to reheat the steel to a dull red without using any blast, and give it a second hammering with light blows until the colour has again almost disappeared.

The four important things to remember in forging a chisel are, therefore : Draw out at a good cherry-red heat : finish with light blows at a dull-red heat ; do not hammer after the colour has disappeared ; hammer as little as possible on the edge, and then only when the steel is fairly hot.

Grinding.—Grind the chisel before it is hardened, as it can be ground faster in this way without the danger of drawing the temper. The shape of the edge of the chisel is very important, although this fact is often overlooked. Fig. 68 shows a chisel ground with a concave edge. If this is driven down on to a flat surface, it is obvious that a great strain will be put on the corners, and they are almost sure to break off. Fig. 69 shows a chisel ground with a perfectly flat edge, If this chisel is driven down on to a flat surface and held perfectly straight the cutting strain will be distributed evenly over the entire edge, and the chisel will be satisfactory. It must be remembered, however, that it is almost impossible to hold a chisel absolutely straight, and,

FIG. 68.

FIG. 69.

FIG. 70.

therefore, either one corner or the other will be severely stressed by the chisel being tilted over. Fig. 70 shows a chisel ground with a slightly convex edge, which is by far the best for ordinary work. The corners of a chisel are always the danger point, and with the convex edge these corners are protected even when the chisel is tilted over considerably to one side or the other.

Hardening and Tempering.—After the chisel has been ground to the desired shape, heat it to a dull cherry-red colour for about 2½ ins. from the end, and quench it vertically in cold water to a depth of 1¼ ins., moving it up and down until no red colour is left in any part of the steel, The part which has been drawn out should now be polished with emery cloth and the temper

drawn to a dark purple or a blue by holding the chisel over the fire or in a furnace. Always draw a chisel a little more in winter than in summer. It has been recommended to harden the chisel back much farther than usual, because a chisel so made can be ground a great many times without redressing. (*Joseph T. Byerson and Son, Chicago*).

To Reduce the Internal Diameter of a Steel Bush.

A bush was required to be a force fit on a 6-in. shaft: and should have been bored 5·990 ins. ± 0·002 in., but was bored 0·015 too large.

The bush was heated to just a red, about 2 ins. up at one end, and just 1 in. of the 2 ins. dipped in cold water. It was next heated another inch or two up, keeping the first cooled inch as cool as possible, and then dipped a further inch into water. This was continued inch by inch, each cooled inch apparently pulling in the inch in the length adjacent to it until the whole of the bush (or sleeve) was pulled in quite twenty thousandths, and required to be skimmed out 0·005 in. to force it on to its shaft. (*J. T. T.*, '*Machinery.*')

Gripping Pieces of Uneven Width in the Machine Vice.

If two or more pieces have to be held in the machine vice for drilling or other operation, and their widths differ slightly, a strip of lead, *s*, placed as shown in fig. 71 will compensate for the

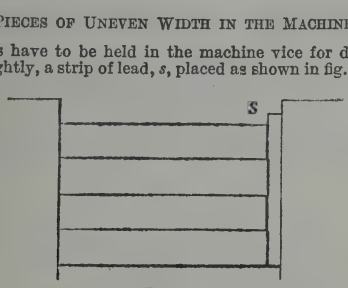

Fig. 71.

irregularity and afford a secure grip. Or a piece of belting, cloth, canvas, wire meshing, etc. will serve the purpose.

Block for Holding Tapered Work in the Vice.

Holding irregular or wedge-shaped parts in the vice while chipping, sawing, or performing other manual operations is awkward unless the parts are supported by blocking. It is possible, however, to hold tapered work quite securely by using a simple block, such as shown at A in

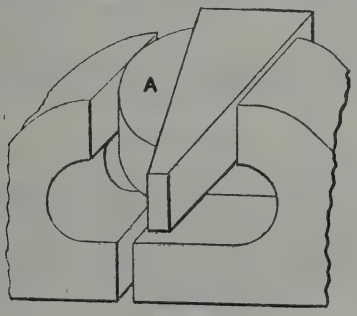

Fig. 72.

fig. 72, in conjunction with the regular vice jaws. This special block should be about the same width as the jaws, the convex side being made semi-circular. It is preferable that the flat side of the block be checked or grooved in order to give it a better grip on the work.

(*G. A., Jr.*, '*Machinery*,' *June* 5, 1924.)

Hardness of Materials.

Different Methods of Determining Hardness.

The test to which a material is generally subjected in order to obtain a measure of its hardness may be of two classes, viz. :—

(1) The resistance offered by the material under investigation, (2) the resistance offered by the material to abrasion or cutting.

Of these, the first finds most extensive favour in practice, and the indenting medium may be a chisel, cone, or sphere. Repeated use on hard materials is inclined to blunt the chisel edge or point of the cone, and the sphere is the agent commonly adopted.

In 1900 Brinell introduced a method of ascertaining the hardness of a material by indenting it with a hardened steel sphere subjected to a predetermined load. The ratio of the load on the sphere to the area of indentation produced gives the hardness figure. The ball commonly used is 10 mm. diameter. The load for the softer materials is usually 500 kilograms, and that for the harder metals 3,000 kilograms.

The load should be applied for at least 30 seconds in order to secure equilibrium between it and the resistance of the material. The diameter of indentation is observed by means of a special microscope fitted with a scale, and from this the depth of indentation can be calculated, since :—

$$\triangle = \tfrac{1}{2}(D - \sqrt{D^2 - d^2}),$$

where, $\triangle$ is the depth of indentation,
d ,, diameter ,,
D ,, ,, of the sphere.

The hardness figure or number N for a load P is given by the expression :—

$$N = \frac{P}{\frac{\pi}{2} D\left(D - \sqrt{D^2 - d^2}\right)} = \frac{P}{\pi D \triangle}.$$

The hardness number is therefore inversely proportional to the diameter of ball and depth of indentation, and for a ball of constant diameter is directly proportional to the load. The hardness numbers for diameters of impressions made by a ball 10 mm. diameter under a load of 3,000 kilograms are given in the table, page 1167.

The depth of indentation may be obtained directly by means of a micrometer microscope by observing the difference between the readings of the datum line on the piston when the parts are brought together and after the load has been applied and removed. This procedure precludes the possibility of including the compression of the piston, sphere, and other parts of the machine beyond the datum line.

As it is difficult to bring the parts together without indenting the specimen to some extent, a small initial load may be applied. Observations of the datum line are then made when the initial load is applied, and also after the full load has been applied, and when the load has been brought back again to its initial value.

By measuring the actual depth of penetration, the error due to the elastic deformation of the sphere (which is included when the diameter is observed) is avoided. This elastic deformation is relatively greatest when the load, and consequently the indentation, is least. As the indentation increases so does the lateral component of the resisting force, and this tends to keep the sphere to its true form.

In testing some cast irons the metal flows from beneath the ball and causes a ridge to be formed which stands proud of the original surface, whilst with bronze and some of the copper alloys the metal is drawn in. In the case of the former the diameter observed is greater than the true value corresponding to the depth of indentation, whilst in the latter case the diameter is less than its true value.

The Shore Scleroscope.

This instrument consists of a small hammer, weighing about $\frac{1}{3}$ of an ounce and fitted with a diamond which is somewhat spherical in shape at the striking end. The hammer is suspended on a stirrup piece fitted to a head on a vertical stand and upon which is also mounted a glass tube about 10 inches long and a graduated scale subdivided into 140 parts. The hammer is released and raised by a pneumatic device and moves within the tube. As the end of the glass tube is made to rest upon the material under investigation, the hammer always falls through a definite height and the measure of hardness is obtained by observing its rebound on the scale. The hammer on striking makes a permanent impression in the material, but as this is very small and irregular in outline it is impossible to measure the depth or diameter with any approach to accuracy.

Abrasion Test.

An early conception was to scratch a smooth surface of the material under investigation with a sharp point of a mineral, a number of minerals being selected to constitute a scale of hardness. In their order of hardness these were :—(1) talc, (2) gypsum, (3) calcite, (4) fluor, (5) apatite, (6) felspar, (7) quartz, (8) topaz, (9) sapphire, (10) diamond. The method is only suitable for materials which differ widely in hardness,

To obtain a measure of hardness of materials which differed but slightly, Professor Turner developed the *Sclerometer*. This instrument consists of a diamond carried at one end of a balance lever in a horizontal plane and which rested upon a knife edge fitted into a vertical pillar. The pillar was free to turn by hand, so that the diamond was made to travel across the smooth face of the metal being investigated. The end of the lever carrying the diamond was loaded and the weight in grams necessary to produce a scratch of standard depth gave a measure of the hardness.

With apparatus similar to the above some have taken the width of the scratch produced by a diamond under a constant load as the measure of hardness. As the scratch is very minute it has to be measured by means of a microscope, and the surface must be smooth and polished, in order to give a sharp definition. The test is therefore more adaptable to the laboratory than to the workshop.

Drilling Test.

This test can be made with an ordinary sensitive drilling machine having a vertically free spindle. A constant load is applied to the spindle, so that the drill is made to penetrate the material under observation. The revolutions made in drilling a hole of predetermined depth gives a measure of the hardness or tenacity.

With the object of observing the variation in the hardness as the drill proceeds, the machine is fitted with a drum which rotates with the descent of the spindle. A screw, attached to the drum support, carries a nut in which is fixed a pencil. The screw is driven from the spindle, and as the nut cannot rotate the pencil moves in the plane parallel to the drum axis. The combined motion caused a diagonal line to be traced on a piece of paper around the drum, the height and horizontal length of the line being proportional to the depth drilled and revolutions respectively. The slope of the line varies with the hardness, and a soft or hard patch in the material under test is shown on the graph by the line becoming steeper or flatter in the order mentioned at that part. The drill is periodically tested for sharpness on a piece of material of standard hardness.

(*Professor Dempster Smith.*)

BRINELL HARDNESS NUMBERS (for load (P) 3,000 Kg.).

DIAMETER OF BALL (D) = 10 mm.

$$H = \frac{P}{D^2}\left(\frac{2/\pi}{1-\sqrt{1-(d/D)^2}}\right)$$

Diam. of Impression. mm. d	Hardness Number. H	Diam. of Impression. mm. d	Hardness Number. H	Diam. of Impression. mm. d	Hardness Number. H	Diam. of Impression. mm. d	Hardness Number. H
mm.		mm.		mm.		mm.	
2·0	946	3·25	351	4·5	179	5·75	105
2·05	898	3·3	340	4·55	174	5·8	103
2·1	857	3·35	332	4·6	170	5·85	101
2·15	817	3·4	321	4·65	166	5·9	99
2·2	782	3·45	311	4·7	163	5·95	97
2·25	744	3·5	302	4·75	159	6·0	95
2·3	713	3·55	293	4·8	156	6·05	94
2·35	683	3·6	286	4·85	153	6·1	92
2·4	652	3·65	277	4·9	149	6·15	90
2·45	627	3·7	269	4·95	146	6·2	89
2·5	600	3·75	262	5·0	143	6·25	87
2·55	578	3·8	255	5·05	140	6·3	86
2·6	555	3·85	248	5·1	137	6·35	84
2·65	532	3·9	241	5·15	134	6·4	82
2·7	512	3·95	235	5·2	131	6·45	81
2·75	495	4·0	228	5·25	128	6·5	80
2·8	477	4·05	223	5·3	126	6·55	79
2·85	460	4·1	217	5·35	124	6·6	77
2·9	444	4·15	212	5·4	121	6·65	76
2·95	430	4·2	207	5·45	118	6·7	74
3·0	418	4·25	202	5·5	116	6·75	73
3·05	402	4·3	196	5·55	114	6·8	71·5
3·1	387	4·35	192	5·6	112	6·85	70
3·15	375	4·4	187	5·65	109	6·9	69
3·2	364	4·45	183	5·7	107	6·95	68

For other test loads the hardness numbers are proportional to those in the table.

British Standard Tables of Brinell Hardness Numbers.*

(No. 240—1926.) *(Abstract.)*

Definition.

1. The Brinell hardness number is the quotient of the applied load divided by the spherical area of the impression. The Brinell hardness number is given by the following formula :—

$$H = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)} = \left(\frac{P}{D^2}\right)\left(\frac{2\pi}{1 - \sqrt{1 - (d/D)^2}}\right)$$

where,

P = Load (in kilogrammes) ; d = Diameter of impression (in millimetres) ;
D = Diameter of ball (in millimetres) ; H = Brinell hardness number.

Note.—The spherical area must be calculated from the average diameter of the impression obtained by taking two readings at right angles, and not from the depth of the impression.

Apparatus.

2. (*a*) The micrometer microscope or other measuring device used shall be capable of measuring the diameter of the impression to ± 0·5 per cent.

Note.—An accuracy of measurement of ± 0·05 mm. (0·002 in.) may be accepted for impressions made with a ball of 10 mm. diameter.

(*b*) The balls used in Brinell hardness testing shall be of hardened steel or of some harder material.

Note.—When ordinary hardened commercial steel balls are used, Brinell hardness numbers exceeding 500 may be subject to error owing to permanent distortion of the ball. The error increases with increasing hardness of the material tested. With hardness numbers above 500 care should be taken to see that the balls are considerably harder than the material to be tested.

(*c*) The standard balls and loads used for Brinell hardness testing shall be as follows :—

Diameter of Ball.	Load.			
	$\frac{P}{D^2} = 1$	$\frac{P}{D^2} = 5$	$\frac{P}{D^2} = 10$	$\frac{P}{D^2} = 30$
mm.	Kg.	Kg.	Kg.	Kg.
1	1	5	10	30
2	4	20	40	120
5	25	125	250	750
10	100	500	1000	3000

The limit on the diameter of the balls shall be ± 0·0025 mm. (0·0001 in.).

Note—The same Brinell hardness number is given by tests on the same uniform material with balls of different diameters when the same value of the ratio $\frac{P}{D^2}$ is used.

Test Specimens.

3. (*a*) The centre of the impression shall be not less than two and a half times the diameter of the impression from any edge of the test specimen.

(*b*) The thickness of the test specimen shall be at least seven times the depth (t) of the impression as given by the formula $t = \frac{P}{\pi D H}$ or, alternatively, shall be such that no bulge or other marking showing the effect of the load appears on the side of the piece opposite the impression.

When tests are made on thin specimens, care should be taken to ensure that the under surface of the specimen is smooth and in good contact with a smooth supporting surface of hardened steel.

(*c*) The surface on which the impression is to be made shall be polished if the diameter of ball used is 1 mm. or 2 mm. If the diameter of ball used is 5 mm. or 10 mm., it is still advantageous to use a polished surface, but, if a high order of accuracy is not required, the surface may alternatively be filed, ground, or smoothly machined.

* By permission of the British Engineering Standards Association.

4. (*a*) The value of the ratio $\frac{P}{D^2}$ shall be as follows :—

For steel and materials of similar hardness	30
For copper alloys and materials of similar hardness	10
For copper	5
For lead and tin and materials of similar hardness	1

It is advisable that the ratio of the diameter of the impression to the diameter of the ball shall not exceed 0·6.

(*b*) The load shall be applied slowly and progressively to the test specimen.

(*c*) The full load shall be maintained for at least 15 seconds when the ratio $\frac{P}{D^2} = 30$ and for 30 seconds when the ratio $\frac{P}{D^2} = 10$, 5 or 1.

Note.—For steel, experiment has shown that an approximate indication of the tensile strength in tons per sq. in. can be obtained by multiplying the Brinell hardness numbers by 0·22. In cold worked material and in exceptional cases the ratio may differ widely from this figure.

The Specification gives twelve tables with diameters (D) of balls varying from 10 mm. to 2 mm. and loads (P) varying from 1000 kg. to 1 kg.

At a recent meeting (1927) of the American Society for Steel Treating a paper was read on the use of an iron-carbon-vanadium alloy for balls for making Brinell tests. When Brinelling steels of such hardness as causes ordinary Brinell balls to deform, the alloy recommended for use in testing consists of 2·9 per cent. carbon and 13 per cent. vanadium, the remainder being iron. Balls made from this material, and heat-treated, are found, when tested on steels of approximately 700 Brinell hardness, to flatten only one-fifth as much as the ordinary balls used and only one-half as much as certain special balls.

The Herbert Pendulum Hardness Tester.

This recently invented instrument consists of an arched weight of 4 kg. pivoted on a fixed ball of 1 mm. diameter, the ball being of hardened steel, ruby, or diamond. The position of the centre of gravity of the instrument can be varied, but for all standard tests the centre of gravity is 0·1 mm. below the centre of the ball, and the instrument constitutes a very short compound pendulum. A curved spirit tube with bubble and scale graduated from 0 to 100 serves to measure the amplitude of the oscillations. On rocking the instrument the specimen is slightly indented, but the degree of hardness is not measured by the indentation but by the swing of the instrument, the readings are, therefore, expeditiously made.

Time Test.

This is the number of seconds taken by 10 single swings of the pendulum when placed gently on the specimen and caused to oscillate through a very small arc. The ' time hardness numbers ' (seconds for 10 swings) vary from 3 seconds on lead to 20 seconds on mild steel, 85 on very hard steel, and 100 on glass.

The pendulum time test, like the Brinell test, measures ' indentation hardness ' or resistance to indentation.

Work-hardening Test.

Another test is that which measures the ' work-hardening capacity ' of metals, or the increase of hardness which can be induced in them by working them cold. In making this test the Pendulum is placed on the specimen in a tilted position with the bubble at 0 on the scale and is then released. The pendulum swings through a certain arc which depends upon the hardness of the metal, and the position of the bubble on the scale at the end of the first swing measures the ' work hardness ' or resistance to working by rolling.

The next operation is to tilt the pendulum and complete the swing by hand. The bubble is then at 100 on the scale and is again released. The effect of tilting the pendulum is to elongate the impression and to harden the rolled surface by cold work. When the pendulum is released the ball rolls back along the hardened surface, and the position of the bubble on the scale at the end of the swing measures the hardness of the work-hardened surface. This process is repeated, the pendulum being tilted alternately to right and to left, and the hardness measured after each successive rolling by the ball until a maximum is reached. The difference between the first reading and the maximum reading measures the work-hardening capacity of the metal. Glass has zero work-hardening capacity. The first reading and the subsequent readings are the same. Manganese steel is shown to be soft by the Brinell test, soft by the pendulum time test, soft by the first reading of the work-hardening test, but after being rolled by the ball it immediately becomes as hard as hardened tool steel, which explains why it cannot be worked.

The time test and the work-hardening test have important applications owing to the ease with which they can be applied to heated specimens. The pendulum equipped with a diamond ball measures the hardness of hot specimens as easily as cold, and the tests are conveniently made while the specimen is actually in the electric furnace.

Machining Aluminium.

In machining aluminium the tools should have more side and top rake than tools for cutting steel. The front clearance of the tool should be about 6°, the top rake from 30° to 50°, making the total angle of the cutting edge of the tool from 35° to 55°, and a side rake of from 10° to 20° aids the cutting action. The size of the angles used varies to some extent with the nature of the alloy and the work being done, the type of tool, and the conditions of use. It is very important to have keen tool edges, for on this factor the success of machining aluminium and its alloys largely depends. Hand stoning on a fine oil stone is recommended after a finish grinding in the preparation of edges.

Parting tools should have a top rake of from 12° to 20° and the front clearance angle should be decreased to about 3° or 4°. Milling cutters give the best results if they are of the coarse tooth spiral type and have a considerable amount of top rake on their cutting edges. Milling cutters with nicked teeth in some cases assist in decreasing the chip size. Face-milling cutters with inserted teeth, helical milling cutters and staggered tooth milling cutters can be made to work well with aluminium if the cutting edges are provided with suitable top rake. Also with considerable top and side rake good threads can be cut in aluminium of the softest quality in an engine lathe using a single-pointed threading tool. It has been found that very satisfactory taps for use in aluminium can be made by chasing threads on annealed high-carbon twist-drills followed by re-tempering and finishing.

Because of its lower modulus of elasticity aluminium has more recoverance than steel after a tapping operation, and the expedient of using slightly over-sized taps is therefore often resorted to in maintaining holes of required dimensions.

While the single-fluted twist drills used in drilling hard wood have been found in some cases to give better results than the usual form of drill, the best type for use with aluminium is that in which the flutes have a greater spiral angle, that is, more twists per inch; straight-fluted twist drills which are often used in drilling brass are quite unsuitable.

The most suitable saws for cutting aluminium are of the coarse tooth type, and hand hack-saw blades of the 'wavy-set' kind, work very satisfactorily.

Aluminium is machined to best advantage by using comparatively high speeds and fine to medium feeds. With ordinary carbon-steel tools speeds between 500 and 800 feet per minute are possible under some conditions and higher speeds are obtainable with high-speed steel tools. The feed may vary from $\frac{1}{4}$-inch for roughing cuts to a few thousandths for finishing cuts. Usually the finer the feed the higher the speed, and the more curl there is to the chip the slower the speed. When machining with coarse feeds it is necessary to remember that aluminium, like other metals, shows a rise in temperature and, moreover, its coefficient of expansion is greater than that of steel and, therefore, due dimensional allowances should be made.

A satisfactory lubricant or cutting compound for general use contains equal parts of kerosene and lard oil, while for heavy cuts and slow feeds, such as in roughing work or tapping, pure lard oil gives good results. In milling, sawing, and drilling, soluble cutting oils are satisfactory and more economical than kerosene and lard oil lubricant. Paraffin-base compounds such as those used in machining brass are quite unsatisfactory for use with aluminium. Alloys of the duralumin type, heat treated, possess the best machining properties, and aluminium-silicon alloys are the most difficult to machine.

(M.C., *Machinery*, Oct. 10, 1927.)

For grinding aluminium a soft or medium soft wheel should be used at speeds up to 10,000 feet per minute for carborundum wheels, and up to 6,000 feet per minute for wheels with shellac or other soft binders. Coarse wheels may be prevented from clogging by rubbing them with paraffin wax.

Single cut files should invariably be used for aluminium. Clogged files may be readily cleaned by dipping them in strong caustic soda solution, after which the metal particles are easily wiped off. This process should be followed by washing and drying in sawdust.

Machining Ebonite and Fibre.

Ebonite.

Ebonite should be run at the highest possible speed obtainable on the machine, and a mixture of 1 part of paraffin to 4 of lard oil used as coolant.

Turning tools, drills, reamers, and taps for ebonite should be of high-speed steel, glass hard, except where either diamond* or sapphire tools can be employed.

Drills should be ground away in the flute to allow of easy chip removal, and also to reduce the amount of surface of the tool in contact with the ebonite to a minimum. This principle of reducing contact to the lowest degree should be observed in all tools used on ebonite, since friction (together with the action of the sulphur) is a large factor in producing a temperature which quickly destroys the cutting edges.

Whenever possible, diamond tools* should be used for boring holes which are sufficiently large in diameter to admit a substantially mounted stone and possess a comparatively regular bore. For reaming, use plain flat reamers or bits, having two acute lips or cutting edges, and a

* See p. 1161.

land not exceeding $\frac{1}{16}$ in. in width or, as an alternative, a small bar with a bit or cutter of high-speed steel inserted in the end, this being simple and easily removed.

Tap and dies for ebonite should have narrow lands, and, wherever possible, should be run at a lower speed (if the machine is capable of it) than that employed for the rest of the operations on the component; 60 ft. per minute is a satisfactory speed, and there will be little danger of tearing-up the thread.

Feeds for turning, drilling, and reaming operations on ebonite should always be high, and about three times those used on brass. This remark does not apply so much to forming operations, when the feeds should be a little less than for brass on account of the fragile nature of the material.

Fibre.

Red and black fibre can be worked in much the same manner as ebonite as regards feeds, speeds, and the type of tools employed, but diamond tools are not so satisfactory as on ebonite on account of the irregular quality of these materials, for when the stone strikes a bad patch in the rod or tube there is a tendency to dislodge the diamond or sapphire. Drills, which should be of high-speed steel, should be fed at a higher rate than for ebonite, as should also reamers. The 1 to 4 solution of paraffin and lard oil will be found a good lubricant.

Erinoid, galalith, and other lactic base compounds are best machined when run at a high speed similar to that for ebonite, but, owing to the fact that these materials do not generate heat to the same degree as ebonite or fibre, they do not require any lubricant, and should be run dry. High-speed steel tools should be used, and wherever it is possible to employ a diamond tool* for either boring, turning, or forming, it will be found an advantage to do so. The same points in regard to the type of tools apply to erinoid and galalith as in the case of ebonite, whilst the feeds are approximately the same. ('*Machinery*,' *May* 24, 1923.)

TOOL-STEEL FOR CUTTING EBONITE AND FIBRE.

High-speed steel frequently fails to give satisfactory results when machining ebonite and similar materials. Certain of the leading steel makers produce steels specially for work of this character. Edgar Allen & Co., Ltd., Sheffield, for example, make such a steel that requires to be quenched out from a temperature of 780° C., after which it is let down to a straw colour.

Saving Worn Parts by Electro-deposition.†

This process (developed at the Westinghouse Research Laboratory) has been used to build up shafts, pins, bolts, gear centres, and similar parts, and can be employed to build up the worn surfaces inside automobile engine cylinders, also for building up parts accidentally machined under size.

A plating bath is made up of 2·5 lbs. of commercial ferrous ammonium sulphate per gallon of water plus a small amount of ferrous carbonate (freshly precipitated and kept under water in order to keep the solution practically neutral) plus a small amount of powdered charcoal, which helps to prevent pitting. The equivalent amounts of commercial ferrous sulphate and ammonium sulphate may be substituted for the ferrous ammonium sulphate. If the solution is made up from the ferrous sulphate and ammonium sulphate, the granular or 'crystal meal' ferrous sulphate should be used. The ammonium sulphate must prove to be free from sulphocyanate when tested with ferric-sulphate or ferric-chloride.

All small pieces are plated in earthenware jars, and large pieces in lead-lined wooden tanks or stoneware tanks. Waterproof cement tanks can also be used. The anodes are made of 'Armco' iron, cylindrical in shape. Micarta discs with a hole cut in the centre are fitted in each end of the anodes. The pieces to be plated are made the cathode and held stationary so that they extend into the plating solution through the holes in the micarta discs. The anodes are attached to a device which moves them up and down, thus keeping the plating solution stirred and the ferrous carbonate and charcoal in suspension. The temperature is held at approximately 60° C., a few degrees variation either way not doing any harm. A current density of 0·43 ampere per sq. in. is used. This deposits metal at a rate that increases the diameter 0·006 in. per hour.

This method of procedure applies only to pieces such as shafts, bolts, pins, etc. For pieces such as gear centres, automobile cylinders, etc., where the inside diameter needs to be reduced, the anode is made to go down through the centre, and micarta rings are fastened to the anode to obtain the required stirring. The current density could be raised considerably, but as the density specified adds the deposited material at the rate of 0·003 in. on a side, or increases the diameter at the rate of 0·006 in. per hour, it is evident that the ordinary repair job requiring an increase in diameter of approximately 0·010 in. to 0·020 in. can be quickly completed.

To clean the work, the piece to be plated is made the cathode in an alkaline solution consisting of 6 to 10 per cent. of caustic soda and 5 to 10 per cent. of commercial sodium carbonate, using a current density of 3 amperes per sq. in. for a period of three minutes. It is then washed in running water, transferred to a 30 per cent. commercial sulphuric acid solution, and given a high enough current density to make it passive for a period of three minutes or longer, according to the condition of the piece. If it is free from rust to begin with, three minutes is long enough, but if especially rusty it requires a longer time.

* See p. 1161.

† *Machinery*, Nov. 8, 1923 (*Abstract*).

The piece being cleaned should come out of the acid cleaning solution bright and silvery, except in the case of cast iron, which will be black due to the graphite content. When taken from the acid cleaning solution, the piece is washed in running water and immediately transferred to the plating bath without giving it a chance to dry and form a thin film of rust. It is essential for the current density to be kept high enough (at least 3 amperes per sq. in.) in the acid solution so that the piece being cleaned is kept passive. When passive, there is a rapid evolution of gas, and the piece is bright and silvery in appearance when it is taken out, but if allowed to become active, it has a dull black appearance. When a piece is covered with oil or grease it is cleaned with petrol or benzol before being cleaned electrolytically.

If the method of cleaning and plating is properly followed, the deposited metal will be free from pits, bright and velvety in appearance, and will adhere perfectly to the parent metal.

As it is impossible to build up a piece accurately to size, it is necessary to build the work up a few thousandths over-size and then turn or grind it to the finish size. This method of recovery can be used with steel, cast iron, or case-hardened material, and the deposited material can be case-hardened when necessary.

If there are portions of the work that are not to be plated or built up, for protection these parts are coated with a mixture of 90 per cent. hydroline and 10 per cent. paraffin. The hydroline must have a high enough melting point so that it will not soften and run at 60° C. This protective coat is applied by melting the mixture and then dipping the piece to be coated, or by painting the mixture on with a brush. After the piece is plated, the protective coat can be readily removed by washing with benzol.

The following equipment would be required for a small plant: One 30-volt motor-generator set, 500 to 1,000 amperes capacity, according to capacity needed for cleaning; one 8 to 10-volt motor-generator set, 200 to 400 amperes capacity, or some other source of direct current such as storage batteries for plating; one or more ¼-horse-power alternating-current motors for the stirring device; one or more reduction gears for the stirring device; and the necessary ammeters, voltmeters, crocks, heating coils, rheostats, switches, wire, tools, etc.

Metal Spraying.*

The unit of all the metal-spraying processes is the wire spraying pistol, a small and handy apparatus (weighing about 3½ lbs.), similar in appearance to a paint pistol, but differing in its operation and design. The wire (of the metal to be sprayed) (about 1 mm. in diameter) is pulled into the pistol and pushed through the nozzle (at a rate of about 12 ft. per min.) by means of rollers actuated by a small air turbine in the case. The pistol is fed with oxygen and some combustible gas under pressure, and also with compressed air, which projects minute particles of metal from the ever-melting end of the wire, the spray covering a surface about 2 ins. in diameter at a distance of 5 ins. from the nozzle.

The metal-spraying pistol will spray all metals (magnesium excepted) which can be obtained n wire form and which will fuse in the oxy-hydrogen flame.

For small articles, such as may be treated in rumbling barrels, a mechanical device has been introduced. Similarly, a machine is being operated which uniformly sprays with lead the outside of long metal pipes for use in the chemical industry. The interior of tubes may be sprayed by attaching to the ordinary pistol a long adapter, at the end of which a rotating nozzle is fixed. This produces a fan-shaped spray, and is driven by the air-blast used for projecting the metal. Thus, with the same unit, or pistol, tubes up to 12 ft. or so in length may be coated internally, so long as they are of sufficiently large bore to allow the introduction of the rotating end—that is to say, 1½ in. or more in internal diameter.

The preparatory sand-blasting of tubes internally presents some difficulty. The present-day practice is to sand-blast almost every article which is to be metal sprayed, and it is strongly advocated that where possible the article to be sprayed be heated. Devices are in use with which heating, sand-blasting, and spraying are carried out mechanically in one and the same machine, and the production of other such special machines is but a matter of time and of demand. For metal work sand-blast pressures of about 30 lbs. per sq. in. and hard black flint sands of about 20-mesh grade are recommended. After sand-blasting the surface should be sprayed at once, to avoid the possibility of contamination with grease and dirt.

Sprayed metal is being used successfully as a coating on ships' propellers. Composite coatings of more than one metal have given high resistance to corrosion. For example, zinc followed by aluminium is very suitable in cases of attack by atmospheres containing SO_2. It has been shown that the successful composite coatings are those of metals nearly related in the electro-chemical series. Very good results have been obtained by spraying zinc upon iron and steel objects—this has the advantage over practically all other methods of corrosion resistance, that it can be applied when and where desired over the top of rivets, cold-worked portions, and in general upon part or all of articles which are fully built up.

* Abstract of paper on 'Metal Spraying and Sprayed Metal,' by T. Henry Turner and W. E. Ballard, read before the Institute of Metals Sept. 1924.

Building up Solid Articles by Spraying.

In a steel mould copper, zinc, tin, aluminium, and iron bars have been produced by spraying longitudinally for one set of tests, and transversely for a second set of tests. It was found that the bars so produced could all be sawn, filed, planed, turned, and machined much in the same way as solid metal. The bars had a clear metallic ring when struck.

Tested by scratch or by scleroscope, the sprayed metal is decidedly harder than similar metal when cast. However, when tested by the ball indentation method there seems little difference between the two, although the sprayed metal is in some cases slightly softer than the cast.

The oxygen consumption with hydrogen as the combustible gas (in cu. ft. per lb. of metal sprayed) is as follows:—lead, 2·64; tin, 2·86; zinc, 5·32; copper, 10·82; nickel, 14·6; iron, 17·4; aluminium, 22·7.

The approximate consumption of oxygen with other gases is given by multiplying the foregoing quantities by 1·7 for coal-gas, and 0·8 for acetylene.

The amount of 'metal (in lbs.) sprayed per hour,' using hydrogen, is as follows:—lead, 16·0; tin, 7·5; zinc, 5·5; aluminium, 1·5; copper, 1·25; bronze, 1·25; brass, 1·375. The metal 'deposited' is rather less than this.

The air pressure used in England is usually about 45 lbs. per sq. in., whereas on the Continent it is usual to employ a pressure of 35 lbs. The higher pressure used in England has been found to be an undoubted advantage when spraying lead, tin, and zinc, but it would be better if the air pressure were varied with the metals being sprayed. The higher pressure of 45 lbs. per sq. in. should be used with tin, and the lower pressure of 35 lbs. per sq. in. used when such metals as copper are sprayed.

The process is at the present time used in France and Germany to a considerable extent on shipping work, and for the protection of overhead transmission line poles and wireless masts for big stations. It is being increasingly used in this country for the protection of certain portions of ships and for propellers. Both wooden and steel bulkheads are being coated with zinc in many shipyards. It has also been used very successfully, in Germany, to replace the usual copper cable rail connectors on electric railways, so that at present on the Berlin and Hamburg underground railways there are miles of rail without a copper connector. During the war, when copper was scarce in Germany, the copper cables were removed from the electric railways in Berlin and electric connection between the two rails secured by sand-blasting *in situ* the rail ends and the inside surfaces of the fish-plates. These surfaces were then immediately sprayed with zinc, and when bolted together again gave excellent electrical contact, and apparently they have been satisfactory ever since. The electrical resistance of this type of joint has been found to be even less than with the best copper cable joints. It has become the practice of the Siemens-Schuckert works to install this type of joint in place of the customary one.

[See also 'Metal Spraying,' by T. H. Turner and N. F. Bugden. 15*s*. Charles Griffin & Co., Ltd., London.

SECTION XXI

PART II

GRINDING, ABRASIVES, AND POLISHING APPLIANCES.

ABRASIVE MATERIALS — NATURAL GRINDSTONES — ABRASIVE WHEELS AND BLOCKS — LUBRICATION — DRY VERSUS WET GRINDING — SELECTION OF WHEELS — SPEEDS OF WHEELS — MOUNTING ABRASIVE WHEELS — GRINDING MACHINES — WHEEL GUARDS — GRINDING PROCEDURE — CYLINDRICAL GRINDING — EXTERNAL GRINDING — CENTRELESS GRINDING — INTERNAL GRINDING — SURFACE GRINDING — GRINDING ALLOWANCES — POLISHING — SAND BLASTING.

Revised and amplified by Alfred B. Searle
(Consulting Advisor on Abrasive Materials)

GRINDING, ABRASIVES, AND POLISHING APPLIANCES.

The appliances used for grinding and polishing may be divided into two chief groups :—

(*a*) The *abrasive materials*, which may be in the form of powders, liquids, wheels, blocks, cups, etc.

(*b*) The *machines* used in the application of such materials, and commonly known as 'Grinding and Polishing Machines.'

Abrasive Materials.*

The chief *natural* abrasive and polishing materials are sandstone, sand, emery, corundum, diamond dust, pumice, rotten stone, tripoli powder, rouge, lime, whiting, and chalk. The chief *artificial* abrasives are : (i) carbon silicide, which is known by various trade names, such as carborundum ; and (ii) fused or crystalline alumina or artificial corundum, which is also known under a variety of trade names.

These materials are ground and then sifted so as to ensure the particles being of sizes suitable to the particular purpose for which they are to be used ; this being a matter of great importance.

These abrasive materials may be used in the form of powders, or suspended in water, oil, or other convenient liquids (as liquid polishes), or they may be made into grindstones, wheels, blocks, etc.

Natural Grindstones.

Natural grindstones are made by cutting blocks of suitable stone to the desired size and shape. The stones used for this purpose are shown by the following table :—

* For further details see *Abrasives*, by A. B. Searle (Pitman).

FOR GRINDING MACHINISTS' TOOLS.

Name of Stone.	Kind of Grit.	Texture of Stone.	Colour of Stone.
Nova Scotia	All kinds, from finest to coarsest	All kinds, from hardest to softest	Blue, or yellowish-grey
Bay Chaleur (New Brunswick)	Medium to finest	Soft and sharp	Uniformly light blue
Liverpool or Meling	Medium to fine	Soft, with sharp grit	Reddish

FOR WOOD-WORKING TOOLS.

Name of Stone.	Kind of Grit.	Texture of Stone.	Colour of Stone.
Wickerolz	Medium to fine	Very soft	Greyish-yellow
Liverpool or Meling	Medium to fine	Soft, with sharp grit	Reddish
Bay Chaleur (New Brunswick)	Medium to finest	Soft and sharp	Uniformly light blue
Huron, Michigan	Fine	Soft and sharp	Uniformly light blue

FOR GRINDING BROAD SURFACES, AS SAWS OR IRON PLATES.

Name of Stone.	Kind of Grit.	Texture of Stone.	Colour of Stone.
Newcastle	Coarse to medium	Hard	Yellow
Independence	Coarse	Hard to medium	Greyish white
Massillon	Coarse	Hard to medium	Yellowish white

Maximum Speed of Natural Grindstones.

Except under expert advice, grindstones should not be run at a higher peripheral speed than 3,400 ft. per min. This corresponds to the following speeds of rotation:—

Diameter of Stone.	Revolutions per Minute.	Diameter of Stone.	Revolutions per Minute.	Diameter of Stone.	Revolutions per Minute.
Ft. Ins.		Ft. Ins.		Ft. Ins.	
8 0	135	6 0	180	4 0	270
7 6	144	5 6	196	3 6	308
7 0	154	5 0	216	3 0	360
6 6	166	4 6	240		

TO TRUE GRINDSTONES.

Drive at a moderate speed and true up with a piece of iron tube. Keep turning the tube, which should be held at right angles, and turn it as the edge grinds away. The stone should be *dry*, not wet.

Abrasive Wheels and Blocks.

The particles of abrasive material are held together by clay or by a mixture of materials in which clay is an important ingredient, the wheels being moulded from a plastic state and afterwards burned in kilns at a temperature of about 1,400° C. In other abrasive wheels, the binding materials are shellac, rubber, or silicate of soda.

Abrasive wheels, blocks, etc., are classified according to the nature of the abrasive (corundum, carborundum, emery, etc.), the size of the abrasive particles and the hardness or tenacity of the bond.

Much economy, speed, and quality can be obtained by using abrasive wheels in the place of files, especially when the wheels are used on the varied machines to which they are applied. The great profit to be derived from the general introduction of abrasive wheels is due to saving in wages, files, increased output, and improved work.

It should no longer be assumed that a grinding wheel cannot remove metal and shape work as quickly as a steel tool, but the latter should be used when it can do the work more cheaply, and the grinding wheel when it excels. Poor wheels, or good wheels wrongly used, will still remove metal slowly, but a modern grinding wheel used in a modern machine is a milling cutter just as truly as if made of steel, and is to be regarded as a cutter with millions of teeth, which, while they may not cut so deeply, can cut more rapidly—as, for example, at speeds of 6,000 or more surface feet per minute. Cams and crankshafts can be produced more cheaply by grinding than by turning. With automatic grinders it is possible to turn out work even more rapidly. Where 300 pieces per day were ground by piecework, 2,300 are now produced. As the knowledge of grinding becomes more common, and the opposition on the part of the workmen to increased production is overcome, the field for grinding will be still more extended.

(*C. H. Norton before Amer. Soc. of Mech. Engrs.*)

The *grade* of a wheel is represented by a letter, being the hardest and the softest. The term 'grade' is confined to the relative hardness of the wheel or block as a whole, and does not refer to the hardness of the abrasive particles. This distinction is important, because the cutting or abrasive power depends quite as much on the bonding material as on the abrasive particles.

No wholly satisfactory method of grading abrasive wheels, etc., has yet been devised. various mechanical devices of testing having proved unsatisfactory. The method adopted by manufacturers consists in gouging the wheel with a tool resembling a screw-driver, the 'feel' indicating the grade with fair accuracy to an experienced tester. It is, however, almost impossible to compare accurately the grades of abrasive wheels made with different bonds, as they do not work equally satisfactorily with any material.

The term '*grit*' is used to indicate the sizes of the abrasive particles present, and it is usually expressed by figures indicating the number of meshes per linear inch in a sieve through which the abrasive particles will pass completely. Thus, in a 60-grit wheel or block the abrasive particles will pass completely through a sieve having 60 holes per linear inch. It should be observed that the grit only indicates the largest particles, and has no reference to their average diameter nor to the proportion of much smaller particles present. It is understood, however, that there is only a small proportion of particles sufficiently fine to pass through a sieve which is represented by the next grit figure.

GRIT SIZES OF GRINDING WHEELS.

Class of Work.	Emery.	Alundum.	Corundum.	Carborundum.
Glass and marble polishing	150	200	240	—
Fine hardened steel work	40–80	46–100	50–120	60–150
Sharpening milling cutters	40–50	46–50	46–60	50–80
General machine shop use	20–24	20–30	20–36	24–40
Brass castings	16–20	20–30	24–36	30–40
Agricultural implements	14–20	16–24	16–30	16–36
Rough castings	10–16	12–16	12–20	14–36
Marble	—	—	—	2–4

(*Engineering News.*)

WHEELS FOR DIFFERENT MATERIALS AND OPERATIONS.

Material.	Operation.	Classification.
	External Work.	
Soft Steel	General	24 Comb. L.M. Alundum
,,	Fine finish	60 L. ,,
Hard Steel	General	60 J.K. ,,
,,	Fine finish	80 K. ,,
Cast Iron	General	24 K. Crystolon
,,	Chilled Rolls (Roughing)	36 K. ,,
,,	,, (Finishing)	60 J. ,,
	Internal Work.	
Soft Steel	—	46 K. Alundum
Hard Steel	—	60 J.K. ,,
,, Fine finish	Fine finish	80 K. ,,
Cast Iron	—	36 J. Crystolon
,,	—	38–46 J. Alundum

(*W. D. Adamson.*)

Material.	Wheel Maker.	Bond.	Classification.
Copper (Roughing) .	Norton Co. . .	Elastic . .	36–50 Crystolon
„ (Finishing) .	„ . .	Vitrified . .	80 L „
Aluminium . .	„ . .	Elastic . .	24–46 Soft to Med. Crystolon
„ . .	Vitrified Wheel Co..	Elastic . .	24–46 Medium Carbolon

The *suitability* of an abrasive wheel or block for any given purpose depends on the grade or hardness of the wheel as a whole, on the grit or size of the abrasive particles, and on the *bond* which unites them together.

For grinding steels and the harder materials, *i.e.* materials with a high tensile strength, wheels or blocks composed of an aluminous abrasive (corundum emery) are preferable. For cast iron, chilled iron, brass, soft bronzes, aluminium, copper, granite, marble, leather, wood, and other materials of lower tensile strength, wheels or blocks composed of a carbide abrasive (carborundum, crystolon, etc.) should be used. The binding agent which unites the particles of abrasive also determines the suitability of the wheel or block for any given purpose. Thus—

(i). Rubber-bonded abrasives are very tough and resistant, and so are specially suitable where a bond of exceptional strength is required in conjunction with a thin wheel or ring, as in the case with various cutting operations, such as slotting iron plates, sawing stone, cutting glass and saw teeth, or sharpening milling cutters of awkward shape, as well as forcutting metals, grinding chilled iron rolls, and for other work where a fine finish is required. Shellac-bonded wheels are too soft for this purpose. They are also used where it is necessary that the shape of the abrasive article should be retained as long as possible. This is particularly the case with the thin cutting discs used by watchmakers, dentists, etc.

(ii). Shellac-bonded wheels are used for cutter and reamer grinding, pointing drills, sharpening knives, saws, and other edge tools, and for similar purposes as rubber-bonded wheels, but as they are more elastic they can be used to give a finer finish. They will not stand high temperatures, but can be used for wet or dry grinding. They are less porous and less free cutting than wheels with a vitrified bond. They are singularly free from 'glazing,' as the baked shellac has lost the stickiness characteristic of the natural material.

(iii) Silicate wheels are very close in texture, and as they cut freely they are very useful for grinding tools and cutlery.

(iv). Abrasive articles made with a vitrified bond are characterised by a high porosity, a great resistance to heat and acids, and great freedom in cutting. They may be used for almost any purpose if care is taken to select them of suitable grit and grade, though when very thin cutting wheels are required it is often preferable to use a shellac—or rubber-bond may be preferable. If too much bond is present the abrasive articles tend to 'glaze' badly, owing to the bond not falling away with sufficient rapidity from the cutting points. With too little bond, on the contrary, the articles will be weak and, in the case of wheels, cylinders, or rotating rings, they may be dangerous on account of their liability to break when in use.

Lubrication.

The rate, effect, and efficiency of the grinding are also affected by the water or other lubricant applied to the wheel when in use. The function of the water is to carry away the heat resulting from the friction between the abrasive and the article being ground, and to wash away any loose particles dislodged by the grinding.

The water supply for all external grinding operations should be ample in volume without force. Using, say, a 14 in. diameter wheel, not less than 5 gallons and up to 10 gallons per minute should be used; on larger wheels 20 to 50 gallons per minute.

For many purposes, solutions of soap or emulsions of oil and water are preferable to plain water. A solution of carbonate of soda containing 2 oz. per gallon has the advantage of not producing rust, especially if ½ or ¼ pint of lard oil is mixed with it.

In grinding aluminium it is advisable to use a lubricant of lard, oil, kerosene, or a mixture of kerosene and gasolene or lard, or oil and gasolene.

Dry *versus* Wet Grinding.

In certain circumstances water may—or must—be dispensed with. Whenever it is necessary to see the edge of the wheel distinctly, to be sure of reaching some particular spot, water cannot be used, as it obstructs the view. Work revolving in the chuck or on the faceplate is also generally ground dry, as water is awkward to deal with on ordinary machines under such conditions.

Cutters are also usually ground dry, although special care has to be taken to prevent 'drawing the temper' of the cutting edges. The amount to be removed is, in most cases, small, so that the sacrifice of time is balanced by the greater convenience of dry grinding.

More material can be ground away by dry internal grinding than by wet, and it is fairly common practice to run water on the work externally to dissipate as much heat as possible whilst grinding dry internally. On such classes of work as aeroplane cylinder grinding, or ring gauges, where a high degree of accuracy and finish is essential, water must be used, but it should be in such volume as to prevent as far as possible the chips being carried round to the wheel and interfering with the cut.

In *wet grinding*, care should be taken that the water supply is steady and adequate, and particular attention must be paid to this in the case of tool grinders, where it is of the utmost importance that the tool should be effectively covered with water, to obviate any loss of temper in the steel during the process of grinding. Some grinding machines provide for this ; *e.g.* in one such patent machine the water is forced by a centrifugal pump through a series of small holes in the tool rest itself in such a manner as to completely envelop the tool being ground. A noticeable feature of this grinder is that there is total absence of splashing.

Selection of an Abrasive Wheel.

In the selection of an abrasive wheel the most important points to be kept in mind are *suitability for the particular class of work*, and *safety from accident*.

It is obvious to everyone that a wheel specially manufactured for fettling iron castings is not the one to be used for needle pointing, but few people, except those connected with the trade, have any conception of the number of kinds or classes into which such wheels have been divided and subdivided, each main group (designated by symbols, B, S, SS, G, R, M, etc.) being varied in hundreds of ways to suit the work.

The general practice is to state the purpose for which the wheels are required and leave the selection to the judgment of the makers ; it is to their interest to give satisfaction. The other particulars to be given when ordering are—quantity required, diameter, thickness, and size of centre hole.

Grindstones are softer when wet than dry, and should not be left partly immersed in water, or they will wear unevenly. Stones made with sorel cement (basic magnesium chloride) as a bond should not be used for wet grinding as the cement is disintegrated by water.

Speed of Wheels.

This varies somewhat according to the make and the purpose for which they are used.

The peripheral speed of a grinding wheel—which is a function of its diameter and the number of revolutions per minute which the wheel makes—has a marked effect on the apparent hardness of the wheel. Hence, the hardness or grade of an abrasive wheel or cylinder appears to vary with the speed at which it rotates. Thus, by running a soft wheel above its normal speed it appears to become harder, and by reducing the speed of a hard wheel it appears to become softer. Hence, by varying the speed within reasonable limits a wheel which is normally too soft or too hard may be used satisfactorily.

As a wheel wears, its peripheral speed is reduced and the wheel appears to soften, but by increasing the number of revolutions per minute so that the original peripheral speed is obtained the wheel appears to regain its former hardness. Many workers suppose that the faster the work revolves the greater will be the output, and so they use very hard wheels which require maximum driving power and cause a maximum wear of the machine. Yet, in most cases, they produce work of inferior quality which requires a longer time and greater effort to produce than if softer wheels and slower work speeds were used.

The following speeds are typical, but should be modified to suit particular cases :—

Application.	*Peripheral Speed in Feet per Min.*
Cylindrical grinding	5,500 to 6,500
Snagging and general off-hand grinding on bench and floor stands	5,000 ,, 6,000
Surface grinding	4,000 ,, 5,000
Knife grinding	2,000 ,, 3,000
Hemming cylinders	2,100 ,, 2,400
Tool grinding	3,000 ,, 4,000*
Vertical surface grinding machines	4,000 ,, 4,500
Elastic and rubber cut-off wheels	9,000 ,, 12,000
Polishing wheels	about 7,000

* Some large users of grinding wheels regard as maximum peripheral speeds for machinist's tools 0–1,000 ft. per min., and for carpenter's tools 550–600 ft. per min.

For speeds higher than the above, slightly softer grades should be used to off-set the harder cutting action; for lower speeds slightly harder grades than would be ordinarily supplied should be used.

For polishing purposes a much lower speed is desirable; thus, the cloth wheels known as 'mops' or 'dollys' used for buffing metals usually run 20 ft. per second.

It is impossible to state exactly the speed at which any article or part to be ground should rotate. It is largely a matter of experiment, as the speed should be suited to the abrasive and to the nature of the material to be ground. With Norton cylindrical grinders a peripheral work-speed of 60 to 80 ft. per minute is often used for roughing, and 30 to 40 ft. per minute for finishing. It is customary to rough-grind at a higher surface speed of work than on finish-grinding.

In grinding cylinders the speed at which the article to be ground rotates is of great importance, as by running the grinding wheels at a constant speed and varying the speed of rotation of the article to be ground it is easy to secure uniform results from wheels having a variation in speed of 2,000 ft. per minute, and a variation from true grade within practical wheel-making limits. Thus, by varying the speed of the article to be ground, the necessity for variable revolutions for the wheel, or close limits of speed and grade for the wheel, are made unnecessary, and variable speed for the work accomplishes all that variable wheel spindles can accomplish, and much more, in a more simple way, at less expense.

The following grinding-wheel speeds are recommended for different types of grinding, in a recent number of *Grits and Grinds*, published by the Norton Co. of America:—

Type of Grinding.	Recommended peripheral speed (feet per minute).	Maximum peripheral speed (feet per minute).
Cylindrical grinding	5,500	6,500
Internal grinding	5,000	6,000
Snagging and general off-hand grinding on bench and floor stands	5,000	6,000
Surface grinding	4,000	5,000
Knife grinding	3,500	4,000
Hemming cylinders	2,100	2,400
Wet tool grinding	5,000	6,000
Cutlery grinding	4,000	5,000
Shellac and rubber cutting-off wheels	9,000	12,000

Mounting Abrasive Wheels.

If there is a large area of contact the method of mounting and safeguarding abrasive wheels and the condition of the grinding machine are of great importance. A grinding wheel should

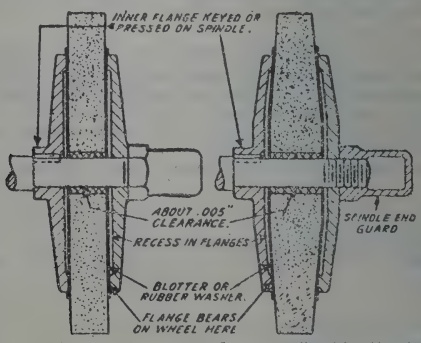

FIG. 1.

be fixed carefully and securely between recessed steel or iron plates or washers about half the diameter of the wheel, with a sheet of thin rubber insertion, or one or two thicknesses of brown paper, on each side between the wheel and the washer-plates (fig. 1).

The wheel should not project more than 2 ins. beyond the flanges. Both flanges should be of equal diameter, to avoid cross-straining of the wheel. The inner flange should be keyed to the shaft and abutting against a shoulder on the same. Various firms have special mountings which have proved satisfactory.

The grinding wheel should never be mounted without washers. The hole in it should be slightly larger than the diameter of the spindle, as the wheel must not be driven tight on to the spindle. Care should be taken in screwing up very thin wheels that too much force is not applied. No wheel of more than 12 ins. diameter should be put on a spindle 1 in. thick, and other sizes in proportion.

Before using, the wheels should be trued up on their own spindles with a truing tool, and they should also be turned up when they get out of truth through wear. Grinding wheels should revolve towards the rests, and the rests should be moved close to the wheels so as to prevent work being jammed between the rest and the wheel. The rest must never be moved while the wheel is in motion.

Wheel Guards.

For safety, a protection hood made of rolled steel is preferred. The hood should cover as much of the wheel as possible and also the spindle rod. The hood should be constructed to act as a dust hood which when connected with an exhaust system will eliminate the injurious effects of wheel dust. The wheel should be kept true and the work rest close to it.

Face or Cup Wheels ought to be protected by being well and properly secured inside a Safety Adjustable Chuck, designed to allow only a small portion of the wheel to project whilst at work, and constructed so as to secure and support the wheel as close to the grinding face as possible.

To meet the requirements of factory inspectors, a number of emery wheel guards, good, bad, and indifferent, have been introduced by manufacturers. The two features to be looked for in an appliance of this kind are :

(1) That it is of ample strength, and (2) that it can be readily adjusted to follow the wear of the wheel.

It is essential that the guard should be kept close to the periphery of the wheel in order to limit the flight of any portion which may break away.

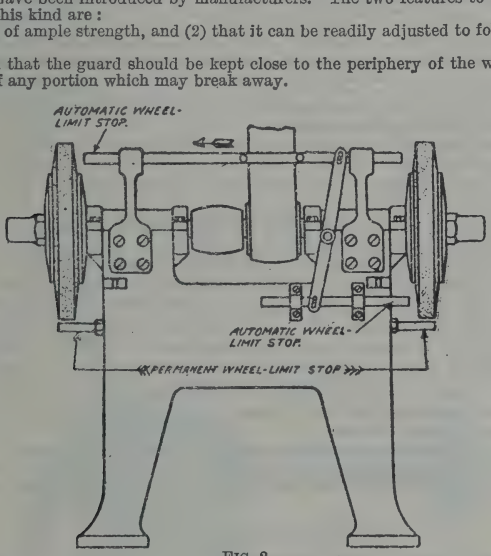

FIG. 2.

Machines fitted with two or more speeds should be provided with safety devices to prevent the maximum speed of the wheel being exceeded. In fig. 2 is shown a two-speed machine fitted with stops to limit the diameter and to prevent the belt being shifted to the high-speed pulley when the wheel exceeds a predetermined diameter.

GRINDING MACHINES.

The modern grinding machine is practically a finishing machine in which the work produced needs no further correction. The sliding surfaces of the machine must be perfectly true planes, and there must not be rigidity, particularly in the grinding-wheel head. It must be heavy enough

to carry the largest and broadest wheels with which the machine may be possibly fitted, and also to overcome any possible want of balance in the wheel itself. The spindle and its bearings should be of ample proportions. The machine should be easily operated and controlled in its movements, so that a maximum amount of work can be obtained from it.

It is imperative that grinding machines be specially designed for the purpose intended, made of the best quality and workmanship, and that great care be taken in securing a suitable foundation as free from jar and shake as possible. The stands or bodies of the machines ought to be of a sufficient strength and massiveness to correspond with the size of wheel used. The same remark applies to the spindle, which must run in long and accurately bored bearings.

If the spindle is loose and cannot be put in good condition, a harder grade of wheel must be used than would ordinarily be recommended, so as to overcome the tendency to pound the wheel face to pieces. Light, flimsy machines, and those improperly secured to the foundation, also require harder grades than would ordinarily be used. Machines are frequently placed in the middle of a wooden floor which vibrates badly, and in this case harder wheels must be used than for a machine on a firm, solid foundation. A machine which is too light or imperfectly made is always a nuisance and is liable to prove very expensive. It is only too easy for good work to be spoiled by such machines, and they add unnecessarily to the cost of grinding, because they cannot be driven at the most appropriate speed for the work and because of various 'dodges' which must be used to obtain satisfactory results.

Rotary abrasive appliances may be mounted in a fixed frame—in which case the article to be ground, cut, or polished is moved gradually forward—or the work may be fixed and the abrasive mounted on a moving frame, so that it travels both forward and from side to side. There is an increasing feeling that this principle is wrong even in light machines; it is impracticable in heavy ones, where a wheel-head may weigh between 1 and 2 tons. When a heavy wheel is grinding to within $\frac{1}{1000}$th part of an inch, revolving at a speed of 6,000 ft. per minute at the surface, and operating across a cutting face from 2 ins. to 4 ins. wide, it is clearly not a good mechanical proceeding to traverse such a mass under such conditions. The present practice, therefore, is to put plenty of mass into the wheel-head and to support it rigidly directly from the floor. Then the only movement which it receives is that of feeding inwards to the work. Incidentally, also, the necessary travel of the table requires a long table, which, again, avoids excessive wear. A slow table or traverse speed should be used when taking heavy cuts, but for finishing a high traverse speed is preferable.

The belt-drives from cumbrous overhead shafts have disappeared from all except the smaller and medium-sized machines, as electric drives have largely displaced this clumsy method and permit overhead-travelling cranes, or overhead tracks, to have free range. The large cylindrical grinding machines of to-day, therefore, have no belt-drive from above. A motor is installed somewhere alongside the bed, and the grinding wheel is belt-driven from that; the work speeds and the wheel-feeds are arranged through gears enclosed in boxes protected from grit. The convenience of this arrangement, which is only rendered possible by the electric drive, is inducing manufacturers to adopt similar arrangements for the smaller machines.

In the best machines no mild steel and cast iron is used for shafts and gears. High carbon or alloy steels alone are used for these. Nickel, nickel-chrome, or chrome-vanadium steels ensure strength and durability, without which the small shafts and gears of the pitches would soon show serious wear. Friction is reduced by the universal fitting of ball-bearings for taking circular and end thrust. Lubrication is provided in various ways, ring-oiling to the main bearings, forced water-supply to the work and the wheel, and a large supply-tank or tanks with a circulating pump. New forms of steadies have been evolved, and more are used, besides which steadies for some duties are specially designed. The necessity for supporting work almost continuously receives more recognition than it formerly did, and the work is better supported on the bottom and in opposition to the wheel.

As good grinding machines are costly, concessions to the requirements of the smaller firms, in the form of various attachments, are inevitable, but the tendency is towards using plain grinding machines, each limited to one set of functions, every detail being considered and worked out for that duty alone.

Van Dorn Tool Post Grinder.

This machine, fig. 3 (made by the Van Dorn & Dutton Co., Cleveland, Ohio), is furnished with an internal attachment as shown. It may be used for internal and external grinding on the lathe, tool grinding on the milling machine, and surface grinding on the shaper or planer. The spindle makes 4,500 revolutions per minute, and the weight of the machine is about 24 lbs. These machines are extremely useful on a wide variety of work in all engineering shops.

All parts of these machines are made accurately to gauge, ensuring perfect interchangeability. All adjustments may be easily made without removing any part of the machine. The taper bearing at the wheel end ensures the correct bearing adjustment being maintained. The bearing for taking the end thrust may be adjusted to exceptionally fine limits. The bearings are bronze and the lubricating system is very efficient. The motor is air cooled. The armature is form wound, a commutator of special design giving great rigidity and perfect insulation. The windings are insulated by a special process. The brushes are easily accessible. Adjustable rear handles are on hand types.

Bearings.—The design of the bearings is a special feature of Van Dorn grinders. The bearing for the wheel end is so constructed that adjustment for compressing the bearing can be effected

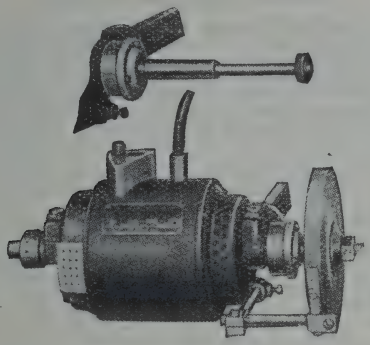

FIG. 3.

in addition to expanding; thus a perfect running fit can be obtained, whilst efficient locking arrangements ensure that the adjustment cannot be disturbed.

Longitudinal adjustment is accomplished by means of a double thrust bearing provided with a dial cap. By depressing a locking pin the dial may be moved in either direction, enabling the adjustment to be made within very fine limits.

PORTABLE PRECISION GRINDERS.

This grinder, fig. 4 (*The Consolidated Pneumatic Tool Co., Ltd.*), is specially adapted for fettling castings and grinding out cylinders; for this latter purpose it is fitted with a shaft

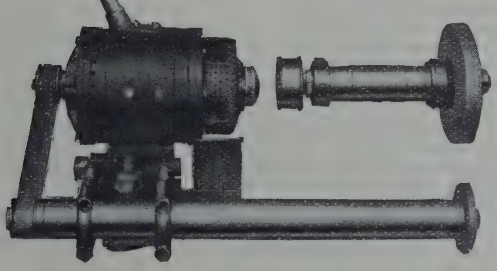

FIG. 4.

extension. The arrangement consists of a high-speed motor mounted in a special arbor, and belted to a shaft which carries an emery wheel. Two or more replaceable shafts are provided, one taking a large, and the other a very small wheel, so that a wide variety of grinding work, from motor cranks and cylinders to valves, jigs, and small tools, can be done.

Grinding Procedure.*

Cylindrical Grinding—External.

The best average *surface speed* of modern grinding wheels, as made to-day from artificial abrasives, is about 6,000 ft. per minute for external cylindrical grinding, and the useful speed range is from 6,500 to 5,500 ft. per minute; below this speed excessive wheel wear is liable and very probable, and grinding machines should be arranged so that the effective life of the wheel falls within this range. It is of the utmost importance that the speed of the wheel be maintained during the cutting operation, no matter what the speed may be, and the drive should be sufficiently powerful to prevent slowing down during momentary heavy cutting. Not only is the wheel wasted by being allowed to slow down, but the wheel face is destroyed and more frequent truing up is necessary. It is more economical, from the point of view of wheel wear to metal removed, to keep the speed up so that softer and freer cutting wheels can be used, the speed enabling them to stand up to heavy cutting without undue wear, and, further, such wheels have very little tendency to glazing.

The *grade* of the wheel is determined by the material to be ground and the rigidity or otherwise of the work, and whether it is of large or small diameter. No definite rule can be laid down for the adoption of any particular grade, but it is unusual in general machine work to require more than two wheels to a machine, one to grind all classes of steel work and the other to deal with all cast metals. Closer grading can be done where the work is all of one class, as, for instance, a machine may be employed wholly on cast-iron pistons, crankshafts, or piston-rods, etc., in which cases particular grades of wheels can be employed.

The *diameter* of the wheels should be as large as possible.

The direct result of using large diameter wheels is economy of operation, the cost of wheel per cubic inch of material removed being less than in the case of the smaller wheel.

The *wheel width* has a direct result on the output, providing it is made use of, and to utilise a wide wheel to its full extent the table-travel must correspond.

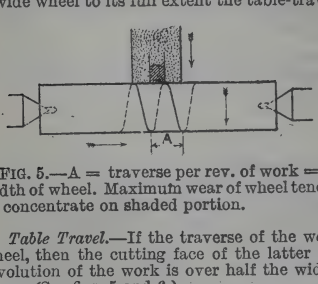

FIG. 5.—A = traverse per rev. of work = ⅔ width of wheel. Maximum wear of wheel tends to concentrate on shaded portion.

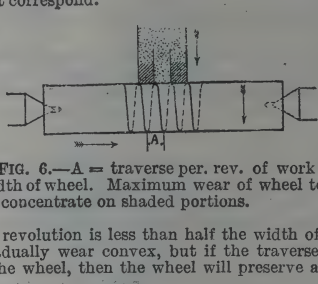

FIG. 6.—A = traverse per. rev. of work = ⅓ width of wheel. Maximum wear of wheel tends to concentrate on shaded portions.

Table Travel.—If the traverse of the work per revolution is less than half the width of the wheel, then the cutting face of the latter will gradually wear convex, but if the traverse per revolution of the work is over half the width of the wheel, then the wheel will preserve a flat face. (See figs. 5 and 6.)

The ideal traverse per revolution of the work is about two-thirds the width of the wheel, but it should not, except for finishing, be less than half the width.

The table should travel as rapidly as can be used. (See '*cross feed*,' page 1185.)

The main factor governing production on external cylindrical grinding machines is the combination of wide wheels with fast table speeds, as, other things being equal, the machine which possesses these advantages is the most efficient tool.

The *work speed* has only an indirect effect on the output. With a good wheel it makes little difference to the finish obtained whether the work surface speed be, say, 30 or 60 ft. per minute, except that, if the lower speed is persisted in, it limits the table travel, and so in turn limits the output. For external cylindrical grinding the practice is to work on an average surface speed of 60 ft. per minute as a basis. Low work speed is directly conducive to distortion and inaccuracy. The heat created by the cutting action of the wheel must be dissipated or distributed as quickly as possible, and can only be done by a higher work speed and table travel aided by an ample flow of water.

Vibrations in the work itself and disintegration of the grinding wheel are more liable to occur in large diameter and heavy work than in small work. It is much easier to control vibration in small diameter work, and it would be almost impossible to rotate it at such a high speed as to disintegrate the surface of the wheel, but the tendency would be to cause unnecessary wheel wear, and if the table speed was such that the traverse was less than half the width of the wheel the later would wear more at the corners than in the centre.

Vibrations on heavy work are much more difficult to control, and much depends on the

* Abstract of Paper read by H. H. Asbridge before the Manchester Association of Engineers.

machine and method of supporting the work. No definite rule can be laid down, as so much depends on circumstances. For instance, it would be both permissible and advisable to run an 8-in. tube at a higher surface speed than an 8-in. solid shaft, the limiting factor in the tube being a surface speed such as would cause disintegration of the wheel face, there being no heavy body of metal to set up vibration, whereas in the shaft the limiting factor would be a surface speed sufficient to set up an oscillatory motion difficult to control, and which would prevent the shaft from being ground to a perfect cylinder. This same defect could also be obtained by using a too slow surface speed, due to insufficient dissipation of the heat created by the grinding wheel. Between these two extremes there is a wide margin of surface speed at which grinding can be sucessfully carried on.

A good rule is to get a wheel suitably graded for the work, and when once a suitable grade is found it should be recorded, as wheels such as are made from artificial abrasives can be duplicated within very fine limits.

The *cross feed* to the grinding wheel should operate at each reversal of the table, that is, at the end of each stroke; this is necessary to distribute the work over the whole width of the grinding wheel. Production is not governed so much by the amount of cross feed as by other conditions. There should be as much cross feed as the work, the machine, or the grinding wheel will stand; this will be from ·0005 in. to ·0015 in. on the work diameter at each reversal of table. Under these conditions, a machine with a fast table travel will give maximum output with a comparatively light cross feed, as compared with a machine having only a slow table speed, and will have the advantage also of not stressing the work to the same extent. The wheel will remove more material for a given wheel wear, and the machine will be more economical in power.

Over-run of work should be avoided (see p. 1187.)

The *time required* in external grinding cannot be calculated with any approach to accuracy on the usual basis of cutting speed and feed, etc.

The finish grinding of a shaft of a given diameter and length is not a constant operation with an abrupt termination, as in other methods of machining, but is an operation starting at zero, rising quickly to the point at which possibly the maximum cutting capacity of the wheel is demanded, and then falling gradually to zero or finished size, and the finer the limit fixed for the finished diameter, the more gradual will be the closing stages of the operation. Grinding times must, therefore, so far as the wheel is concerned, be based on a mean of its cutting capacity, much lower than its maximum.

The formula, as deduced from the above method, is as follows:

Diameter of work in inches × length in feet × constant = grinding time in minutes for the removal of $\frac{1}{32}$ in. in diameter and finishing to commercial limit.

TABLE OF CONSTANTS.

Diameter of Work.	Size of Wheel.	Constant.
4-in. shaft and upwards.	26 ins. by 3 ins.	1·3
3-in. ,,	,,	1·4
2-in. ,,	,,	1·8
1½-in. ,,	,,	2·2
1-in. ,,	,,	3
3-in. shaft and upwards.	14 ins. by 2 ins.	2·2
2-in. ,,	,,	3
1½-in. ,,	,,	3·7
1-in. ,,	,,	5
3-in. shaft and upwards.	12 ins. by 1 in.	3
2-in. ,,	,,	3·8
1½-in. ,,	,,	4·5
1-in. ,,	,,	6·3

For the removal of $\frac{1}{64}$ in. in diameter allow $\frac{2}{3}$ of time obtained. For work below 1 in. diameter the grinding time tends to increase, depending entirely on rigidity of support afforded to same. Extra time should be allowed to special limits, such as may be required for drive fits, etc., or for special finished surfaces, such as are necessary for spindles, gauges, etc.

Centreless Grinding *

The objections to the use of centres to support the work during grinding, and the difficulty of accurately grinding gudgeon pins, crank pins, and other relatively long pieces of small diameter

* Particulars supplied by S. W. Dowding & Co., 66 Victoria Street, S.W. 1.

can be avoided, and any irregularity caused by warpage in hardening removed by supporting the work in a suitable guide block. Two patterns (fig. 7) of guide blocks are used—one for rough grinding, and the other for finishing—the difference being in the relative positions of the three guide blades.

For rough grinding the near blade is adjusted so that the work projects beyond the lower front blade C, slightly more than the thickness of the material to be removed, whilst the upper blade, A, is given a clearance of 0·005–0·020 ins. In finishing, the upper and lower blades are more nearly vertical. The work is finished after it has been passed several times through the block.

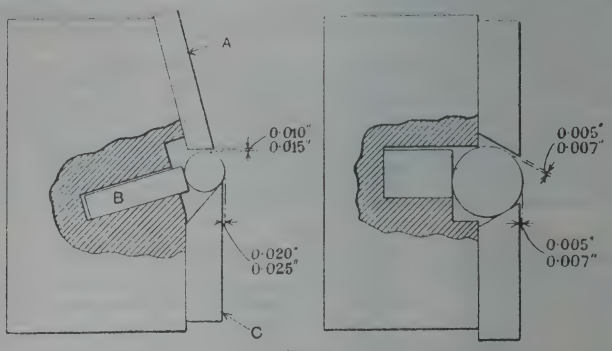

FIG. 7.

The face of the grinding wheel is conical, and is dressed to an included angle of 4–6 degrees, so that it has the effect of an increased surface speed as the work passes across the wheel face and compels the work to rotate slowly.

Lubrication and cooling of the work are essential.

The grinding is effected more rapidly than when centres are used.

Internal Grinding.

The idea that internal grinding cannot be satisfactorily accomplished at spindle speeds less than 30,000 to 50,000 r.p.m. is erroneous. Provided that there is rigidity in the spindle employed, the grinding-wheel diameter has little effect on production. The effective speed range of a good grinding wheel is very much greater than in any other form of grinding, and ranges from 1,000 to 4,000 ft. per minute, and much of the most successful grinding is done at the surface speed of from 1,500 to 2,500 ft., but a very rigid spindle is necessary.

There are two types of internal spindles, the 'tube' type having a bearing immediately behind the wheel (this type is not to be recommended for holes, say, less than 6 ins. in length, as holes of this length, and longer, are generally insufficiently large in bore to admit of a substantial spindle), and the 'adaptor' type. The construction of the latter type is such that the spindle bearings never enter the hole being ground, the wheel being carried on an adaptor fitted into the main spindle and held by a draw bolt, or, if the work to be ground is of limited range, the adaptor portion is formed integral with the main spindle. For general commercial work the loose adaptor is preferable, as long or short, heavy or light adaptors can be used suitable for the particular work in hand. The fact that the main spindle in this instance never enters the hole permits of it being made of liberal dimensions. The Churchill Machine Tool Co. fix the higher limit of such spindles at 1,500 r.p.m., and so long as the rigidity is there behind the adaptor no higher speed is necessary for holes from ¼ in. upwards.

The *wheel width* has a direct result on the output.

Given a spindle with the necessary rigidity, the use of wide wheels and a high table speed are the governing factors in obtaining maximum production. The standard practice of the above firm is to use all wheels from ½ in. to 3 ins. diameter ¾ in. wide, above 3 ins. diameter 1 in. wide. Such wheels are of no advantage unless combined with high traverse speeds, in order to utilise as much of the wheel width as possible, and also to dissipate the heat generated evenly.

Table traverse speeds up to 9 ft. and 10 ft. per min. are commonly applied to internal grinding machines.

The *work speed* in internal grinding can be varied considerably above or below the speed which has been previously determined to be the best for the particular work in hand. Such variation would have very little effect on production, but might affect the finish obtained. In standard practice a work surface speed of from 100 to 120 ft. per minute is used as a basis or starting point, and varied according to circumstances.

The *cross feed* requires special care in internal grinding.

Whatever type of internal grinding spindle is used (where the work to be ground is carried on a rotating spindle) there is bound to be overhang from its supporting bracket, with more or less unavoidable spring, and whilst the slide carrying the spindle can be set to a predetermined position with great accuracy, it does not follow that the hole being ground will have reached the desired size, owing to the spring in the spindle. This fact makes the use of automatic cross feed almost impossible of accomplishment if the amount of the feed has to equal the amount of cut which the wheel will take at each traverse of the table. Hand-operated cross feed fitted with an adjustment dead stop is therefore to be preferred.

In another type of internal grinding, the work is stationary and the grinding wheel has imparted to it a planetary motion whilst rotating at a high speed on its own axis, the planetary spindle being eccentrically adjustable whilst grinding is proceeding. This type of machine has been employed for grinding motor-car cylinders when cast *en bloc*, and the possibilities of this type of machine for finishing holes are great.

Over-run of work should be avoided; that is, the wheel should never be allowed to leave the work, the traverse being only just sufficient to allow of not more than one-third of the width of the wheel projecting beyond the end of the work. If the wheel is allowed to run off, the result in external grinding will be to have the face of the wheel sheared away by the sharp ends of the work; and in internal grinding the hole will be bell-mouthed.

Surface Grinding.

There are two methods of surface grinding—one using the periphery of the grinding wheel, and the other the edge of the wheel. The wheel in the latter case is of cup form and carried on either a vertical or horizontal spindle, the more widely used being the vertical spindle type. The two methods are further subdivided according to the manner in which the work is moved, machines being made with the work carried on a reciprocating table, or on a circular revolving table, briefly classified as follows:—

1. Horizontal spindle surface grinding machine, where the work is reciprocated under the grinding wheel.

2. Horizontal spindle ring and surface grinding machine. In this machine the work is carried on a circular revolving table, generally made in the form of a magnetic chuck, and rotated under the grinding wheel.

3. Vertical spindle ring and surface grinding machine, where the grinding wheel is of cup form, carried on a vertical spindle, and the work is carried on a circular rotating table, generally in the form of a magnetic chuck and rotated under the wheel.

4. Vertical spindle surface grinding machine, where the wheel is of cup form carried on a vertical spindle, and the work is carried on a table reciprocating under the wheel.

The first and fourth types are the most commonly used, and intended for the grinding of flat surfaces of all kinds and in all materials.

The second and third types are widely used for grinding the sides of disc work, such as circular knives and saws, piston rings, disc valves, etc., using the rotary table. The second type of machine with the horizontal spindle leaves the work with a concentric finish, whereas the third type of machine with the cup wheel leaves the work with a radial finish, and which in some classes of work is objectionable, particularly, for instance, in piston rings, where the concentric finish is preferred. So far as production is concerned the vertical spindle ring and surface grinding machine will give a greater output than the horizontal spindle ring and surface grinding machine. Both machines can be arranged to grind flat, concave, or convex surfaces.

The most largely used machine for regular commercial purposes is the machine with the vertical spindle, owing to its greater productive capacity.

The best *wheel speed* for all-round surface grinding is about 4,000 ft. per minute, with very little margin of speed—that is, if a wheel is working successfully at 4,000 ft. per minute, it cannot be varied up or down from this speed without affecting production, consequently the vertical spindle machine with the cup wheel has a great advantage in this respect, due, of course, to the wheel retaining its diameter as it wears.

The grade of the wheel for surface grinding demands far closer attention than in any other type of grinding. The only remedy for a wheel that is too hard or too soft is to change it for a wheel of the correct grade.

A high *table speed* is the main factor governing output, using suitable grinding wheels, but the machine which will so work that the temperature is even throughout the whole ground surface will produce the most accurate results.

The vertical surface grinding machine with the cup wheel, which covers the full width of work at each stroke of the table, has a distinct advantage over the horizontal spindle machine using the periphery of the wheel, and which would have to be traversed transversely in order to cover a work surface wider than the width of wheel.

Quite apart, however, from the question of heat distribution, the vertical spindle machine has the greater productive capacity, and for grinding wide surfaces or groups of small articles this type of machine has the advantage of the horizontal spindle machine. The vertical surface grinding machine is now being adopted in all classes of engineering works, and wherever flat surfaces have to be produced, such as in machine-tool work, there is no method that can be compared with it for cheapness of production.

A machine of this type added to the equipment of any works, and used for the production of flat surfaces has, more than any other type of grinding machine, a beneficial effect throughout the works, and in this respect raises automatically the standard of work produced. In this way, given an accurate machine, it is so very easy to true up straight edges and similar tools and keep them all in a constant high state of perfection; and by having a machine of this type always in readiness to produce flat surfaces the result is that more accurate work is automatically produced throughout the works.

The *time required* for grinding a given surface can be ascertained with fair accuracy once a basis is found, based on area ground and amount of metal removed. Under normal working conditions, a grinding wheel has a certain capacity for the removal of metal, based on its cutting area or its diameter and width.

Examples of Grinding.

The following examples will serve to show what may be expected from wheels which are suited to the conditions and work in hand :—

A batch of 72 soft steel spindles of diameters ranging from 1½ inch down to $\frac{9}{16}$ inch by 8 inches long, and having from ·010 to ·015 inch left for grinding, were finished in an average time of 4½ minutes each. The wheel was Norton 'Alundum' 60.M, running at a speed of 6,500 ft. per minute, and it lost ·0005 inch diameter for every six spindles ground. The work speed was 30 ft. for $\frac{9}{16}$ diameter, and 60 ft. for 1½ inch diameter, and the grinding limit was ·00025 inch.

Cast-iron spindle tubes 2½ inches diameter by 12 inches long took an average time of 10 minutes each to finish. The grinding limit was ·00025 inch, and the amount removed ·010 to ·015 inch. The wheel was Norton 'Alundum' 46.H, running at 5,500 ft. per minute, and it lost ·001 inch in diameter on every tube. The speed of the work was 30 ft. per minute.

These examples are given as indicating an amount of reduction in wheel size which should not be exceeded under ordinary conditions. *(Churchill Machine Tool Co. Ltd.)*

Grinding Allowances.

(For Norton and Heald Grinding Machines.)

Frequent inquiries as to the amount of stock which should be left on turned and bored work to be ultimately finished to size by grinding had led to the answer that this depends on several factors which must be ascertained before a correct allowance can be determined. The object aimed at should be to so proportion the work between the lathe and the grinding machine that the total time taken by both in producing the desired degree of finish and accuracy is reduced to the minimum.

In a desire to turn out a 'good job' the turner sometimes overlooks the fact that a smooth piece of work having only a small allowance may take as long to finish in the grinding machine as a rough-turned job on which more metal is left.

The chart, fig. 8, shows the grinding allowances which are recommended for turned or bored work up to 12 ins. diameter. Although the amounts specified may, to some, appear excessive, they may be allowed with confidence in establishments possessing a grinding department run according to modern ideas of efficiency and lathes sufficiently powerful to take the coarse feeds recommended.

Curves A and A¹ show maximum and minimum amounts to be left on the diameter of rough turned work over 12 diameters long.

Curves B and B¹ show maximum and minimum amounts to be left on the diameter of rough turned work under 12 diameters long.

Curves C and C¹ show maximum and minimum amounts to be left on diameter of smooth turned and bar-lathe work over 12 diameters long.

Curves D and D¹ show maximum and minimum amounts to be left on diameters of smooth turned and bar-lathe work under 12 diameters long.

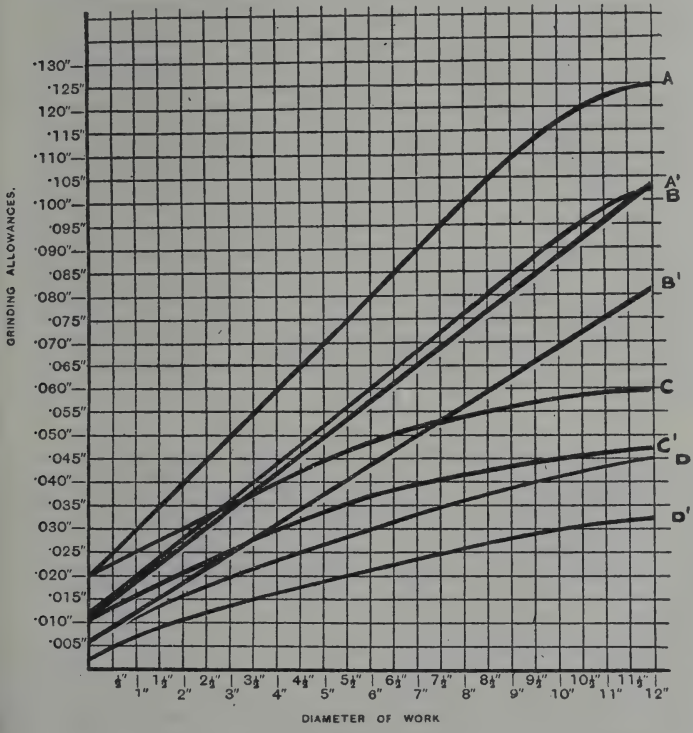

FIG. 8.—Grinding Allowances for Norton Cylindrical Grinding Machines.

NOTE.—By 'rough turned,' is meant work having coarse traverse marks, the measurements being taken on the top of the ridges. The following are the finest feeds which should be employed :—

For work up to 2 ins. diameter	30 per inch
For work from 2 ins. to 4 ins. diameter	20 ,,
For work from 4 ins. to 8 ins. diameter	16 ,,
For work from 8 ins. to 12 ins. diameter	8 ,,

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Case-hardened work is an exception, because the finish must be fairly smooth to allow regular penetration of the casing compound. Use curves C and C¹ for all such work.

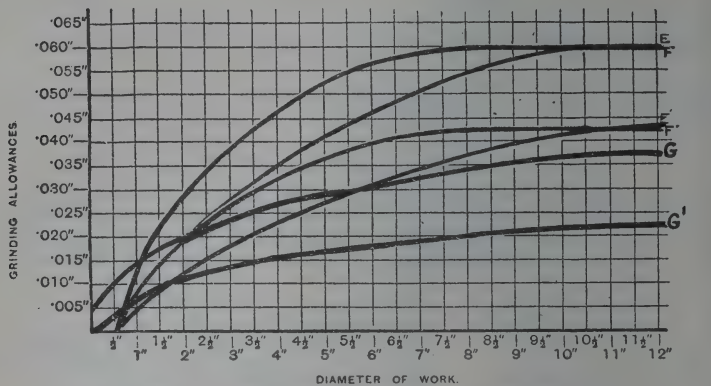

FIG. 9.—Grinding Allowances for Heald Internal Grinding Machines.

Curves E and E′ (fig. 9) show maximum and minimum amounts to be left in the bore of mild steel work that is to be case-hardened before grinding.

Curves F and F¹ show maximum and minimum amounts to be left in the bore of carbon or high-speed steel work that is to be hardened before grinding.

Curves G and G¹ show maximum and minimum amounts to be left in the bore of soft work, whether steel, cast iron, or brass.

NOTES.

The following explanatory notes will serve to show the theory followed out, and will assist in determining allowances for the exceptional jobs which will occasionally present themselves :—

Taking first *external work*, as being the more common, it will be noted that a larger allowance is made on articles which exceed twelve diameters length than in the case of shorter jobs. This is to save lathe work.

A job over twelve diameters long will spring considerably under a good cut, and there is a possibility of bends making their appearance. The largest possible allowance is therefore made on this work, so that the turner need not waste the time which would be taken in producing articles more nearly parallel and straight.

Then, again, a distinction is made between rough-turned work and that which is produced by a fine feed or made on turret lathes with a box tool.

For all work turned between centres, with the exception of that which is to be carbonised for case-hardening, the use of a coarse traverse is advocated, the finest feed per inch that should be used for various diameters being specified on the chart. Work which is to be carbonised must be turned with a fairly smooth finish, so as to allow regular penetration of the casing compound ; therefore the allowance specified for smooth work over twelve diameters long should be used for case-hardened work whatever its length. If such work is holiow it may distort after quenching, therefore great care must be exercised in hardening, as the allowance above specified cannot be exceeded or the hard skin would be entirely removed in grinding to size.

The allowance for carbon and high-speed steel work which is hardened will be the same as that provided for soft work, as any distortion which occurs must be corrected in the straightening press before grinding.

Internal work, which is dealt with by the lower portion of the chart, is divided into three classes as follows :—

1. Mild steel case-hardened.
2. Carbon or high-speed steel hardened.
3. Soft work, whether steel, cast iron, or bronze.

Hardened and case-hardened work in which the hole is less than half an inch in diameter should, as shown in the chart, be bored or reamed to standard size, as there will be a sufficient

shrinking when the quenching takes place to provide a grinding allowance. It will be noted that the amount allowed in case-hardened work increases very rapidly up to 6 ins. diameter; this is to allow for distortion in hardening. Above this size the increase is slow, and care should be taken to avoid excessive distortion, as no larger allowance can be made, otherwise the hard skin would be removed by the grinding operation. In determining the allowance for soft work it should be remembered that the class of finish given to the hole will decide whether the high or low limit should be worked to. Thus, in holes which are rough drilled or bored, the allowance should approach the maximum, whilst in reamed holes the minimum allowance should be left.

(*Alfred Herbert Ltd., Coventry.*)

Polishing.

For grinding and polishing *marble*, *stones*, and *glass*, crushed steel has proved very satisfactory, on account of its hardness, sharpness and toughness. It is, however, but little used in this country, sand, carbide, or aluminous abrasives being generally employed. For cutting stone, marble, and glass, a metal wheel with loose sand and water is largely employed, but grinding wheels of carbide and aluminous abrasives of medium grade and 36–50 grit are being increasingly employed. For producing a rough surface on glass, the sand-blast process is largely used.

For *smoothing wood* and similar materials, garnet-emery and sand, mounted on paper or cloth, are largely employed, garnet being especially suitable for hard woods. For finishing wooden handles, sand mounted in endless belts is largely used.

In the leather industries, and especially in the manufacture of boots and shoes, corundum and carborundum cloths are largely used for heel scouring and breasting and for buffing.

For work in which an *exceptionally hard abrasive* is required, including the truing of abrasive wheels, diamond bort or carbonado are employed.

For polishing steel articles, blocks of carbide or aluminous abrasive or cloth or paper covered with emery or corundum is largely employed.

For polishing other metals, glass, etc., loose powders are employed. Such powders may be used in the dry or wet state, and may be rubbed on to the material to be polished, or they may be applied by means of a wheel (or 'dolly') composed of discs of cloth.

For polishing brass and other softer metals, very fine silica, quartz flour, emery carbide or aluminous abrasives, crocus, rouge, or whiting are employed. For silver and gold well-slaked lime is largely used. The polishing powder is sometimes treated with rouge to disguise its nature and to give white metals a slightly ruddy tint, which improves their appearance.

In the so-called liquid polishes, a little oxalic acid or other chemical detergent is sometimes added to the abrasive powder, or to the liquid in which the latter is suspended.

Power required for Emery Polishing.

Using a calico mop, 12 ins. diameter by 2 ins. wide, it is usual to run these at a speed of 10,000 feet per minute. The average resistance at the circumference of a well-loaded wheel is about 10 lbs., and this would give a h.p. for the mop equal to 3. To this has to be added the friction of the spindle in its journals, and this will depend on the nature of the journal (whether plain or ball), and also the lubrication. The friction is principally due to the pull of the strap, and if its spindle is taken to be $1\frac{1}{2}$ in. diameter, and the value $\mu = \cdot 075$, the frictional h.p. would be about ·25, and if a further ·25 be allowed for acceleration, the h.p. to drive the machine would be $3\frac{1}{2}$. For a 10 in. diameter buff the h.p. would be proportionately less—that is, about 3.

Sand Blasting.

The air pressures used for different materials are, approximately, as follows:—Steel castings or forgings, 80 to 100 lbs.; malleable iron, 70 to 85 lbs.; cast iron, 60 to 70 lbs.; and brass and aluminium, 35 to 50 lbs.

For some classes of work a small nozzle opening, that is, a fine strong jet, may be desirable; for other work a broader stream, covering a larger surface but working at a lower pressure may be best. Table I. gives the relation between air flow in cubic feet of free air per minute at varying pressures, and the horse-power required to produce them by single-stage compression, for nozzles ranging in diameter from $\frac{1}{8}$ to $\frac{3}{8}$ in. inclusive.

Typical cylinder dimensions, together with the displacement and the horse-power required to develop various amounts of air pressure, are given in Table II.

In cases where there is moisture in the air, it is well to make provision for the elimination of the moisture by installing a moisture separator or a suitable heater.

Sand is the most commonly used abrasive on account of its relatively low price. Ordinary sand is inferior to sea sand and silica sand, as the two latter possess greater hardness and are therefore more lasting. Abrasives such as steel grit and shot are used to a certain extent, and the use of these more expensive abrasives is warranted under certain conditions. For classes of work such as electro-plating or galvanising, the metallic dust adhering to the work would make its use prohibitive, because it prevents perfect galvanising, although no difficulty is experienced in this respect with sand.

There is no one abrasive that is best adapted to all classes of work. A selection must be made with due regard to reclaiming means, to greatest economy in operation, and to maximum production. By making tests with various materials, and keeping accurate records of quality of work, output, life of the abrasive, and so on, the one best suited for the individual application is readily determined. Such tests have shown metal abrasives to have about sixty times the life of sand. This apparently large percentage may, however, be offset to a great extent by losses of abrasive in operation or in handling. In good steel foundry practice these losses may be kept as low as 10 per cent., while the average loss due to disintegration, for different grades of sand, amounts to about 20 per cent. per month. The reduction in cleaning time resulting from using metal abrasives instead of sand varies, of course, but a gain of about 15 to 20 per cent. in time appears to be in line with actual practical experience. Metal abrasives do not require large sand-storage bins and have the added advantage of producing less dust, thereby improving the general working conditions.

TABLE I.—FLOW OF FREE AIR FOR DIFFERENT SIZES OF NOZZLES.

	Pressure (cub. ft. per min.) and Corresponding Horse-power Required.							
Diameter of Nozzle. Ins.	20 lbs.	H.P.	30 lbs.	H.P.	40 lbs.	H.P.	50 lbs.	H.P.
$\frac{1}{8}$	7·70	0·63	10·00	1·03	12·30	1·50	14·50	1·99
$\frac{3}{16}$	17·10	1·40	22·50	2·32	27·50	3·26	32·80	4·49
$\frac{1}{4}$	30·80	2·53	40·00	4·12	49·10	5·99	58·20	7·97
$\frac{5}{16}$	48·17	3·95	62·89	6·48	76·60	9·36	90·70	12·43
$\frac{3}{8}$	69·00	5·66	90·00	9·27	110·00	13·42	130·00	17·81
Diameter of Nozzle. Ins.	60 lbs.	H.P.	70 lbs.	HP.	80 lbs.	H.P.	100 lbs.	H.P.
$\frac{1}{8}$	16·80	2·57	19·00	3·19	21·20	3·86	25·73	5·33
$\frac{3}{16}$	37·50	5·74	43·00	7·22	47·50	8·65	57·88	11·98
$\frac{1}{4}$	67·00	10·25	76·00	12·77	85·00	15·47	103·00	21·32
$\frac{5}{16}$	105·00	16·07	119·00	20·00	133·00	24·10	161·00	33·82
$\frac{3}{8}$	151·00	23·10	171·00	28·73	191·00	34·76	232·00	47·90

TABLE II.—CYLINDER DISPLACEMENTS AND HORSE-POWER REQUIREMENTS OF AIR COMPRESSORS.

Cylinder.		Revs. per min.	Piston Displacement. Cub. ft. per min.	Horse-power Requirements.					
				Pressure (cub. ft. per min).					
Diam. Ins.	Stroke. Ins.			50	60	70	80	90	100
6	6	300	57	7	7·5	8·5	9·0	9·5	10
8	8	260	118	14	15·5	16·8	18·0	19·0	20
10	10	235	210	24	27·0	29·0	31·0	33·0	35
12	12	220	340	45	50·0	54·0	58·0	62·0	65

All abrasives should be screened each time before using, to remove particles large enough to clog the nozzle, and also to eliminate fine particles which only produce dust and have no abrasive quality, but which consume some of the pressure. Screen separators, frequently operated by compressed air, may be used for this purpose. (*Abstract, C.M.S., 'Machinery,' Jan.* 13, 1921.

SECTION XXI

PART III

STEAM-HAMMERS.

(*Messrs. B. & S. Massey, Ltd., Openshaw.*)

Three standard types of steam-hammer are made by B. & S. Massey, Ltd.—the 'Overhanging Form with Slides,' the 'Arch Form with Slides,' and the 'Rigby type without Slides.' All these hammers can be made suitable for driving by compressed air instead of steam.

Overhanging Form with Slides.

These hammers (fig. 1) are usually preferred for general smith-work. The anvils are accessible to the workman from three sides, and the tups are supported and accurately guided by the slides making it possible to do accurate stamping in dies.

Each hammer has two separate standards, with a space between them, through which long bars can be passed. All the hammers are double-acting and are fitted with equilibrium working valves.

Up to and including the 12-cwt. size, the hammers are fitted with a combined self-acting and handworked valve gear; the 15-cwt. and larger sizes are ordinarily fitted with Massey's Handworked Expansion Valve Gear, but a combined self-acting and handworked gear can be fitted if desired.

The pistons, which are forged solid with the piston-rods, are fitted with steel piston-rings. The palletts are made of tough forged steel with planed and hardened faces.

The anvil blocks are about 8 times the weight of the falling mass, and in the 12 cwt. and smaller sizes they are turned to fit the bored baseplates; this greatly increases the efficiency of the hammers when it is desired to use them for stamping in dies.

Fig. 1.

DIMENSIONS, WEIGHTS, AND MEMORANDA OF OVERHANGING FORM STEAM-HAMMERS WITH SLIDES.

Standard sizes	½ cwt.	1 cwt.	1½ cwt.	2 cwt.	3 cwt.
Intermediate size					
Diameter of cylinder	4½″	5½″	6″	6″	7½″
Longest stroke	11″	12″	13″	13″	17″
Clear space between slides	5½″	6½″	6″	6″	8¼″
Overhang to pallett centres	7¾″	9″	10″	10″	11″
Total height from floor	5′ 5″	5′ 8″	6′ 9″	6′ 10″	8′ 1″
Steam and exhaust pipes	1″ & 1¼″	1″ & 1¼″	1¼″ & 1½″	1¼″ & 1½″	2″ & 2½″
Approximate weight	1 ton	1½ tons	2 tons	2½ tons	3 tons
Without anvil block	¾ ton	⅞ ton	1½ tons	1½ tons	2 tons
Without anvil block and baseplate					1½ tons
*Diameter of bar worked efficiently	1½″	2″	2½″	3″	4″
†Approximate steam consumption (lbs. per hour)—					
(*a*) On hard blows	115 lbs.	215 lbs.	315 lbs.	410 lbs.	420 lbs.
(*b*) Average on mixed blows	19 lbs.	35 lbs.	50 lbs.	64 lbs.	73 lbs.

Standard sizes	4 cwt.	5 cwt.	6 cwt.	7 cwt.	8 cwt.
Intermediate sizes					
Diameter of cylinder	8″	9″	9″	10″	10″
Longest stroke	19″	21″	21″	24″	24″
Clear space between slides	10½″	10½″	10½″	11½″	11½″
Overhang to pallett centres	11″	13″	13″	14″	14″
Total height from floor	8′ 9′	9′ 0″	9′ 0″	9′ 7″	9′ 7″
Steam and exhaust pipes	2″ & 2½″	2½″ & 3″	2½″ & 3″	2½″ & 3″	2½″ & 3″
Approximate weight	3⅝ tons	5 tons	5½ tons	6½ tons	7 tons
Without anvil block	2¼ tons	3 tons	3 tons	3⅜ tons	3⅜ tons
Without anvil block and baseplate	1½ tons	2¼ tons	2¼ tons	2⅜ tons	2⅜ tons
*Diameter of bar worked efficiently	4¾″	6″	6½″	7″	7¼″
†Approximate steam consumption (lbs. per hour)—					
(*a*) On hard blows	520 lbs.	620 lbs.	710 lbs.	800 lbs.	880 lbs.
(*b*) Average on mixed blows	89 lbs.	105 lbs.	119 lbs.	134 lbs.	147 lbs.

Standard sizes	10 cwt.	12 cwt.	15 cwt.	20 cwt.	25 cwt.
Intermediate size					
Diameter of cylinder	12″	12″	13⅜″	14½″	15⅜″
Longest stroke	27″	27″	30″	33″	36″
Clear space between slides	13″	13″	14½″	16″	17″
Overhang to pallett centres	16″	16″	18″	20″	22″
Total height from floor	12′ 0″	12′ 0″	12′ 2″	13′ 0″	13′ 8″
Steam and exhaust pipes	3″ & 3½″	3″ & 3½″	3″ & 3½″	3½″ & 4½″	3½″ & 4½″
Approximate weight	9½ tons	10½ tons	13½ tons	18½ tons	22¾ tons
Without anvil block	5½ tons	5½ tons	7½ tons	10½ tons	13 tons
Without anvil block and baseplate	4 tons	4½ tons	5½ tons	7½ tons	9½ tons
*Diameter of bar worked efficiently	8″	8¼″	10″	12″	13½″
†Approximate steam consumption (lbs. per hour)—					
(*a*) On hard blows	1040 lbs.	1190 lbs.	1420 lbs.	1750 lbs.	2100 lbs.
(*b*) Average on mixed blows	170 lbs.	195 lbs.	228 lbs.	275 lbs.	330 lbs.

* All these figures are necessarily rough approximations.

They are meant to apply to average engineers' smithwork, and are for efficient results on this class of work, with a steam pressure of about 60 lbs. per sq. in.

Even for this they may for occasional jobs be considerably exceeded.

There are many classes of work which require much larger hammers, and some classes which require smaller hammers than those indicated, owing chiefly to the varying amount which has to be done at a heat.

† Steam Consumption.

A steam pressure of about 60 lbs. per sq. in. is assumed.

During ordinary forging there are many blows of less than full force, and there are also necessary pauses (holding up) for adjusting work or tools during a heat.

While line (*a*), page 1194, gives the consumption on continuous hard blows only, line (*b*) gives the consumption as ordinarily reduced by these circumstances. Further, under average smithy conditions, a hammer may be assumed to be actually in motion about 15 minutes in every hour, and the figures given in line (*b*) are based on this assumption.

In cases in which one boiler is put down solely to drive one hammer, the capacity of such boiler should be fixed according to line (*a*), page 1194, because otherwise the pressure would fall too low during a normal run of hard blows.

Arch Form with Slides.

These hammers, fig. 2, are made in sizes ranging from 3 cwt. to 10 tons and over, and the design provides a maximum of strength and rigidity. The 15 cwt. and larger sizes are fitted with Massey's Handworked Expansion Valve Gear.

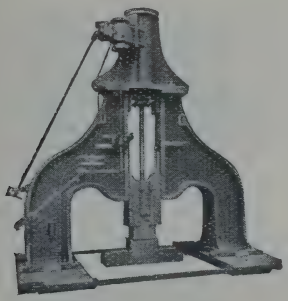

Fig. 2.—Arch Form.

Rigby Type without Slides.

These hammers, fig. 3, which are made in sizes from 3 cwt. to 3 tons, are particularly suitable where forgings of large size and awkward shape have to be dealt with. The strokes are longer

Fig. 3.—Rigby Type.

and the cylinders larger in diameter than in the other forms described. All sizes are fitted with Massey's Handworked Expansion Valve Gear.

Energy and Velocity of Blow.

If

a = area of piston, in square inches : p = average pressure of steam on piston during downward stroke, in pounds per square inch : S = stroke of piston, in feet : W = falling weight in pounds : E = energy of blow after full stroke and before striking, in foot-pounds, friction being neglected ;

$$E = (ap + W)S.$$

If

P = total pressure on piston = pa : F = total force causing downward acceleration = $P + W = pa + W$: g = acceleration due to gravity = 32·2 : V = velocity after full stroke and before striking, in feet per second, friction again being neglected ;

$$V^2 = \frac{2Fg S}{W}.$$

No commercial use is made of these calculations, either for the naming of sizes of hammers or for any other purpose.

The question is sometimes asked : *What weight of blow does the hammer strike ?*

The force of a blow cannot be stated in terms of weight at all, because the pressure of a weight is continuous, whereas the force of a blow is expended in a moment. It has, however, been ascertained, by careful experiments, that the maximum blow of a 5-cwt. double-acting steam-hammer, with moderate steam pressure, produces a crushing effect upon a piece of hot iron as great as that produced by a load of about 30 tons, and a ¼-cwt. double-acting steam-hammer a crushing effect equal to that produced by a load of about 2½ tons.

Naming Sizes of Steam-Hammers.

In naming the sizes of steam-hammers, no account is taken of the pressure of steam upon the piston. Thus, a 5-cwt. hammer is one in which the falling mass weighs at least 5 cwt., but of course the force of the blow is greatly increased by the pressure of steam above the piston accelerating the fall.

Steam Pipes for Steam Hammers.

See 'Steam Pipe Bends,' Section XXX, Part II.

Foundations.

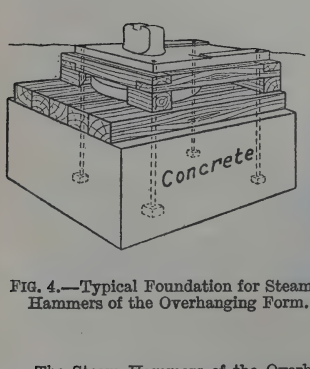

Fig. 4.—Typical Foundation for Steam-Hammers of the Overhanging Form.

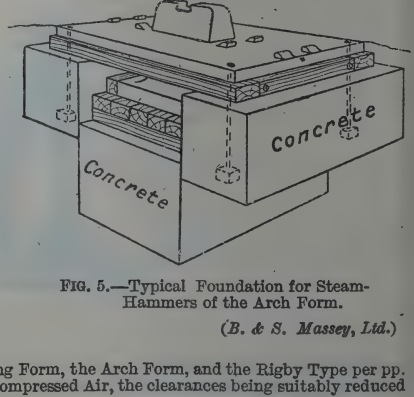

Fig. 5.—Typical Foundation for Steam-Hammers of the Arch Form.

(*B. & S. Massey, Ltd.*)

The Steam Hammers of the Overhanging Form, the Arch Form, and the Rigby Type per pp. 1193-1195 can all be driven equally well by Compressed Air, the clearances being suitably reduced

PNEUMATIC POWER HAMMERS.

Massey Patent Pneumatic Power Hammers, Overhanging Form with Slides.

These hammers (fig. 6) are arranged for belt or for direct electric drive. They are similar to steam-hammers in many respects, and are about equal to them in working capacity, assuming the steam-hammers to be working under ordinary conditions of pressure, etc.

It is very important to note that the size name of each hammer indicates the true weight of its falling parts.

The anvil block is set diagonally, to enable long bars to be worked in either direction.

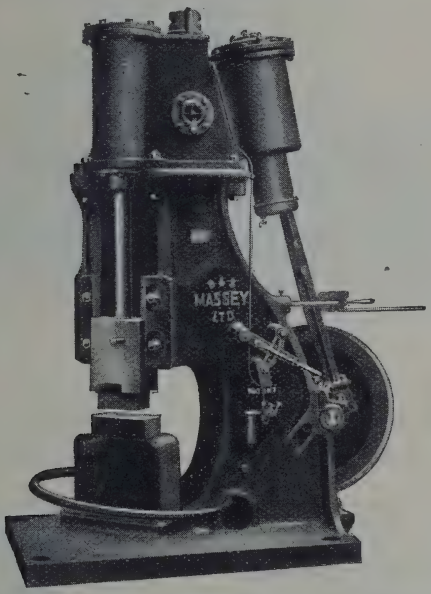

Fig. 6.

The essential feature of the hammers lies in the connecting together of two cylinders—the hammer cylinder and the pump cylinder—by air passages which are governed by a valve under the control of the operator. See fig. 7, p. 1198.

When the piston reciprocates with the valve in the 'not working' position (as shown) air flows freely through the valve from one side of the piston to the other. The tup therefore remains stationary on the anvil.

As the valve is moved upwards the by-pass through the valve is gradually closed, so that when position 4 is reached, all the air is forced from the top of the pump to the top of the hammer, and from the bottom of the pump to the bottom of the hammer, thus producing full-force automatic blows. The positions intermediate between 3 and 4 provide a wide variation in the character of blow and the length of stroke.

With the valve in position 1, the reservoir is charged from the top and bottom of the pump and is, at the same time, in communication with the bottom of the hammer. This gives a perfectly smooth rise and a steady 'Hold-up.'

When the valve is moved to position 2, the bottom of the hammer is opened to atmosphere, and compressed air from the reservoir passes into the top, thus throwing down the tup and striking a single blow.

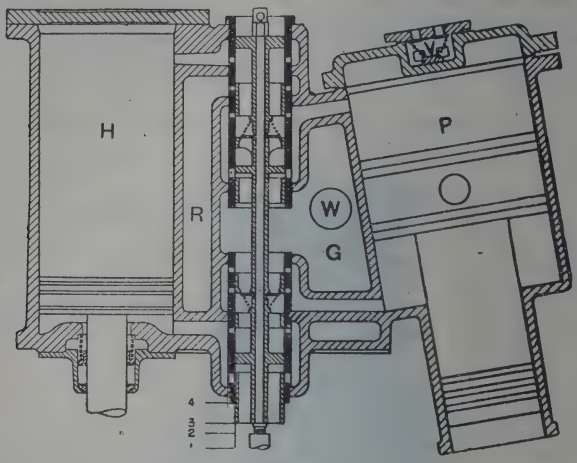

FIG. 7.

While the valve is kept in this position, the tup is held down with full pressure above the piston.

Inlet valves V and W supply air to the top and bottom of the system.

DIMENSIONS, WEIGHTS, AND MEMORANDA OF PNEUMATIC POWER-HAMMERS.

OVERHANGING FORM WITH SLIDES.

Standard sizes	½ cwt.	1 cwt.	2 cwt.	3 cwt.	5 cwt.	7 cwt.	10 cwt.	15 cwt.	20 cwt.
Longest stroke (inches)	11	12	14	17	21	24	27	30	33
Driving pulley diam. and width of belt (inches)	21×2½	24×3	30×3	33×4	39×5	45×7	48×10	27×6	30×9
Blows per min.	280	240	200	160	140	120	110	100	85
Size of bar worked efficiently (inches square)	1½	2	3	4	6	7	8	10	12
Maximum power (full blow) B.H.P.	4	7	10	16	21	25	35	48	60
Mean consumption in B.T.U. (kwt. hours). approximate	·6	·9	1·5	1·9	2·7	3·3	4·2	5·5	6·6
Size of motor (continuous rating)	3	5	7½	12	15	20	27	35	40
Approximate weight of hammer (tons)	1¼	1¾	3	4½	6¼	9¼	12¼	18¾	23
Ditto, without anvil block (tons)	—	—	2¼	3	4¼	6¾	8¼	13	15¼

(B. & S. Massey, Ltd.

Massey Patent Pneumatic Power Hammers.

Arch Form with Slides.

These hammers, fig. 8, are made in the 30 cwt. and 40 cwt. sizes, and are arranged for 'direct electric drive.' The action and control of the hammers is identical with that of the overhanging

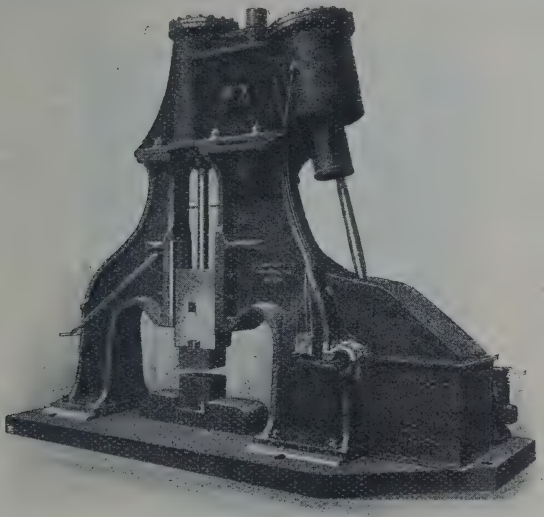

Fig. 8.

form with slides (pp. 1197-98), *i.e.* 'Single Blows' may be struck from any point in the stroke, each requiring a separate movement of the hand lever, or a series of automatic blows may be obtained of any desired force and with long or short strokes.

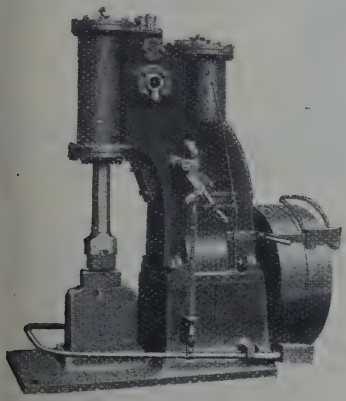

Fig. 9.

'Clear Space Type without Slides.'

These hammers also are identical in action and control with the hammers of the overhanging form with slides (pp. 1197–98). As will be seen from fig. 9 ample clear space is provided for the manipulation of large and awkward forgings, by dispensing with Slides and adopting a special Stuffing Box to guide the rod.

The hammers can be belt or motor driven, and provided with a foot lever in addition to the hand lever, if desired.

DROP STAMPS.

The Massey Friction Drop Stamp

The practice of Stamping, in Dies, parts which have to be made in large numbers, such as motor-car parts, railway wagon parts, etc., etc., has become very general, and the tool usually adopted

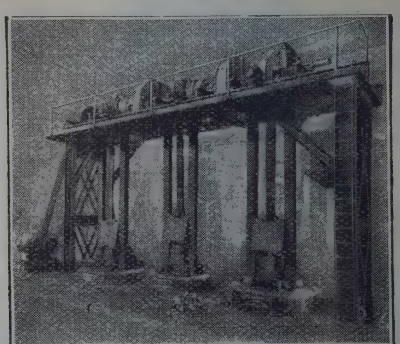

Fig. 10.—Battery of 30-15-20 cwt. Friction Drop Stamps.

for this purpose in this country is the 'drop stamp.' Latterly, the friction lifted type of drop stamp (fig. 10) has tended to supersede the steam lifted type, on account of the improved control, the greater efficiency and the smaller cost of up-keep.

General Construction.

The usual plan is to have two, three, or four drop stamps of different falling weights arranged in a battery. The lifting mechanism in this case is mounted on girder work supported on stanchions, while the falling weight or tup is guided by vertical rolled steel guides resting in recesses in the anvil block, and supported at their upper ends by the girder work in such a way as not to transmit shock to the lifting mechanism.

Details of Friction Lifters.

The lifters themselves resemble a band brake in construction. A steel brake band lined with suitable material, and connected with the lifting arm, is made to grip a constantly revolving drum by means of a lever actuated by hand through a pulling cord, and the tup is thereby raised. As soon as the tension on the cord is released, a spring disengages the band, and the tup falls under the influence of gravity.

A special arrangement is adopted by means of which the grip of the friction band is automatically reduced as the tup rises, thereby making it necessary to maintain a constant pull on the cord in order to prolong the rise of the tup; when, moreover, the cord is held stationary, the tup remains suspended at the point to which it may have been raised, and as stated above, the tup falls when the tension on the cord is released.

It will therefore be seen that a very intimate relation exists between the movements of the tup and those of the pulling cord.

The movement of the hand is only a short one, and the pull required is very slight, but every movement of the hand is reproduced on a larger scale by the tup. Those who are familiar with the old-fashioned kick stamps in which a heavy pull was required the whole length of the

stroke, and which sometimes required two or three men to act as pullers, appreciate very highly the action of friction stamps in which a control as excellent as in the kick stamp is secured with so little labour on the part of the operator.

Method of Driving

The friction lifters are generally mounted on shafts driven by spur gearing from a quick-running back shaft. A flywheel which also serves as a driving pulley is mounted on one end of the back shaft and supplies the reserve of power needed at the moment of picking up the tup.

The drive is usually taken direct from an electric motor placed either on one of the stanchions or in the larger sizes on the floor, or in some other convenient position.

THE MASSEY PATENT AUTOMATIC FRICTION DROP STAMPS.

Although it is usual to arrange the friction drop stamps referred to above in batteries, they can, if desired, be made of the self-contained form, and certain sizes of this type can be fitted with the 'Massey' Patent Automatic Lifting Gear.

This gear (fig. 11) combines the principles of the ordinary friction drop stamps with an automatic action obtained by means of a clutch arrangement controlled by cams, the friction band gripping and releasing the drum alternately at the bottom and top of the stroke.

By means of two hand levers the action of the controlling cams can be advanced or retarded, the length of the stroke and the character of the blow being thus altered at will to suit the nature of the work.

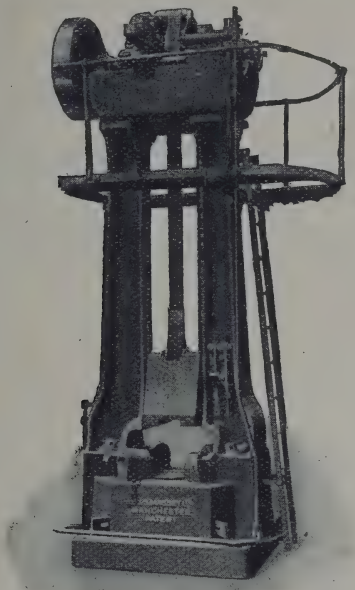

FIG. 11.

By moving these hand levers to their lowest possible positions, the automatic gear can be put out of action entirely, and the stamp worked by hand in the ordinary way.

The tup can be held suspended at any point by means of a friction hold-up gear actuated by a foot lever, and as this gear is independent of the rotating shaft, no power is consumed in holding up.

When the automatic gear is in use, the hold-up gear comes into action as soon as the foot lever is released, and the tup at once rises to the top of its stroke wherever this may have been set, and is held suspended there.

(*B. & S. Massey, Ltd.*)

SECTION XXII

SCREW THREADS AND SCREWS — BOLTS AND NUTS — LOCK NUTS—SPANNERS—PIPE FLANGES—KEYS—SCREW TAPS—COUPLINGS—PULLEY ARMS AND BOSSES

(Revised by Professor Dempster Smith, M.B.E., M.Sc.Tech., M.I.Mech.E.)

SECTION XXII

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SCREW THREADS AND SCREWS.

Forms of Screw Threads.

Figs. 1, 2, 3, and 4 show four usual forms of thread, each of 1 inch pitch.

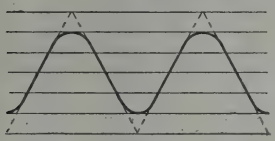

FIG. 1. Whitworth Thread-form.

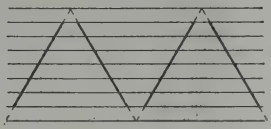

FIG. 2. American Thread-form.

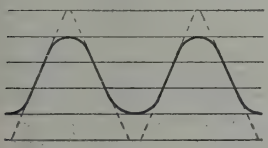

FIG. 3. Swiss Thread-form.

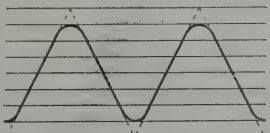

FIG. 4. Steinlen Thread-form

In the *Whitworth* or *English Standard* thread (fig. 1) the angle made by the two sides of the thread is 55° for all sizes of thread. One-sixth of the depth of the triangle is rounded off the top and bottom, so that the angle of 55° gives for the actual depth rather more than three-fifths and less than two-thirds of the pitch.

In the *American* (*Sellers'*) thread (fig. 2) the angle made by the two sides of the triangle is 60°, and one-eighth of the depth is cut off the top and bottom of the triangle, leaving a flat one-eighth of the pitch in width.

In the *Swiss* or *Thury* thread (fig. 3) the angle made by the two sides of the thread is 47½° and one-fifth of the depth is rounded off the top and bottom of the triangle.

For screw-plate Swiss threads the depth of the thread is three-fifths the length of the pitch.

The top of the ridge is formed by a circular arc (*a*), the radius of which equals one-sixth of the pitch. The space between two consecutive ridges is formed at the side next the core by a circular arc (*b*), the radius of which equals one-fifth of the pitch.

The Swiss thread for screws made in the lathe is the *Steinlen* thread (fig. 4). The angle made by the two sides of the thread is 58° 8′, and the radius of the connecting arcs is ·1011 of the pitch. The generating figure is an isosceles triangle, of which the base and the height are equal to the pitch. One-eighth of the depth is rounded off the top and bottom of the triangle.

The *British Association* thread is similar to that of Thury, except that the top and bottom of the threads are both rounded to the same radius, namely, two-elevenths of the pitch.

Screw Threads.

Whitworth's Standard Threads.

Dimensions in Inches.				Threads per Inch.	Pitch in Millimètres.	Dimensions in Inches.				Threads per Inch.	Pitch in Millimètres.
Outside Diameter.	Diameter at Bottom of Thread.	Size for Tapping.	Pitch.			Outside Diameter.	Diameter at Bottom of Thread.	Size for Tapping.	Pitch.		
$\frac{1}{32}$	·0293	—	·0066	150	·169	$2\frac{3}{8}$	2·054	$2\frac{1}{10}$	·25	4	6·35
$\frac{1}{16}$	·0413	$\frac{3}{64}$	·0166	60	·4233	$2\frac{1}{2}$	2·18	$2\frac{3}{16}$	·25	4	6·35
$\frac{3}{32}$	·0671	$\frac{5}{64}$	·0208	48	·529	$2\frac{5}{8}$	2·304	$2\frac{5}{16}$	·25	4	6·35
$\frac{1}{8}$	·093	$\frac{9}{32}$	·025	40	·635	$2\frac{3}{4}$	2·384	$2\frac{3}{8}$	·2857	$3\frac{1}{2}$	7·257
$\frac{5}{32}$	·112	$\frac{1}{8}$	·0312	32	·793	$2\frac{7}{8}$	2·509	$2\frac{7}{16}$	·2857	$3\frac{1}{2}$	7·257
$\frac{3}{16}$	·134	$\frac{9}{64}$	·0416	24	1·06	3	2·634	$2\frac{1}{2}$	·2857	$3\frac{1}{2}$	7·257
$\frac{7}{32}$	·165	$\frac{11}{64}$	·0416	24	1·06	$3\frac{1}{8}$	2·759	$2\frac{9}{16}$	·2857	$3\frac{1}{2}$	7·257
$\frac{1}{4}$	·186	$\frac{5}{16}$	·05	20	1·27	$3\frac{1}{4}$	2·856	$2\frac{5}{8}$	·3077	$3\frac{1}{4}$	7·815
$\frac{5}{16}$	·241	$\frac{1}{4}$	·0555	18	1·41	$3\frac{3}{8}$	2·98	$2\frac{11}{16}$	·3077	$3\frac{1}{4}$	7·815
$\frac{3}{8}$	·295	$\frac{19}{64}$	·0625	16	1·587	$3\frac{1}{2}$	3·105	$2\frac{3}{4}$	·3077	$3\frac{1}{4}$	7·815
$\frac{7}{16}$	·346	$\frac{23}{64}$	·0714	14	1·814	$3\frac{5}{8}$	3·23	$2\frac{13}{16}$	·3077	$3\frac{1}{4}$	7·815
$\frac{1}{2}$	·393	$\frac{13}{32}$	·0833	12	2·116	$3\frac{3}{4}$	3·32	$3\frac{1}{16}$	·3333	3	8·466
$\frac{9}{16}$	·455	$\frac{15}{32}$	·0833	12	2·116	$3\frac{7}{8}$	3·448	$3\frac{1}{16}$	·3333	3	8·466
$\frac{5}{8}$	·508	$\frac{33}{64}$	·0909	11	2·39	4	3·573	$3\frac{3}{16}$	·3333	3	8·466
$\frac{11}{16}$	·571	$\frac{37}{64}$	·0909	11	2·39	$4\frac{1}{8}$	3·698	$3\frac{5}{16}$	·3333	3	8·466
$\frac{3}{4}$	·622	$\frac{5}{8}$	·1	10	2·54	$4\frac{1}{4}$	3·804	$3\frac{11}{16}$	·3478	$2\frac{7}{8}$	8·834
$\frac{13}{16}$	·684	$\frac{11}{16}$	·1	10	2·54	$4\frac{3}{8}$	3·93	$3\frac{13}{16}$	·3478	$2\frac{7}{8}$	8·834
$\frac{7}{8}$	·732	$\frac{47}{64}$	·111	9	2·822	$4\frac{1}{2}$	4·054	$4\frac{1}{16}$	·3478	$2\frac{7}{8}$	8·834
$\frac{15}{16}$	·795	$\frac{51}{64}$	·111	9	2·822	$4\frac{5}{8}$	4·18	$4\frac{3}{16}$	·3478	$2\frac{7}{8}$	8·834
1	·840	$\frac{27}{32}$	·125	8	3·175	$4\frac{3}{4}$	4·284	$4\frac{1}{16}$	·3636	$2\frac{3}{4}$	9·236
$1\frac{1}{8}$	·942	$\frac{61}{64}$	·1428	7	3·628	$4\frac{7}{8}$	4·409	$4\frac{7}{16}$	·3636	$2\frac{3}{4}$	9·236
$1\frac{1}{4}$	1·067	$1\frac{1}{16}$	·1428	7	3·628	5	4·534	$4\frac{7}{16}$	·3636	$2\frac{3}{4}$	9·236
$1\frac{3}{8}$	1·161	$1\frac{1}{64}$	·1666	6	4·233	$5\frac{1}{8}$	4·66	$4\frac{11}{16}$	·3636	$2\frac{3}{4}$	9·236
$1\frac{1}{2}$	1·286	$1\frac{19}{64}$	·1666	6	4·233	$5\frac{1}{4}$	4·762	$4\frac{15}{16}$	·3809	$2\frac{5}{8}$	9·676
$1\frac{5}{8}$	1·368	$1\frac{3}{8}$	·2	5	5·08	$5\frac{3}{8}$	4·887	$4\frac{5}{16}$	·3809	$2\frac{5}{8}$	9·676
$1\frac{3}{4}$	1·494	$1\frac{7}{32}$	·2	5	5·08	$5\frac{1}{2}$	5·012	$5\frac{1}{16}$	·3809	$2\frac{5}{8}$	9·676
$1\frac{7}{8}$	1·59	$1\frac{19}{32}$	·2222	$4\frac{1}{2}$	5·644	$5\frac{5}{8}$	5·137	$5\frac{9}{16}$	·3809	$2\frac{5}{8}$	9·676
2	1·715	$1\frac{23}{32}$	·2222	$4\frac{1}{2}$	5·644	$5\frac{3}{4}$	5·24	$5\frac{1}{4}$	·4	$2\frac{1}{2}$	10·16
$2\frac{1}{8}$	1·84	$1\frac{27}{32}$	·2222	$4\frac{1}{2}$	5·644	$5\frac{7}{8}$	5·362	$5\frac{5}{8}$	·4	$2\frac{1}{2}$	10·16
$2\frac{1}{4}$	1·93	$1\frac{15}{16}$	·25	4	6·35	6	5·487	$5\frac{1}{2}$	·4	$2\frac{1}{2}$	10·16

British Standard Whitworth Screw Threads.* (No. 92—1919.) (*Abstract.*)

1	2	3	4	5	6	7	8	9	10	11
Nominal Dia. of Screw.	No. of Threads per in.	Pitch.	Depth of Thread.	Full Diameter.		Effective Diameter.		Core Diameter.		Cross Sectional Area at Bottom of Thread of Bolt.
				Bolt.	Nut.	Bolt.	Nut.	Bolt.	Nut.	
In.		In.	In.	In.	In.	In.	In.	In.	In.	Sq. In.
$\frac{1}{4}$	20	·05000	·03200	·2500	·2520	·2180	·2200	·1860	·1880	·0272
$\frac{5}{16}$	18	·05556	·03555	·3125	·3145	·2769	·2789	·2414	·2434	·0458
$\frac{3}{8}$	16	·06250	·04000	·3750	·3770	·3350	·3370	·2950	·2970	·0683
$\frac{7}{16}$	14	·07143	·04575	·4375	·4395	·3918	·3938	·3460	·3480	·0940
$\frac{1}{2}$	12	·08333	·05335	·5000	·5020	·4466	·4486	·3933	·3953	·1215
$\frac{9}{16}$	12	·08333	·05335	·5625	·5645	·5091	·5111	·4558	·4578	·1632
$\frac{5}{8}$	11	·09091	·05820	·6250	·6270	·5668	·5688	·5086	·5106	·2032
$\frac{3}{4}$	10	·10000	·06405	·7500	·7520	·6860	·6880	·6219	·6239	·3038
$\frac{7}{8}$	9	·11111	·07115	·8750	·8770	·8039	·8059	·7327	·7347	·4216
1	8	·12500	·08005	1·0000	1·0020	·9200	·9220	·8399	·8419	·5540
$1\frac{1}{8}$	7	·14286	·09150	1·1250	1·1270	1·0335	1·0355	·9420	·9440	·6969
$1\frac{1}{4}$	7	·14286	·09150	1·2500	1·2520	1·1585	1·1605	1·0670	1·0690	·8942
$1\frac{1}{2}$	6	·16667	·10670	1·5000	1·5020	1·3932	·3953	1·2866	1·2886	1·3001

* By permission of the British Engineering Standards Association.

BRITISH STANDARD WHITWORTH SCREW THREADS—*continued*.

1	2	3	4	5	6	7	8	9	10	11
Nominal Dia. of Screw.	No. of Threads per in.	Pitch.	Depth of Thread.	Full Diameter.		Effective Diameter.		Core Diameter.		Cross Sectional Area at Bottom of Thread of Bolt.
				Bolt.	Nut.	Bolt.	Nut.	Bolt.	Nut.	
In.		In.	In.	In.	In.	In.	In.	In	In.	Sq. In.
1⅜	5	·20000	·12805	1·7500	1·7520	1·6219	1·6239	1·4939	1·4959	1·7528
2	4·5	·22222	·14230	2·0000	2·0020	1·8577	1·8597	1·7154	1·7174	2·3111
2¼	4	·25000	·16010	2·2500	2·2520	2·0899	2·0919	1·9298	1·9318	2·9249
2½	4	·25000	·16010	2·5000	2·5020	2·3399	2·3419	2·1798	2·1818	3·7318
2¾	3·5	·28571	·18295	2·7500	2·7520	2·5670	2·5690	2·3841	2·3861	4·4641
3	3·5	·28571	·18295	3·0000	3·0020	2·8170	2·8190	2·6341	2·6361	5·4496
3¼	3·25	·30769	·19700	3·2500	3·2520	3·0530	3·0550	2·8560	2·8580	6·4063
3½	3·25	·30769	·19700	3·5000	3·5020	3·3030	3·3050	3·1060	3·1080	7·5769
3¾	3	·33333	·21345	3·7500	3·7520	3·5366	3·5386	3·3231	3·3251	8·6732
4	3	·33333	·21345	4·0000	4·0020	3·7866	3·7886	3·5731	3·5751	10·0272
4¼	2·875	·34783	·22270	4·5000	4·5020	4·2773	4·2793	4·0546	4·0566	12·9118
5	2·75	·36364	·23285	5·0000	5·0020	4·7672	4·7692	4·5343	4·5363	16·1477
5½	2·625	·38095	·24395	5·5000	5·5020	5·2561	5·2581	5·0121	5·0141	19·7301
6	2·5	·40000	·25615	6·0000	6·0020	5·7439	5·7459	5·4877	5·4897	23·6521

BRITISH STANDARD FINE (B.S.F.) SCREW THREADS AND THEIR TOLERANCES.*
(No. 84—1918.) (*Abstract.*)

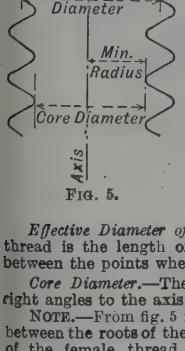

FIG. 5.

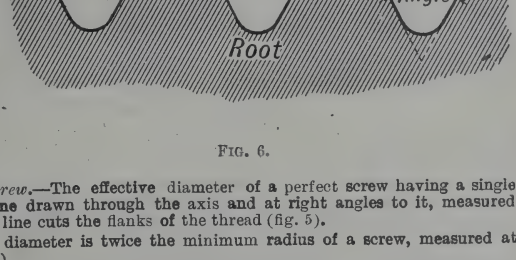

FIG. 6.

Effective Diameter of a Screw.—The effective diameter of a perfect screw having a single thread is the length of a line drawn through the axis and at right angles to it, measured between the points where the line cuts the flanks of the thread (fig. 5).

Core Diameter.—The core diameter is twice the minimum radius of a screw, measured at right angles to the axis (fig. 5).

NOTE.—From fig. 5 it will be seen that the 'core diameter' of the male thread is measured between the roots of the thread; it should be borne in mind, however, that the 'core diameter' of the female thread, being approximately the same dimension, is measured between the crests of the thread.

Full Diameter.—The full diameter is twice the maximum radius of a screw, measured at right angles to the axis (fig. 5).

Crest.—The crest is the prominent part of the thread, whether of the male screw or of the female screw (fig. 6).

Root.—The root is the bottom of the groove of the thread, whether of the male screw or of the female screw (fig. 6).

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Flank of Thread.—The flank of the thread is the straight part of the thread which connects the crests and roots (fig. 6).

Angle of Thread.—The angle of the thread is the angle between the slopes, measured in the axial plane (fig. 6).

Pitch.—The pitch is the distance in inches or millimetres measured along a line parallel to the axis of the screw between the point where it cuts any thread of the screw and the point at which it next meets the corresponding part of the same thread (fig. 6). *The reciprocal of the pitch* measures the number of turns per inch or millimetre, as the case may be.

RECOMMENDATIONS.

Form of Thread.

1. The Association recommend that the Whitworth form of thread, as defined in clause 2, be adopted on all screws of $\frac{7}{32}$ in. diameter and above, having British Standard Fine Pitches.

Definition of Whitworth Form of Thread.

2. The following defines the Whitworth thread :—

The *Whitworth Form of Thread* is one in which the angle between the flanks, measured in the axial plane, is 55° ; one-sixth of the sharp triangle is truncated at top and bottom, the threads being rounded equally at crests and roots to a radius which is therefore 0·137329 times the pitch ; the depth of the thread is 0·640327 times the pitch.

TOLERANCES.

—	Full Diameter.	Effective Diameter.	Core Diameter.
Bolt	$3\times\cdot01\sqrt{p}$	$2\times\cdot01\sqrt{p}$	$4\times\cdot01\sqrt{p}$
Nut	$4\times\cdot01\sqrt{p}$	$2\times\cdot01\sqrt{p}$	$3\times\cdot01\sqrt{p}$

The corresponding tolerances on grade and play are :—

$$\text{Grade}=4\times\cdot01\sqrt{p}\ ;\quad \text{Play}=2\times\cdot01\sqrt{p}.$$

In addition, a uniform allowance of 2 thousandths of an inch has been made throughout between the maximum bolt and the minimum nut.

For much work the above tolerances are too large. A second series of tables have therefore been formed by halving the tolerances everywhere. The Association recommend that threads made in accordance with these dimensions be known as ' British Standard Fine Threads (Close Fits).'

The basis of calculation of these tolerances is given below.

—	Full Diameter.	Effective Diameter.	Core Diameter.
Bolt	$1\cdot5\times\cdot01\sqrt{p}$	$\cdot01\sqrt{p}$	$2\times\cdot01\sqrt{p}$
Nut	$2\times\cdot01\sqrt{p}$	$\cdot01\sqrt{p}$	$1\cdot5\times\cdot01\sqrt{p}$

The corresponding tolerances and allowance are :—

$$\text{Grade tolerance}=2\times\cdot01\sqrt{p}\ ;\quad \text{play tolerance}=\cdot01\sqrt{p}\ ;\quad \text{allowance}=0\cdot002\text{ in.}$$

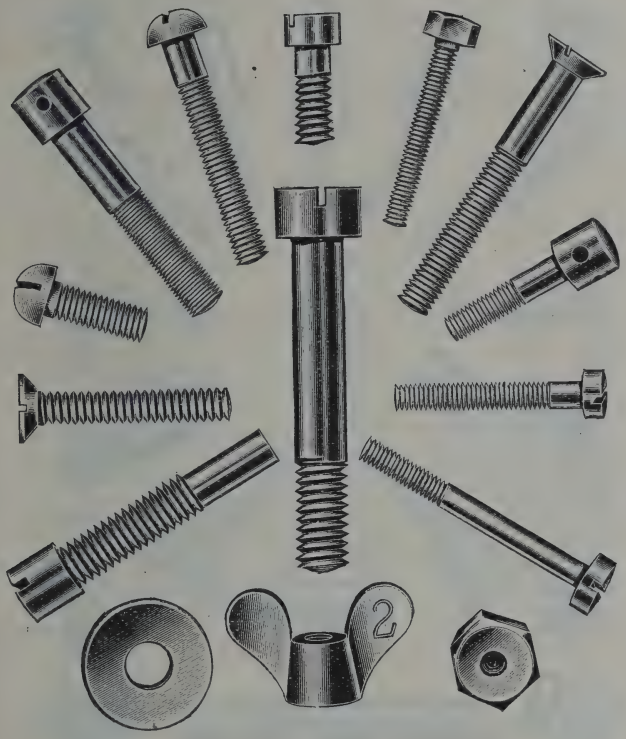
The pitches given in the following table are based on the following formulæ :—

For sizes up to and including screw threads of 1 inch diameter, $P=\frac{\sqrt[3]{d^2}}{10}$.

For sizes above 1 inch diameter, up to and including screw threads of 6 ins. diameter, $P=\frac{\sqrt[3]{d^2}}{10}$

$$\text{Pitch}=\frac{1}{\text{No. of threads per inch}}\ ;\ \text{depth of thread}=0\cdot640327\times\text{pitch}\ ;$$

$$\text{Rounding at crest and root}=0\cdot137329\times\text{pitch}.$$



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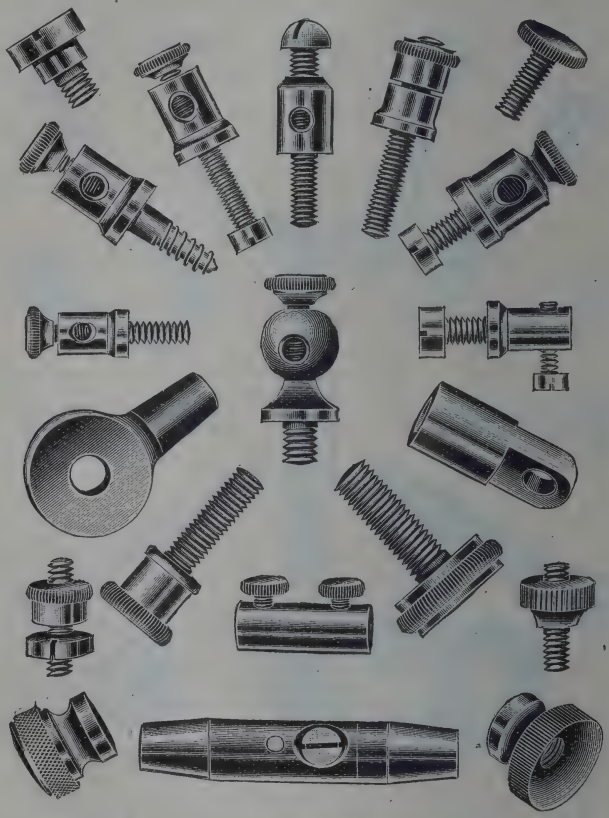

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THEORETICAL DIMENSIONS OF BRITISH STANDARD FINE SCREW THREADS.

1	2	3	4	5	6	7	8	9	10	11	12
Nominal Diameter of Screw.	No. of Threads per inch.	Pitch.	Depth of Thread.	Full Diameter.		Effective Diameter.		Core Diameter.		Cross Sectional Area at Bottom of Thread of Bolt.	Nominal Diameter of Screw.
				Bolt.	Nut.	Bolt.	Nut.	Bolt.	Nut.		
in.		in.	in.	in.	in.	in.	in.	in.	in.	sq. in.	in.
7/32	28	·03571	·02285	·2188	·2208	·1960	·1980	·1731	·1751	·0235	7/32
1/4	26	·03846	·02465	·2500	·2520	·2254	·2274	·2007	2027	·0316	1/4
9/32	26	·03846	·02465	·2813	·2833	·2566	·2586	·2320	2340	·0423	9/32
5/16	22	·04545	·02910	·3125	·3145	·2834	·2854	·2543	·2563	·0508	5/16
11/32	20	·05000	·03200	·3750	·3770	·3430	·3450	·3110	·3130	·0760	11/32
3/8	18	·05556	·03555	·4375	·4395	·4019	·4039	·3664	·3684	·1054	3/8
1/2	16	·06250	·04000	·5000	·5020	·4600	·4620	·4200	·4220	·1385	1/2
9/16	16	·06250	·04000	·5625	·5645	·5225	·5245	·4825	·4845	·1828	9/16
5/8	14	·07143	·04575	·6250	·6270	5793	·5813	·5335	·5355	·2235	5/8
11/16	14	·07143	·04575	·6875	·6895	·6418	·6438	·5960	·5980	·2790	11/16
3/4	12	·08333	·05335	·7500	·7520	·6966	·6986	·6433	·6453	·3250	3/4
13/16	12	·08333	·05335	·8125	·8145	·7591	·7611	·7058	·7078	·3913	13/16
7/8	11	·09091	·05820	·8750	·8770	·8168	·8188	·7586	·7606	·4520	7/8
1	10	·10000	·06405	1·0000	1·0020	·9360	·9380	·8719	·8739	·5971	1
1 1/8	9	·11111	·07115	1·1250	1·1270	1·0539	1·0559	·9827	·9847	·7585	1 1/8
1 1/4	9	·11111	·07115	1·2500	1·2520	1·1789	1·1809	1·1077	1·1097	·9637	1 1/4
1 3/8	8	·12500	·08005	1·3750	1·3770	1·2950	1·2970	1·2149	1·2169	1·1592	1 3/8
1 1/2	8	·12500	·08005	1·5000	1·5020	1·4200	1·4220	1·3399	1·3419	1·4100	1 1/2
1 5/8	8	·12500	·08005	1·6250	1·6270	1·5450	1·5470	1·4649	1·4669	1·6854	1 5/8
1 3/4	7	·14286	·09150	1·7500	1·7520	1·6585	1·6605	1·5670	1·5690	1·9285	1 3/4
2	7	·14286	·09150	2·0000	2·0020	1·9085	1·9105	1·8170	1·8190	2·5930	2
2 1/4	6	·16667	·10670	2·2500	2·2520	2·1433	2·1453	2·0366	2·0386	3·2577	2 1/4
2 1/2	6	·16667	·10670	2·5000	2·5020	2·3933	2·3953	2·2866	2·2886	4·1065	2 1/2
2 3/4	6	·16667	·10670	2·7500	2·7520	2·6433	2·6453	2·5366	2·5386	5·0535	2 3/4
3	5	·20000	·12805	3·0000	3·0020	2·8719	2·8739	2·7439	2·7459	5·9133	3

BRITISH ASSOCIATION SCREW THREADS.

No.	Approximate Dimensions in Decimals of an Inch.		Threads per Inch.	Exact Dimensions in Millimetres.		No.	Approximate Dimensions in Decimals of an Inch.		Threads per Inch.	Exact Dimensions in Millimetres.	
	Diam.	Pitch.		Diam.	Pitch.		Diam.	Pitch.		Diam.	Pitch.
25	·010	·0028	353	0·25	0·072	12	·051	·0110	90·7	1·3	0·28
24	·011	·0031	317	0·29	0·080	11	·059	·0122	81·9	1·5	0·31
23	·013	·0035	285	0·33	0·089	10	·067	·0138	72·6	1·7	0·35
22	·015	·0039	259	0·37	0·098	9	·075	·0154	65·1	1·9	0·39
21	·017	·0043	231	0·42	0·11	8	·087	·0169	59·1	2·2	0·43
20	·019	·0047	212	0·48	0·12	7	·098	·0189	52·9	2·5	0·48
19	·021	·0055	181	0·54	0·14	6	·110	·0203	47·9	2·8	0·53
18	·024	·0059	169	0·62	0·15	5	·126	·0232	43·0	3·2	0·59
17	·028	·0067	149	0·70	0·17	4	·142	·0260	38·5	3·6	0·66
16	·031	·0075	134	0·79	0·19	3	·161	·0287	34·8	4·1	0·73
15	·035	·0083	121	0·90	0·21	2	·185	·0319	31·4	4·7	0·81
14	·039	·0091	110	1·0	0·23	1	·209	·0354	28·2	5·3	0·90
13	·047	·0098	101	1·2	0·25	0	·236	·0394	25·4	6·0	1·00

British Standard Brass Thread.

This is a pipe thread system adopted for thin brass tubing, gas burner fittings, and general brass work; it has a Whitworth thread of a constant pitch of $\frac{1}{36}$-in., or 26 threads per inch.

Diameter. In.	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
Threads per inch .	26 throughout		—	—	—	—
Depth of Thread In.	0·02461 throughout		—	—	—	—
Core Diameter In.	0·0758	0·2008	0·3258	0·4508	0·5758	0·700
Tapping Size . In.	No. 47	No. 6	Q	$\frac{29}{64}$	$\frac{37}{64}$	$\frac{45}{64}$

Diameter. In.	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	—
Threads per Inch .	26 throughout		—	—	—	—
Depth of Thread In.	0·02461 throughout		—	—	—	—
Core Diameter In.	0·8258	0·9508	1·0758	1·2008	1·4508	—
Tapping Size . In.	$\frac{53}{64}$	$\frac{61}{64}$	$1\frac{5}{64}$	$1\frac{13}{64}$	$1\frac{29}{64}$	—

Whitworth's Standard Screws for Watch and Instrument Makers.

No. denoting Thousandths of an Inch in Diameter.	Threads per Inch.	No. denoting Thousandths of an Inch in Diameter.	Threads per Inch.	No. denoting Thousandths of an Inch in Diameter.	Threads per Inch.	No. denoting Thousandths of an Inch in Diameter.	Threads per Inch.
10	400	18 & 19	250	34	150	65	80
11	400	20	210	36	150	70	80
12	350	22	210	38	120	75	80
13	350	24	210	40	120	80	60
14	300	26	180	45	120	85	60
15	300	28	180	50	100	90	60
16	300	30	180	55	100	95	50
17	250	32	150	60	100	100	50

Swiss Screw Threads. (*Thury.*)

No.	Exact Dimensions in Millimetres.		Ratio of Successive Diameters	Approx. Diam. in Decimals of an Inch.	Threads per Inch.	No.	Exact Dimensions in Millimetres.		Ratio of Successive Diameters	Approx. Diam. in Decimals of an Inch.	Threads per Inch.
	Pitch.	External Diameter.					Pitch.	External Diameter.			
25	0·0718	0·254	0·879	0·0100	353·70	2	0·810	4·66	0·881	0·1835	31·35
24	0·0798	0·289	0·881	0·0114	318·30	1	0·900	5·29	0·882	0·2083	28·22
23	0·0886	0·328	0·882	0·0129	286·65	0	1	6	0·881	0·2362	25·40
22	0·0985	0·372	0·872	0·0146	255·32	— 1	1·11	6·81	0·881	0·2681	22·85
21	0·109	0·426	0·889	0·0168	233·02	— 2	1·23	7·73	0·881	0·3043	20·65
20	0·122	0·479	0·882	0·0189	208·19	— 3	1·37	8·77	0·881	0·3453	18·54
19	0·135	0·543	0·882	0·0214	188·40	— 4	1·52	9·95	0·880	0·3917	16·73
18	0·150	0·616	0·881	0·0243	169·33	— 5	1·69	11·3	0·883	0·4449	15·02
17	0·167	0·699	0·880	0·0275	152·32	— 6	1·88	12·8	0·883	0·5039	13·48
16	0·185	0·794	0·881	0·0313	137·29	— 7	2·09	14·5	0·879	0·5709	12·15
15	0·206	3·901	0·883	0·0355	123·30	— 8	2·32	16·5	0·882	0·6496	10·94
14	0·229	1·02	0·879	0·0402	110·91	— 9	2·58	18·7	0·882	0·7362	9·84
13	0·254	1·16	0·879	0·0457	100·00	—10	2·87	21·2	0·880	0·8346	8·85
12	0·282	1·32	0·886	0·0520	90·07	—11	3·19	24·1	0·880	0·9488	7·97
11	0·314	1·49	0·909	0·0587	80·89	—12	3·54	27·4	0·884	1·0787	7·17
10	0·349	1·64	0·854	0·0646	72·77	—13	3·93	31·0	0·881	1·2043	6·46
9	0·387	1·92	0·881	0·0756	65·63	—14	4·37	35·2	0·880	1·3858	5·81
8	0·430	2·18	0·879	0·0858	59·06	—15	4·86	40·0	0·881	1·5748	5·22
7	0·478	2·48	0·883	0·0976	53·13	—16	5·40	45·4	0·882	1·7874	4·84
6	0·531	2·81	0·881	0·1106	47·80	—17	6·00	51·5	0·882	2·0276	4·23
5	0·590	3·19	0·881	0·1256	43·05	—18	6·66	58·4	0·881	2·2992	3·82
4	0·656	3·62	0·881	0·1425	38·71	—19	7·40	66·3	0·882	2·6103	3·43
3	0·729	4·11	0·882	0·1618	34·84	—20	8·23	75·2	0·882	2·9607	3·08

British Association Screw Threads.

These screw threads (p. 1209) have been standardised by the British Engineering Standards Association, and the latest dimensions are given in Report C.L. (M.) 7271—1919.

French Standard Threads.

Diam. in Millimètres.	Pitch in Millimètres.			Diam. in Millimètres.	Pitch in Millimètres.		
	Cail or Railway.	Ducommun.	Armengaud's.		Cail or Railway.	Ducommun.	Armengaud's.
3	—	·5	—	25	3	3	3
4	—	·75	—	28	3	3	—
5	1	·75	1·4	30	3	3·5	3·4
6	1	1	—	32	3	3·5	—
7	1·25	1·2	—	35	3·5	4	3·8
7·5	—	—	1·6	38	3·5	4	—
8	1·25	1·25	—	40	4	4	4·2
9	1·5	1·5	—	42	4	4·5	—
10	1·5	1·5	1·8	45	4	4·5	4·6
12	1·5	1·75	—	47	4·5	5	—
12·5	—	—	2	50	4·5	5	5
14	2	—	—	55	—	5	5·4
15	2	2	2·2	60	—	6	5·8
17·5	—	—	2·4	65	—	6	6·2
18	2	2·5	—	70	—	7	6·6
20	2	2·5	2·6	75	—	7	7
22·5	—	—	2·8	80	—	7	7·4
23	2·5	3	—				

American Standard Threads.

(*Sellers'.*)

Dimensions in Inches.					Threads per Inch.	Pitch in Millimètres.	Dimensions in Inches.					Threads per Inch.	Pitch in Millimètres.
Outside Diameter.	Diameter at Bottom of Thread.	Size for Tapping.	Pitch.	Width of Flat.			Outside Diameter.	Diameter at Bottom of Thread.	Size for Tapping.	Pitch.	Width of Flat.		
$\frac{1}{4}$	·185	$\frac{3}{16}$	·05	·0062	20	1·27	2	1·711	$1\frac{23}{32}$	·2222	·0277	$4\frac{1}{2}$	5·644
$\frac{5}{16}$	·24	$\frac{1}{4}$	·0555	·0069	18	1·41	$2\frac{1}{4}$	1·961	$1\frac{31}{32}$	·2222	·0277	$4\frac{1}{2}$	5·644
$\frac{3}{8}$	·294	$\frac{19}{64}$	·0625	·0078	16	1·587	$2\frac{1}{2}$	2·175	$2\frac{5}{16}$	·25	·0313	4	6·35
$\frac{7}{16}$	·345	$\frac{23}{64}$	·0714	·0089	14	1·814	$2\frac{3}{4}$	2·425	$2\frac{7}{16}$	·25	·0313	4	6·35
$\frac{1}{2}$	·4	$\frac{13}{32}$	·0769	·0096	13	1·95	3	2·628	$2\frac{11}{64}$	·2857	·0357	$3\frac{1}{2}$	7·257
$\frac{9}{16}$	·454	$\frac{15}{32}$	·0833	·0104	12	2·116	$3\frac{1}{4}$	2·878	$2\frac{27}{64}$	·2857	·0357	$3\frac{1}{2}$	7·257
$\frac{5}{8}$	·506	$\frac{33}{64}$	·0909	·0114	11	2·39	$3\frac{1}{2}$	3·1	$3\frac{7}{64}$	·3077	·0384	$3\frac{1}{4}$	7·815
$\frac{11}{16}$	·62	$\frac{17}{32}$	·1	·0125	10	2·54	$3\frac{5}{8}$	3·317	$3\frac{21}{64}$	·3333	·0416	3	8·466
$\frac{3}{4}$	·731	$\frac{37}{64}$	·1111	·0139	9	2·822	4	3·567	$3\frac{37}{64}$	·3333	·0416	3	8·466
1	·837	$\frac{21}{32}$	·125	·0156	8	3·175	$4\frac{1}{4}$	3·798	$3\frac{43}{64}$	·3478	·0434	$2\frac{7}{8}$	8·834
$1\frac{1}{8}$	·939	$\frac{53}{64}$	·1428	·0178	7	3·628	$4\frac{1}{2}$	4·027	$4\frac{1}{32}$	·3636	·0454	$2\frac{3}{4}$	9·236
$1\frac{1}{4}$	1·064	$1\frac{5}{64}$	·1428	·0178	7	3·628	$4\frac{3}{4}$	4·255	$4\frac{17}{64}$	·3809	·0478	$2\frac{5}{8}$	9·676
$1\frac{3}{8}$	1·158	$1\frac{11}{64}$	·1666	·0208	6	4·233	5	4·48	$4\frac{31}{64}$	·4	·05	$2\frac{1}{2}$	10·16
$1\frac{1}{2}$	1·283	$1\frac{19}{64}$	·1666	·0208	6	4·233	$5\frac{1}{4}$	4·73	$4\frac{47}{64}$	·4	·05	$2\frac{1}{2}$	10·16
$1\frac{5}{8}$	1·389	$1\frac{25}{64}$	·1818	·0227	$5\frac{1}{2}$	4·62	$5\frac{1}{2}$	4·953	$4\frac{51}{64}$	·421	·0526	$2\frac{3}{8}$	10·68
$1\frac{3}{4}$	1·49	$1\frac{3}{4}$	·2	·025	5	5·08	$5\frac{3}{4}$	5·203	$5\frac{13}{64}$	·421	·0526	$2\frac{3}{8}$	10·68
$1\frac{7}{8}$	1·615	$1\frac{7}{8}$	·2	·025	5	5·08	6	5·423	$5\frac{7}{16}$	·444	·0555	$2\frac{1}{4}$	11·29

Comparison of U.S. Standard and Whitworth Screw Threads.

The difference in form that exists between the Whitworth and the U.S. standard screw thread is shown in fig. 7. The comparison is based upon a screw with 1 thread per inch. Clearances and interferences for the two forms of threads having any other pitch may therefore be obtained by dividing the respective values given in the diagram by the number of threads per inch under consideration.

In order to fit a U.S. standard screw into a Whitworth tapped hole or nut, round the outside corners of the screw and change the outline of the thread below the pitch line by slightly filing the flanks. These changes are indicated in the figure by the sectional areas. If it is desired to fit a Whitworth screw into a U.S. standard tapped hole or nut, drill out the hole or nut, using a drill which is larger than the tap drill required for an equal size U.S. standard tap, as shown by

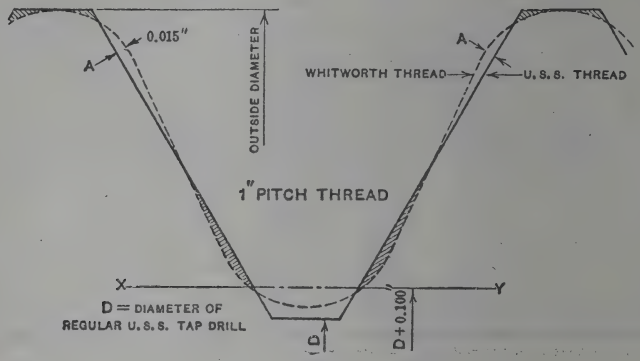


FIG. 7.

the line XY in the diagram. For 1 thread per inch, this increase in diameter of the tap drill will be 0·100 inch, and for other numbers of threads the amount of increase will be found by dividing 0·100 inch by the number of threads per inch. Thus, for 10 threads per inch, 0·100 ÷ 10 = 0·010 inch. The flanks of the Whitworth thread above the pitch line are then filed slightly as indicated at A in the illustration.

The methods mentioned are recommended only for fastening screws and ordinary threaded parts, and should not be employed where accurate threads are required.

(G. R. R. in 'Machinery.')

International System of Metrical Screw Threads.

(Système International.)

Dia. of Bolt in mm.	Pitch in mm.	Dia. of Bolt in mm.	Pitch in mm.	Dia. of Bolt in mm.	Pitch in mm.	Dia. of Bolt in mm.	Pitch in mm.	Dia. of Bolt in mm.	Pitch in mm.
3	0·55	8	1·25	18	2·5	36	4	60	5·5
3·5	0·55	9	1·25	20	2·5	39	4	64	6
4	0·7	10	1·5	22	2·5	42	4·5	68	6
4·5	0·7	11	1·5	24	3	45	4·5	72	6·5
5	0·85	12	1·75	27	3	48	5	76	6·5
6	1	14	2	30	3·5	52	5	80	7
7	1	16	2	33	3·5	56	5·5		

Fig. 8 shows the shape and proportions of the threads of the International System of metrical screw threads, also the maximum and minimum deviations allowed from the normal.

INTERNATIONAL SYSTEM OF METRICAL SCREW THREADS.

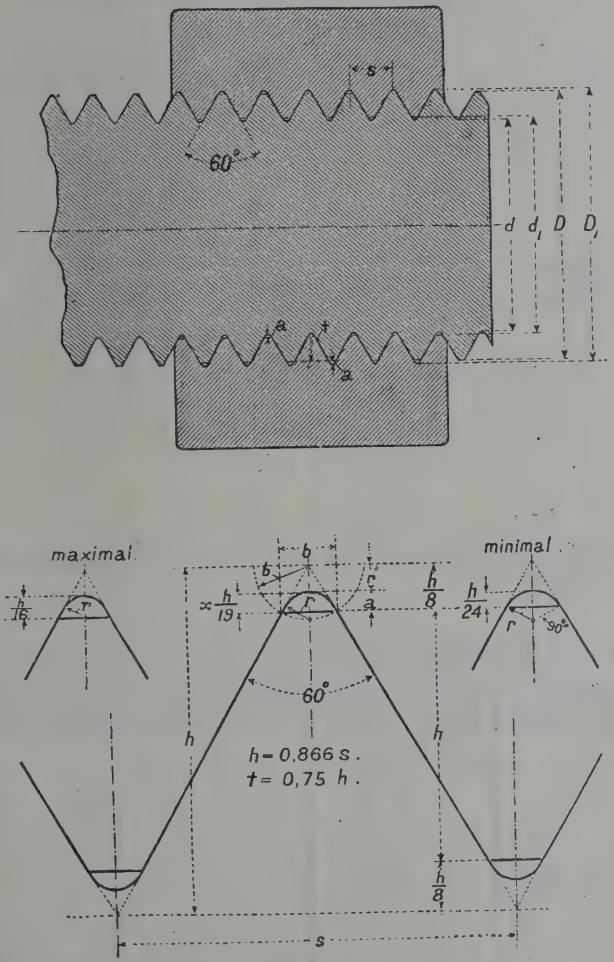


FIG. 8.

Wood Screws.

(Sometimes termed 'Screw Nails.')

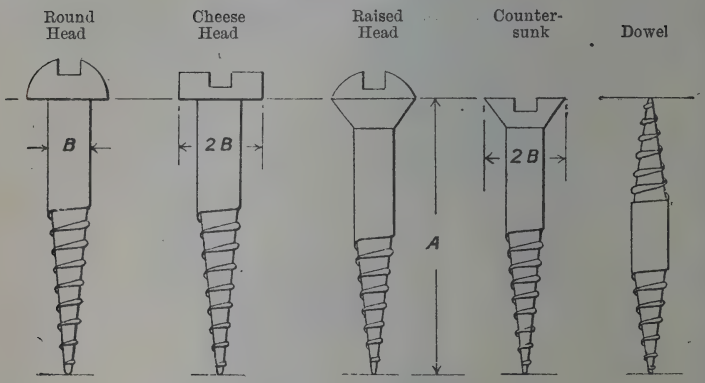


FIG. 9.

Wood screws are measured, as regards length (A), from the point to the portion normally flush with the surface of the material into which they are driven. Dowel screws are measured from point to point.

The number (size or thickness) (B) refers to the diameter of the shank or neck, and for screws of Nettlefold's manufacture is as follows :—

Number.	Diameter.	Number.	Diameter.	Number.	Diameter.	Number.	Diameter.
	In.		In.		In.		In.
1	·066	9	·178	17	·290	25	·402
2	·080	10	·192	18	·304	26	·416
3	·094	11	·206	19	·318	27	·430
4	·108	12	·220	20	·332	28	·444
5	·122	13	·234	21	·346	29	·458
6	·136	14	·248	22	·360	30	·472
7	·150	15	·262	23	·374	31	·486
8	·164	16	·276	24	·388	32	·500

Formula for ascertaining diameter of screw :—

(·014 × No.) + ·052 in. = diameter.

Example :—(·014 × 16) + ·052 in. = ·224 + ·052 = ·276 diameter of No. 16.

The diameter of the head may be taken as twice the thickness of the neck.

Numerous lengths are obtainable in each size from ¼ in. in the smaller sizes to 9 ins. in No. 32.

Larger sizes are made to order but not gauged, and most sizes are obtainable in iron or brass

(*H. A. Miles.*)

TABLE OF WOOD SCREWS.

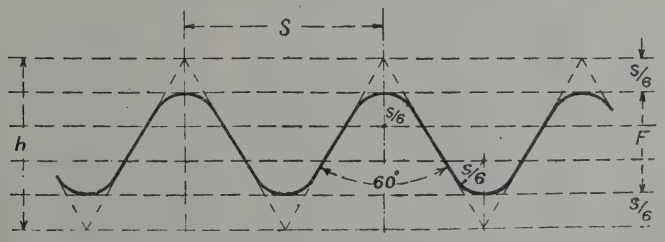
Number.	Clear Drill.	Diameter.	Diameter of Head.	Number.	Clear Drill.	Diameter.	Diameter of Head.
00	56	·046″	·120″	7	25	·149″	·300″
0	53	·059″	·140″	8	20	·161″	·330″
1	49	·073″	·160″	9	16	·171″	·365″
2	44	·086″	·175″	10	12	·189″	·390″
3	40	·098″	·200″	11	7	·201″	·420″
4	35	·110″	·225″	12	3	·213″	·450″
5	30	·128″	·250″	13	1	·228″	·475″
6	28	·140″	·275″	14	¼″	·250″	·500″

(*H. T. R. Grantham.*)

NOTE ON WOOD SCREWS.

Wood screws may be put into the hardest of wood by the following process: A screw of the same size to be used is ground down to the form of a half-round bit. A hole, equal in diameter to the size of the screw at the bottom of the thread, is drilled into the wood, and the half-round tap is screwed in. This cuts a good thread, into which the screw may easily be screwed. Before introducing the screw, give it a good greasing with tallow, so that no binding can take place.

CYCLE ENGINEERS' INSTITUTE STANDARD THREADS.



$h = 0{\cdot}866\,S.$ $F = 0{\cdot}5327\,S.$

FIG. 10.

The dimensions given below are for right-hand threads except those marked ** which are for left-hand threads only, and that marked * (i.e. $\frac{9}{16}$ in.) is for right or left hand threads.

Diameter in Inches. Decimals and Fractions.	No. of Threads per In.	Diameter in Inches. Decimals and Fractions.	No. of Threads per In.	Diameter in Inches. Decimals and Fractions.	No. of Threads per In.
·056 —	62	·154 —	40	·375 $\frac{3}{8}$	26
·064 —	62	·175 —	32	*·5625 $\frac{9}{16}$	20
·072 —	62	·1875 $\frac{3}{16}$	32	1·000 1	26
·080 —	62	·250 $\frac{1}{4}$	26	**1·290 —	24
·092 —	56	·266 —	26	1·370 —	24
·104 —	44	·281 —	26	**1·4375 $1\frac{7}{16}$	24
·125 $\frac{1}{8}$	40	·3125 $\frac{5}{16}$	26	1·5000 $1\frac{1}{2}$	24

Screw Heads.

British Standard Heads for Small Screws.*

(No. 57—1920.) (*Abstract.*)

For all classes of head the diameter to be 1·75 times the full diameter of the thread.

The width of saw-cuts to be according to the formula,

$$S = \cdot 2\ D + \cdot 1m,$$

where

S = width of saw-cut, and D = full diameter of the thread in millimetres.

The standard depth of saw-cut to equal one-half the total depth of the head in all cases, such depth being measured at the centre of the head.

Pipe Threads.

Whitworth's Standard Threads for Gas and Water Pipes.

Dimensions in Inches.			Number of Threads per Inch.	Dimensions in Inches.			Number of Threads per Inch.
Internal Diameter of Pipe.	External Diameter of Pipe.	Diameter at Bottom of Thread.		Internal Diameter of Pipe.	External Diameter of Pipe.	Diameter at Bottom of Thread.	
$\frac{1}{8}$	·382	·336	28	$1\frac{7}{8}$	2·245	2·128	11
$\frac{1}{4}$	·518	·451	19	2	2·347	2·23	11
$\frac{3}{8}$	·656	·589	19	$2\frac{1}{8}$	2·467	2·351	11
$\frac{1}{2}$	·826	·734	14	$2\frac{1}{4}$	2·587	2·47	11
$\frac{5}{8}$	·902	·811	14	$2\frac{3}{8}$	2·794	2·678	11
$\frac{3}{4}$	1·04	·949	14	$2\frac{1}{2}$	3	2·882	11
$\frac{7}{8}$	1·189	1·097	14	$2\frac{5}{8}$	3·124	3·009	11
1	1·309	1·192	11	$2\frac{3}{4}$	3·247	3·13	11
$1\frac{1}{8}$	1·492	1·375	11	$2\frac{7}{8}$	3·367	3·251	11
$1\frac{1}{4}$	1·65	1·533	11	3	3·485	3·368	11
$1\frac{3}{8}$	1·745	1·628	11	$3\frac{1}{4}$	3·698	3·581	11
$1\frac{1}{2}$	1·882	1·765	11	$3\frac{1}{2}$	3·912	3·795	11
$1\frac{5}{8}$	2·022	1·965	11	$3\frac{3}{4}$	4·125	4·008	11
$1\frac{3}{4}$	2·16	2·042	11	4	4·340	4·223	11

* By permission of the British Engineering Standards Association.

BRITISH STANDARD PIPE THREADS.*
(No. 21—1909.) (*Abstract.*)

1	2	3	4	5	6	7	8	9	10	11
Nominal Bore of Tube.	Approximate Outside Diameter of Black Tube.	Gauge Diameter.	Depth of Thread.	Core Diameter, Measured at same Distance from End of Pipe as the Gauge Diameter.	Number of Threads per Inch.	Length of Thread.		Distance of Gauge Diameter from Pipe-end. (Class I. Taper Screw.)		
						L on Pipe-end. Min.	In Coupler. Min.	Standard.	Max.	Min.
Ins.	Ins.	Ins.	In.	Ins.		Ins.	Ins.	Ins.	Ins.	Ins.
1/8	3/8	·383	·0230	·337	28	3/8	3/4	1/5 3 (·1563)	·18	·13
1/4	17/32	·518	·0335	·451	19	7/16	7/8	3/16 (·1875)	·22	·16
3/8	11/16	·656	·0335	·589	19	1/2	1	1/4 (·2500)	·29	·21
1/2	27/32	·825	·0455	·734	14	5/8	1 1/4	1/4 (·2500)	29	·21
5/8	15/16	·902	·0455	·811	14	5/8	1 1/4	1/4 (·2500)	·29	·21
3/4	1 1/16	1·041	·0455	·950	14	3/4	1 1/2	3/8 (·3750)	·44	·31
7/8	1 5/32	1·189	·0455	1·098	14	3/4	1 1/2	3/8 (·3750)	·44	·31
1	1 5/16	1·309	·0580	1·193	11	7/8	1 3/4	3/8 (·3750)	·44	·31
1 1/4	1 11/16	1·650	·0580	1·534	11	1	2	1/2 (·5000)	·58	·42
1 1/2	1 29/32	1·882	·0580	1·766	11	1	2	1/2 (·5000)	·58	·42
1 3/4	2 3/16	2·116	·0580	2·000	11	1 1/8	2 1/4	5/8 (·6250)	·73	·52
2	2 3/8	2·347	·0580	2·231	11	1 1/8	2 1/4	5/8 (·6250)	·73	·52
2 1/4	2 5/8	2·587	·0580	2·471	11	1 1/4	2 1/2	11/16 (·6875)	·80	·57
2 1/2	3	2·960	·0580	2·844	11	1 1/2	2 1/2	11/16 (·6875)	·80	·57
2 3/4	3 1/4	3·210	·0580	3·094	11	1 5/8	2 5/8	13/16 (·8125)	·95	·68
3	3 1/2	3·460	·0580	3·344	11	1 5/8	2 3/4	13/16 (·8125)	·95	·68
3 1/2	3 3/4	3·700	·0580	3·584	11	1 1/2	3	7/8 (·8750)	1·02	·73
3 1/2	4	3·950	·0580	3·834	11	1 1/2	3	7/8 (·8750)	1·02	·73
3 3/4	4 1/4	4·200	·0580	4·084	11	1 1/2	3	7/8 (·8750)	1·02	·73
4	4 1/2	4·450	·0580	4·334	11	1 5/8	3 1/4	1 (1·0000)	1·17	·83
4 1/2	5	4·950	·0580	4·834	11	1 5/8	3 1/4	1 (1·0000)	1·17	·83
5	5 1/2	5·450	·0580	5·334	11	1 3/4	3 1/2	1 1/4 (1·1250)	1·31	·94
5 1/2	6	5·950	·0580	5·834	11	1 7/8	3 3/4	1 1/4 (1·2500)	1·46	1·04
6	6 1/2	6·450	·0580	6·334	11	2	4	1 3/8 (1·3750)	1·60	1·15
7	7 1/2	7·450	·0640	7·322	10	2 1/8	4 1/4	1 3/8 (1·3750)	1·60	1·15
8	8 1/2	8·450	·0640	8·322	10	2 1/4	4 1/2	1 1/2 (1·5000)	1·75	1·25
9	9 1/2	9·450	·0640	9·322	10	2 1/4	4 1/2	1 1/2 (1·5000)	1·75	1·25
10	10 1/2	10·450	·0640	10·322	10	2 3/8	4 1/4	1 5/8 (1·6250)	1·90	1·35
11	11 1/2	11·450	·0800	11·290	8	2 1/2	5	1 5/8 (1 6250)	1·90	1·35
12	12 1/2	12·450	·0800	12·290	8	2 1/2	5	1 5/8 (1·6250)	1·90	1·35
13	13 3/4	13·680	·0800	13·520	8	2 5/8	5 1/2	1 5/8 (1·6250)	1·90	1·35
14	14 3/4	14·680	·0800	14·520	8	2 3/4	5 1/2	1 3/4 (1·7500)	2·04	1·46
15	15 3/4	15·680	·0800	15·520	8	2 3/4	5 1/2	1 3/4 (1·7500)	2·04	1·46
16	16 3/4	16·680	·0800	16·520	8	2 7/8	5 3/4	1 7/8 (1·8750)	2·19	1·56
17	17 3/4	17·680	·0800	17·520	8	3	6	2 (2·0000)	2·33	1·67
18	18 3/4	18·680	·0800	18·520	8	3	6	2 (2·0000)	2·33	1·67

NOTES ON TABLE.

Columns 1 and 2 of the table give the nominal bore of the tube and the full diameter of the screw in the coupler for use with that tube. The diameter of this screw has been chosen, in all cases, so that the coupler can be screwed by hand on to the tube, leaving from four to eight threads exposed.

The Association have preserved the Old Whitworth Standards as far as possible in the simplified dimensions for screwing sizes on tubes up to 2¼ ins. nominal bore. The Association have been guided in fixing the gauge diameters of the larger screwing sizes by the advantages of making the outside diameters of the tubes even quarters of inches.

* By permission of the British Engineering Standards Association.

AMERICAN GAS PIPE THREADS.

Nominal Diameter in Inches.	Outside Diameter in Inches.	No. of Threads per Inch.	Nominal Diameter in Inches.	Outside Diameter in Inches.	No. of Threads per Inch.
$\frac{1}{8}$	0·405	28	$2\frac{1}{2}$	2·875	8
$\frac{1}{4}$	0·54	18	$2\frac{3}{4}$	—	—
$\frac{3}{8}$	0·675	18	3	3·5	8
$\frac{1}{2}$	0·84	14	$3\frac{1}{2}$	4·0	8
$\frac{5}{8}$	—	—	4	4·5	8
$\frac{3}{4}$	1·05	14	$4\frac{1}{2}$	5·0	8
$\frac{7}{8}$	—	—	5	5·563	8
1	1·315	$11\frac{1}{2}$	6	6·625	8
$1\frac{1}{4}$	1·66	$11\frac{1}{2}$	7	7·625	8
$1\frac{1}{2}$	1·9	$11\frac{1}{2}$	8	8·625	8
$1\frac{3}{4}$	—	—	9	9·688	8
2	2·375	$11\frac{1}{2}$	10	10·75	8
$2\frac{1}{4}$	—	—			

Bolts and Nuts.

According to the Whitworth system of standard sizes of bolts and nuts, the thickness of the bolt-head is seven-eighths of the diameter, and the nut is equal to the diameter.

In the Sellers' (American) system the heads and nuts are hexagonal, the thickness of the heads and of the nuts being equal to 1 diameter minus one-sixteenth inch. The breadth across the flats is equal to $1\frac{1}{2}$ diameters plus one-sixteenth inch.

WHITWORTH STANDARD HEXAGON BOLTS AND NUTS.

Dimensions in Inches.									
Size of Bolt and Thickness of Nut.	Nut across Flats.	Nut across Corners.	Tapping Hole.	Thickness of Bolt-head.	Size of Bolt and Thickness of Nut.	Nut across Flats.	Nut across Corners.	Tapping Hole.	Thickness of Bolt-head.
$\frac{1}{8}$	·338	·390	·093	·1093	$2\frac{3}{8}$	4·18	4·82	2·39	2·4062
$\frac{3}{16}$	·448	·517	·134	·164	$2\frac{7}{8}$	4·34	5·02	2·5	2·5156
$\frac{1}{4}$	·525	·606	·186	·2187	3	4·53	5·23	2·63	2·625
$\frac{5}{16}$	·601	·694	·241	·2734	$3\frac{1}{8}$	4·69	5·41	2·75	2·7343
$\frac{3}{8}$	·709	·819	·295	·3281	$3\frac{1}{4}$	4·85	5·60	2·85	2·8256
$\frac{7}{16}$	·820	·947	·346	·3828	$3\frac{3}{8}$	5·01	5·78	2·98	2·9531
$\frac{1}{2}$	·920	1·06	·393	·4375	$3\frac{1}{2}$	5·17	5·98	3·1	3·0624
$\frac{9}{16}$	1·01	1·16	·455	·4921	$3\frac{5}{8}$	5·36	6·19	3·23	3·1718
$\frac{5}{8}$	1·1	1·27	·508	·5468	$3\frac{3}{4}$	5·55	6·41	3·32	3·2812
$\frac{11}{16}$	1·2	1·38	·571	·6016	$3\frac{7}{8}$	5·75	6·64	3·45	3·3906
$\frac{3}{4}$	1·3	1·5	·622	·6562	4	5·95	6·87	3·57	3·5
$\frac{13}{16}$	1·39	1·6	·684	·7064	$4\frac{1}{8}$	6·16	7·11	3·69	3·6094
$\frac{7}{8}$	1·48	1·7	·732	·7656	$4\frac{1}{4}$	6·37	7·36	3·8	3·7046
$\frac{15}{16}$	1·57	1·82	·795	·8203	$4\frac{3}{8}$	6·60	7 62	3·93	3·8271
1	1·67	1·95	·84	·875	$4\frac{1}{2}$	6·82	7·88	4·05	3·9374
$1\frac{1}{8}$	1·86	2·15	·942	·9843	$4\frac{5}{8}$	7·06	8·15	4·18	4·0469
$1\frac{1}{4}$	2·05	2·36	1·06	1·0937	$4\frac{3}{4}$	7·3	8·43	4·28	4·1562
$1\frac{3}{8}$	2·21	2·55	1·16	1·2031	$4\frac{5}{8}$	7·55	8·72	4·4	4·2656
$1\frac{1}{2}$	2·41	2·78	1·28	1·3125	5	7·8	9·01	4·53	4·375
$1\frac{5}{8}$	2·57	2·97	1·37	1·4128	$5\frac{1}{8}$	8·06	9·31	4·66	4·4844
$1\frac{3}{4}$	2·75	3·18	1·49	1·5312	$5\frac{1}{4}$	8·35	9·64	4·76	4·5936
$1\frac{7}{8}$	3·02	3·48	1·59	1·6406	$5\frac{3}{8}$	8·6	9·93	4·88	4·7031
2	3·15	3·63	1·71	1·75	$5\frac{1}{2}$	8·85	10·22	5·01	4·8124
$2\frac{1}{8}$	3·34	3·85	1·84	1·8523	$5\frac{5}{8}$	9·15	10·57	5·13	4·9218
$2\frac{1}{4}$	3·54	4·09	1·93	1·9687	$5\frac{3}{4}$	9·45	10·91	5·24	5·0312
$2\frac{3}{8}$	3·75	4·33	2·05	2·0781	$5\frac{7}{8}$	9·75	11·26	5·36	5·1406
$2\frac{1}{2}$	3·89	4·49	2·18	2·1875	6	10	11·55	5·48	5·25
$2\frac{5}{8}$	4·05	4·67	2·30	2·2968					

AMERICAN STANDARD HEXAGON NUTS AND BOLTS (*Sellers'*).

Dimensions in Inches.

Size of Bolt and Thickness of Nut.	Nut across Flats.	Nut across Corners.	Tapping Hole.	Thickness of Bolt-head.	Size of Bolt and Thickness of Nut.	Nut across Flats.	Nut across Corners.	Tapping Hole.	Thickness of Bolt-head.
1/4	·5	·577	·185	·197	2	3·125	3·609	1·711	1·576
5/16	·597	·685	·240	·2472	2 1/4	3·5	4·042	1·961	1·7628
3/8	·687	·794	·294	·2954	2 1/2	3·875	4·475	2·175	1·97
7/16	·781	·902	·345	·3447	2 3/4	4·25	4·908	2·425	2·1528
1/2	·875	1·0106	·4	·394	3	4·625	5·341	2·628	2·364
9/16	·968	1·1187	·454	·4432	3 1/4	5	5·775	2·878	2·561
5/8	1·062	1·227	·506	·4925	3 1/2	5·375	6·208	3·1	2·758
3/4	1·25	1·443	·62	·591	3 3/4	5·75	6·641	3·317	2·954
7/8	1·437	1·66	·731	·6895	4	6·125	7·074	3·567	3·152
1	1·625	1·876	·837	·788	4 1/4	6·5	7·507	3·798	3·349
1 1/4	1·812	2·093	·939	·8864	4 1/2	6·875	7·94	4·027	3·5256
1 3/8	2	2·31	1·064	·985	4 3/4	7·25	8·373	4·255	3·743
1 1/2	2·187	2·526	1·158	1·0764	5	7·625	8·806	4·48	3·94
1 3/4	2·375	2·743	1·283	1·182	5 1/4	8	9·24	4·73	4·137
1 7/8	2·562	2·959	1·389	1·2805	5 1/2	8·375	9·67	4·953	4·334
1 3/4	2·75	3·176	1·49	1·379	5 3/4	8·75	10·106	5·203	4·531
1 7/8	2·937	3·393	1·615	1·477	6	9·125	10·539	5·423	4·728

WHITWORTH STANDARD BOLTS AND NUTS. SAFE LOAD IN LBS.

Diam. of Bolt.	Diam. at Bottom of Thread.	Area at Bottom of Thread.	APPROXIMATE SAFE LOAD IN LBS.					
			At 4,000 lbs. per Sq. In.	At 5,000 lbs. per Sq. In.	At 6,000 lbs. per Sq. In.	At 7,000 lbs. per Sq. In.	At 8,000 lbs. per Sq. In.	At 9,000 lbs. per Sq. In.
Ins.	Ins.	Sq. Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
3/16	0·134	0·014	56	70	84	98	112	126
1/4	0·186	0·027	108	135	162	189	216	243
5/16	0·241	0·046	184	230	276	322	378	414
3/8	0·295	0·068	272	340	408	478	546	614
7/16	0·346	0·094	376	470	504	628	752	846
1/2	0·393	0·121	484	605	726	850	970	1,090
9/16	0·455	0·155	620	775	930	1,085	1,240	1,395
5/8	0·508	0·204	816	1,020	1,224	1,418	1,620	1,824
11/16	0·571	0·256	1,024	1,280	1,536	1,792	2,048	2,304
3/4	0·622	0·304	1,216	1,520	1,824	2,126	2,430	2,734
13/16	0·684	0·367	1,468	1,835	2,202	2,569	2,936	3,303
7/8	0·733	0·422	1,688	2,110	2,532	2,954	3,376	3,800
15/16	0·795	0·496	1,984	2,480	2,976	3,472	3,968	4,464
1	0·840	0·554	2,216	2,770	3,324	3,880	4,430	4,990
1 1/16	0·942	0·697	2,788	3,485	4,182	4,880	5,575	6,270
1 1/8	1·067	0·894	3,576	4,470	5,364	6,250	7,145	8,035
1 3/16	1·162	1·058	4,232	5,290	6,348	7,400	8,455	9,510
1 1/4	1·287	1·299	5,196	6,495	7,794	9,030	10,320	11,610
1 5/16	1·369	1·472	5,888	7,360	8,832	10,290	11,760	13,230
1 3/8	1·494	1·753	7,012	8,765	10,518	12,210	13,950	15,700
1 7/16	1·590	1·986	7,944	9,930	11,916	13,900	15,890	17,875
1 1/2	1·720	2·311	9,244	11,555	13,866	16,170	18,480	20,790
1 9/16	1·930	2·926	11,704	14.630	17,556	20,475	23,400	26,325
1 5/8	2·180	3·733	14,932	18,665	22,398	26,125	29.855	33,590

WHITWORTH STANDARD BOLTS AND NUTS. SAFE LOAD IN LBS.—*cont.*

Diam. of Bolt.	Diam. at Bottom of Thread.	Area at Bottom of Thread.	APPROXIMATE SAFE LOAD IN LBS. At 4,000 lbs. per Sq. In.	At 5,000 lbs. per Sq. in.	At 6,000 lbs. per Sq. In.	At 7,000 lbs. per Sq. In.	At 8,000 lbs. per Sq. In.	At 9,000 lbs. per Sq. In.
Ins.	Ins.	Sq. Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
2¾	2·384	4·464	17,856	22,320	26,784	31,220	35,680	40,140
3	2·634	5·450	21,800	27,250	32,700	38,080	43,520	48,960
3¼	2·856	6·402	25,608	32,010	38,412	44,814	51,216	57,618
3½	3·105	7·563	30,252	37,815	45,378	57,940	60,504	68,065
3¾	3·320	8·673	34,692	43,365	52,038	60,710	69,384	78,057
4	3·573	10·027	40,108	50,135	60,162	70,190	80,216	90,240
4¼	3·804	11·365	45,480	56,825	68,190	79,575	90,960	102,305
4½	4·054	12·908	51,632	64,540	77,448	90,356	103,264	116,172
4¾	4·284	14·404	57,616	72,020	86,424	100,830	115,232	129,636
4½	4·534	16·146	64,584	80,730	96,876	113,020	129,168	145,314
5	5·012	19·720	78,880	98,600	118,320	138,040	157,760	177,480
5½	5·487	23·640	94,560	118,200	141,840	165,200	189,120	212,760

BRITISH STANDARD HEXAGONAL BRIGHT AND BLACK NUTS AND BOLT-HEADS.*
(No. 28—1908, and 190—1924.) (*Abstract.*)

Diameter of Bolt.	Nuts. Width across Flats. Max.	Nuts. Width across Flats. Min.	Nuts. Width across Corners. Approximate Max. †	Nuts. Thickness. Max.	Nuts. Thickness. Min.	Lock Nuts. Thickness. Max.	Lock Nuts. Thickness. Min.	Bolt-Heads. Thickness. Max.	Bolt-Heads. Thickness. Min.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
¼ (·25)	·525	·520	·61	·26 *·27*	·25	·18 *·19*	·17	·23 *·24*	·22
5/16 (·375)	·710	·705	·82	·39 *·40*	·38	·26 *·27*	·25	·34 *·35*	·33
⅜ (·5)	·920	·915	1·06	·51 *·52*	·50	·34 *·35*	·33	·45 *·46*	·44
7/16 (·625)	1·100	1·092	1·27	·64 *·65*	·63	·43 *·44*	·42	·56 *·57*	·55
½ (·75)	1·300	1·292	1·50	·76 *·77*	·75	·51 *·52*	·50	·67 *·68*	·66
9/16 (·875)	1·480	1·468	1·71	·89 *·90*	·88	·59 *·60*	·58	·78 *·79*	·77
1	1·670	1·658	1·93	1·01 *1·02*	1·00	·68 *·69*	·67	·89 *·90*	·88
1¼ (1·25)	2·050	2·035	2·37	1·27 *1·28*	1·25	·85 *·86*	·83	1·11 *1·12*	1·09
1½ (1·5)	2·410	2·390	2·78	1·52 *1·53*	1·50	1·02 *1·03*	1·00	1·33 *1·34*	1·31
1¾ (1·75)	2·760	2·735	3·19	1·77 *1·78*	1·75	1·19 *1·20*	1·17	1·55 *1·56*	1·53
2	3·150	3·125	3·64	2·02 *2·03*	2·00	1·35 *1·36*	1·33	1·77 *1·78*	1·75
2¼ (2·25)	3·550	3·535	4·10	2 27 *2·28*	2·25	1·52 *1·53*	1·50	1·99 *2·00*	1·97
2½ (2·5)	3·890	3·875	4·49	2·52 *2·53*	2·50	1·69 *1·70*	1·67	2·21 *2·22*	2·19
2¾ (2·75)	4·180	4·165	4·83	2·77 *2·78*	2·75	1·85 *1·86*	1·83	2·43 *2·44*	2·41
3	4·530	4·515	5·23	3·02 *3·03*	3·00	2·02 *2·03*	2·00	2·65 *2·66*	2·63
3¼ (3·25)	4·850	4·830	5·60	3·27 *3·28*	3·25	2·19 *2·20*	2·17	2·86 *2·86*	2·84
3½ (3·5)	5·180	5·160	5·98	3·52 *3·53*	3·50	2·35 *2·36*	2·33	3·08 *3·09*	3·06
3¾ (3·75)	5·550	5·530	6·41	3·77 *3·78*	3·75	2·52 *2·53*	2·50	3·30 *3·31*	3·28
4	5·950	5·930	6·87	4·02 *4·03*	4·00	2·69 *2·70*	2·67	3·52 *3·53*	3·50
4½ (4·5)	6·820	6·795	7·88	4·53 *4 54*	4·50	3·03 *3·03*	3·00	3·97 *3·98*	3·94
5	7·800	7·775	9·01	5·03 *5·04*	5·00	3·36 *3·37*	3·33	4·41 *4·42*	4·38
5½ (5·5)	8·850	8·820	10·22	5·53 *5·54*	5·50	3·70 *3·71*	3·67	4·84 *4·84*	4·81
6	10·000	9·970	11·55	6·03 *6·04*	6·00	4·03 *4·04*	4 00	5·28 *5·29*	5·25

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† The figures in this column represent the maximum width across the corners correct to two decimal places. The figures in italics are those for *black* nuts

A chamfer of 30° from the face should be adopted on all bright nuts and bolt-heads. The interior diameter of the chamfer circle should not be appreciably less than the width across the flats.

BRITISH STANDARD WHITWORTH SCREW THREADS. TOLERANCES FOR NUTS.

1	2	3	6	7	8	9	10	11	12	13	14
Nominal Dia. of Screw.	No. of Threads per inch.	Pitch.	Full Diameter.			Effective Diameter.			Core Diameter.		
			Min.	Tol.	Max.	Min.	Tol.	Max.	Min.	Tol.	Max.
In.		In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1/4	20	·05000	·2520	·0090	·2610	·2200	·0045	·2245	·1880	·0067	·1947
5/16	16	·06250	·3770	·0100	·3870	·3370	·0050	·3420	·2970	·0075	·3045
3/8	12	·08333	·5020	·0115	·5135	·4486	·0058	·4544	·3953	·0087	·4040
7/16	11	·09091	·6270	·0121	·6391	·5688	·0060	·5748	·5106	·0090	·5196
1/2	10	·10000	·7520	·0126	·7646	·6880	·0063	·6943	·6239	·0095	·6334
9/16	9	·11111	·8770	·0133	·8903	·8059	·0067	·8126	·7347	·0100	·7447
1	8	·12500	1·0020	·0141	1·0161	·9220	·0071	·9291	·8419	·0106	·8525
1 1/8	6	·16667	1·5020	·0163	1·5183	1·3953	·0082	1·4035	1·2886	·0122	1·3008
2	4·5	·22222	2·0020	·0189	2·0209	1·8597	·0094	1·8691	1·7174	·0141	1·7315
2 1/4	4	·25000	2·5020	·0200	2·5220	2·3419	·0100	2·3519	2·1818	·0150	2·1968
3	3·5	·28571	3·0020	·0214	3·0234	2·8190	·0107	2·8297	2·6361	·0160	2·6521
3 1/4	3·25	·30769	3·5020	·0222	3·5242	3·3050	·0111	3·3161	3·1080	·0166	3·1246
4	3	·33333	4·0020	·0231	4·0251	3·7886	·0115	3·8001	3·5751	·0173	3·5924
4 1/2	2·875	·34785	4·5020	·0236	4·5256	4·2793	·0118	4·2911	4·0566	·0177	4·0743
5	2·75	·36364	5·0020	·0241	5·0261	4·7692	·0121	4·7813	4·5363	·0181	4·5544
6	2·5	·40000	6·0020	·0253	6·0273	5·7459	·0126	5·7585	5·4897	·0190	5·5087

BRITISH STANDARD WHITWORTH SCREW THREADS. TOLERANCES FOR BOLTS.*

(No. 92—1919.) (*Abstract.*)

1	2	3	6	7	8	9	10	11	12	13	14
Nominal Dia. of Screw.	No. of Threads per inch.	Pitch.	Full Diameter.			Effective Diameter.			Core Diameter.		
			Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
Ins.		In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1/4	20	·05000	2500	·0067	·2433	·2180	·0045	·2135	·1860	·0090	·1770
5/16	16	·06250	·3750	·0075	·3675	·3350	·0050	·3300	·2950	·0100	·2850
3/8	12	·08333	·5000	·0087	·4913	·4466	·0058	·4408	·3933	·0115	·3818
7/16	11	·09091	·6250	·0090	·6160	·5668	·0060	·5608	·5086	·0121	·4965
1/2	10	·10000	·7500	·0095	·7405	·6860	·0063	·6797	·6219	·0126	·6093
9/16	9	·11111	·8750	·0100	·8650	·8039	·0067	·7972	·7327	·0133	·7194
1	8	·12500	1·0000	·0106	·9894	·9200	·0071	·9129	·8399	·0141	·8258
1 1/8	6	·16667	1·5000	·0122	1·4878	1·3933	·0082	1·3851	1·2866	·0163	1·2703
2	4·5	·22222	2·0000	·0141	1·9859	1·8577	·0094	1·8483	1·7154	·0189	1·6965
2 1/4	4	·25000	2·5000	·0150	2·4850	2·3399	·0100	2·3299	2·1798	·0200	2·1598
3	3·5	·28571	3·0000	·0160	2·9840	2·8170	·0107	2·8063	2·6341	·0214	2·6127
3 1/4	3·25	·30769	3·5000	·0166	3·4834	3·3030	·0111	3·2919	3·1060	·0222	3·0838
4	3	·33333	4·0000	·0173	3·9827	3·7866	·0115	3·7751	3·5731	·0231	3·5500
4 1/2	2·875	·34783	4·5000	·0177	4·4823	4·2773	·0118	4·2655	4·0546	·0236	4·0310
5	2·75	·36364	5·0000	·0181	4·9819	4·7672	·0121	4·7551	4·5343	·0241	4·5102
6	2·5	·40000	6·0000	·0190	5·9810	5·7439	·0126	5·7313	5·4877	·0253	5·4624

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British Standard Fine Screw Threads. Tolerances for Nuts.

1	2	3	6	7	8	9	10	11	12	13	14
Nominal Dia. of Screw.	No. of Threads per inch.	Pitch.	Full Diameter.			Effective Diameter.			Core Diameter.		
			Min.	Tol.	Max.	Min.	Tol.	Max.	Min.	Tol.	Max.
In.		In.	In.	In.	In.	In.	In.	In.	In.	In.	In
¼	26	·03846	·2520	·0078	·2598	·2274	·0039	·2313	·2027	·0059	·2086
5/16	20	·05000	·3770	·0090	·3860	·3450	·0045	·3495	·3130	·0067	·3197
⅜	16	·06250	·5020	·0100	·5120	·4620	·0050	·4670	·4220	·0075	·4295
7/16	14	·07143	·6270	·0107	·6377	·5813	·0053	·5866	·5355	·0080	·5435
½	12	·08333	·7520	·0115	·7635	·6986	·0058	·7044	·6453	·0087	·6540
9/16	11	·09091	·8770	·0121	·8891	·8188	·0060	·8248	·7606	·0090	·7696
⅝	10	·10000	1·0020	·0126	1·0146	·9380	·0063	·9443	·8739	·0095	·8834
11/16	9	·11111	1·1270	·0133	1·1403	1·0559	·0067	1·0626	·9847	·0100	·9947
¾	9	·11111	1·2520	·0133	1·2653	1·1809	·0067	1·1876	1·1097	·0100	1·1197
13/16	8	·12500	1·3770	·0141	1·3911	1·2970	·0071	1·3041	1·2169	·0106	1·2275
⅞	8	·12500	1·5020	·0141	1·5161	1·4220	·0071	1·4291	1·3419	·0106	1·3525
15/16	8	·12500	1·6270	·0141	1·6411	1·5470	·0071	1·5541	1·4669	·0106	1·4775
1	7	·14286	1·7520	·0151	1·7671	1·6605	·0076	1·6681	1·5690	·0113	1·5803
2	7	·14286	2·0020	·0151	2·0171	1·9105	·0076	1·9181	1·8190	·0113	1·8303
2¼	6	·16667	2·2520	·0163	2·2683	2·1453	·0082	2·1535	2·0386	·0122	2·0508
2½	6	·16667	2·5020	·0163	2·5183	2·3953	·0082	2·4035	2·2886	·0122	2·3008
2¾	6	·16667	2·7520	·0163	2·7683	2·6453	·0082	2·6535	2·5386	·0122	2·5508
3	5	·20000	3·0020	·0179	3·0199	2·8739	·0089	2·8828	2·7459	·0134	2·7593

British Standard Fine Screw Threads. Tolerances for Bolts.*

(No. 84–1918.) (*Abstract.*)

1	2	3	6	7	8	9	10	11	12	13	14
Nominal Dia. of Screw.	No. of Threads per inch.	Pitch.	Full Diameter.			Effective Diameter.			Core Diameter.		
			Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.
In.		In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
¼	26	·03846	·2500	·0059	·2441	·2254	·0039	·2215	·2007	·0078	·1929
5/16	20	·05000	·3750	·0067	·3683	·3430	·0045	·3385	·3110	·0090	·3020
⅜	16	·06250	·5000	·0075	·4925	·4600	·0050	·4550	·4200	·0100	·4100
7/16	14	·07143	·6250	·0080	·6170	·5793	·0053	·5740	·5335	·0107	·5228
½	12	·08333	·7500	·0087	·7413	·6966	·0058	·6908	·6433	·0115	·6318
9/16	11	·09091	·8750	·0090	·8660	·8168	·0060	·8108	·7586	·0121	·7465
⅝	10	·10000	1·0000	·0095	·9905	·9360	·0063	·9297	·8719	·0126	·8593
11/16	9	·11111	1·1250	·0100	1·1150	1·0539	·0067	1·0472	·9827	·0133	·9694
¾	9	·11111	1·2500	·0100	1·2400	1·1789	·0067	1·1722	1·1077	·0133	1·0944
13/16	8	·12500	1·3750	·0106	1·3644	1·2950	·0071	1·2879	1·2149	·0141	1·2008
⅞	8	·12500	1·5000	·0106	1·4894	1·4200	·0071	1·4129	1·3399	·0141	1·3258
15/16	8	·12500	1·6250	·0106	1·6144	1·5450	·0071	1·5379	1·4649	·0141	1·4508
1	7	·14286	1·7500	·0113	1·7387	1·6585	·0076	1·6509	1·5670	·0151	1·5519
2	7	·14286	2·0000	·0113	1·9887	1·9085	·0076	1·9009	1·8170	·0151	1·8019
2¼	6	·16667	2·2500	·0122	2·2378	2·1433	·0082	2·1351	2·0366	·0163	2·0203
2½	6	·16667	2·5000	·0122	2·4878	2·3933	·0082	2·3851	2·2866	·0163	2·2703
2¾	6	·16667	2·7500	·0122	2·7378	2·6433	·0082	2·6351	2·5366	·0163	2·5203
3	5	·20000	3·0000	·0134	2·9866	2·8719	·0089	2·8630	2·7439	·0179	2·7260

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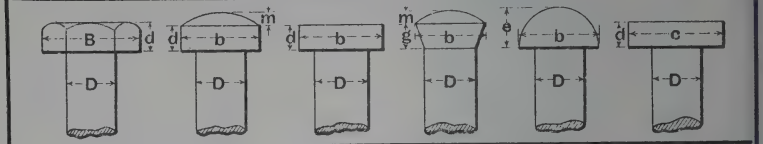
French Standard Bolts and Nuts.

Diameter of Screw.		Diameter of Bottom of Thread.		Pitch of Thread.	Number of Threads per Inch.	Width across Flats.		Width across Corners.		Thickness of Head.	
Millimètres.	Inches.	Millimètres.	Inches.	Millimètres.		Millimètres.	Inches.	Millimètres.	Inches.	Millimètres.	Inches.
5	·196	3·30	·13	1·4	18·14	13·97	·55	16·0	·63	5	·196
7·5	·295	5·58	·22	1·6	15·87	17·27	·68	19·81	·78	7	·275
10	·393	7·87	·31	1·8	14·11	22·35	·88	25·90	1·02	9	·355
12·5	·492	9·90	·39	2	12·70	26·42	1·04	30·48	1·20	11	·433
15	·589	12·19	·48	2·2	11·55	30·48	1·20	35·05	1·38	13	·51
17·5	·688	14·73	·58	2·4	10·58	34·54	1·36	39·87	1·57	15	·59
20	·787	16·76	·66	2·6	9·77	38·60	1·52	44·45	1·75	17	·67
22·5	·885	19·20	·76	2·8	9·07	42·67	1·68	49·27	1·94	19	·75
25	·984	21·34	·84	3	8·46	46·74	1·84	53·84	2·12	21	·83
30	1·178	25·90	1·02	3·4	7·47	54·86	2·16	63·50	2·50	24	·94
35	1·376	30·48	1·20	3·8	6·68	62·99	2·48	72·64	2·86	27	1·06
40	1·574	35·56	1·40	4·2	6·05	71·12	2·80	82·04	3·23	31	1·22
45	1·770	39·62	1·56	4·6	5·52	79·25	3·12	91·44	3·60	35	1·38
50	1·968	44·19	1·74	5	5·08	87·37	3·44	100·80	3·97	38	1·50
55	2·162	48·76	1·92	5·4	4·70	95·50	3·76	110·2	4·34	41	1·65
60	2·356	52·83	2·08	5·8	4·38	103·63	4·08	119·8	4·72	44	1·73
65	2·554	57·42	2·26	6·2	4·09	111·76	4·40	129·0	5·08	48	1·89
70	2·752	61·97	2·44	6·6	3·85	118·88	4·72	138·4	5·45	52	2·05
75	2·950	66·04	2·60	7·0	3·63	128·02	5·04	147·8	5·82	56	2·20
80	3·149	70·61	2·78	7·4	3·43	136·14	5·36	157·5	6·20	60	2·36

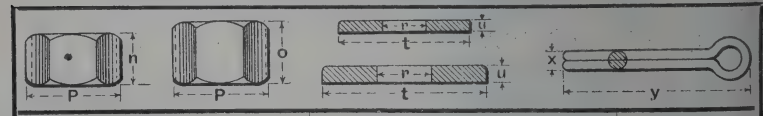
FRENCH BOLTS. (SIZES GENERALLY USED.)



Diameter of Bolt. *D*	Pitch of Thread.	Diameter of Hexagon Heads. *B*	Diameter of Heads for Iron *b*	Side of Square for Wood. *c*	Height of Spherical Heads. *e*	Height of Counter Sink. *g*	Height of Round and Square Heads. *d*	Height of Rise. *m*
mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
8	1¼	16	14	18	6	4	5	1
9	1¼	18	15	20	9	5	6	1
10	1½	20	16	24	10	5	6	1
12	1½	24	20	28	12	6	7	1
14	2	28	22	32	13	7	8	1
15	2	30	24	35	14	7	9	2
16	2	32	26	36	15	8	10	2
18	2	36	28	42	16	9	11	2
20	2½	40	32	46	18	10	12	2
22	2½	44	36	54	20	11	14	3
25	3	50	40	58	22	12	15	3
28	3	56	44	65	24	14	17	4
30	3	60	48	70	26	15	18	4
32	3½	64	52	74	28	16	19	4
35	4	70	56	80	31	17	21	5

(The actual depth of the thread is generally equal to ·75 of the pitch.)

FRENCH NUTS, WASHERS, AND BOLT-PINS. (SIZES GENERALLY USED.)



Nuts.				Washers.				Bolt-pins.	
Diameter of bolt. *D*	Height of Nut. *n*	Diameter of Hexagon. *P*	Extra Stout. *o*	Diameter of Hole. *r*	Outside Diameter for Iron. *s*	Outside Diameter for Wood. *t*	Thickness. *u*	Length. *y*	Diameter. *x*
mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
8	8	16	11	8½	19	22	2	16	2
9	9	18	12	9½	21	24	2	18	2
10	10	20	14	10½	25	28	3	20	3
12	12	24	16	12½	29	33	3	24	3
14	14	28	18	14½	34	38	3	28	3
15	15	30	20	15½	37	41	4	30	4
16	16	32	21	16½	40	45	4	32	4
18	18	36	24	18½	45	50	5	36	5
20	20	40	27	20½	50	55	5	40	5
22	22	44	29	22½	55	61	6	44	6
25	25	50	33	23½	62	68	6	50	6
28	28	56	37	29	69	75	7	56	7
30	30	60	40	31	74	80	7	60	7
32	32	64	42	33	78	85	7	64	8
35	35	70	46	36	86	94	8	70	9

ROUND BOLT HEADS.

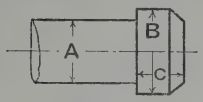


FIG. 11.

PROPORTIONS OF ROUND-HEADED BOLTS.

A	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$
B	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{4}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{9}{16}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{16}$	$2\frac{1}{4}$	$2\frac{3}{8}$
C	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{5}{16}$

CAPPED NUTS.

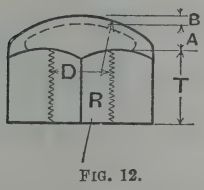


FIG. 12.

D = dia. of bolt ; R = D

T = D ; A = $\frac{D}{2}$; B = $\frac{1}{8}$ in.

Nut Locking.

In the common locking arrangement, in which a thick and thin nut are employed, the thin nut should have a thickness approximately equal to two-thirds that of the standard nut.

LIST OF SPLIT PINS AND BOLT-END LENGTHS FOR NUT LOCKING.

Diameter of Bolt or Pin.	Diameter of Split Pin.	Length of Split Pin through Shank.	Length of Split Pin through Nut.	Length over Grip for Drilled Bolt.	Length over Grip for Undrilled Bolt.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
$\frac{3}{8}$	$\frac{3}{32}$	1	$1\frac{1}{2}$	$\frac{3}{4}$	1'
$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{8}$
$\frac{5}{8}$	$\frac{5}{32}$	$1\frac{1}{2}$	2	$1\frac{1}{16}$	$\frac{7}{8}$
$\frac{3}{4}$	$\frac{5}{32}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{3}{16}$	$\frac{7}{8}$
$\frac{7}{8}$	$\frac{1}{4}$	2	$2\frac{1}{4}$	$1\frac{3}{4}$	1
1	$\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{8}$
$1\frac{1}{8}$	$\frac{1}{4}$	$2\frac{1}{2}$	3	$1\frac{5}{8}$	$1\frac{1}{4}$
$1\frac{1}{4}$	$\frac{1}{4}$	$2\frac{1}{2}$	3	$1\frac{3}{4}$	$1\frac{3}{8}$
$1\frac{3}{8}$	$\frac{1}{4}$	$2\frac{1}{2}$	$3\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{3}{8}$
$1\frac{1}{2}$	$\frac{1}{4}$	3	4	$2\frac{1}{4}$	$1\frac{3}{8}$
$1\frac{5}{8}$	$\frac{1}{4}$	$3\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{3}{8}$	$1\frac{3}{8}$
$1\frac{3}{4}$	$\frac{1}{4}$	$3\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{7}{8}$
$1\frac{7}{8}$	$\frac{1}{4}$	$3\frac{1}{2}$	$4\frac{1}{2}$	$2\frac{3}{8}$	2
2	$\frac{1}{4}$	$3\frac{3}{4}$	$4\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{1}{8}$

NOTE.—Length of a split pin is always measured overall.

('*Machinery.*')

BRITISH STANDARD WHITWORTH CASTLE NUTS.*
(190—1924.) (*Abstract*).

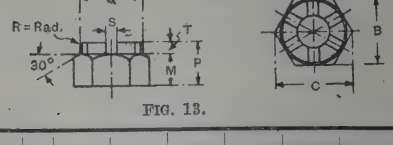


FIG. 13.

Thickness of hexagon and from face of nut to bottom of slot.	Min.	M	0·240	0·365	0·490	0·615	0·740	0·990	1·230	1·480	1·730
	Max.		0·250	0·375	0·500	0·625	0·750	1·000	1·250	1·500	1·750
Thickness of Castle nut.	Min.	P	0·334	0·505	0·677	0·802	0·974	1·270	1·558	1·855	2·198
	Max.		0·344	0·515	0·687	0·812	0·984	1·280	1·578	1·875	2·218
Diameter of castellated portions.	Min.	Q	0·500	0·685	0·895	1·065	1·265	1·635	2·015	2·370	2·715
	Max.		0·510	0·695	0·905	1·085	1·285	1·655	2·035	2·390	2·735
Approximate width of slot .		S	0·084	0·125	0·165	0·165	0·208	0·250	0·290	0·333	0·416
Approximate depth of slot .		T	0·094	0·140	0·187	0·187	0·234	0·280	0·328	0·375	0·468
Radius on castellated portion		R	0·05	0·06	0·06	0·07	0·08	0·09	0·11	0·13	0·14

TO LOCK A NUT.

(1).

In the absence of any of the regular nut-locking devices the work can still be done with an ordinary nut and washer. The stud or bolt used is first filed flat on one side at A, fig. 14, to

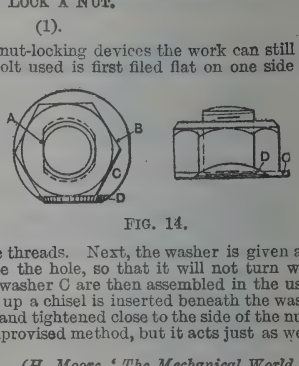


FIG. 14.

the depth of the threads. Next, the washer is given a few taps on one edge to elongate the hole, so that it will not turn when on the bolt. The nut B and washer C are then assembled in the usual manner, and when tightened up a chisel is inserted beneath the washer and the edge turned up at D, and tightened close to the side of the nut by hammering.

This is an improvised method, but it acts just as well as the regular locking devices.

(*H. Moore, 'The Mechanical World,' June* 22, 1923.)

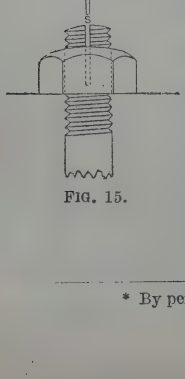


FIG. 15.

(2).

A slot S (fig. 15) is cut in the bolt with a hack-saw, and when the nut is tightly screwed home a cold chisel wedge C, whose width is less than the diameter of the bolt, is driven into the slot S (and then withdrawn) so as to spread out the end of the bolt, thus preventing the nut from unscrewing.

A serrated steel wedge can be driven into the slot if the nut is not required to be unscrewed again. (*H. R. Kempe.*)

* By permission of the British Engineering Standards Association.

LOCK NUTS FOR FEEDING SCREWS OF MACHINE TOOLS.

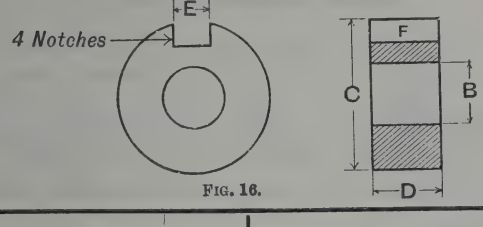


FIG. 16.

Dimensions in Inches.					Number of Threads per Inch.	Dimensions in Inches.					Number of Threads per Inch.
B.	C.	D.	E.	F.		B.	C.	D.	E.	F.	
$\frac{1}{8}$	1	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{32}$	14	$1\frac{1}{4}$	$2\frac{7}{8}$	$1\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{16}$	11
$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	"	14	$1\frac{3}{8}$	$3\frac{1}{16}$	$\frac{7}{8}$	"	"	11
$\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{8}$	"	$\frac{1}{8}$	14	$1\frac{7}{8}$	$3\frac{1}{4}$	$1\frac{5}{16}$	"	"	11
$\frac{5}{16}$	$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{1}{4}$	"	11	2	$3\frac{1}{2}$	1	"	"	11
$\frac{3}{8}$	$1\frac{3}{4}$	$\frac{1}{2}$	"	"	11	$2\frac{1}{4}$	4	1	$\frac{7}{16}$	$\frac{7}{32}$	8
$\frac{1}{2}$	2	$\frac{9}{16}$	$\frac{5}{16}$	$\frac{5}{32}$	11	$2\frac{1}{2}$	$4\frac{3}{8}$	$1\frac{1}{8}$	"	"	8
$\frac{5}{8}$	$2\frac{1}{4}$	$\frac{5}{8}$	"	"	11	$2\frac{3}{4}$	$4\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	8
$\frac{3}{4}$	$2\frac{1}{2}$	$\frac{11}{16}$	"	$\frac{3}{16}$	11	3	$5\frac{1}{2}$	$1\frac{3}{8}$	"	"	6
$1\frac{1}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$	"	"	11						

A pair of these nuts is used for locking purposes.

WING NUTS.

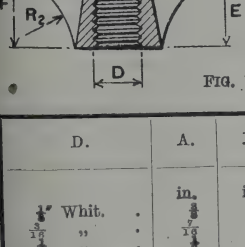
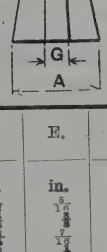


FIG. 17.



WING NUT PROPORTIONS.

The following table gives various dimensions for wing nuts threaded for bolts from $\frac{1}{8}$-inch to 1-inch Whitworth. The dimensions chosen are representative of usual practice.

D.	A.	B.	C.	E.	F.	G.	H.	R_1.	R_2.
	in.	in.	in.	in.	in.	in.	in.	in.	in.
$\frac{1}{8}$" Whit.	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{8}$
$\frac{3}{16}$ "	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{1}{16}$	$\frac{5}{16}$	$\frac{3}{16}$
$\frac{1}{4}$ "	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{3}{8}$	$\frac{1}{4}$
$\frac{5}{16}$ "	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{16}$	$\frac{7}{16}$	$\frac{5}{16}$
$\frac{3}{8}$ "	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{3}{8}$
$\frac{7}{16}$ "	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{1}{16}$	$\frac{9}{16}$	$\frac{7}{16}$
$\frac{1}{2}$ "	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{16}$	$\frac{5}{8}$	$\frac{1}{2}$
$\frac{9}{16}$ "	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{11}{32}$	$\frac{1}{16}$	$\frac{11}{16}$	$\frac{9}{16}$
$\frac{5}{8}$ "	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{13}{16}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{1}{16}$	$\frac{3}{4}$	$\frac{5}{8}$
$\frac{11}{16}$ "	$\frac{15}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{13}{32}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{11}{16}$
$\frac{3}{4}$ "	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{15}{16}$	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{1}{16}$	$\frac{7}{8}$	$\frac{3}{4}$
$\frac{13}{16}$ "	$1\frac{1}{16}$	$\frac{15}{16}$	$\frac{13}{16}$	1	$\frac{5}{8}$	$\frac{15}{32}$	$\frac{1}{16}$	$\frac{15}{16}$	$\frac{13}{16}$
$\frac{7}{8}$ "	$1\frac{1}{8}$	1	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{1}{16}$	1	$\frac{7}{8}$
$\frac{15}{16}$ "	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{15}{16}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{17}{32}$	$\frac{1}{16}$	$1\frac{1}{16}$	$\frac{15}{16}$
1 "	$1\frac{1}{4}$	$1\frac{1}{8}$	1	$1\frac{3}{16}$	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{1}{16}$	$1\frac{1}{8}$	1
	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$\frac{7}{8}$	$\frac{19}{32}$	$\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{1}{16}$
	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{5}{16}$	$\frac{15}{16}$	$\frac{5}{8}$	$\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{8}$
	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{3}{8}$	1	$\frac{21}{32}$	$\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$
	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{1}{16}$	$\frac{11}{16}$	$\frac{1}{16}$	$1\frac{3}{8}$	$1\frac{1}{4}$
	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$\frac{23}{32}$	$\frac{1}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$
	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{9}{16}$	$1\frac{3}{16}$	$\frac{3}{4}$	$\frac{1}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$
	$1\frac{11}{16}$	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$\frac{25}{32}$	$\frac{1}{16}$	$1\frac{9}{16}$	$1\frac{7}{16}$
	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{11}{16}$	$1\frac{5}{16}$	$\frac{13}{16}$	$\frac{1}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$
	$1\frac{13}{16}$	$1\frac{11}{16}$	$1\frac{9}{16}$	$1\frac{3}{4}$	$1\frac{3}{8}$	$\frac{27}{32}$	$\frac{1}{16}$	$1\frac{11}{16}$	$1\frac{9}{16}$
	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{13}{16}$	$1\frac{7}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	$1\frac{3}{4}$	$1\frac{5}{8}$
	$1\frac{15}{16}$	$1\frac{13}{16}$	$1\frac{11}{16}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{29}{32}$	$\frac{1}{16}$	$1\frac{13}{16}$	$1\frac{11}{16}$
	2	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{15}{16}$	$1\frac{9}{16}$	$\frac{15}{16}$	$\frac{1}{16}$	$1\frac{7}{8}$	$1\frac{3}{4}$
	$2\frac{1}{16}$	$1\frac{15}{16}$	$1\frac{13}{16}$	2	$1\frac{5}{8}$	1	$\frac{1}{16}$	$1\frac{15}{16}$	$1\frac{13}{16}$
	$2\frac{1}{8}$	2	$1\frac{7}{8}$	$2\frac{1}{16}$	$1\frac{11}{16}$	$1\frac{1}{32}$	$\frac{1}{16}$	2	$1\frac{7}{8}$
	$2\frac{3}{16}$	$2\frac{1}{16}$	2	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{1}{16}$	$\frac{1}{16}$	$2\frac{1}{16}$	2
	$2\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{16}$	$2\frac{3}{16}$	$1\frac{13}{16}$	$1\frac{3}{32}$	$\frac{1}{16}$	$2\frac{1}{8}$	$2\frac{1}{16}$
	$2\frac{5}{16}$	$2\frac{3}{16}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{5}{32}$	$\frac{1}{16}$	$2\frac{3}{16}$	$2\frac{1}{8}$
	$2\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{3}{16}$	$2\frac{5}{16}$	$1\frac{15}{16}$	$1\frac{7}{32}$	$\frac{1}{16}$	$2\frac{1}{4}$	$2\frac{3}{16}$
	$2\frac{7}{16}$	$2\frac{5}{16}$	$2\frac{1}{4}$	$2\frac{3}{8}$	2	$1\frac{9}{32}$	$\frac{1}{16}$	$2\frac{5}{16}$	$2\frac{1}{4}$
	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{1}{16}$	$1\frac{11}{32}$	$\frac{1}{16}$	$2\frac{3}{8}$	$2\frac{5}{16}$

Keys and Keyways.

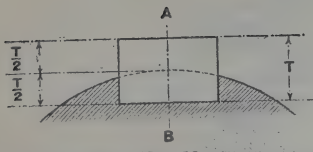


FIG. 18.

BRITISH STANDARD KEYS, KEY BARS, AND KEYWAYS.*

(No. 46—1909.) (*Abstract.*)

The keyway shall be cut in the shaft to a depth equal to one-half the thickness of the standard key it is intended to receive, and this depth shall be measured at the centre line (A–B) of the keyway.

Designation.	Shafts.		Key.		Key Bar.				Keyway.		
	Over.	To	Nominal Width.	Nominal Thickness.	Min. Width.	Min. Thickness.	Max. Width.	Max. Thickness.	Min. Width.	Tolerance.	Max. Width.
	Ins. Diam.	Ins. Diam.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	In.	Ins.
B.S.K. 1	1·25	1·50	0·375	0·2500	0·377	0·2520	0·379	0·2540	0·3740	–0·0010	0·375
B.S.K. 4	2·50	3·00	0·750	0·5000	0·752	0·5020	0·754	0·5040	0·7480	–0·0020	0·750
B.S.K. 7	4·00	5·00	1·250	0·8125	1·252	0·8145	1·255	0·8175	1·2480	–0·0020	1·250
B.S.K.10	7·00	8·00	2·000	1·3750	2·002	1·3770	2·006	1·3810	1·9970	–0·0030	2·000

Handles.

PROPORTIONS OF COOK HANDLES.

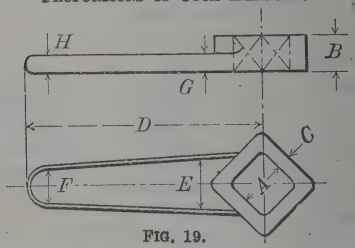


FIG. 19.

A.	B.	C.	D.	E.	F.	G.	H.
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{16}$	5	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$
$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{4}$	6	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{3}{16}$
$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	7	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{7}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	8	1	$\frac{7}{8}$	$\frac{5}{16}$	$\frac{1}{4}$
1	1	$\frac{1}{4}$	9	$1\frac{1}{8}$	1	$\frac{5}{16}$	$\frac{1}{4}$
$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{1}{4}$	10	$1\frac{1}{4}$	1	$\frac{5}{16}$	$\frac{1}{4}$
$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{16}$	11	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{16}$
$1\frac{3}{8}$	$1\frac{3}{8}$	$\frac{5}{16}$	12	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{16}$
$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{8}$	13	$1\frac{5}{8}$	$1\frac{3}{8}$	$\frac{7}{16}$	$\frac{3}{8}$
$1\frac{5}{8}$	$1\frac{5}{8}$	$\frac{3}{8}$	13	$1\frac{3}{4}$	$1\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
$1\frac{11}{16}$	$1\frac{3}{4}$	$\frac{7}{16}$	13	$1\frac{7}{8}$	$1\frac{5}{8}$	$\frac{7}{16}$	$\frac{3}{8}$
$1\frac{7}{8}$	$1\frac{7}{8}$	$\frac{7}{16}$	$13\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{16}$
$1\frac{15}{16}$	$1\frac{1}{2}$	$\frac{7}{16}$	$13\frac{1}{2}$	2	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{16}$

(*'Machinery,' June* 3, 1921.)

* By permission of the British Engineering Standards Association

PROPORTIONS OF MACHINE HANDLES.

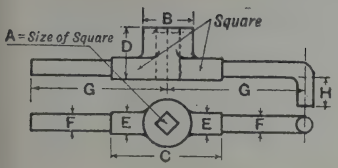


FIG. 20.

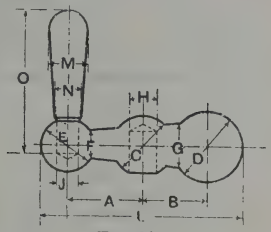


FIG. 21.

TABLE—FIG. 20.

Size of Square	A.	B.	C.	D.	E.	F.	G.	H.
$\frac{1}{2}$	$\frac{9}{16}$	1	2	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$	3	$2\frac{1}{2}$
$\frac{5}{8}$	$\frac{11}{16}$	$1\frac{1}{4}$	$2\frac{1}{2}$	2	$\frac{11}{16}$	$\frac{5}{8}$	4	$2\frac{1}{2}$
$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{3}{8}$	3	$2\frac{1}{4}$	$\frac{13}{16}$	$\frac{3}{4}$	5	3
$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{3}{8}$	$3\frac{1}{2}$	$2\frac{3}{4}$	$\frac{15}{16}$	$\frac{7}{8}$	6	$3\frac{1}{2}$
1	$1\frac{1}{16}$	$1\frac{7}{8}$	4	3	1	1	$7\frac{1}{2}$	4
$1\frac{1}{8}$	$1\frac{1}{16}$	$2\frac{1}{8}$	$4\frac{1}{4}$	$3\frac{1}{4}$	1	1	$8\frac{1}{2}$	4
$1\frac{1}{4}$	$1\frac{5}{16}$	$2\frac{3}{8}$	$4\frac{1}{2}$	$3\frac{1}{4}$	$1\frac{1}{8}$	1	9	4

TABLE—FIG. 21.

A.	B.	C.	D.	E.	F.	G.	H.	J.	L.	M.	N.	O.
$1\frac{1}{2}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{5}{16}$	$3\frac{13}{16}$	$\frac{5}{8}$	$\frac{3}{8}$	$2\frac{1}{2}$
$2\frac{1}{2}$	2	$1\frac{1}{2}$	$1\frac{3}{8}$	1	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	$5\frac{7}{16}$	$\frac{5}{8}$	$\frac{3}{8}$	3
3	$2\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{5}{16}$	$7\frac{1}{16}$	$\frac{3}{4}$	$\frac{7}{16}$	$3\frac{1}{2}$
$3\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{9}{16}$	$\frac{5}{16}$	$9\frac{1}{16}$	$\frac{7}{8}$	$\frac{7}{16}$	4
$4\frac{1}{2}$	$4\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{5}{8}$	$\frac{5}{16}$	$10\frac{5}{16}$	1	$\frac{1}{2}$	$4\frac{1}{2}$

PROPORTIONS OF MACHINE HAND WHEELS.

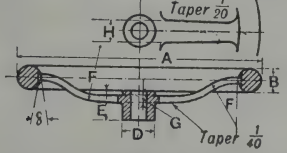


FIG. 22.

A.	B.	C.	D.	E.	F.	G.	H.
4	$\frac{3}{8}$	$\frac{3}{64}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{3}{8}$
5	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{1}{2}$
6	$\frac{5}{8}$	$\frac{5}{64}$	$\frac{7}{8}$	$\frac{7}{8}$	1	$\frac{3}{4}$	$\frac{5}{8}$
7	$\frac{3}{4}$	$\frac{3}{32}$	1"	1"	$1\frac{1}{16}$	$\frac{7}{8}$	$\frac{3}{4}$
8	$\frac{13}{16}$	$\frac{7}{64}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	1	$\frac{13}{16}$
9	$\frac{15}{16}$	$\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$\frac{15}{16}$
10	1	$\frac{9}{64}$	$1\frac{5}{16}$	$1\frac{5}{16}$	$1\frac{5}{16}$	$1\frac{1}{8}$	1
12	$1\frac{1}{4}$	$\frac{5}{32}$	$1\frac{11}{16}$	$1\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{4}$

Spanners.

British Standard Spanners.*

(No. 192—1924.) (*Abstract.*)

The angle between the head and the shank of spanners should be 15°, 30°, or 45°.

Dimensions of British Standard Spanners.

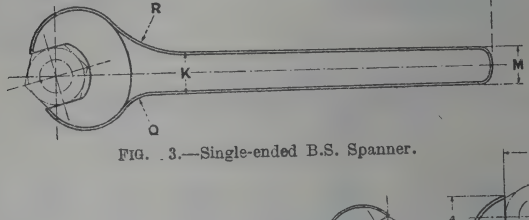


Fig. 3.—Single-ended B.S. Spanner.

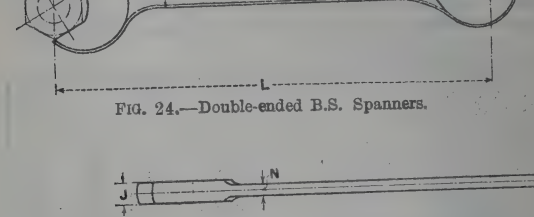


Fig. 24.—Double-ended B.S. Spanners.

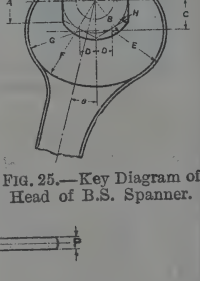


Fig. 25.—Key Diagram of Head of B.S. Spanner.

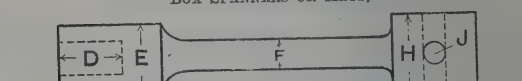


Fig. 26.—Front View of B.S. Spanners.

Box Spanners or Keys.

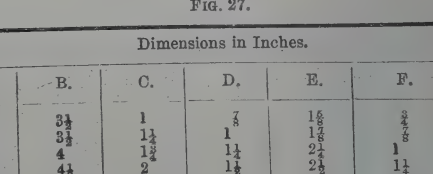


Fig. 27.

Dimensions in Inches.

Nut.	A.	B.	C.	D.	E.	F.	H.	J.
$\frac{5}{8}$	$1\frac{1}{2}$	$3\frac{1}{2}$	1	$\frac{7}{8}$	$1\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{7}{16}$
$\frac{3}{4}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{4}$	1	$1\frac{7}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{3}{4}$	4	$1\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{4}$	1	$1\frac{1}{2}$	$\frac{11}{16}$
1	2	$4\frac{1}{2}$	2	$1\frac{1}{2}$	$2\frac{3}{4}$	$1\frac{1}{4}$	2	
$1\frac{1}{8}$	$2\frac{3}{8}$	5	$2\frac{1}{4}$	$1\frac{5}{8}$	$2\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{1}{4}$	$\frac{15}{16}$
$1\frac{1}{4}$	$2\frac{3}{8}$	$5\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{3}{4}$	3	$1\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{1}{16}$
$1\frac{1}{2}$	3	$5\frac{1}{2}$	3	2	$3\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{1}{16}$

* By permission of the British Engineering Standards Association.

Dimensions of British Standard Spanners.

All dimensions are in inches.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dia. of Bolt.		Dimensions of Spanner.																	
B.S.W.	B.S.F.	Max.	Min.	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R
—	$\frac{7}{32}$	0·418	0·415	0·234	0·239	0·178	0·104	0·313	0·501	0·295	0·021	0·167	0·312	3·25	0·275	0·112	0·099	0·261	0·748
—	$\frac{1}{4}$	0·450	0·447	0·273	0·263	0·200	0·112	0·355	0·565	0·336	0·022	0·180	0·336	3·50	0·296	0·121	0·107	0·281	0·806
$\frac{1}{4}$	*$\frac{9}{32}$ $\frac{5}{16}$	0·530	0·527	0·313	0·307	0·232	0·132	0·410	0·653	0·387	0·050	0·212	0·395	5	0·348	0·142	0·126	0·331	0·949
$\frac{5}{16}$	$\frac{5}{16}$	0·605	0·602	0·391	0·359	0·277	0·151	0·496	0·786	0·470	0·063	0·242	0·451	5	0·398	0·162	0·144	0·378	1·083
$\frac{3}{8}$	$\frac{7}{16}$	0·715	0·712	0·469	0·427	0·331	0·178	0·593	0·939	0·563	0·075	0·286	0·533	6	0·470	0·192	0·170	0·447	0·280
$\frac{7}{16}$	$\frac{1}{2}$	0·825	0·822	0·547	0·494	0·384	0·206	0·689	1·090	0·654	0·088	0·330	0·615	6	0·542	0·221	0·196	0·516	1·477
$\frac{1}{2}$	$\frac{9}{16}$	0·925	0·922	0·583	0·546	0·419	0·231	0·747	1·186	0·708	0·100	0·370	0·690	8	0·608	0·248	0·220	0·578	1·656
$\frac{9}{16}$	$\frac{5}{8}$	1·015	1·012	0·656	0·604	0·466	0·253	0·833	1·321	0·791	0·113	0·406	0·757	8	0·667	0·272	0·242	0·634	1·817
$\frac{5}{8}$	*$\frac{11}{16}$	1·105	1·102	0·729	0·661	0·513	0·276	0·920	1·455	0·873	0·125	0·442	0·824	9	0·726	0·296	0·263	0·691	1·978
*$\frac{11}{16}$	$\frac{3}{4}$ *$\frac{13}{16}$	1·205	1·202	0·802	0·723	0·562	0·301	1·009	1·596	0·958	0·138	0·482	0·899	9	0·792	0·323	0·287	0·753	2·157
$\frac{3}{4}$	$\frac{7}{8}$	1·305	1·302	0·875	0·785	0·611	0·326	1·098	1·736	1·043	0·150	0·522	0·974	10	0·857	0·350	0·311	0·816	2·336
*$\frac{13}{16}$	*$\frac{15}{16}$	1·395	1·392	0·880	0·824	0·632	0·348	1·127	1·790	1·068	0·163	0·558	1·041	10	0·917	0·374	0·332	0·872	2·497
$\frac{7}{8}$	1	1·485	1·482	0·948	0·880	0·677	0·371	1·209	1·918	1·146	0·175	0·594	1·103	12	0·976	0·398	0·353	0·928	2·658
*$\frac{15}{16}$	—	1·585	1·582	1·016	0·941	0·724	0·396	1·294	2·052	1·227	0·188	0·634	1·182	12	1·041	0·425	0·377	0·991	2·837
1	$1\frac{1}{8}$	1·675	1·672	1·083	0·997	0·769	0·418	1·376	2·181	1·305	0·200	0·670	1·250	15	1·100	0·449	0·399	1·047	2·998
$1\frac{1}{8}$	$1\frac{1}{4}$	1·870	1·864	1·125	1·090	0·826	0·467	1·465	2·335	1·386	0·225	0·748	1·395	15	1·229	0·501	0·445	1·169	3·348
$1\frac{1}{4}$	*$1\frac{3}{8}$	2·060	2·054	1·250	1·203	1·914	0·514	1·622	2·583	1·534	0·250	0·824	1·537	18	1·353	0·552	0·490	1·288	3·688
*$1\frac{3}{8}$	$1\frac{1}{2}$	2·230	2·224	1·375	1·309	0·998	0·557	1·775	2·823	1·680	0·275	0·892	1·664	18	1·465	0·598	0·531	1·394	3·992
$1\frac{1}{2}$	*$1\frac{5}{8}$	2·420	2·414	1·500	1·422	1·086	0·604	1·933	3·073	1·830	0·300	0·968	1·805	21	1·590	0·649	0·576	1·313	4·332
*$1\frac{5}{8}$	$1\frac{3}{4}$	2·590	2·584	1·625	1·528	1·170	0·647	2·086	3·313	1·976	0·325	1·036	1·932	21	1·702	0·694	0·616	1·619	4·637
$1\frac{3}{4}$	2	2·770	2·764	1·750	1·637	1·256	0·692	2·240	3·556	2·122	0·350	1·108	2·066	23	1·820	0·742	0·659	1·731	4·958
*$1\frac{7}{8}$	—	3·030	3·024	1·875	1·780	1·359	0·757	2·418	3·844	2·289	0·375	1·212	2·260	23	1·991	0·812	0·721	1·894	5·424
2	$2\frac{1}{4}$	3·160	3·154	2·000	1·869	1·435	0·789	2·559	4·062	2·425	0·400	1·264	2·357	26	2·076	0·847	0·752	1·975	5·657

* The Association recommends that for general use the nuts and bolts corresponding with these spanner sizes be dispensed with.

Pipe Flanges.

Flanges and Bolts of Cast-iron Pipes.

Diameter of Pipe.	Diameter of Flange.	Flange Thickness.	Size of Bolts.	Number of Bolts.	Bolt Circle.	Weight per Foot.
Ins.	Ins.	Ins.	Ins.		Ins.	Lbs.
1½	6	⅜	½	3	4½	—
2	6½	⅜	½	4	4	8·74
2½	7½	1	⅝	4	5½	10·58
3	8	1	⅝	4	6	14·8
3½	8½	1	¾	4	6½	22·1
4	9½	1 1/16	¾	6	7½	30·8
4½	10	1 1/16	¾	6	7¾	36·3
5	11	1⅛	¾	6	8¾	52
6	12½	1⅛	¾	6	—	58·7
7	14	1 3/16	¾	8	11½	71·8
8	15	1 3/16	¾	8	12½	79·1
9	16½	1¼	¾	8	14	—
10	17½	1¼	¾	10	14¾	—
11	19	1 5/16	⅞	10	16	—
12	20	1 5/16	⅞	10	17	—

For steam pipes allow 2½ inches per 100 feet for expansion.

British Standard Pipe Flanges.*

(No. 10—Part 2—1926.) (*Abstract.*)

Table D.—For Working Steam Pressures up to 50 lbs. per sq. in.

Nominal Pipe Size.	Diameter of Flange.	Diameter of Bolt Circle.	Number of Bolts.	Diameter of Bolts.	Thickness of Flanges.		
					Cast Iron	Cast Steel and Bronze.	Stamped or Forged Iron or Steel.
Ins.	Ins.	Ins.		Ins.	Ins.	Ins.	Ins.
¼	3¾	2⅝	4	½	½	⅜	3/16
⅜	4	2⅞	4	½	½	⅜	7/16
1	4¼	3¼	4	½	½	⅜	5/16
1¼	4¾	3 7/16	4	½	⅝	½	¼
1½	5¼	3⅞	4	½	⅝	½	¼
2	6	4½	4	⅝	¾	9/16	5/16
2½	6½	5	4	⅝	¾	9/16	5/16
3	7¼	5¾	4	⅝	¾	9/16	⅜
3½	8	6½	4	⅝	¾	9/16	⅜
4	8½	7	4	⅝	⅞	11/16	⅜
5	10	8½	8	⅝	⅞	11/16	½
6	11	9½	8	⅝	⅞	11/16	½
7	12	10½	8	⅝	1	¾	½
8	13¼	11½	8	⅝	1	⅞	½
9	14½	12¾	8	⅝	1	⅞	⅝
10	16	14	8	¾	1	⅞	⅝
12	18	16	12	¾	1⅛	⅞	⅝
14	20¾	18½	12	⅞	1⅛	1	¾
15	21¾	19½	12	⅞	1⅛	1	¾
16	22¾	20½	12	⅞	1⅛	1	¾
18	25⅛	23	12	⅞	1⅜	1⅛	⅞
20	27½	25¼	16	⅞	1⅜	1¼	1
21	29	26½	16	⅞	1⅜	1¼	1
24	32½	29½	16	1	1⅜	1⅜	1⅛

Bolt holes.—For ½-in. and ⅝-in. bolts the diameters of the holes to be 1/16-in. larger than the diameter of the bolts, and for larger sizes of bolts ⅛-in. Bolt holes to be drilled off centre lines.

* By permission of the British Engineering Standards Association.

Tables E. F, H, and J relate to pressures up to 100 lbs., 150 lbs., 250 lbs., and 350 lbs., respectively.

TABLE K.—For Working Steam Pressures up to 450 lbs. per sq. in.

Nominal Pipe Size.	Actual Outside Diameter of Wrought Pipe.	Diameter of Flange.	Diameter of Bolt Circle.	Number of Bolts.	Diameter of Bolts.	Thickness of Flange. Cast Steel and Bronze; Stamped or Forged Steel.
ins.	ins.	ins.	ins.		ins.	ins.
¼	13/32	4½	3¼	4	⅝	¾
⅜	1 7/16	4½	3¼	4	⅝	¾
½	1 11/16	5	3½	4	⅝	⅞
1	1 15/16	5½	3⅞	4	⅝	⅞
1¼	2 3/16	6	4½	4	¾	1
1½	2 7/16	6½	5	8	⅝	1
2	2⅞	7¼	5¾	8	¾	1¼
2½	3	8	6¾	8	¾	1⅜
3	3½	9	7½	8	⅞	1⅜
3½	4	9½	7¾	8	⅞	1½
4	4½	10½	8½	8	1	1⅝
5	5½	11	9¼	12	⅞	1⅝
6	6½	12	10¼	12	1	1⅝
7	7½	13½	11½	12	1	1¾
8	8⅝	14½	12½	12	1	1⅞
9	9½	16	14	16	1	2
10	10¾	17	15	16	1	2
12	12¾	19½	17	16	1⅛	2¼
14	15	22½	20	16	1¼	2⅜
15	16	23¾	21¼	20	1¼	2½
16	17	24¾	22¼	20	1¼	2⅝

Bolt holes.—For ¼-in. and ⅝-in. bolts the diameters of the holes to be $\frac{1}{16}$-in. larger than the diameter of the bolts, and for larger sizes of bolts ⅛-in. Bolt holes to be drilled off centre lines.

TABLE M.—Welded-on Flanges for Pipe Lines for Working Steam Pressures up to 250 lbs.

Nominal Pipe Size.	Actual Outside Diameter of Wrought Pipe.	Diameter of Flange.	Diameter of Bolt Circle.	Number of Bolts.	Diameter of Bolts.	Thickness of Flange. Steel (stamped or forged).
ins.	ins.	ins.	ins.		ins.	ins.
2	2⅜	6	4¾	4	⅝	11/16
2½	3	6½	5	4	⅝	¾
3	3½	7½	5¾	8	⅝	¾
3½	4	8	6½	8	⅝	⅞
4	4½	8½	7¼	8	⅝	⅞
5	5½	10	8½	8	¾	1
6	6½	11	9½	8	¾	1⅛
7	7½	12	10½	12	¾	1⅛
8	8⅝	13½	11½	12	¾	1¼
9	9½	14½	12⅝	12	¾	1¼
10	10¾	16	14	12	⅞	1⅜
12	12¾	18	16	16	⅞	1⅜
14	15	20½	18½	16	1	1⅜
15	16	21⅝	19½	16	1	1⅜
16	17	22¾	20½	16	1	1½
18	19	25½	23	20	1	1⅝
20	21	27⅝	25½	20	1⅛	2
21	22	29	26½	24	1⅛	2
24	25	32½	29½	24	1¼	2¼

Bolt holes.—For ¼-in. and ⅝-in. bolts the diameters of the holes to be $\frac{1}{16}$-in. larger than the diameter of the bolts, and for larger sizes of bolts ⅛-in. Bolt holes to be drilled off centre lines.

Tables L and P relate to pressures up to 150 lbs. and 350 lbs. per sq. in., respectively.

American Standard Pipe Flanges.

Pipe Size. Inches.	Pipe Thickness, Inches.	Thickness nearest Fraction, Inches.	Stress on Pipe per Square Inch at 200 lbs.	Radius of Fillet, Inches.	Flange Diameter, Inches.	Flange Thickness at Hub for Iron Pipe, Inches.	Flange Thickness at Edge, Inches.	Width Flange Face, Inches.	Bolt Circle Diameter, Inches.	Number of Bolts.	Bolt Size Diameters, Inches.	Bolt Length, Inches.	Stress on each Bolt per Square Inch at Bottom of Thread at 200 lbs.
2	·409	7/16	460	1/8	6	1	5/8	2	4 3/4	4	1/2 5/8	2	825
2½	·429	7/16	550	1/8	7	1 1/16	11/16	2 1/4	5 1/2	4	1/2 5/8	2 1/4	1,050
3	·448	7/16	690	1/8	7 1/2	1 1/4	3/4	2 1/2	6	4	1/2 5/8	2 1/2	1,330
3½	·466	1/2	700	1/8	8 1/2	1 1/4	13/16	2 1/2	7	4	5/8 3/4	2 1/2	2,530
4	·486	1/2	800	1/8	9	1 3/8	15/16	2 1/2	7 1/2	4	5/8 3/4	2 1/2	2,100
4½	·498	1/2	900	1/8	9 1/4	1 3/8	15/16	2 3/8	7 3/4	8	5/8 3/4	2 1/2	1,430
5	·525	1/2	1,000	1/8	10	1 1/2	1	2 3/8	8 1/2	8	5/8 3/4	2 1/2	1,630
6	·563	9/16	1,060	1/8	11	1 5/8	1 1/16	2 1/2	9 1/2	8	5/8 3/4	2 3/4	2,360
7	·60	5/8	1,120	1/8	12 1/2	1 5/8	1 1/16	2 3/4	10 3/4	8	5/8 3/4	3	3,200
8	·639	5/8	1,280	1/8	13 1/2	1 3/4	1 1/8	2 3/4	11 3/4	8	5/8 3/4	3	4,190
9	·678	11/16	1,310	3/16	15	1 3/4	1 1/8	3	13 1/4	12	5/8 3/4	3 1/4	3,610
10	·713	11/16	1,330	3/16	16	2	1 3/16	3	14 1/4	12	5/8 3/4	3 1/4	2,970
12	·79	13/16	1,470	3/16	19	2	1 1/4	3 1/2	17	12	5/8 3/4	3 1/2	4,280
14	·864	7/8	1,600	3/16	21	2	1 3/8	3 1/2	18 3/4	12	3/4 7/8	3 3/4	4,280
15	·904	15/16	1,600	3/16	22 1/4	2	1 3/8	3 5/8	20	16	3/4 7/8	3 3/4	3,660
16	·946	1	1,600	3/16	23 1/2	2 1/4	1 7/16	3 5/8	21 1/4	16	3/4 7/8	4	4,210
18	1·02	1 1/16	1,690	1/4	25	…	1 9/16	3 3/4	22 3/4	16	1 1 1/8	4 1/4	4,540
20	1·09	1 1/8	1,780	1/4	27 1/2	…	1 11/16	3 3/4	25	20	1 1 1/8	4 1/2	4,490
22	1·18	1 3/16	1,850	1/4	29 1/2	…	1 13/16	3 3/4	27 1/4	20	1 1 1/4	4 3/4	4,320
24	1·25	1 1/4	1,920	1/4	31 1/2	32	…	1 7/8	3 3/4	4	29 1/4	29	20	1 1 1/4	5	5,130
26	1·30	1 5/16	1,980	1/4	33 3/4	34 1/4	…	1 7/8	2	4 1/8	31 1/4	31 3/4	24	1 1 1/4	5 1/4	5,030
28	1·38	1 3/8	2,040	1/4	36	36 1/2	…	1 7/16	2 1/16	4	4 1/4	33 1/2	34	28	1 1 1/4	5 3/4	5,000
30	1·48	1 1/2	2,000	1/4	38	38 3/4	…	1 1/2	2 1/8	4	4 3/8	35 1/2	36	28	1 1/8 1 1/4	6 1/4	4,590
36	1·71	1 3/4	1,920	1/4	44 1/2	45 3/4	…	1 3/4	2 3/8	4 1/4	4 7/8	42	42 3/4	32	1 1/2 1 3/8	6 1/2	4,790
42	1·87	2	2,100	1/4	51	52 3/4	…	1 7/8	2 5/8	4 1/2	5 3/8	48 1/2	49 1/2	36	1 1/4 1 1/2	7 1/4	5,700
48	2·17	2 1/4	2,130	1/4	57 1/2	59 1/2	…	2	2	4 3/4	5 3/4	54 3/4	56	44	1 3/8 1 1/2	7 3/4	6,090

The double sets of figures for flanges of pipe sizes above 24 in. are intended one for pressures of 200 lbs. and the other for less; this also applies to the two sizes of bolts.

TABLE OF GENERAL DIMENSIONS, FLEXIBILITY, ETC., OF JOINTS FOR THE VICTAULIC SYSTEM OF FLEXIBLE PIPE LINES.

Victaulic Joints for Mild Steel Expanded-End Pipes.						Victaulic Joints for Thickened-End Pipes (Cast-Iron)					
Bore.	A.	B.	C.	Angularity to adjacent pipe.	Gap between pipeends.	Bore.	A.	B.	C.	Angularity to adjacent pipe.	Gap between pipeends.
1½	3 3/16	4 7/16	1½	1 in 16	½	3	5 9/16	7½	2	1 in 32	½
2	3 11/16	6	1⅝	1 in 21	⅛	4	6¼	8¾	2¼	1 in 40	⅛
2½	4 7/16	6⅝	1¾	1 in 26	⅛	5	8⅛	10½	2½	1 in 50	⅛
3	5	7⅛	1¾	1 in 30·5	⅛	6	9⅛	11⅓	2½	1 in 58	⅛
3½	5⅝	8	2	1 in 34·5	⅛	7	10⅝	13¼	2⅝	1 in 68	⅛
4	6½	8⅝	2	1 in 38·5	⅛	8	11⅝	14½	2⅝	1 in 76	⅛
5	7½	9⅝	2	1 in 46·5	⅛	9	12⅞	15¾	2¾	1 in 85	⅛
6	8 7/16	11	2	1 in 55	⅛	10	14 3/16	17	2¾	1 in 94	⅛
7	9⅞	12½	2⅛	1 in 63	⅛	12	16½	19¾	2¾	1 in 112	⅛
8	11	13¾	2⅛	1 in 72	⅛						
9	12⅛	14¾	2⅛	1 in 80	⅛						
10	13⅛	16⅛	2½	1 in 88	⅛						
12	15⅛	18¼	2½	1 in 104	⅛						

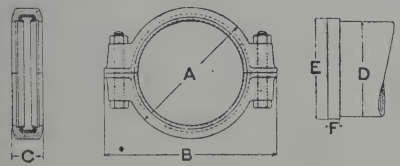


Fig. 28.

DIMENSIONS OF PIPE-ENDS FOR VICTAULIC SYSTEM OF FLEXIBLE JOINTS, AS STANDARDISED BY TUBE MAKERS.

Expanded Ends.				Thickened Ends.			
Nom. Bore.	O.D. Pipe. (D.)	O.D. Expanded End. (E.)	Length of Expanded End. (F.)	Nom. Bore.	O.D. Pipe. (D.)	O.D. Thickened Ends. (E.)	Length of Thickened End. (F)
1½	1⅝	2	5/8	3	3·76	4	5/8
2	2⅛	2⅝	5/8	4	4·8	5	11/16
2½	3	3¼	5/8	5	5·9	6¼	11/16
3	3½	3 13/16	5/8	6	6·98	7¼	11/16
3½	4	4 5/16	11/16	7	8·06	8¼	11/16
4	4½	4 13/16	11/16	8	9·14	9¼	11/16
5	5½	5 13/16	11/16	9	10·2	10⅜	13/16
6	6½	6⅞	11/16	10	11·26	11½	13/16
7	7½	7⅞	11/16	12	13·6	14	13/16
8	8½	9	13/16				
9	9½	10	13/16				
10	10½	11	13/16				
12	12½	13	13/16				

Screw Taps and Tapping.

Whitworth's Standard Taps.

Dimensions in Inches.						Threads per Inch.
Outside Diameter.	Full Length.	Length of Screw Part.	Length of Square.	Size of Square.	Diameter at Bottom of Thread.	
1/16	1 1/2	5/8	3/16	—	·0413	60
3/32	1 5/8	3/4	3/16	—	·0671	48
1/8	1 3/4	7/8	1/4	—	·093	40
5/32	1 7/8	7/8	1/4	—	·112	32
3/16	2	1	5/16	—	·134	24
7/32	2 1/8	1 1/16	5/16	—	·165	24
1/4	2 1/4	1 1/8	3/8	—	·186	20
5/16	2 1/2	1 1/8	7/16	5/32	·241	18
3/8	2 5/8	1 1/2	1/2	7/32	·295	16
7/16	3 1/4	1 3/4	1/2	9/32	·346	14
1/2	3 1/2	2	9/16	5/16	·393	12
9/16	3 3/4	2	9/16	5/16	·455	12
5/8	4	2 1/4	5/8	3/8	·508	11
11/16	4 1/4	2 3/8	11/16	3/8	·571	11
3/4	4 1/2	2 1/2	3/4	7/16	·622	10
13/16	4 3/4	2 5/8	3/4	7/16	·684	10
7/8	5	2 7/8	13/16	1/2	·732	9
15/16	5 1/2	3	13/16	1/2	·795	9
1	5 1/2	3 1/4	7/8	5/8	·84	8
1 1/8	6	3 1/2	1	11/16	·942	7
1 1/4	6 1/2	3 3/4	1 1/8	13/16	1·067	7
1 3/8	7 1/2	4 1/4	1 1/4	1	1·161	6
1 1/2	8	4 3/4	1 1/4	1	1·286	6
1 5/8	8 1/2	5 1/4	1 1/4	1	1·368	5
1 3/4	9	5 1/4	1 3/8	1 1/8	1·494	5
1 7/8	9 1/2	5 3/4	1 3/8	1 1/8	1·59	4 1/2
2	10	6	1 1/2	1 5/16	1·715	4 1/2
2 1/8	10 1/2	6 1/4	1 1/2	1 3/8	1·84	4 1/2
2 1/4	11	6 3/4	1 5/8	1 1/2	1·93	4
2 3/8	11 1/2	7 1/4	1 5/8	1 5/8	2·054	4
2 1/2	12	7 3/4	1 3/4	1 5/8	2·18	4
2 5/8	12 1/2	8 1/4	1 3/4	1 3/4	2·304	4

Table of B.A. Drill Sizes for Tapping.

Number.	Standard.		Working.			Number.	Standard.		Working.		
	Clear.	Tap.	Clear.	Hard Brass Tapping.	Soft Iron Tapping.		Clear.	Tap.	Clear.	Hard Brass Tapping.	Soft Iron Tapping.
0	15/64	12	15/64	10	9	8	44	51	43	49	48
1	4	19	3	15	15	9	48	53	48	52	51
2	13	26	12	24	23	10	51	55	50	54	53
3	20	30	19	29	28	11	53	57	53	55	55
4	28	34	27	32	31	12	55	62	55	57	57
5	30	40	30	37	36	13	56	65			
6	35	44	34	43	42	14	61	70			
7	40	48	39	46	45						

(*H. T. R. Grantham.*)

TABLE OF DRILL AND TAPPING SIZES.

Whitworth.		Metric.		Gas.		British Association.				
Size	Drill.	Size.	Drill.	Size.	Drill.	Size.	Drill.	Clearance.	Diam. of Head.	
1/8	No. 38			1/8	11/32	0	9-11	15/64	27/64	Drill Gauge.
3/32	,, 25			1/4	29/64	1	15-17	3-4	23/64	
1/16	,, 9			3/8	19/32	2	24-25	12-13	21/64	
1/4	1/4			1/2	37/64	3	28-29	19-20	9/32	
5/16	19/64			3/4	51/64	4	31-33	27-28	1/4	
3/8	11/32	5	3·9 or 24	1	1 3/16	5	36-39	30	15/64	
7/16	27/64	5½	4·2 - 19	1¼	1 17/32	6	42-43	34-35	3/16 Full	9
1/2	29/64	6	4·5 - 16	1½	1 49/64	7	45-48	39-40	11/64	16
9/16	33/64	7	5·4 - 3	2	2 5/32	8	48-51	43-44	5/32	24
5/8	37/64	8	6·25 - D	2¼	2 23/32	9	51-53	48	9/64	30
11/16	41/64	9	7 - J	3	3 9/32	10	53-55	50-51	1/8	32
3/4	11/16	10	8 - 5/16	3½	3 3/4	11	55 56	53		
13/16	47/64	12	9·5 - V	4	4 1/4	12	57-61	55		
7/8	51/64	14	11·5 = 29/64			13	63	56		
15/16	27/32	16	13·0 - 33/64			14	69	61		
1	59/64	18	14·5 - 37/64			15	71	·035 or 65		
1 1/8	1 5/64	20	16·5 - 41/64			16	74	·031 - 68		
1¼	1 1/16	22	18 - 45/64			17	76	·027 - 70		
1 3/8	1 9/32	24	20 - 25/32			18	78	·024 - 72		
1½	1 3/8	26	21 - 53/64			19	79	·021 - 74		
1 5/8	1 19/32	28	23 - 29/32			20		·019 - 75		
1¾	1 27/64	30	24·5 - 31/32			21		·017 - 77		
1 7/8	1 31/32	32	1 3/64			22		·015 - 78		
2	1 33/32	36	30			23		·013 - 80		
2¼	1 31/32	40	1 5/16			24		·011		
2½	2 7/32					25		·010		

(*H. T. R. Grantham.*)

TAPPING.

It is a common occurrence for a tap to break when tapping hard metal. If the tap is ground away on the point, so that the first five or six threads are gradually bevelled, the risk of breakage may be largely avoided. The effect of grinding the end of the tap is to break up the chips into smaller pieces, and thus prevent clogging the threads of the tap. This will be found to be especially advantageous in tapping very hard rolled steel.

An easy rule for approximating tap-drill sizes is to deduct 1½ times the pitch from the outside diameter of the tap. In the case of a ⅜-in. tap, 16-pitch thread, for instance, 1½ times 1/16 = 3/32, and ⅜ − 3/32 = 9/32 = the diameter of the drill required for a ⅜-in. tap.

CORRECT TAP GRINDING.

Grinding a tap consists usually of grinding the taper at the end of the tap, and the clearance back of the cutting edge thus formed. This taper may be long, as in nut taps; short, as in plug taps; or almost none, as in bottoming taps. The principle remains the same in each case. What is required is that each flute shall have exactly the same taper, just enough clearance so that it will cut freely, and not enough to needlessly weaken the cutting edge.

Prior to the advent of tap-grinding machinery nearly all taps were ground by hand, with a resultant lack of uniformity in taper and clearance. Fig. 29 shows a section of a four-flute tap with each flute ground differently in the matter of clearance or backing off. The flute A, at the left, is ground with a straight-line clearance just sufficient to have the heel of the flute actually clear and not drag. This calls for an angle of 15°, as indicated, and results in a weak cutting edge, but the strongest possible with a straight-line clearance at the heel.

The flute B, at the top, shows a 15° convex clearance. A glance shows this to be excessive. Flute C, at the right, shows a straight-line clearance of 5°, and nearly half of the flute at the back is not cleared at all, leaving the tap to ride on that portion and keep the front of the flute from cutting. Flute D, at the bottom, shows a perfect grind for ordinary work. It is a 5° convex

clearance, and shows that with this small but sufficient clearance angle at the cutting edge, the back is perfectly cleared.

In addition to the correct clearance of taps, a uniform angle of taper for all flutes is necessary. The results of different tapers obtained by hand-grinding are indicated in fig. 27. Even a slight variation from the uniform taper angle means power wasted and taps broken. As the blunt angle flute strikes the side of a drilled hole, it throws the cutting end of the tap off centre and imparts to it a wabbling motion. This means a tapped hole that is oversized, allowing the screw to fit loosely. Tap A is correctly ground and will tap a hole true to size, properly located and

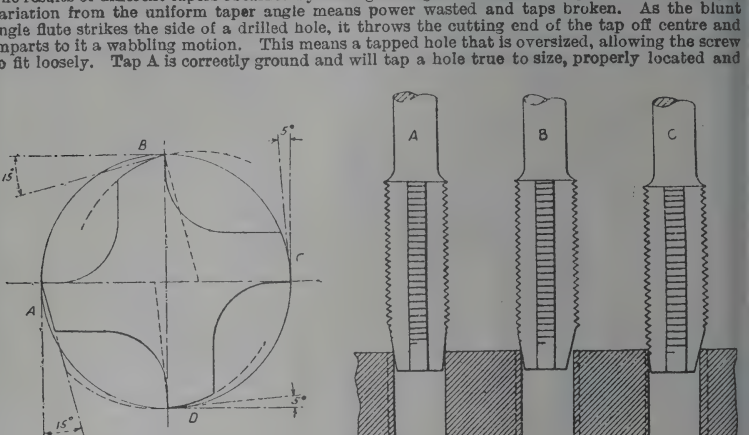


FIG. 29.

with smooth, accurately shaped threads. Tap B is ground with one flute at a more blunt angle than the other. This blunt flute is shown just as it strikes the drilled hole. Tap C shows a similar tap after it has been crowded over. The condition developed is readily seen.

(*' Railway Mechanical Engineer.'*)

THE "GUN" TAP.

A method of grinding a tap to give a cutting action similar to that of a turning tool is shown in fig. 30, which shows a ' Gun ' tap made by the Greenfield Tap & Die Corporation of America. The makers claim that the slope B of the face of the leading cutting edges (which are slightly hook-shaped, the edge being ground to give a negative rake) at A curls and projects the chips forward in an axial direction in front of the tap as tapping proceeds, the form of the chips, in steel, being spiral and more or less continuous. In this way the vicinity of the cutting operation at each flute is

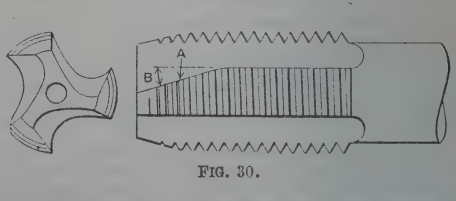


FIG. 30.

kept clear of swarf and the tap cuts freely, even through a long hole. The tap does not have to be backed out of long holes to clear a collection of chips from the flutes.

It is stated that the cutting pressure necessary with the ' Gun ' tap is 50 to 60 per cent. less than with an ordinary tap for the same size of thread. In deep holes the ' Gun ' tap has cut a full thread over four diameters long at a cutting pressure of 300 lbs., whereas an ordinary tap pulled up after tapping a full thread for a length of two diameters, the load being then 1,100 lbs., and stalling the machine.

Pipe Thread Tap Heads.

The Sheffield Small Tool Manufacturers have adopted the following list of sizes for the squares of pipe thread taps:—

No. of □.	Size of □ Inches. Fraction.	Size of □ Inches. Decimal.	Whitworth Thread Taps. Inches.	International Thread Taps. Millimetres.	Gas Tap. Inches.
0	7/64	·109	1/8	3 to 3½	—
1	9/64	·140	5/32	4 to 4½	—
2	5/32	·156	3/16	5	—
3	13/64	·203	¼	6 to 7	—
4	15/64	·234	5/16 and 3/8	8 to 10	⅛
5	9/32	·281	7/16	11 to 12	—
6	5/16	·312	½ and 9/16	13 to 14	¼
7	25/64	·390	5/8 and 11/16	15 to 17	3/8
8	29/64	·453	¾ and 13/16	18 to 21	½
9	35/64	·546	7/8 and 15/16	22 to 23	—
10	41/64	·640	1	24 to 26	⅝ and ¾
11	23/32	·718	1⅛	27 to 30	—
12	13/16	·812	1¼	31 to 33	⅞ and 1
13	27/32	·843	1⅜	34 to 36	—
14	29/32	·906	1½	37 to 41	1¼
15	1 5/64	1·078	1⅝ and 1¾	42 to 46	1½ and 1¾
16	1 13/64	1·203	1⅞ and 2	47 to 52	—
17	1 3/8	1·375	2⅛ and 2¼	54 to 58	2 and 2¼
18	1 7/16	1·500	2⅜ and 2½	60 to 64	—
19	1 29/64	1·625	2⅝ and 2¾	66 to 70	—
20	1 3/4	1·750	2⅞ and 3	72 to 76	2½ to 3

Intermediate diameters have same squares as sizes below.

The heads of fluted hand reamers have same size squares as Whitworth taps and International thread taps, respectively.

The sizes of squares are stated in fractions and in decimals of inches, to facilitate measurement with either the mechanics' rule or the micrometer calliper.

No. of □ may be quoted when ordering tap wrenches.

Work-tables of Machine Tools.

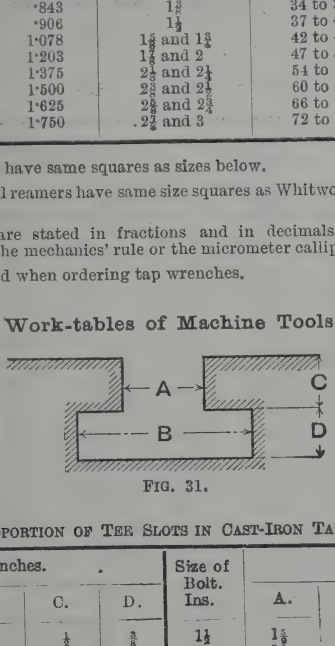


Fig. 31.

Proportion of Tee Slots in Cast-Iron Tables.

Size of Bolt. Ins.	Inches. A.	Inches. B.	Inches. C.	Inches. D.	Size of Bolt. Ins.	Inches. A.	Inches. B.	Inches. C.	Inches. D.
½	9/16	1	½	⅜	1½	1 5/8	2⅝	1½	1 1/16
⅝	11/16	1 1/16	⅝	½	1¾	1 7/8	3	1¾	1¼
¾	13/16	1 1/4	¾	⅝	2	2⅛	3½	2	1 5/16
⅞	15/16	1 5/16	⅞	11/16	2¼	2⅜	3⅞	2¼	1½
1	1 1/16	1 13/16	1	¾	2½	2⅝	4½	2½	1 5/8
1¼	1 3/16	1 15/16	1 5/16	13/16	2¾	2⅞	4¾	2¾	1¾
1½	1 5/16	2 3/16	1½	⅞	3	3⅛	5	3	1 7/8

Keeping Bolts in Place in Open-slotted Tables.

When bolts have to be used for repeat work in drilling machine or other open-slot types of tables, the flopping about and dropping of these bolts becomes a time-wasting nuisance. Fig. 32 shows two methods of holding them firmly in position, so that work can be removed

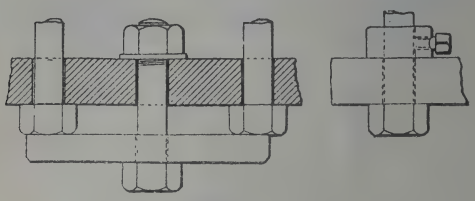


Fig. 32.

and a fresh piece substituted with the minimum of inconvenience. In the one case a clamp is suspended from a bolt and drawn up against the heads; in the other a loose collar is slipped down the bolt and tightened with a set-screw, an easier way than troubling to thread the bolt right down and putting a nut on. (*'Machinery.'*)

Pulley Arms and Bosses.

Diam. of Pulley. Ins.	Section of Arms. at Boss. Ins.	Section of Arms. at Rim. Ins.	Depth of Rib round the Boss. Ins.	Thickness of Metal round Shaft for Shaft Diameters in Ins. $1\frac{1}{2}$ to 2.	$2\frac{1}{8}$ to 3.	$3\frac{1}{8}$ to 4.	$4\frac{1}{8}$ to 5.	$5\frac{1}{8}$ to 6.
12	$1\frac{3}{4}\times\frac{1}{2}$	$1\frac{1}{4}\times\frac{1}{2}$	$\frac{5}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
15	$1\frac{7}{8}\times\frac{5}{8}$	$1\frac{3}{8}\times\frac{5}{8}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
18	$2\times\frac{3}{4}$	$1\frac{1}{2}\times\frac{5}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
21	$2\frac{1}{8}\times\frac{7}{8}$	$1\frac{5}{8}\times\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
24	$2\frac{1}{4}\times\frac{15}{16}$	$1\frac{3}{4}\times\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
27	$2\frac{1}{4}\times1$	$2\times\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
30	$2\frac{3}{4}\times1$	$2\frac{1}{4}\times\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$
33	$2\frac{7}{8}\times1\frac{1}{16}$	$2\frac{1}{4}\times\frac{7}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$
36	$3\times1\frac{1}{16}$	$2\frac{3}{4}\times\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$
39	$3\frac{1}{8}\times1\frac{1}{8}$	$2\frac{1}{4}\times1$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{7}{8}$
42	$3\frac{1}{4}\times1\frac{1}{8}$	$2\frac{3}{4}\times1$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{7}{8}$
45	$3\frac{3}{8}\times1\frac{1}{8}$	$2\frac{3}{4}\times1$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
48	$3\frac{1}{2}\times1\frac{1}{2}$	$2\frac{7}{8}\times1\frac{1}{16}$	$1\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
54	$3\frac{3}{8}\times1\frac{1}{2}$	$3\times1\frac{1}{16}$	$1\frac{3}{4}$	—	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{8}$
60	$3\frac{3}{4}\times1\frac{1}{4}$	$3\frac{1}{8}\times1\frac{1}{8}$	2	—	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{8}$
66	$4\times1\frac{3}{8}$	$3\frac{1}{4}\times1\frac{1}{4}$	2	—	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$
72	$4\frac{1}{2}\times1\frac{3}{8}$	$3\frac{1}{4}\times1\frac{5}{16}$	$2\frac{1}{8}$	—	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{3}{8}$
84	$4\frac{1}{2}\times1\frac{1}{2}$	$3\frac{3}{4}\times1\frac{1}{4}$	$2\frac{1}{4}$	—	2	$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{1}{2}$

Pulleys up to 17 ins. diam., 4 arms: from 18 ins. to 6 ft. diam., 6 arms; 6 ft. diam. upwards 8 arms.

Bolt Spacing.

Fig. 33 shows minimum spacings and pitches for Whitworth studs, bolts, and nuts, which will give sufficient space to enable a spanner to be used. Being for use with hexagonal nuts, a movement of 60° full is allowed for the spanner.

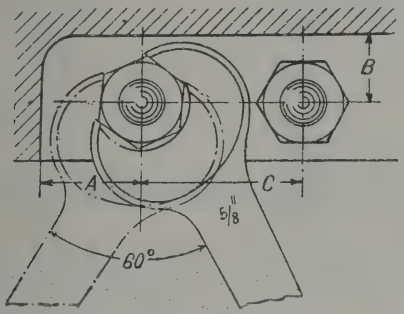


FIG. 33.

BOLT-SPACING TABLE.

Bolt Diameter.		Space A		Space B.		Pitch C.	
In.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
$\frac{1}{4}$	6·4	$\frac{5}{8}$	15·9	$\frac{7}{16}$	11·1	1	25·4
$\frac{5}{16}$	7·9	$\frac{11}{16}$	17·5	$\frac{1}{2}$	12·7	$1\frac{1}{8}$	28·6
$\frac{3}{8}$	9·5	$\frac{15}{16}$	23·8	$\frac{5}{8}$	15·9	$1\frac{7}{16}$	36·5
$\frac{7}{16}$	11·1	1	25·4	$\frac{13}{16}$	20·6	$1\frac{1}{2}$	38·1
$\frac{1}{2}$	12·7	$1\frac{1}{16}$	27·0	$\frac{7}{8}$	22·2	$1\frac{3}{4}$	44·4
$\frac{9}{16}$	14·3	$1\frac{1}{8}$	28·6	$\frac{15}{16}$	23·8	$1\frac{13}{16}$	46·0
$\frac{5}{8}$	15·9	$1\frac{5}{16}$	33·3	1	25·4	$2\frac{1}{4}$	57·1
$\frac{11}{16}$	17·5	$1\frac{3}{8}$	34·9	$1\frac{1}{16}$	27·0	$2\frac{5}{16}$	58·7
$\frac{3}{4}$	19·1	$1\frac{7}{16}$	36·5	$1\frac{1}{8}$	28·6	$2\frac{1}{2}$	63·5
$\frac{13}{16}$	20·6	$1\frac{1}{2}$	38·1	$1\frac{1}{4}$	31·7	$2\frac{9}{16}$	65·0
$\frac{7}{8}$	22·2	$1\frac{5}{8}$	41·3	$1\frac{5}{16}$	33·3	$2\frac{3}{4}$	69·8
1	25·4	$1\frac{7}{8}$	47·6	$1\frac{1}{2}$	38·1	3	76·2
$1\frac{1}{8}$	28·6	$2\frac{1}{8}$	54·0	$1\frac{1}{2}$	42·9	$3\frac{1}{2}$	88·9
$1\frac{1}{4}$	31·7	$2\frac{3}{8}$	60·3	$1\frac{7}{8}$	47·6	4	101·6
$1\frac{3}{8}$	34·9	$2\frac{1}{2}$	63·5	$2\frac{1}{8}$	54·0	$4\frac{3}{8}$	111·1
$1\frac{1}{2}$	38·1	$2\frac{5}{8}$	66·7	$2\frac{1}{4}$	57·1	$4\frac{5}{8}$	117·5
$1\frac{5}{8}$	41·3	$2\frac{3}{4}$	69·8	$2\frac{3}{8}$	60·3	$4\frac{3}{4}$	120·7
$1\frac{3}{4}$	44·4	$2\frac{7}{8}$	73·0	$2\frac{1}{2}$	63·5	5	127·0
2	50·8	$3\frac{3}{8}$	85·7	$2\frac{5}{8}$	66·7	$5\frac{5}{8}$	142·9
$2\frac{1}{4}$	57·1	$3\frac{7}{8}$	98·4	3	76·2	$6\frac{1}{4}$	158·8
$2\frac{1}{2}$	63·5	$4\frac{1}{4}$	108·0	$3\frac{1}{4}$	79·4	$6\frac{7}{8}$	174·6
$2\frac{3}{4}$	69·8	$4\frac{3}{8}$	111·1	$3\frac{3}{8}$	85·7	$7\frac{3}{8}$	187·3
3	76·2	$4\frac{7}{8}$	123·8	$3\frac{3}{4}$	95·2	$7\frac{3}{4}$	196·9

(*W. C. Hart, 'Mechanical World,' June 22, 1923.*)

Cast-Iron Muff Couplings.

Dimensions in Inches.					No. of Bolts.
Dia. of Shaft.	A. Dia. of Muff.	B. Thickness of Lug.	Length of Coupling	D. Dia. of Bolt.	
$1\frac{1}{4}$	$3\frac{3}{4}$	$\frac{13}{16}$	$5\frac{1}{4}$	$\frac{5}{8}$	2
$1\frac{1}{2}$	$4\frac{3}{4}$	$\frac{13}{16}$	$6\frac{1}{2}$	$\frac{5}{8}$	2
2	$5\frac{1}{2}$	$\frac{15}{16}$	$8\frac{1}{2}$	$\frac{3}{4}$	2
$2\frac{1}{2}$	$6\frac{1}{4}$	$\frac{15}{16}$	$9\frac{3}{4}$	$\frac{3}{4}$	3
$2\frac{3}{4}$	$7\frac{1}{4}$	1	$11\frac{1}{2}$	$\frac{3}{4}$	3
3	$7\frac{3}{4}$	1	13	$\frac{7}{8}$	3
$3\frac{1}{2}$	$8\frac{1}{2}$	$1\frac{1}{16}$	15	$\frac{7}{8}$	3
4	$9\frac{1}{2}$	$1\frac{1}{8}$	$16\frac{1}{2}$	1	3
$4\frac{1}{2}$	$10\frac{1}{2}$	$1\frac{3}{16}$	18	1	3
5	$11\frac{1}{2}$	$1\frac{1}{4}$	20	1	3

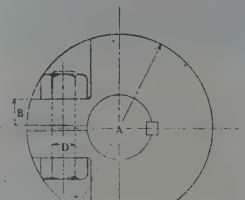
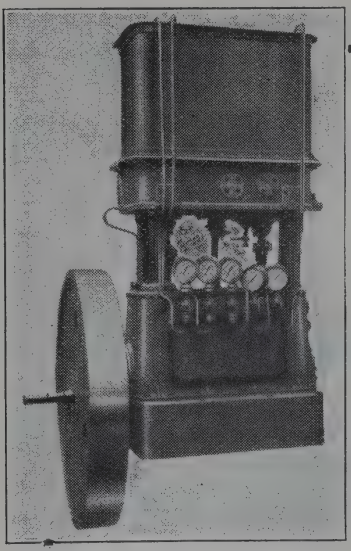


FIG. 34.

SECTION XXIII

THE ATMOSPHERE — WIND — AIR RESISTANCE — WIND-MILLS—TRANSMISSION OF POWER BY COMPRESSED AIR—AIR COMPRESSORS—PNEUMATIC DESPATCH TUBES

(With Contributions by Edward Butler, M.I.Mech.E., R. A. Sturgeon, A.M.I.C.E., and R. Myles Hook.)



BROTHERHOOD COMPRESSORS

for
Air
Oxygen
CO_2
Hydrogen
Ammonia
&c.

The illustration shows a five-stage compressor designed for a working pressure of $2\frac{3}{4}$ tons per square inch.

This is one example of the unrivalled range of Brotherhood Compressors.

(*See Editorial pages* 1254-1257.)

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SECTION XXIII

THE ATMOSPHERE—WIND—AIR-RESISTANCE—WINDMILLS—AIR COMPRESSION—AIR COMPRESSORS—PNEUMATIC DESPATCH TUBES.

The Atmosphere.

Air consists, by volume, of oxygen 20·84 parts, of nitrogen, 79·16 parts; and by weight, of oxygen 23·15 parts, and of nitrogen 76·85 parts. Also 0·03 to 0·04 per cent., by volume, of carbonic acid.*

One cubic foot of ordinary dry air at normal pressure, temp. 62° F., weighs 532·5 grains (saturated 529 grains); or 1 lb. of air contains 13·146 cubic feet.

Dry air is 819 times lighter than water. Aqueous vapour, 1·4 per cent. by volume.

At 60° a cubic foot of saturated air contains 0·00083 lb. of moisture. This increases to 0·00285 lb. at 100° and 0·030 lb. at 200°. These are exactly the same as the weight of a cubic foot of saturated steam at the given temperatures.

The viscosity of air in C.G.S. units is 1·48 at 15° C. (59° F.) and 1·49 at 16·5° C. (61·7° F.).

The mean weight of a column of air 1 inch square and 45 miles high is 15 lbs.

Density of air $= \left(\frac{1}{4}\right)^{\frac{h}{6\cdot8}} = (0\cdot8156)$; Pressure of air, $p = 14\cdot7\,(0\cdot8156)^{h}$ lbs. per sq. in.

$$h = \frac{\log.\frac{p}{14\cdot7}}{-0\cdot0885228}$$

where h = height in miles above surface of earth.

At 6·8 miles above the surface of the earth the air is 4 times lighter than at the earth's surface; at 13·6 miles, 16 times; at 20·4 miles, 64 times. Total weight of atmosphere, 5,300 billion tons.

According to a writer in *Nature*, the result of experiments made with forty balloons (sent up in Great Britain) has been that the isothermal layer was reached more than thirty times. Its average height was 35,000 ft. (10·7 kiloms.); it is rather higher with a high barometer. The mean temperature found was − 53·6° F. (−77° C.), considerably higher than the Continental mean. The extremes observed in England were −22° F., near Ditcham Park, Hants, on July 24, and −78° F., near Oxford, on September 12, 1907. On the same day, November 11, 1907, the temperature was −42° F. at Ditcham at 36,000 ft. altitude, −58° F. in Oxfordshire at 38,500 ft., and −74° F. near Manchester at 37,000 ft. The existence of an isothermal layer in equilibrium in which the fall of temperature suddenly stops, and yet in which such great differences of temperature occur at spots not very far from one another, is difficult to understand, especially considering the low atmospheric pressure at these heights. (See also page 216.)

To consume 1 lb. of coal requires 11½ lbs., or 150 cubic feet, of air to combine with it.

The work stored up in 1 cu. ft. of air at atmospheric pressure, i.e. the work it would do if allowed to expand into an absolute vacuum = 5,188 ft. lbs.

The expansion of air, like all other elastic fluids, is uniform at all temperatures.

---

* Air contains 15 parts of 'neon' and 5 parts of 'helium,' in one million volumes (*Dewar*).

If h = height of barometrical column of mercury ; K = number of square inches in section of tube ; 13,568 ozs., or 848 lbs. = weight of cubic foot of mercury at mean temperature : p = number of pounds pressure of air on square inch of surface ; then

Pressure of atmosphere on K sq. ins. $= p \times K$. Weight of column of mercury $= \frac{Kh}{1728} \times 848$.

But column of mercury balances the pressure of the atmosphere ; therefore

$$p \times K = \frac{Kh}{1728} \times 848, \quad \text{or,} \quad p = \frac{848}{1728} \times h = \frac{53h}{108} = \frac{h}{2} \text{ very nearly.}$$

Hence it appears that *the pressure of the atmosphere in pounds per square inch is very nearly equal to half the column of mercury in the barometer-tube in inches.*

The column of mercury in the barometer in this country varies from 28 to 31 ins. ; therefore the mean column is 29·5 ins. ; and by the foregoing result the mean pressure of the atmosphere will be about 14·7 lbs. per square inch.

Rankine assumes a standard English atmosphere to be 14·704 lbs. per square inch in the latitude of London, or equal to a mercury column 29·922 ins. high at 32° F., which = 30 ins. at 57·8° F.

The metrical atmosphere, 760 mm. (29·922 ins.), at 0° C. (32° F.) = 1·0333 kilograms per square cm., or 14·6967 lbs. per square inch, at Paris = 14·686 lbs. at New York.

To find the barometric height, H, at any latitude, l,

$$H = 760 \times \frac{(1 + 0{\cdot}00531 \sin^2 48° 50')}{(1 + 0{\cdot}00531 \sin^2 l)} \text{ mm.},$$

where 48° 50′ is the latitude of Paris.

The altitude or head of the atmosphere at uniform density will be that of a column of water 33·95 ft. high divided by the specific gravity of air (·0012046), or 28,183 ft. The velocity due at the foot of this head will be : $V = 8{\cdot}02 \sqrt{28183} = 1346{\cdot}4$ ft. per second, the velocity at which the air will pass into a vacuum. The motions and effects of gases by the force of gravity are precisely the same as those of liquids. Under like conditions a conduit will discharge 30·55 times more air than water.

Liquid Air.

Liquid air is produced by passing highly compressed air through a counter flow heat exchanger followed by an expansion device. On expansion the air is cooled and the cold air thus produced passes back through the heat exchanger, so cooling the incoming compressed air. The cooling is thus self-intensive, and finally results in liquefaction of part of the expanded air. The unliquefied part escapes through the heat exchanger, and so keeps up the cooling effect. The expansion may take place through a nozzle, or in an expansion engine with the output of external work. The initial pressure used varies in different systems from about 45 atms. to 200 atms. About 8 to 12 per cent. of the air supply is liquefied, and the power required is from 1 to 2 h.p. hrs. per lb. of liquid produced, according to size and type of plant employed.

The critical temperature of air, above which it cannot be liquefied, is −140° C., and the corresponding critical pressure is 39 atms. The boiling point at atmospheric pressure is about −190° C., and the latent heat of evaporation about 50 calories. The specific gravity of the liquid is about 0·88.

If liquid air (21 per cent. O_2) is allowed to evaporate quietly it gives off a vapour containing about 7 per cent. O_2 owing to the fact that nitrogen boils at a temperature 12° C. lower than that of oxygen. The remaining liquid consequently becomes richer in oxygen as evaporation proceeds, and the boiling point rises until finally a temperature of −184° C. is reached (the boiling point of liquid oxygen).

The chief use of liquid air is in the process of obtaining oxygen and nitrogen from the atmosphere by means of liquefaction and distillation. Argon and neon are also obtained in the same way by additions to the ordinary oxygen or nitrogen apparatus.

Liquid air as such is used industrially for obtaining very low temperatures. One application is the freezing of mercury vapour during the evacuation of radio valves where the evacuation is performed by mercury vapour pumps. The mercury vapour is prevented from reaching the valves by the insertion of a liquid air trap in the pump circuit. A somewhat kindred use is the charcoal pump, in which specially prepared charcoal is cooled in liquid air. When so cooled the charcoal absorbs a large volume of air, and so can produce a higher vacuum than is obtainable by any other known method.

Liquid oxygen is used in breathing apparatus either for mine rescue work or for high altitude flying. It is also used in conjunction with special cartridges as an explosive for use in quarries

and mines. The chief advantages of this explosive lie in the facts (1) that it can generally be manufactured on the spot, as suitable material for the cartridges can be obtained almost anywhere, and (2) that neither the cartridge nor the liquid oxygen is in itself explosive. The actual soaking of the cartridge which renders it explosive is only performed immediately before nsertion into the bore hole.

See also Section XXXIII, Part I.

Velocity of Air.

When air passes into an air of less density, the velocity of its passage is measured by the difference of the densities of the two.

H and h = densities of the air in inches of mercury; t = temperature (F.°) at the time of passage; and V = velocity of air in feet per second.

$$V = 1347{\cdot}4\sqrt{\frac{H-h}{h}\left(1+0{\cdot}002088t\right)}.$$

Pressure against a Plane Surface moved through the Air.

P = pressure against plane. a = area of plane, in square feet. v = velocity, in feet per second
v_1 = velocity in miles per hour.

$P = {\cdot}00142av^2$ lbs.* $\quad P = {\cdot}0029av_1^2$ lbs.*

$P = ({\cdot}003 + {\cdot}00004q)\,av_1^2$ lbs.,† where q = ratio of sides of rectangular plate.

The quantity ·003 decreases as v_1 increases, being ·0029 for 90 miles, and ·0032 for 0 to 25 miles.

Horse-power required to move a Plane Surface against the Air.

H.P. = horse-power. a = area of plane, in square feet. v = velocity, in feet per minute.

$H.P. = {\cdot}000{,}000{,}000{,}010{,}6av^3$.

TABLE SHOWING HORSE-POWER CONSUMED IN MOVING A PLANE SURFACE AGAINST THE AIR.

Speed in		H.P. per Sq.Ft. of Effective Surface.	Speed in		H.P. per Sq. Ft. of Effective Surface.
Miles per Hour.	Feet per Min.		Miles per Hour.	Feet per Min.	
10	880	0·00722	50	4,400	0·903
15	1,320	0·0244	75	6,600	3·05
20	1,760	0·0514	100	8,800	7·23
25	2,200	0·110	150	13,200	24·4
30	2,640	0·195	200	17,600	57·8

As a result of tests, M. Eiffel found that, for velocities of from 60 ft. to 130 ft. per second, the resistance offered by air to a moving surface is practically proportional to the square of the velocity, although the exponent increases slightly and gradually when velocities exceeding 100 ft. per second are employed. The resistance or pressure in pounds, P, is represented by the product KSV^2, where K is a constant depending on the size and shape of the surface tested; S is the area of the surface in square feet, and V is the velocity in miles per hour. At ordinary temperatures and a barometric pressure of 760 mm., M. Eiffel found that the value of the coefficient K ranged from 0·00286 to 0·00327, the latter value being apparently a maximum attained only with large surfaces. Thus, for a circular surface of 1 sq. ft., the value of K was 0·00286, for a square surface of the same area 0·00295, and for an area of 10 sq. ft. 0·00323. He also found that the resistance of an inclined surface is practically the same as that of a normal one, when the perpendicular to the surface makes an angle less than 30° with the direction of motion. For greater angles the resistance proportionately decreases (zero at 90°). On pressure boards ranging from 25 sq. ft. to 100 sq. ft. in area, which were mounted at the top of a 50 ft. tower, Dr. T. E. Stanton found, from a large number of experiments, that the mean value of this constant was 0·0032.

Dr. Hutton deduced that the resistance of air varied as the square of the velocity nearly, and to an inclined surface as the 1·84 power of the sine × cosine.

The figure of a plane makes no appreciable difference in the resistance, but the convex surface of a hemisphere, with a surface double the base, has only half the resistance.

At high velocities the resistance becomes nearly a constant quantity.

The resistance of the air to a train of cars in a dead calm was found to be $\frac{1}{356}$ of their weight.

The velocity of a train of cars which gave a resistance of $\frac{1}{256}$ of the load with a fair wind was 34½ miles per hour, and only 27¾ with an adverse wind.

* T. E. Stanton, National Physical Laboratory. † Hagen

Flow of Air.

Weight of Air Passing Through a Nozzle.

The weight of air at atmospheric pressure passing through a properly-designed nozzle into any vacuum of not less than 8 lbs. may be calculated as follows (Leblanc) :—

W = lb. weight per hour ; A = area of nozzle neck in square inches ; T = atmospheric temperature in deg. Cent.

$$W = \frac{20330A}{\sqrt{T + 273}}$$

Air Friction.

Recent experiments on the flow of air through smooth sheet steel ducts varying in size from 12 ins. to 48 ins. in diameter, at velocities ranging from 1,000 ft. to 2,400 ft. per min., appear to show that the average value of the coefficient of friction is 0·0035.

Impulse of Wind.

V = velocity of wind. D = direct impulse in pounds on one square foot.

$D = V^2 \times \cdot00271$, where V is in miles per hour } *
$D = V^2 \times \cdot00312$, where V is in knots per hour }

Velocity in Statute Miles per Hour.	Impulse in Pounds per Square Foot.	Velocity in Knots per Hour.	Impulse in Pounds per Square Foot.	Kind of Wind.
1	·00271	1	·00312	Light air.
2	·0108	2	·0125	
3	·0244	3	·0281	
4	·0434	4	·0499	Light wind.
5	·0678	5	·0780	
6	·0976	6	·112	Light breeze.
7	·133	7	·153	
8	·173	8	·200	Moderate breeze.
9	·220	9	·253	
10	·271	10	·312	Fresh breeze.
11	·328	11	·378	
12	·390	12	·449	
13	·458	13	·527	
14	·531	14	612	
15	·610	15	·702	Strong breeze.
16	·694	16	·799	
17	·783	17	·902	
18	·878	18	1·01	
19	·978	19	1·13	
20	1·08	20	1·25	
22	1·31	22	1·51	Moderate gale.
24	1·56	24	1·80	
26	1·83	26	2·11	Fresh gale.
28	2·12	28	2·45	
30	2·44	30	2·81	
32	2·78	32	3·19	Strong gale.
34	3·13	34	3·61	
36	3·51	36	4·04	
38	3·99	38	4·51	Heavy gale.
40	4·34	40	4·99	
45	5·22	45	6·32	Storm.
50	6·78	50	7·80	
60	9·76	60	11·2	Hurricane.
70	13·3	70	15·3	
80	17·3	80	20·0	
90	22·0	90	25·3	
100	27·1	100	31·2	

Model experiments carried out in a wind tunnel at Washington show that a wind blowing at 76 miles per hour produces a pressure of 22 lb. per sq. ft. on a tall building.

Wind Velocity by Robinson Anemometer.

If v = velocity of anemometer cups in miles per hour ; V = velocity of wind in miles per hour; then,

$$V = 2v + 4.$$

Instrument fails to record velocities below 4 miles per hour.

(*W. H. Dines*, 'Report of Astronomer Royal, 1921.'

* Recent researches have shown that the constants ·00271 and ·00312 are apparently too small by about 6 per cent.

WINDMILLS.

(Contributed by Edward Butler, M.I.Mech.E.)

The driving shaft of a windmill situated on level ground should, with a tower of moderate height, be tilted *upwards* at an angle of 6° to 8°. If on a low hill with the fall against the prevailing wind the shaft is better horizontal, but when situated on a steep hill the best result will be obtained by tilting the shaft *downwards* a few degrees.

The shaft should be mounted so that the driving-wheel faces the wind in either direction, and at a height ranging from 20-25 ft. on high ground, and 50-70 ft. on low ground, and so that it is clear of buildings or trees.

The tower should, in ordinary circumstances, be of sufficient strength to hold up against a 40-mile storm with a wind pressure of 8 lbs. per sq. ft. On exposed elevations subject to wind velocities exceeding this, a windmill unless specially constructed is not suitable.

WIND ACTION.

Velocity per hour in miles.	Pressure per sq. ft. in lbs.	Description of Wind.	Action on Windmill.
5	0·125	Faint breeze . .	Will not drive.
8	0·33	Breeze . . .	Will start against light load.
10	0·5	Fresh breeze . .	Will run slowly.
15	1·125	Good wind . .	Will run steadily.
20	2·	Strong wind . .	Gives best service.
25	3·125	Very strong wind .	Maximum useful effect.
30	4·5	Gale	Should be partly furled or held out of the wind.
40	8·	Storm	Must be totally put out of action.
60	18·	Violent storm .	Not safe.
80	30·	Hurricane . .	" "
100	50·	Tornado . . .	" "

Power of Windwheels.

The total momentum of wind is,

$$\frac{0{\cdot}08}{32{\cdot}2} \times \text{area} \times \text{velocity}^2 = 0{\cdot}0025\ AV^2, \text{ approximately.}$$

The turning moment at starting, for each vane, equals

$$0{\cdot}002\ AV^2 \cos\theta r,$$

and when in motion is

$$0{\cdot}0015\ AV^2 \cos\theta r \text{ for moderate speed,}$$

the constant ·0015 decreasing to 0·0012 with increase of speed:

where A = area of vane; V = velocity of wind; θ = angle to the axis of rotation; r = mean radius; 0·08 is the mean weight of one cubic foot of air. Velocity in ft. per sec. is to miles per hour as 22 is to 15.

HORSE-POWER OF WINDWHEELS.

Shaft or b.h.p. of a 4-armed wheel with cloth sails

$$= \frac{v^2 r^2}{512477}\ (\textit{Rankine}), \quad \frac{4\ A v^3}{1145833}\ (\textit{Weisbach}).$$

The brake h.p. of a multi-vaned wheel

$$= \frac{0{\cdot}6 \times 0{\cdot}78\ (D^2 - d^2) \times V^2}{33000};$$

where,

A = area of one vane; D = total diameter of wheel; d = clearance diameter at centre; = radius of sail tips; V = velocity in feet per second.

A windwheel (Dutch pattern) with four cloth sails, each 24 ft. in length and 6 ft. in breadth, will develop 4·5 b.h.p. in a 20-mile wind.

Windwheels with multiple vanes have a considerable advantage in starting with low velocity winds and in slow running.

The power of a windwheel is not so great as is popularly supposed. A 16 ft. wheel, for instance, with multiple cambered steel vanes, only develops about 1 b.h.p. in a 15-mile wind, and this is reduced to less than one-half in a 10-mile wind, although increased to nearly double in a 20-mile wind.

Construction.

According to windmill practice (old type) the wheel may have 4, 5, or 6 cloth sails of rectangular form, the length being equal to five times the breadth; but the total surface should not exceed one-third of the whole surface described by the radial arms carrying the sails. The angles of the cross bars for supporting the sails, which commence at one-seventh from the wheel centre, are usually 24°, 21°, 18°, 9°, 3°, from the plane of motion.

While more power can be gained by increasing the sail surface to more than one-half the wheel area, the difficulty is such with the old practice of using cloth sails that the sail area seldom exceeds one-third and is more often reduced to one-fourth.

The angles of the sails to the plane of motion, according to Smeaton, should be 20°, 19°, 18°, 16°, 12½°, 7°; and again, to Forrester, as 24°, 21°, 18°, 14°, 9°, 3°.

In multi-vane windwheels, the vanes—either oil-soaked wood slats, or cambered steel plates of light construction and galvanised—are carried by a series of 6-8 steel or wooden arms, fixed to a steel boss. The arms are braced to an extension of the wheel boss by tension rods. The vanes are fastened to two sets of cross-bars, connecting the arms together, in sections of 8 to 15, according to wheel diameter and angle to the plane of motion; this varies from 20° to 40°, but is generally 25° in flat or cambered vanes of uniform angle. The steeper the angle the narrower the vanes, to reduce whirl resistance. For direct connected pumps the angle is steeper than for geared down pumps. Steel vanes are cambered more for rigidity than for any increased driving efficiency. There is some advantage in forming the angle to suit the radius, but is not of such consequence as with wide cloth sails. What is of more importance is for the shaft to run in well lubricated roller bearings and for the turntable to move freely so that the wheel shall be held square to a light wind.

Power Control.

In windwheels with wide cloth sails, these are furled to suit either the load or the wind. In wheels with multiple vanes the usual practice is to fit a governor-vane on one side, at a right-angle to the wheel shaft, and for the tail-vane to be swivelled to the turntable, and to be held end-on either by a spring or a weight, or, better still, by a series of weights chained together. These weights should be proportioned for the governor-vane so as to pull the turntable, and the wheel with it, partly out of the wind as soon as the velocity increases 20-25 m.p.h., and to bring round the wheel edge-on to the wind in a storm.

Wind Pumps.

The popularity of wind-driven pumps is due to the introduction of the multiple-vaned wheel and to automatic governing, in combination with light easily-erected steel towers, the average power developed ranging from 1 to 6 shaft h.p., with a wind velocity of 15 m.p.h. (22 ft. per sec.), a 20-mile wind nearly doubling this power, and a 10-mile wind generating about half the power obtained by a 15-mile wind.

In ordinary practice the pumping capacity of a wind engine, as expressed in pounds of water raised per minute by pressure-head in feet, rarely exceeds from 25 to 35 per cent. of the wheel h.p., but is influenced by wheel diameter, the angle of the vanes, and the method of transmitting the power to the plunger.

In geared-down transmissions, the wheel-shaft pinion should be situated at the side of the pump wheel, and not above or below it. This disposition reduces friction and maintains correct alignment and mesh of the cogs.

Owing to the very inadequate fly-wheel effect of a windwheel, it works at considerable disadvantage in driving single-acting pumps direct, and only less so when geared down; double acting, or better, 3-throw single-acting pumps, oppose a more equable torque, but are impracticable for small installations. For this reason a rack or mangle transmission is peculiarly applicable to a wind-driven pump, as shown in the higher duty and efficiency in the table below.

The location of a wind pump is generally influenced more by the available water supply than from any consideration of available wind-power, the tower usually being constructed high enough—50 to 70 ft.—to clear all obstacles around for a distance of 300 to 400 ft. Under normal conditions eight hours' pumping only can generally be relied upon as a daily average; so that to make an installation successful a storage-tank or reservoir should be provided, the minimum capacity of which may with advantage equal from four to seven days' pumping, although a larger reserve is often allowed for.

TABLE SHOWING THE WORKING OF SIX SELECTED WIND ENGINES DURING TRIALS OF 150 HOURS, BY THE ROYAL AGRICULTURAL SOCIETY.

Name of Engine.	Diam. of Wheel in Feet.	Total No. of Gallons Pumped.	Total Pressure Head in Feet.	Total Revolutions of Wheel.	Total No. of Double Strokes of Pump.	Transmission.	Ratio of Wheel to Pump.	Particulars of Pumps. Diam. in Ins.	Particulars of Pumps. Stroke in Ins.	Single or Double Acting.	Average Water H.P. per Minute.
Canadian-Imperial	16	79,000	200	308,000	42,000	rack gear	5	4	22	double	·53
Henry Sykes, Ltd.	16	49,000	200	210,000	210,000	direct crank	1	2·5	8	„	·33
J. W. Titt . .	16	46,000	200	285,000	285,000	„ „	1	3·25	6·12	„	·30
Thomas & Son .	16	41,000	200	307,000	122,000	geared „	2·5	4	8	single	·275
R. Warner & Co. .	16	40,000	200	330,000	160,000	„ „	2	3·5	5	double	·268
J. W. Titt . .	16	36,000	200	230,000	88,000	„ „	2·5	4·5	8	„	·242

TABLE SHOWING PERFORMANCES OF WIND-PUMPING ENGINES, SHOWING QUANTITY IN IMPERIAL GALLONS PUMPED AGAINST A TOTAL HEAD OF 200 FEET, AS REGISTERED BY METER, PER DAY OF 10 HOURS.

Average Wind Velocity in miles per hour for each day.	Results of Two Engines with 8 ft. diameter wheels.		Results of Six Engines with 12 ft. diameter wheels.		Results of Seven Engines with 16 ft. diameter wheels.		Results of Three Engines with 20 ft. diameter wheels.		Result of Engine with 30 ft. diameter wheel.	
	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
5	—	—	650	320	1,200	350	—	—	940	—
8	—	—	1,500	900	3,000	600	1,600	800	4,000	—
10	—	—	2,000	950	4,000	1,600	3,500	1,200	7,000	—
12	—	—	2,400	1,000	4,200	2,000	4,100	3,800	8,000	—
15	400	—	4,000	1,250	5,600	3,750	6,000	4,000	13,000	—
18	700	—	3,500	1,700	5,200	4,500	—	—	19,000	—
20	900	700	4,200	1,400	6,930	4,200	—	—	21,000	—
22	800	—	4,500	1,500	7,600	3,300	—	—	23,000	—
24	—	—	4,950	1,600	10,400	3,600	—	—	24,000	—
	CORRECTED AVERAGE CAPACITY IN GALLONS PER HOUR RAISED 50 FEET.									
15	250		1,000		1,500		2,200		5,000	

AIR COMPRESSION.

RELATION BETWEEN PRESSURE AND VOLUME.

If

p = actual pressure of air in a container; p_1 = actual pressure of air when compressed;
P = gauge „ „ „ P_1 = gauge „ „ „
v = volume of air at pressure p; v_1 = volume of air when compressed;

then,

$$\frac{p}{p_1} = \frac{P + 14{\cdot}7}{P_1 + 14{\cdot}7} = \frac{v_1}{v},$$

the compressed air being *at the same temperature* as the air before compression—that is to say, if the heat due to the compression is allowed to become dissipated.

If the air is compressed from atmospheric pressure (i.e. if gauge pressure P = 0), then

$$\frac{14{\cdot}7}{P_1 + 14{\cdot}7} = \frac{v_1}{v},$$

or,

$$P_1 = 14{\cdot}7\frac{v - v_1}{v_1}, \quad \text{and} \quad v_1 = v\frac{14{\cdot}7}{P_1 + 14{\cdot}7}.$$

Example 1.—What gauge pressure (P_1) would be required to reduce 5 cub. ft. (v) of air at atmospheric pressure down to 3 cub. ft. (v_1), at the same temperature?

$$P_1 = 14{\cdot}7\frac{5 - 3}{3} = 9{\cdot}80 \text{ lbs.}$$

Example 2.—What volume (v_1) will 1 cub. ft. of air occupy when compressed to 30 lbs. gauge pressure (P_1), at the same temperature?

$$v_1 = 1\frac{14{\cdot}7}{30 + 14{\cdot}7} = 329 \text{ cub. ft.}$$

If the heat is not allowed to disappear when the air is compressed, then

$$\frac{14{\cdot}7}{P_1 + 14{\cdot}7} = \left(\frac{v_1}{v}\right)^{1{\cdot}408}$$

or,

$$P_1 = 14{\cdot}7\frac{v^{1{\cdot}408} - v_1^{1{\cdot}408}}{v_1^{1{\cdot}408}}, \quad \text{and} \quad v_1 = v\left(\frac{14{\cdot}7}{P_1 + 14{\cdot}7}\right)^{{\cdot}7102}.$$

If $P_1 = 30$, as in the case of *Example* 2, then the value of v_1 instead of being ·329, will be

$$(·329)^{{\cdot}7102} = ·454 \text{ cub. ft.}$$

WORK AND HORSE-POWER IN COMPRESSED AIR.

(1)

Work.

The effective work, W, stored up in 1 cu. ft. of compressed air (or the work required to compress the air) at a gauge pressure (pressure above atmosphere) of P_1 lbs. per sq. in. is

$$W = 352{\cdot}94\,(P_1 + 14{\cdot}7)\left(1 - \left(\frac{14{\cdot}7}{P_1 + 14{\cdot}7}\right)^{0{\cdot}29}\right) \text{ ft. lbs.}$$

Example.—1 cu. ft. of compressed air at a gauge pressure of 10 lbs. (the resulting heat not being allowed to disappear when the compression takes place) will contain:

$$352{\cdot}94 \times 24{\cdot}7\left(1 - \left(\frac{14{\cdot}7}{24{\cdot}7}\right)^{0{\cdot}29}\right) = 352{\cdot}94 \times 24{\cdot}7(1 - 0{\cdot}86028) = 1{,}218 \text{ ft. lbs. o}$$

effective work, *i.e.* the work it would do in expanding down to atmospheric pressure.

Horse-Power.

The H.P. required to produce 1 cu. ft. per min. of compressed air at P_1 lbs. pressure, i

$$W \div 33{,}000, \quad \text{or,} \quad H.P. = 0{\cdot}0107\,(P_1 + 14{\cdot}7)\left(1 - \left(\frac{14{\cdot}7}{P_1 + 14{\cdot}7}\right)^{0{\cdot}29}\right).$$

Example.—To produce 1,000 cu. ft. per min. of compressed air at 10 lbs. pressure woul require

$$H.P. = 1{,}218 \div 33{,}000 \times 1{,}000 = 36{\cdot}9.$$

(2)

Work.

The effective work, w, stored up in 1 cu. ft. of air at atmospheric pressure when compressed to a gauge pressure of P_2 lbs. per sq. in., is

$$w = 352{\cdot}94 \times 14{\cdot}7 \left(\left(\frac{P_2 + 14{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 1 \right) = 5188{\cdot}2 \left(\left(\frac{P_2 + 14{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 1 \right) \text{ ft. lbs.}$$

Example.—1 cu. ft. of atmospheric air, when compressed to a gauge pressure of 10 lbs. (the resulting heat not being allowed to disappear when the compression takes place), will contain

$$5188{\cdot}2 \left(\left(\frac{24{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 1 \right) = 5188{\cdot}2 \, (1{\cdot}1624 - 1) = 843 \text{ ft. lbs. of effective work.}$$

Horse-Power.

The H.P. required to compress 1 cu. ft. per min. of air at atmospheric pressure to P_1 lbs. gauge pressure, is

$$W \div 33{,}000, \text{ or, } \text{H.P.} = 0{\cdot}157 \left(\left(\frac{P_1 + 14{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 1 \right).$$

Example.—To compress 1,000 cu. ft. per min. of atmospheric air to 10 lbs. gauge pressure would require

$$\text{H.P.} = 843 \div 33{,}000 \times 1{,}000 = 25{\cdot}6.$$

(3)

$$\frac{W}{w} = \left(\frac{P_1 + 14{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}7102}.$$

Example.—If $P_1 = 10$ lbs.,

$$\frac{W}{w} = \left(\frac{24{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}7102} = 1{\cdot}446.$$

INCREASE OF TEMPERATURE OF AIR BY COMPRESSION.

If air at atmospheric pressure and at a temperature $t_1°$ F. be compressed suddenly to a gauge pressure P_1, then the temperature will be raised to $t_2°$ F., where

$$t_2° = (459 + t_1°) \left(\frac{P_1 + 14{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 459.$$

Example.—If air at 32° F. temperature ($t_1°$) be compressed to 10 lbs. gauge pressure (P_1), then temperature $t_2°$ of air will be raised to

$$t_2° = 491 \left(\frac{24{\cdot}7}{14{\cdot}7} \right)^{0{\cdot}29} - 459 = 491 \times 1{\cdot}162 - 459 = 112° \text{ F.}$$

PRESSURE OF AIR PRODUCED BY INCREASE OF TEMPERATURE.

If air at atmospheric pressure in a closed vessel and at $t_1°$ F. be raised to $t_2°$ F., then the gauge pressure, P_1, of the air will be

$$P_1 = 14{\cdot}7 \left(\frac{459 + t_2}{459 + t_1} \right)^{3{\cdot}45} - 14{\cdot}7.$$

Example.—If $t_1° = 32$, $t_2° = 112$, then $P_1 = 14{\cdot}7 \left(\frac{571}{491} \right)^{3{\cdot}45} - 14{\cdot}7 = 24{\cdot}7 - 14{\cdot}7 = 10$ lbs.

INCREASE OF VOLUME OF AIR BY INCREASE OF TEMPERATURE.

If a volume, V_1, of air at atmospheric pressure and at $t_1°$ F. be raised to $t_2°$ F., the air being allowed to expand freely, then the volume V_2 at $t_2°$ F. will be

$$V_2 = V_1 \frac{461 + t_2°}{461 + t_1°}.$$

Example.—If volume V_1 of air at 32° ($t_1°$) be 1,000, then volume V_2 at 525° ($t_2°$) will be:

$$V_2 = 1{,}000 \frac{461 + 525}{461 + 32} = 1{,}000 \times \frac{986}{493} = 2{,}000.$$

The following table gives the increase in volume from 32° F:—

INCREASE OF VOLUME OF AIR BY INCREASE OF TEMPERATURE FROM 32° F.

F.°	V.	F.°	V.	F.°	V.	F.°	V.	F.°	V.
32	1,000	49	1,034	66	1,069	83	1,103	100	1,138
33	1,002	50	1,037	67	1,071	84	1,105	110	1,158
34	1,004	51	1,039	68	1,073	85	1,107	120	1,178
35	1,006	52	1,041	69	1,075	86	1,110	130	1,199
36	1,008	53	1,043	70	1,077	87	1,112	140	1,219
37	1,010	54	1,045	71	1,079	88	1,114	150	1,239
38	1,012	55	1,047	72	1,081	89	1,116	160	1,260
39	1,014	56	1,049	73	1,083	90	1,118	170	1,280
40	1,016	57	1,051	74	1,085	91	1,120	180	1,300
41	1,018	58	1,052	75	1,087	92	1,122	190	1,320
42	1,020	59	1,055	76	1,089	93	1,124	200	1,341
43	1,022	60	1,057	77	1,091	94	1,126	210	1,361
44	1,024	61	1,059	78	1,093	95	1,128	212	1,365
45	1,026	62	1,061	79	1,095	96	1,130	300	1,544
46	1,028	63	1,063	80	1,097	97	1,132	400	1,746
47	1,030	64	1,065	81	1,099	98	1,134	500	1,949
48	1,032	65	1,067	82	1,101	99	1,136	525	2,000

AIR COMPRESSORS.

The mechanical efficiency of air compressors is about 60 per cent. at 5 pounds per square inch, increasing to 80 per cent. at 40 pounds per square inch and above. It is quite usual for the best makes to attain an efficiency exceeding 90 per cent., but for general purposes it is wiser to assume the lower figure. In the case of machines of small output and low pressure, the efficiency is frequently below 50 per cent.

In providing a driving unit for an air compressor, the type of machine should be considered before fixing the size of the driver. Thus, the turning effort required by a single-acting, single-cylinder air compressor may vary considerably above and below the mean, and allowance must be made for this, particularly in the case of direct-coupled drives.

DESIGN OF AIR COMPRESSORS.

The best practice adopted in the design of air compressors is as follows:—The maximum terminal pressures are, for one stage, 80 lbs. to 100 lbs. per sq. in.; two stages, 600 lbs. per sq. in.; three stages, 1,500 lbs. per sq. in.; four stages, 2,500 lbs. to 3,000 lbs. per sq. in.; five stages, 4,500 lbs. per sq. in.; and above 4,500 lbs. per sq. in., six or seven stages to 6,000 lbs. per sq. in., which is about the highest pressure for which an air compressor has been constructed. In the case of very small machines these pressures, for a given number of stages, are often exceeded in order to reduce complication. For example, machines have been constructed and work quite satisfactorily when compressing to 2,500 lbs. per sq. in. in two stages. The temperatures attained, however, make it necessary to carry out the cylinder lubrication by soapy water.

(*J. M. Ford, in a paper read before the Greenock Association of Shipbuilders and Engineers.*)

'BROTHERHOOD' AIR COMPRESSORS FOR MODERATE PRESSURES.

(*Peter Brotherhood, Ltd., Peterborough.*)

These compressors are made in a wide range of sizes, for small capacities of the single-acting trunk-piston type and for larger capacities of the double-acting type. The former are lubricated automatically, and the latter by forced lubrication.

BROTHERHOOD AIR COMPRESSOR

FIG. 1.—Details of Valves.

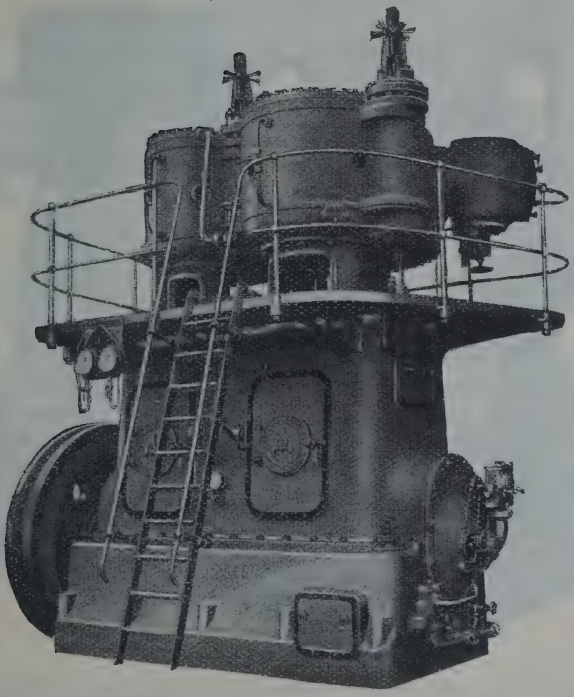


FIG. 2.

BROTHERHOOD AIR COMPRESSOR.

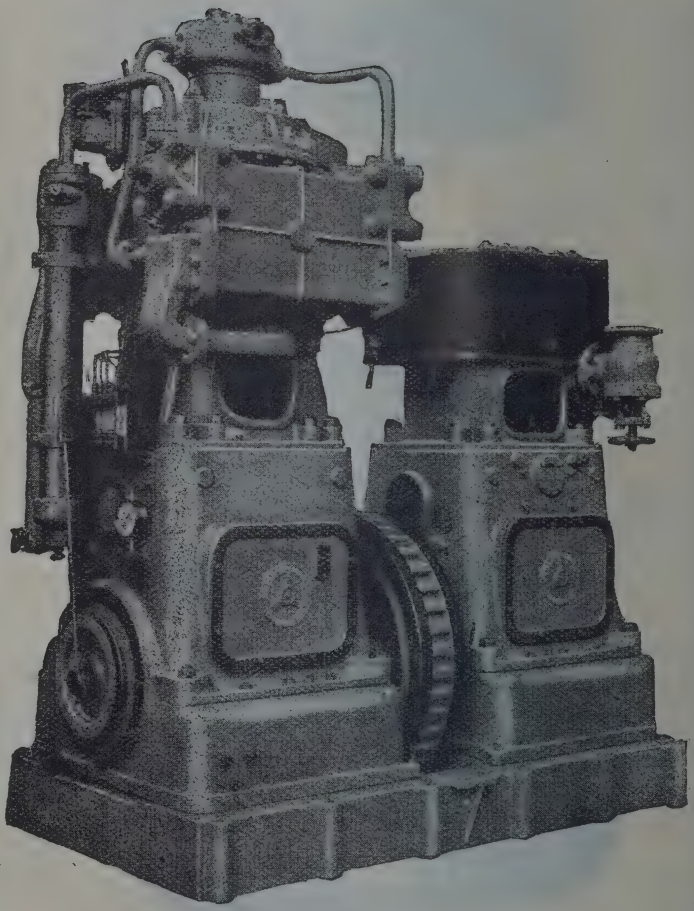


FIG. 3.

The single-acting types are designed for one or two stage, working up to a free air capacity of about 200 cu. ft. per minute, and are suitable for driving by belt, motor, or engine.

The double-acting types include single-line simple and tandem two-stage machines up to about 800 cu. ft. of free air per minute, and two-line simple and two-stage up to about 6,000 and 5,000 cu. ft., respectively.

The valves, which are illustrated on fig. 1, p. 1255, combine a large opening with very small moving mass, and will operate continuously at very high speeds.

The general construction of the double-acting types is shown on fig. 2, which illustrates a two-stage machine of 4,000 cu. ft. free air capacity.

The governing adopted varies according to the form of drive employed; for belt or motor drive the compressor is unloaded and reloaded as the air in the receiver rises or falls above and below the normal. For steam drive the speed is regulated and the air discharge controlled by a combined centrifugal and pressure governor.

'Brotherhood' High-Pressure Compressors for Air or Gas.

(Peter Brotherhood, Ltd., Peterborough.)

Brotherhood multi-stage compressors embody an exceptionally wide range of types resulting from development and research extending over sixty years. Standard types deal with pressures ranging from 600 to 6,000 lbs. per sq. in., in three to six stages of compression.

With the exception of compressors for oxygen, all piston and gland packings are of the metallic ring type, and except for special purposes, all classes have the working parts enclosed and lubricated under pressure.

Fig. 3 shows a three-stage air compressor for auxillary air service for fuel injection and manœuvring in a motor ship.

The capacity of the compressor is 300 cu. ft. of free air per minute compressed to 1,000 lbs. per sq. in. at 350 r.p.m. The compressor is driven by a Brotherhood Force Lubricated Steam Engine developing 140 b.h.p.

Westinghouse Air Compressors.

(Westinghouse Brake and Saxby Signal Co., Ltd., 82 York Rd., King's Cross, London, N. 1.)

The valve motion of the Westinghouse type of steam-driven air compressor is simple and compact, being entirely in the tophead, and all its parts are so arranged as to readily permit of examination or replacement. Should repairs to the valve mechanism be necessary, the tophead can be quickly removed and replaced by another, so that no unnecessary delay need occur through the compressor being put of service, pending repair. The air valves are contained in separate cases, so placed that they can readily be taken out.

The compressors are arranged vertically, and consist of a steam cylinder connected by a centre-piece to an air cylinder, or air cylinders, for either simple, compound, or three-stage compression. The three-stage compressor, figs. 4 and 5, is so constructed that air for compression is inhaled only on the upstroke of the piston, whilst on the downward stroke air at atmospheric pressure is drawn into and circulates around the inner walls of the cylinder and piston, to be again expelled on the succeeding upstroke; thus a supply of cool air is drawn into the interior of the compressor at every alternate stroke, and the compressor is air-cooled internally as well as externally; the result being that air compressed up to 300 lbs. per square inch is delivered at a temperature not exceeding 266° F., rendering the employment of water-cooled jackets unnecessary with this type of compressor.

For service on electric railways, the Westinghouse Brake & Saxby Signal Co., Ltd., manufacture air compressors driven direct by special slow-speed electric motors and also geared compressors driven by high-speed motors. Both of these types are equally suitable for industrial service.

Belliss High-Speed Forced-Lubricated Compressor.

(Belliss & Morcom Ltd., Birmingham.)

This type of compressor, fig. 6, p. 1255, embodies the best features of the Belliss engine, including the system of forced lubrication originated by the firm in 1890 (see Section XXX., Part III.). The working parts are generally the same as those for the 'C' type engine described in the section referred to. The air cylinders are water-jacketed and two-stage, as desirable for pressures in excess of 60 lbs. per sq. in., except in the case of quite small compressors.

WESTINGHOUSE THREE-STAGE AIR COMPRESSOR.

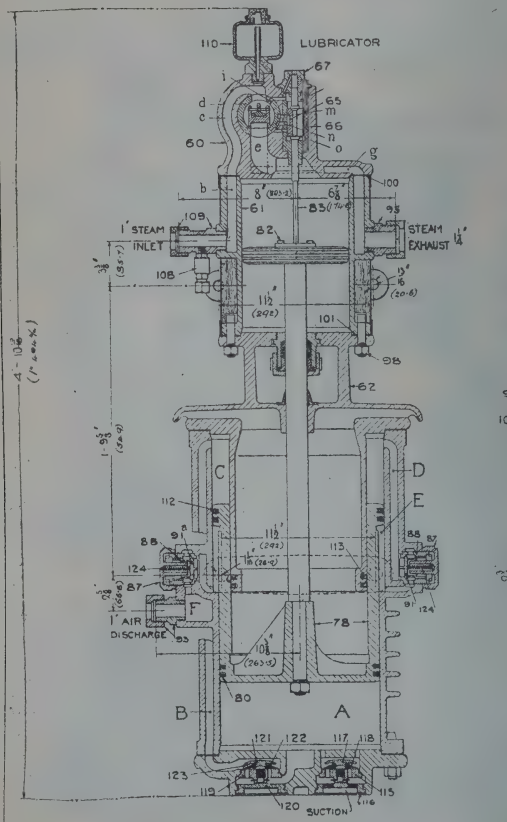


FIG. 4.

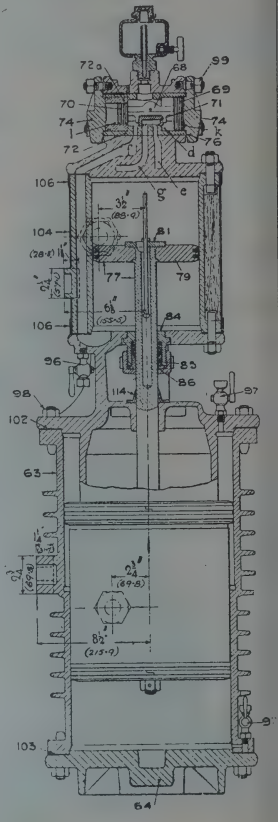
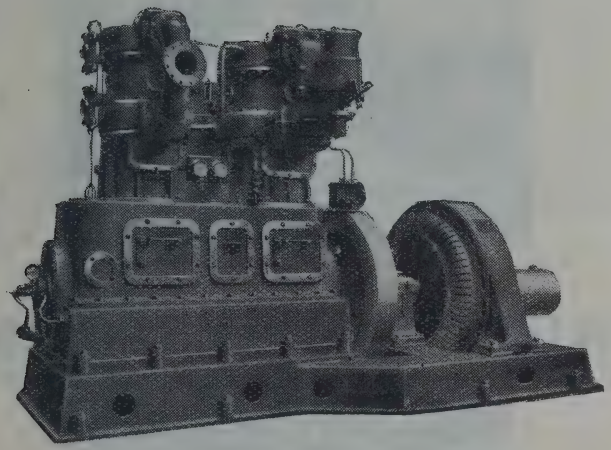


FIG. 5.

'SENTINEL' AIR COMPRESSORS



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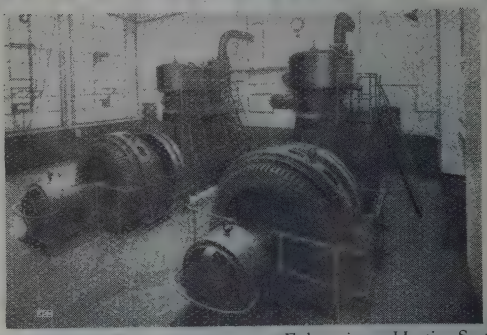

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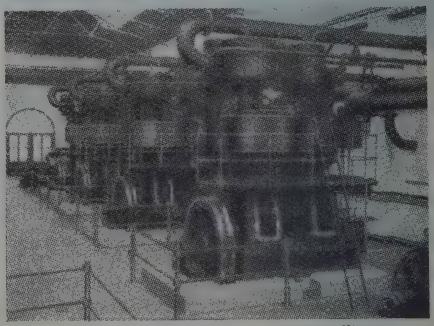
AIR COMPRESSORS

RECIPROCATING AND ROTARY TYPES



4 Steam-Driven Compressors at a Colliery.
Each 3000 cubic feet capacity.

BELLISS & MORCOM, LTD.

BIRMINGHAM.

ESTABLISHED 1852.

F. 1259

The compressor shown is adapted for being directly connected to an electric motor or for rope or belt driving. When operated at constant speed the air supply is controlled by an automatic valve on the inlet as shown, the valve being of the equilibrium double-beat type and con-

BELLISS AIR COMPRESSOR.

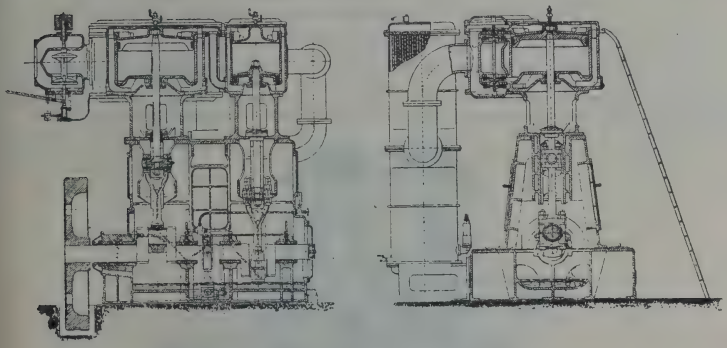


FIG. 6.—The Belliss Two-Stage Air Compressor.

trolled by an air relay, so designed that on the air pressure exceeding the intended pressure by 3 to 5 per cent. the air supply is cut off entirely, the pistons running *in vacuo* until the demand again causes the pressure to fall. As the air supply is not throttled the system is a higly efficient one. Special tests have demonstrated that the power required to run the compressor light

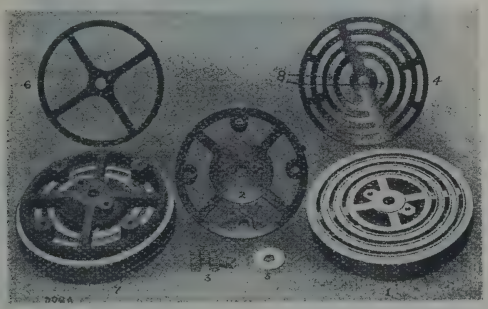


FIG. 7.—Details of Valves used in Belliss Compressors.

may be only 6 per cent. of the full power, and under 9 per cent. for the compressor and motor combined.

One of the chief points in the design of these compressors is the air valves. These are of the Rogler-Hoerbiger patent thin plate type, fig. 7, devised as the result of experience gained during the construction of the Simplon Tunnel, and which have come to be recognised as one of the best types of valves for air compressors. The valves consist of light discs of tempered

steel, perforated to give a multiple opening and falling on a cast-iron grid with suitable cushion and guard plates above. These valves are very reliable, noiseless in action, and a minimum amount of power is lost in operating them.

The Bellis compressors are also made with self-contained steam cylinders, controlled by the makers' patent relay type air governor, designed to vary the speed of the compressor in accordance with the demand for air, there being also a centrifugal governor directly connected to the crankshaft to prevent the speed under any conditions exceeding a predetermined maximum.

The 'Holman' Single-Stage Air Compressor.

(Holman Bros., Camborne)

The Holman P.I. type compressor, fig. 8, has one large outlet valve A in the cylinder cover and one large suction valve B in the piston head. It is a uniflow type engine, i.e. the air is not reversed in direction, but passes through the cylinder from bottom to top. The intake air is drawn direct from the atmosphere through a large inlet port in the side of the cylinder C.

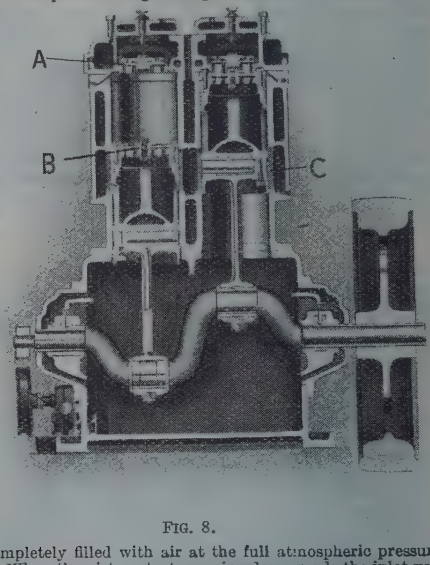


Fig. 8.

The cylinder is completely filled with air at the full atmospheric pressure at every suction stroke of the piston. When the piston starts moving downwards the inlet valve remains behind due to its inertia, and the air immediately enters the cylinder. No partial vacuum whatsoever is caused.

The size of each valve is fixed only by the volume of air passing. Owing to the space available, there is no restriction of the portways, and there is no wire drawing on either the suction or delivery strokes.

Ports are eliminated, the valves being inside the cylinder.

As there is only one valve in the cylinder cover, there is ample space for a large water jacket. The temperature of the delivery valve is exceptionally low for single-stage compression, and valve breakages are eliminated.

The valves are a high-grade steel in the shape of thin plates with portways. They are ground with very great care, so that they bed perfectly on their seatings; they are automatic in action, are unable to rotate, and, therefore, bed always in the same place; they cannot get out of adjustment.

Owing to the large size of the valve ports the lift is small: this, coupled with extreme lightness of the valve plates, reduces the wear and noise to a minimum.

By removing five nuts the delivery valve is withdrawn, the removal of one more nut freeing the suction valve. No water connections need be broken, nor need intake and delivery connections be removed.

The largest machine of this design has a capacity of 272 cub. ft. per min. Above this size the two-stage double-acting principle is adopted. Forced lubrication is used throughout.

The New Holman Rotary Air Compressor.

(Hele-Shaw Beacham System.)

(Holman Bros., Camborne.)

This compressor, fig. 9, is a development of the H.S. Rotary Oil-Pump, which has been in use for some twenty years; it is the joint invention of Dr. H. S. Hele-Shaw, F.R.S., and Mr. T. E. Beacham, B.Sc.

One of the outstanding features of the compressor is the cylindrical body, which rotates round a fixed cylindrical valve. The reciprocal movements of the pistons are effected by means of an eccentric floating ring, which is carried on ball-bearings and rotates freely with, though it is not fixed to, the cylinder body. By combining with this mechanism a special means of sealing and lubrication, the compressor has been made capable of continuous running at a speed of 1,000 or more revolutions per minute in ordinary practice; and in a recent experiment a Holman Rotary Compressor was successfully driven at 2,300 r.p.m.

Details of Construction.

There are two low-pressure and two high-pressure cast-iron cylinders, the sides of each being pierced by slots which receive the gudgeon pins. The centre of the casting is bored to fit the central valve. The ports in the cylinders are conical in form; those of the low-pressure are to the left, and those of the high-pressure to the right, of the centre line. The valve, though

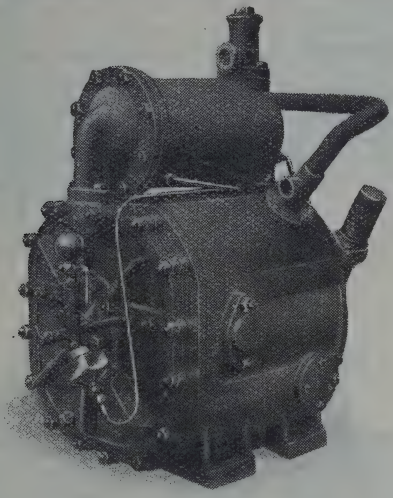


Fig. 9.

of somewhat intricate design, works very efficiently. The automatic lubrication of the valve prevents direct contact with the cylinder casting, so that wear and tear are reduced to a minimum.

A special feature of the low-pressure pistons is a conical protuberance at the base, which fits into a hole of similar shape in the cylinder casting. Grooves in this projection pick up oil from the cylinder walls and supply it automatically to the gudgeon-pin bearings.

The driving shaft is screwed to the cylinder. It is bored at the end to receive the roller-bearing which supports the valve, and is perforated to facilitate lubrication of the ball-bearings and the passage of suction air to the valve.

All rotating parts are enclosed in cast-iron cylindrical casing, provided with a water jacket and carrying the two floating rings, the driving shaft bearing and the inter-cooler and after-cooler.

The two coolers are unique in that they are not of the usual pipe form. They are enclosed in one aluminium casting, the lower portion forming the inter-cooler and the upper portion the after-cooler. The water, which passes between the cooler and the casing, is so directed that the coolest water comes into contact with the coolest air.

Another novel feature is the system of lubrication. The inflowing air is saturated with oil, thus ensuring entirely 'fool-proof' lubrication, perfect air seal round the valve and pistons, and the absorption of heat from the air during compression. A special device, the oil eliminator, into which the air passes from the after-cooler, removes the oil from the air by means of a wire filter, from which the oil passes into the pump.

The volumetric efficiency of the Holman Rotary Compressor is exceptionally high, and the isothermal efficiency is practically constant over the whole range of delivery pressures.

In the smaller sizes the compressor is readily portable, and is very compact.

The compressor has been used by the Admiralty and the Air Ministry.

The Holland 'SLM' Rotary Air Compressor.

(Bernard Holland & Co., 17 Victoria St., London, S.W. 1.)

(1) This Rotary Air Compressor, figs. 9A, 9B, consists essentially of a fixed casing or stator in which is a rotor fitted with blades free to move radially. As the rotor is less in diameter than the bore of the stator or casing and is placed eccentrically within it, there is a crescent-shaped space between

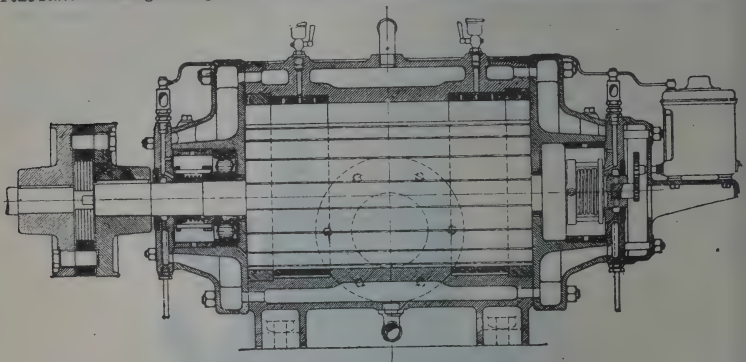


FIG. 9A.—The Holland 'SLM' Rotary Air Compressor.

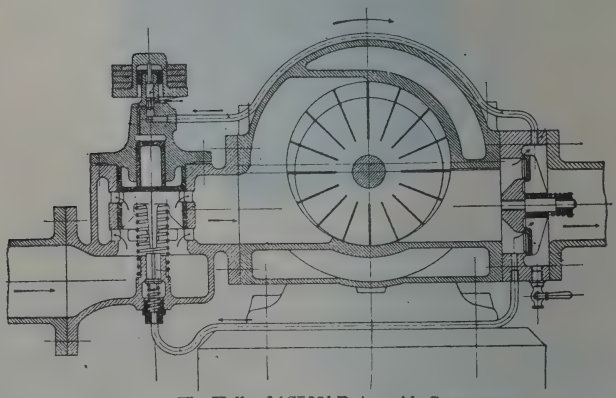


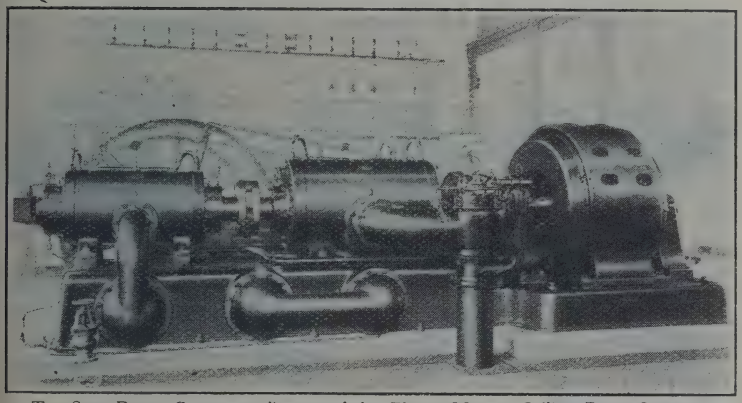
FIG. 9B.—The Holland 'SLM' Rotary Air Compressor.

them. When the rotor is revolved, the blades, maintained by centrifugal force in contact with the casing, divide the crescent-shaped space into cells, which, each in turn, expand from a minimum to a maximum cubic capacity (suction period) and then decrease to a minimum cubic capacity (compression and delivery period).

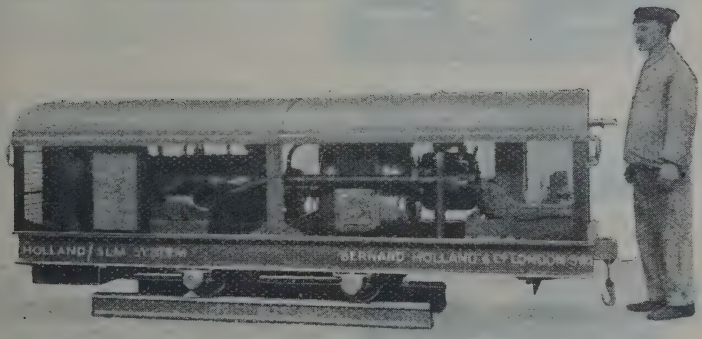
Floating rings, one near each end of the rotor and revolving in unison with it, take the greater part of the thrust of the blades, so restricting and controlling their pressure on the wall of the casing; the consequent low friction and the absence of reciprocating parts and valves allow of this compressor being run at high speeds of revolution without vibration or perceptible wear after long use.

ROTARY AIR COMPRESSORS

Holland S.L.M. System



Two-Stage Rotary Compressor direct coupled to Electric Motor in Colliery Power Station. Capacities up to 7,000 cub. ft. per min.



Portable Rotary Air Compressor for in-Bye Working with explosion-proof Electric Motor.

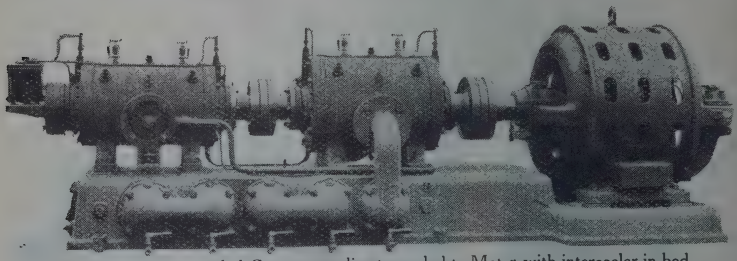
BERNARD HOLLAND & CO.

17 Victoria Street, LONDON, S.W.1.

F. 1262

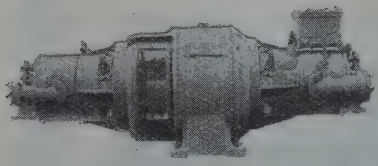
ROTARY AIR COMPRESSORS *and* VACUUM PUMPS

Holland S.L.M. System for all Industries



Two-Stage water-cooled Compressor direct coupled to Motor with intercooler in bed. Pressures up to 150 lbs. per square inch.

Single-Stage water-cooled, belt-driven Compressor. Pressures up to 60 lbs. per sq. inch.



Two-Stage Rotary air-cooled Brake Compressor, with Motor in one unit.

Two-Stage Vacuum Pump in one Casing. Vacuum up to 99·9 per cent.

BERNARD HOLLAND & CO.

17 Victoria Street, LONDON, S.W.1.

F. 1263

Metallic glands of special design dispense with the use of stuffing-boxes and packing. The lubrication is by pump, and is automatic.

Air-cooled single-stage compressors are made for pressures up to 10 lbs. per sq. in., and water-cooled single-stage machines for pressures up to 60 lbs. per sq. in. Water-cooled two-stage machines are supplied for pressures up to 150 lbs. per sq. in. and, dependent on size, up to 200 lbs. per sq. in. They are made in a number of standard sizes ranging from 6 cu. ft. to 4,000 cu. ft. delivery of free air per minute. For certain duties much larger units can be built.

The pumps are particularly suitable for continuous duty, coupled direct to electric motors and other fast-running prime movers; they are also arranged for belt and chain drive. They occupy little space, run without vibration, and need but inexpensive foundations.

(2) These machines can be so arranged as to perform the dual service of compressing and exhausting, one and the same machine being operated, at will, either as a compressor or as a vacuum pump. (See p. 1265).

Air-Compressor Packing.

'BRITIMP' BRAND HOLLOW RING PACKING.

(*British Metallic Packings Co., Ltd., 7 Princes Street, Westminster, S.W.* 1.)

This packing is largely used for high-pressure air and gas compressors, also for water-pumps, hydraulic accumulators, stop valves, emergency valves, expansion joints, gun recoil chambers,

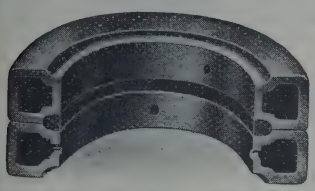


FIG. 9C.

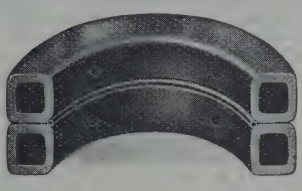


FIG. 9D.

etc. The packing consists of hollow circular rings filled with graphite. The inner walls of the rings contain small holes through which the graphite is squeezed, thus providing the necessary lubrication. The rings are made in two forms, as shown in figs. 9C and 9D.

See also pp. 1805, 1844, and 1949.

Air-Compressor Lubrication.

An oil suitable for air-compressors should always be highly filtered, because such oil will have a minimum tendency to form carbon deposits. Oils compounded with vegetable or animal oils are quite unsuitable for air cylinders.

Use only a straight-run, highly filtered, pure mineral oil of the lowest natural flash test consistent with the viscosity necessary to lubricate the cylinders and provide a proper piston seal.

The correct viscosities (worked out by the members of the Compressed Air Society, U.S.A., all of whom are builders of air-compressors) are given in the following tables, showing the proper specifications for both paraffin and asphaltic oils of various viscosities.

PHYSICAL TESTS OF PARAFFIN-BASE OILS. (*W. F. Osborne.*)

	Minimum.	Average.	Maximum.
Gravity, Baumé	28–32 deg.	25–30 deg.	25–27 deg.
Flash point, open cup	375–400 deg. F.	400–425 deg. F.	425–500 deg. F.
Fire	425–450 deg. F.	450–475 deg. F.	475–575 deg. F.
Viscosity (Saybolt) at 100 deg. F.	120–180 sec.	230–315 sec.	Up to 1,500 secs.
Colour	Yellowish	Reddish	Dark red to green
Congealing point (pour test)	20–25 deg. F.	30 deg. F.	35–45 deg. F.

PHYSICAL TESTS OF ASPHALTIC BASE OILS.

	Minimum.	Average.	Maximum.
Gravity, Baumé	20–22 deg.	19·8–21 deg.	19·5–20·5 deg.
Flash point, open cup	305–325 deg. F.	315–335 deg. F.	330–375 deg. F.
Fire	360–380 deg. F.	370–400 deg. F.	385–400 deg. F.
Viscosity (Saybolt) at 100 deg. F.	175–225 sec.	275–325 sec.	475–750 sec.
Colour	Pale yellow	Pale yellow	Pale yellow
Congealing point (pour test)	0 deg. F.	0 deg. F.	0 deg. F.

Cooling Water for Air Compressors.

Cooling water for cylinder jackets, cylinder heads, and intercoolers should always be turned on before the compressor is started. In case of stage compression, the greatest efficiency is obtained with the outlet water from the intercooler at a low temperature. The water supply to air cylinders and intercooler should be independent of each other, and the flow controlled by a valve on the inlet. The water should be shut off when the compressor is stopped, and in freezing weather all jacket drains should be opened. Outlet water should flow into open funnels so that frequent temperature readings can be made, a rise in temperature indicating deficient cooling, carbonised discharge valves, or leaking piston rings. The use of the thermo-siphon cooling system is not recommended.

NOTE ON AIR-COMPRESSOR OPERATION.

A bad practice in air-compressor operation is to put the air-discharge pipes through the intake duct. This serves directly to defeat the gain of the cool duct, because the hot discharge pipe heats the incoming air. On one such installation the incoming air was heated 6° F. by the presence of the discharge pipe in the intake duct. In this case there was a direct throwing away of about 1½ per cent. of power, which amounted to throwing away 11½ lbs. of coal every time 1,000 lbs. was shovelled into the furnace, day in and day out. In estimating such a heating loss a rough figure is 1 per cent. loss for each 5° F. intake-temperature rise.

VACUUM PUMPS.

THE BAILEY PATENT SLIDE VALVE 'DRY' VACUUM PUMP.

(Sir W. H. Bailey & Co., Ltd., Manchester.)

In the 'K' Vacuum Pump the slide-valve is without a stuffing-box, and the spring delivery valve is not carried by the slide-valve, but works vertically on a stationary seat, easily accessible even when the machine is running. By this arrangement the slide-valve does not run in the interior of the valve chest, but on the outside of it, and is, consequently, easy to fit and adjust; it has no stuffing-box to its spindle.

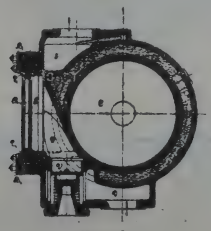


FIG. 9E.

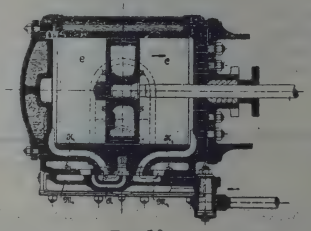


FIG. 10.

Fig. 9E shows a transverse section, and fig. 10 a longitudinal section of the standard air cylinder of the 'K' pump. The cylinder and back covers are water-jacketed, the front cover is cast in one with the cylinder, and a joint between the cylinder and the frame is avoided. In the larger sizes the front cover is water-jacketed.

The action of the valve is as follows :—

The air or gases enter by the suction pipe S and pass to the spaces S1 and S2. In fig. 9E the piston is passing towards the left-hand side and draws air into the cylinder from S2 through the space M2 and the port K2. At the same time it discharges the air drawn in during the preceding stroke by K1, P, and D, the slide-valve being set in relation to the crank so that the spaces S1 or S2 and D are put into communication at the right moment with the corresponding ends of the cylinder. Besides the ports M1 and M2, through which the gases pass into the cylinder, and the port P1 through which they are discharged, the slide-valve has a compensating or equalising port A which communicates between the discharge side of the piston and the suction side, thus equalising the pressure. When the piston has reached the dead point this port opens, for an instant of time, the communication between the two sides of the piston, the cylinder being cut off from the inlet and outlet by the slide-valve. The tension or pressure in the clearance space is thus reduced almost to the suction tension or pressure, and the piston can now draw air in much sooner, the effective suction stroke or volumetric efficiency being thereby increased. In addition to the slide-valve there is a spring valve V. The slide-valve governs the beginning and the end of both suction and discharge strokes. The spring valve has no effect on the volumetric efficiency of the pump, as without it the same volume would be drawn in, but it is necessary in order to reduce the power required to drive to the lowest possible limit. The slide-valve opens the suction and discharge at the beginning of each stroke and closes at the dead point so that the pump can be used for any degree of vacuum. The opening of the discharge port at a time when the air or gases are not yet compressed to atmospheric pressure would permit the air in the discharge pipe to flow back into the cylinder, causing back pressure and loss of power. The spring valve prevents this, as it separates the external air from the cylinder and prevents it from entering the cylinder when the slide-valve opens the discharge. When the air or gases in the cylinder are compressed to atmospheric pressure the spring valve opens automatically and the discharge commences. The influence of the spring valve therefore only affects the power for driving as previously stated ; it works vertically, is always accessible even when the machine is running, and is noiseless.

The single type pumps will maintain a vacuum of over 29·8 ins. of mercury when exhausting from a closed vessel. When a higher vacuum is necessary, the Bailey Double Vacuum Pump is recommended. This pump will maintain a vacuum of over 29·95 ins. of mercury at normal temperature and with a barometric pressure of 30 ins.

These pumps are particularly suitable as air pumps for condensers for steam engines, central condensation plants, cooling towers, condensers for evaporating plants, vacuum drying plants, distillers, filtering plants, etc.

The Holland 'SLM' Rotary Vacuum Pump.

(*Bernard Holland & Co.*, 17 *Victoria St.*, *London*, *S.W.* 1.)

This machine is rotary and is similar in general design to the Holland 'SLM' Compressor; it runs without vibration at the same high speeds of revolution and possesses all the characteristics of that machine, including the ability to perform, at will, the dual service of exhausting and compressing when arranged with the appropriate inlet and outlet piping. The single-stage air-cooled pumps will maintain a vacuum of 60 per cent. or 18 ins. of mercury with a barometric pressure of 30 ins., and under the same conditions the single-stage water-cooled pumps will produce a vacuum of 96 per cent. or 28·8 ins. of mercury, and the two-stage water-cooled machines, when exhausting from a closed circuit, will maintain a vacuum of over 99·9 per cent. or 29·97 ins. of mercury.

These machines, like the compressors, will run continuously with little attention, and maintain their efficiency after long use.

See also p. 1262.

Snifting Valves.

These valves open for the purpose of allowing the passage of air, but close if liquids attempt to pass; they are used in hydraulic systems, and also in motor-cars. In a simple form the arrangement is shown by fig. 11.

B is a light float with a leather washer at the top ; O is an outlet pipe ; X is the pressure system. Air is free to pass in and out, but if liquid is passing out, B is carried up and seals the outlet pipe.

In connection with air vessels for pumps, a snifting valve is utilised to recharge such with air; two cocks may be used, one at the top and one at the bottom of the vessel, so

that water may be drawn off below and air re-admitted above. If it be desired to admit it automatically while at work, a 'snifting valve,' a separate air-pump, or an air-injector may be adopted. The valve, fig. 12, is placed between the suction and delivery valves, and

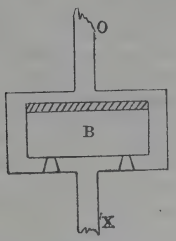


FIG. 11.

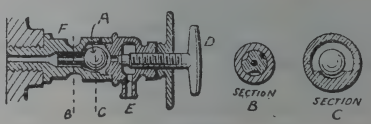


FIG. 12.

consists of a gun-metal chamber, F, containing a ball, A, which rolls backward and forward on account of the pump stroke. When rolled leftward, air is drawn inward at E, while the escape of water on return stroke is prevented by a rightward roll, and the whole may be put out of action or adjusted by a screwed plug, D.

PNEUMATIC DESPATCH TUBES.

TUBES.

The tubes used in the Pneumatic Despatch Service (telegrams only) of the British Post Office are 3, 2¼, and 1½ inches in diameter, the 2¼-inch being the size in most general use. The tubes are manufactured in lengths of about 28 feet. The tubes are of lead, and are enclosed in cast-iron pipes for mechanical protection. Each length of lead pipe is laid in a wooden trough as soon as manufactured, so that it may be handled without fear of bending. A tightly fitting polished steel 'mandril,' 1 foot long, and of the exact gauge of the tube, attached to a strong chain, and lubricated with soft soap, is then drawn through the entire length of the tube. This operation insures the tube being smooth, cylindrical, and uniform throughout. The jointing of the lead tubes is effected as follows: Previous to the placing of the tubes in the trench, a strong chain is passed through it, and a polished steel mandril, 6 inches long and slightly less in diameter than the diameter of the tube, is heated and attached to the chain, and pushed half its length into the end of the tube already laid; the new length of tube is then forced over the projecting end of the mandril until the tube ends (which have been previously cut flat) butt perfectly together; a plumber's wipe joint is then made. By this means the tube is made perfectly air-tight, and the mandril keeps the surface of the tube under the joint as smooth as at any other part of its length. After the joint has been completed, the mandril is drawn out by the chain attached to it, the next length is drawn on and the process repeated.

CARRIERS.

The carriers in which the messages are placed consist of a cylindrical tube of gutta-percha covered with felt: a 'skirt' projects beyond the open end of the carrier. The pressure behind causes the skirt to expand until it exactly fits the tube and thus prevents the air leaking past. The front of the carrier is provided with a buffer or piston, formed of several discs of felt, which exactly fits the tube. To prevent the messages getting out of the carrier, the end is closed by an elastic band, which can be stretched sufficiently to allow the messages to be put in.

The length, over all, of a carrier for a 2¼-inch tube is 6¾ inches; the inside measurements of the gutta-percha tube or message holder being—length 4½ inches, diameter 1¼ inches. The weight of such a carrier when empty is a little over 3 ounces.

The 3- and 2¼-inch carriers will, on the average, take 65 and 25 messages respectively.

The speed of the carrier may be roughly stated to range from 20 to 30 miles an hour for tubes not exceeding a mile in length.

WORKING PRESSURE AND VACUUM.

The standard pressure is 10 lbs. per sq. in., and the standard vacuum 6½ lbs. per sq. in.

For a given effective pressure, carriers travel most rapidly in pressure tubes when the air supply is *intermittent*, *i.e.* when the message tube is only connected with the compressed air mains during such times as carriers are actually traversing the tubes. The reason of this is, that

Originators of Pneumatic Cash Tubes.

LAMSON PNEUMATIC DESPATCH TUBES

of every type

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the compressed air with which the portion of the tube in front of the carrier is full, and which has to be displaced by the advancing carrier, weighs more than the uncompressed air, and consequently requires a greater amount of power to move it. The difference in the two cases is, however, not great, but the higher the pressure the greater is the difference in speed due to this cause. With 6 lbs. pressure, the carrier takes only 3 per cent. longer time with continuous than with intermittent working, whilst with 14 lbs. pressure it takes nearly 6 per cent. longer time.

In the case of carriers propelled by the exhaustion of the air, if the exhaustion is not commenced until the carrier is inserted at the further end, then the carrier commences to move as soon as the exhaustion at that end reaches a few ounces only, and the full exhaustion effect is not felt until the carrier has been moving for some time. When, however, the exhaustion is continuous the carrier on its insertion practically starts off under the full pressure: hence its speed is greater than in the first case. The continuous system of vacuum working, where one tube is used for the 'up' traffic (i.e. the traffic from the distant to the central or 'power' station) only, is easily effected, whether the traffic is heavy or light; but the intermittent system for the 'down,' or pressure working, which, as pointed out, gives the greatest speed, cannot always be followed out, as during the busy hours of the day the carriers have to be despatched in such quick succession that the current of air in the tube is practically continuous.

Power Required to Work Tubes.

The actual power required for working *continuously* the tubes at a pressure of 10 lbs. per square inch (the standard pressure) is, theoretically, 3·35 horse-power for a 2½-inch tube 1 mile long; but in practice 50 per cent. requires to be added to allow for losses from various causes, *i.e.* the actual horse-power should be 5. With 10 lbs pressure the time occupied in the transit of a carrier through a tube 1 mile long is 2½ minutes.

In order to neutralise the intermittent action of the pumps, and ensure a uniform flow of air, reservoirs or 'containers' are provided. These are arranged to have sufficient capacity to give out a reserve supply when the load on the tubes becomes abnormal, as occasionally happens.

For a given transit time the actual horse-power required is much less in the case of vacuum than in the case of pressure working. Thus, for example, the transit time for 10 lbs. pressure is the same as for 6½ lbs. vacuum, but the horse-power required in the two cases would be as 1·83 to 1. Inasmuch, however, as the tubes cannot practically be worked only by vacuum, the calculations for transit time and horse-power must be based on pressure working. The actual power necessary must be largely governed by local conditions, and no definite rule can be laid down. The power required to work any tube or number of tubes is usually computed, however, on the estimated traffic in carriers per hour which each tube is required to carry. This figure multiplied into the volume of the tube and divided by 60 gives the volume of air swept out per minute (if there is a number of tubes the figures are of course aggregated), and this affords the capacity of the pump at the required pressure.

Pumping Machinery.

The air compressors used for this system are driven by electric motors, oil, steam, or gas engines, and are provided according to the present standard practice with one or more cylinders arranged to draw from the vacuum container and compress the air thus drawn into the pressure container. Automatically controlled auxiliary valves are interposed in the inlet and delivery mains of the pump. They are controlled pneumatically by means of a by-pass connection with the pressure container in such manner that if (*a*) the pressure in the pressure container is low and the vacuum in the vacuum container high, so that the pump is deprived of air to compress, the auxiliary inlet valve on the vacuum main opens to atmosphere and admits free air for compression until the pressure in the pressure container is restored, when the valve shuts. On the other hand, (*b*) if the vacuum is low and the pressure is high, so that the pump would have to discharge against considerable back pressure the air it exhausts from the vacuum container, the auxiliary valve in the pressure main opens to atmosphere until the vacuum is restored. A non-return valve on the container side of each auxiliary valve prevents the loss of pressure or vacuum whilst either auxiliary is open to atmosphere. This system, besides economising in plant and space, absorbs and utilises certain losses which are inevitable with independent pumping for both services.

Transit Time.

Table I. enables the transit time for any diameter and length of tube at any pressure to be calculated, and from Table II. can be ascertained the pressure required to drive a carrier through any tube in any time. The chart, fig. 13 (p. 1270), based on Table I., shows the Transit Time variation for different lengths of tubes of three sizes, 1½ in., 2½ ins., and 3 ins., each worked at 10 lbs. pressure.

I.—Tables for calculating Time of Transit of a Carrier through a Tube.

Formula: $t = \cdot00872\sqrt{l^3} \times \frac{1}{\sqrt{P}} \times \frac{1}{\sqrt{d}} = A \times B \times C$ secs.

$A = \cdot00872\sqrt{l^3}$.

l	A	l	A	l	A	l	A	l	A
Yds.		Yds.		Yds.		Yds.		Yds.	
50	3·08	1,050	297	2,050	809	3,050	1,470	4,050	2,250
100	8·72	1,100	318	2,100	839	3,100	1,510	4,100	2,290
150	16·0	1,150	340	2,150	869	3,150	1,540	4,150	2,330
200	24·7	1,200	362	2,200	900	3,200	1,580	4,200	2,370
250	34·5	1,250	385	2,250	921	3,250	1,620	4,250	2,420
300	45·3	1,300	409	2,300	962	3,300	1,650	4,300	2,460
350	57·1	1,350	433	2,350	993	3,350	1,690	4,350	2,500
400	69·8	1,400	457	2,400	1,030	3,400	1,730	4,400	2,550
450	83·2	1,450	482	2,450	1,060	3,450	1,770	4,450	2,590
500	97·5	1,500	507	2,500	1,090	3,500	1,810	4,500	2,630
550	112	1,550	532	2,550	1,120	3,550	1,840	4,550	2,680
600	128	1,600	558	2,600	1,160	3,600	1,880	4,600	2,720
650	144	1,650	584	2,650	1,190	3,650	1,920	4,650	2,770
700	161	1,700	611	2,700	1,220	3,700	1,960	4,700	2,810
750	179	1,750	638	2,750	1,260	3,750	2,000	4,750	2,850
800	197	1,800	666	2,800	1,290	3,800	2,040	4,800	2,900
850	216	1,850	694	2,850	1,330	3,850	2,080	4,850	2,950
900	235	1,900	722	2,900	1,360	3,900	2,120	4,900	2,990
950	255	1,950	751	2,950	1,400	3,950	2,170	4,950	3,040
1,000	276	2,000	780	3,000	1,430	4,000	2,210	5,000	3,080

$B = \frac{1}{\sqrt{P}}$.

P	B	P	B	P	B	P	B	P	B
Lbs.		Lbs.		Lbs.		Lbs.		Lbs.	
·25	2·000	4·25	·485	8·25	·348	12·25	·286	16·25	·248
·50	1·410	4·50	·471	8·50	·343	12·50	·283	16·50	·246
·75	1·150	4·75	·459	8·75	·338	12·75	·280	16·75	·244
1·00	1·000	5·00	·447	9·00	·333	13·00	·277	17·00	·243
1·25	·894	5·25	·436	9·25	·329	13·25	·275	17·25	·241
1·50	·816	5·50	·426	9·50	·324	13·50	·272	17·50	·239
1·75	·756	5·75	·417	9·75	·320	13·75	·270	17·75	·237
2·00	·707	6·00	·408	10·00	·316	14·00	·267	18·00	·236
2·25	·667	6·25	·400	10·25	·312	14·25	·265	18·25	·234
2·50	·633	6·50	·392	10·50	·309	14·50	·263	18·50	·232
2·75	·603	6·75	·385	10·75	·305	14·75	·260	18·75	·231
3·00	·577	7·00	·378	11·00	·301	15·00	·258	19·00	·229
3·25	·555	7·25	·371	11·25	·298	15·25	·256	19·25	·228
3·50	·534	7·50	·365	11·50	·295	15·50	·254	19·50	·226
3·75	·517	7·75	·359	11·75	·292	15·75	·252	19·75	·225
4·00	·500	8·00	·354	12·00	289	16·00	·250	20·00	·224

$C = \frac{1}{\sqrt{d}}$.

d	C	d	C	d	C	d	C	d	C
Ins.		Ins.		Ins.		Ins.		Ins.	
1·00	1·000	3·25	·555	5·50	·426	7·75	·359	10·00	·316
1·25	·894	3·50	·534	5·75	·417	8·00	·354	10·25	·312
1·50	·816	3·75	·517	6·00	·408	8·25	·348	10·50	·309
1·75	·756	4·00	·500	6·25	·400	8·50	·343	10·75	·305
2·00	·707	4·25	·485	6·50	·392	8·75	·338	11·00	·301
2·25	·667	4·50	·471	6·75	·385	9·00	·333	11·25	·298
2·50	·633	4·75	·459	7·00	·378	9·25	·329	11·50	·295
2·75	·603	5·00	·447	7·25	·371	9·50	·324	11·75	·292
3·00	·577	5·25	·436	7·50	·365	9·75	·320	12·00	·289

Example: Required, the transit time, t, of a carrier through a tube 4 ins. in diameter (C) and 2,000 yds. long (A), worked at 7 lbs. pressure (B). $t = 780 \times 8 \times \cdot500 = 147$ secs.

II.—TABLES FOR CALCULATING PRESSURE REQUIRED TO DRIVE A CARRIER THROUGH A TUBE IN A GIVEN TIME.

Formula : $P = \cdot00007604\, l^2 \times \frac{1}{t^2} \times \frac{1}{d} = A_1 \times B_1 \times C_1$.

$A_1 = \cdot00007604\, l^2$.

l (Yds.)	A_1	l (Yds.)	A_1	l (Yds.)	A_1	l (Yds.)	A_1	l (Yds.)	A_1
50	9·51	1,050	88,000	2,050	655,000	3,050	2,160,000	4,050	5,050,000
100	76·0	1,100	101,000	2,100	704,000	3,100	2,270,000	4,100	5,240,000
150	257	1,150	116,000	2,150	756,000	3,150	2,380,000	4,150	5,430,000
200	608	1,200	131,000	2,200	810,000	3,200	2,490,000	4,200	5,630,000
250	1,190	1,250	149,000	2,250	866,000	3,250	2,610,000	4,250	5,840,000
300	2,050	1,300	167,000	2,300	925,000	3,300	2,730,000	4,300	6,050,000
350	3,260	1,350	187,000	2,350	987,000	3,350	2,860,000	4,350	6,260,000
400	4,870	1,400	209,000	2,400	1,050,000	3,400	2,990,000	4,400	6,480,000
450	6,930	1,450	232,000	2,450	1,120,000	3,450	3,120,000	4,450	6,700,000
500	9,500	1,500	257,000	2,500	1,190,000	3,500	3,260,000	4,500	6,930,000
550	12,700	1,550	283,000	2,550	1,260,000	3,550	3,400,000	4,550	7,240,000
600	16,400	1,600	312,000	2,600	1,340,000	3,600	3,550,000	4,600	7,400,000
650	20,900	1,650	342,000	2,650	1,420,000	3,650	3,700,000	4,650	7,650,000
700	26,100	1,700	374,000	2,700	1,500,000	3,700	3,850,000	4,700	7,890,000
750	32,100	1,750	408,000	2,750	1,580,000	3,750	4,010,000	4,750	8,150,000
800	38,900	1,800	443,000	2,800	1,670,000	3,800	4,170,000	4,800	8,410,000
850	46,700	1,850	482,000	2,850	1,760,000	3,850	4,340,000	4,850	8,670,000
900	55,400	1,900	522,000	2,900	1,850,000	3,900	4,510,000	4,900	8,950,000
950	65,200	1,950	564,000	2,950	1,950,000	3,950	4,690,000	4,950	9,220,000
1,000	76,000	2,000	608,000	3,000	2,050,000	4,000	4,870,000	5,000	9,510,000

$B_1 = \frac{1}{t^2}$.

t (Secs.)	B_1	t (Secs.)	B_1	t (Secs.)	B_1	t (Secs.)	B_1	t (Secs.)	B_1
5	·0400	105	·0000907	205	·0000238	305	·0000107	405	·00000610
10	·0100	110	·0000826	210	·0000227	310	·0000104	410	·00000595
15	·00444	115	·0000756	215	·0000216	315	·0000101	415	·00000581
20	·00250	120	·0000694	220	·0000207	320	·00000977	420	·00000567
25	·00160	125	·0000640	225	·0000198	325	·00000947	425	·00000554
30	·00111	130	·0000592	230	·0000189	330	·00000918	430	·00000541
35	·000816	135	·0000520	235	·0000181	335	·00000891	435	·00000529
40	·000625	140	·0000510	240	·0000174	340	·00000865	440	·00000517
45	·000494	145	·0000476	245	·0000167	345	·00000840	445	·00000505
50	·000400	150	·0000444	250	·0000160	350	·00000816	450	·00000494
55	·000331	155	·0000416	255	·0000154	355	·00000794	455	·00000483
60	·000278	160	·0000391	260	·0000148	360	·00000772	460	·00000473
65	·000237	165	·0000367	265	·0000142	365	·00000751	465	·00000463
70	·000204	170	·0000346	270	·0000137	370	·00000731	470	·00000453
75	·000178	175	·0000326	275	·0000132	375	·00000711	475	·00000443
80	·000156	180	·0000309	280	·0000128	380	·00000693	480	·00000434
85	·000138	185	·0000292	285	·0000123	385	·00000675	485	·00000425
90	·000123	190	·0000277	290	·0000119	390	·00000658	490	·00000417
95	·000111	195	·0000263	295	·0000115	395	·00000641	495	·00000408
100	·000100	200	·0000250	300	·0000111	400	·00000625	500	·00000400

$C_1 = \frac{1}{d}$.

d (Ins.)	C_1	d (Ins.)	C_1	d (Ins.)	C_1	d (Ins.)	C_1	d (Ins.)	C_1
1·00	1·000	3·25	·308	5·50	·182	7·75	·129	10·00	·100
1·25	·800	3·50	·286	5·75	·174	8·00	·125	10·25	·0976
1·50	·667	3·75	·267	6·00	·167	8·25	·121	10·50	·0952
1·75	·571	4·00	·250	6·25	·160	8·50	·118	10·75	·0930
2·00	·500	4·25	·235	6·50	·154	8·75	·114	11·00	·0909
2·25	·444	4·50	·222	6·75	·148	9·00	·111	11·25	·0889
2·50	·400	4·75	·211	7·00	·143	9·25	·108	11·50	·0870
2·75	·364	5·00	·200	7·25	·138	9·50	·105	11·75	·0851
3·00	·333	5·25	·190	7·50	·133	9·75	·103	12·00	·0833

Example ; Required, the pressure, P, to drive a carrier through a tube 5 ins. in diameter (C_1) and 2.000 yds. long (A_1) in 200 secs. (B_1). $P = 608{,}000 \times \cdot0000250 \times \cdot200 = 3$ lbs.

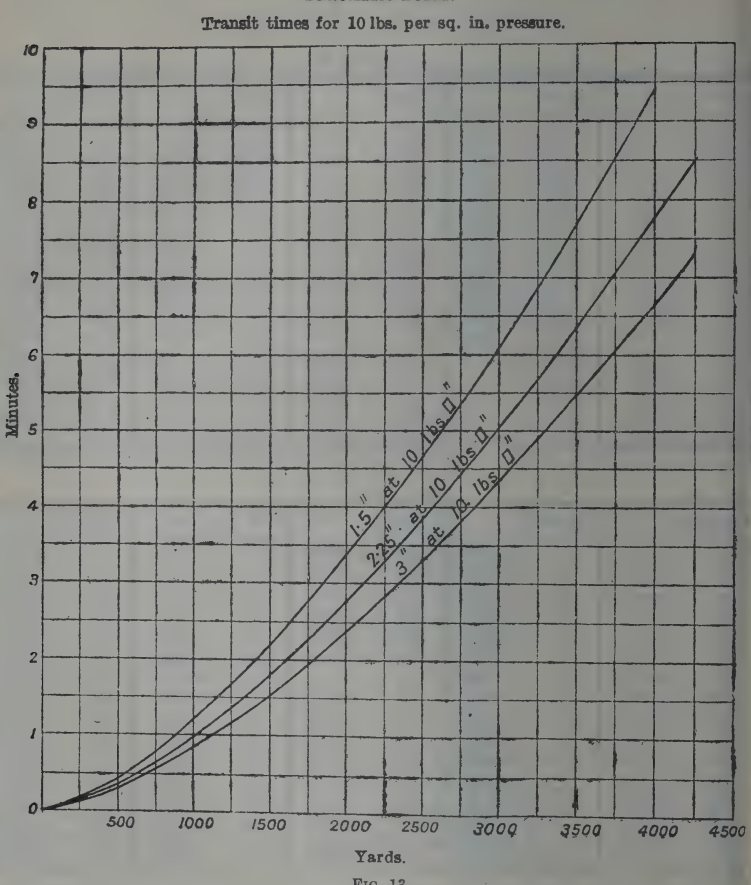

FIG. 13.

PNEUMATIC HOUSE TUBES.

These are, in the British Post Office Service, usually of brass or copper, and in some cases are operated on lines similar to the foregoing system, but considerable modifications have been introduced.

A very general system for warehouses is a circular one with loops into the various apartments which it is desired to connect.

The air is continually circulated by means of a blower of the Roots type which is joined at one end of the tube, whilst the other is open to atmosphere.

Carriers are despatched from a station by being inserted in the 'return' pipe of the loop and are received on the 'flow' pipe, suitable receiving apparatus being provided for the interception of a withdrawal of the carrier without interrupting the flow of air, which is made to travel through a by-pass.

SECTION XXIV

REFRIGERATION—REFRIGERATING MACHINERY—ICE MAKING—COLD STORAGE

(Contributed by Hal Williams, M.I.Mech.E., M.I.E.E., Consulting Engineer, and A. G. Clausen, A.M.I.Mech.E.)

SECTION XXIV

REFRIGERATION—REFRIGERATING MACHINERY—ICE MAKING—COLD STORAGE.*

(Contributed by Hal Williams, M.I.Mech.E., M.I.E.E., Consulting Engineer, and A. G. Clausen, A.M.I.Mech.E.)

Refrigeration, or the mechanical production of low temperatures for commercial use, is a process of removing heat at a low level and discharging it at a high level on the thermometer scale.

In a steam-power plant heat is applied to evaporate water in a boiler; a small proportion of the heat supplied is converted into useful work in the engine, and the balance which cannot be utilised is rejected to the condensing water.

A refrigerating machine is simply a reversed heat engine; the cold air machines are now obsolete, and in all modern plant heat is taken up by the evaporation of some suitable working fluid termed the 'refrigerant,' and more heat is applied, generally in the form of power, to compress the resulting vapour to such a pressure that it can be condensed.

The sum of the heat taken up by evaporation and that added as power is then discharged in a condenser, to water of the prevailing normal temperature, the refrigerant is condensed, and as a liquid is in a state to complete the cycle of operations.

The performance of a refrigerating machine is the ratio of the number of heat units abstracted to those applied as power, and for a reversible cycle with a perfect fluid is $\frac{T_1}{T - T_1}$

where

T = absolute temperature of condensation;
T_1 = " " " evaporation.

A refrigerating machine working on the compression system—which is practically universal—is shown diagrammatically in fig. 1 (see p. 1274) and consists of four essential parts:

(1) The evaporator or refrigerator, in which the refrigerant boils or evaporates at a low pressure and temperature.
(2) A gas pump or compressor to withdraw the vapour formed in the evaporator and compress it to such a pressure that it can be condensed by the water supply available.
(3) The condenser in which the compressed gas is condensed at a high pressure.
(4) The regulating or expansion valve, provided with fine adjustment to control the rate of flow of the condensed liquid from the condenser into the evaporator.

Starting with the liquid refrigerant in the condenser, the thermal cycle is as follows:

The liquid at condenser pressure and temperature is permitted to flow through the regulating valve into the evaporator.

On passing the valve a proportion immediately evaporates, taking up its latent heat from the remainder, which in this way is cooled to the evaporator temperature.

The remainder evaporates at constant pressure and temperature, taking up its latent heat from the air, brine, water, or other substance that is in contact with the exterior surface of the evaporator, and which is correspondingly reduced in temperature.

The proportion of the liquid evaporated to cool the remainder to the temperature of evaporation is not available for refrigeration, and represents a loss as compared to the ideal or reversible cycle.

The liquid should therefore be cooled to as low a temperature as is practicable by ordinary means before passing the regulating valve, and its specific heat, considered as a fraction of its latent heat, should be low.

The vapour leaving the evaporator may be either:

(*a*) In a dry saturated state;
(*b*) Slightly superheated, or having its temperature a few degrees above its saturation temperature.
(*c*) In a wet state, or carrying with it some particles of unevaporated liquid.

With (*a*) and (*b*) the condition of working known as 'dry compression' is obtained and the work of compression, converted into heat, raises the temperature of the refrigerant so that it is discharged from the compressor in a superheated condition.

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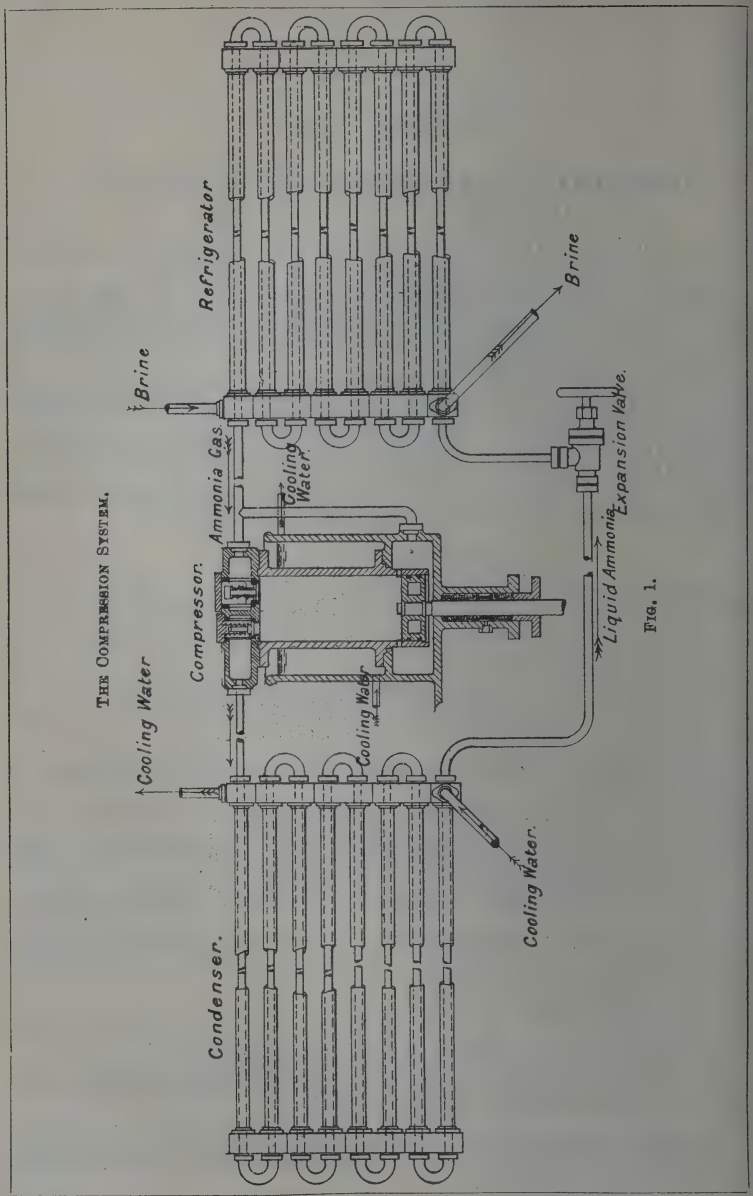
* For further information the reader is referred to 'Mechanical Refrigeration,' by Hal Williams (Sir Isaac Pitman & Sons, Ltd.), from which publication certain of the tables and data included in this section have been condensed.

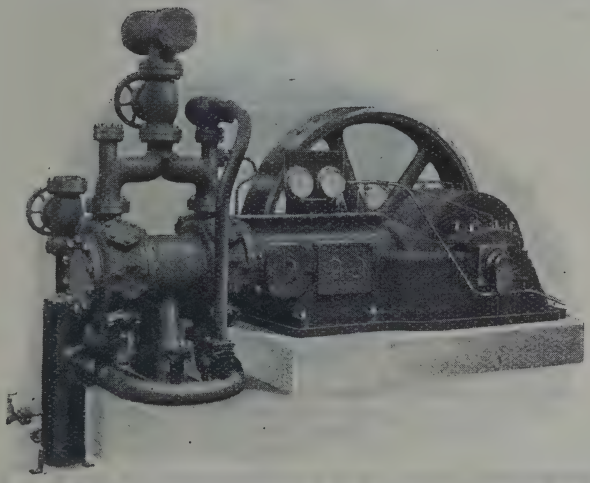


THE COMPRESSION SYSTEM.

FIG. 1.

REFRIGERATING & ICE MAKING MACHINERY

AIR COOLING & DRYING.
LOW TEMPERATURE WORK.
PIPE COILS. LAYOUTS.
HIGH PRESSURE GAS COMPRESSORS.



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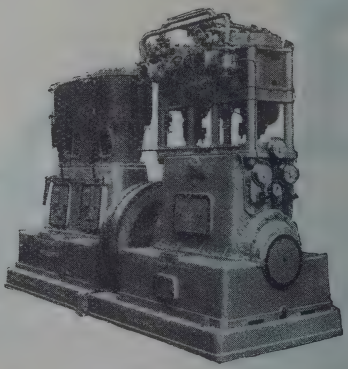

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A small proportion of the heat of compression can be absorbed by water jackets on the discharge side of the compressor. Owing to the low initial temperatures, complete water jacketing cannot be used as with air compressors, as it would cause losses through initial superheating.

With (c) the heat of compression is either partially or wholly taken up by the evaporation of the entrained liquid, and the state of working known as 'wet compression' is obtained when the incoming vapour carries just sufficient liquid to maintain the refrigerant during compression at the temperature corresponding to its saturation pressure.

In practice the refrigerant is as a general rule at some point between the states giving either completely dry or wet compression.

In the condenser the gas, if superheated, must first be cooled down to its saturation temperature, when the process of condensation proceeds.

In order to permit the transfer of heat, the temperature of evaporation must be below that to which the air or brine is to be cooled, and similarly the temperature of condensation must be above that of the cooling water used.

The greatest efficiency is obtained when the temperature of evaporation is as high and the temperature of condensation is as low, as possible, so that the surfaces for heat transfer should be large to keep the necessary differences small.

The refrigeration effected per pound of refrigerant can be obtained directly from the tables of properties of the various fluids, by deducting the total heat of the liquid at the condenser temperature from the heat content of the saturated vapour at the evaporator temperature.

The volume of gas that must be pumped by the compressor can be obtained directly in the same way.

The amount by which the actual swept volume of the compressor must be greater than the net volume of the gas, will depend upon the characteristics of any particular compressor and the conditions of working, and averages about 25 per cent.

The power required to drive the compressor can be obtained directly from the Mollier or from the entropy diagrams, or from indicator diagrams for the compressor.

The heat that must be transferred to the condensing water is the sum of the heat abstracted or effective refrigeration, and the heat equivalent of the work done in compression.

The quantity of water required will vary directly with the permitted rise in temperature.

The selection of a working fluid is governed by its limits of pressure and volume over the normal range of temperatures, its critical pressure, and the relative values of its specific heat as a liquid and its latent heat.

Other factors are its action, if any, on the materials used for the construction of machinery or on lubricating oils, its poisonous properties, and its inflammability.

There are many fluids that can be used, but by far the most important are Ammonia and CO_2. Sulphuric ether was often used in the early days of refrigeration, and SO_2 has been employed to a considerable extent on the Continent of Europe.

SO_2 methyl-chloride, occasionally ethyl-chloride, and other fluids, are also used for the very small machines of the household type that are now made in large numbers.

Ammonia Compression Refrigerating Machines.

TABLE I.—PROPERTIES OF ANHYDROUS AMMONIA, NH_3.

Temperature. ° F.	Absolute Pressure. Lbs. per sq. in.	Volume Vapour. Cu. ft. per lb.	Total Heat.		Latent Heat. B.Th.U.'s per lb.
			Liquid. B.Th.U.'s per lb.	Vapour. B.Th.U.'s per lb.	
−22	17·34	15·43	19·2	604·3	585·1
−13	21·99	12·36	28·9	607·5	578·6
− 4	27·59	9·99	38·6	610·5	571·9
5	34·27	8·15	48·3	613·3	565·0
14	42·18	6·70	58·2	616·1	557·9
23	51·47	5·56	68·0	618·6	550·6
32	62·29	4·64	77·9	621·0	543·1
41	74·80	3·90	87·9	623·2	535·3
50	89·19	3·30	97·9	625·2	527·3
59	105·60	2·80	108·1	627·1	519·0
68	124·30	2·39	118·3	628·8	510·5
77	145·40	2·05	128·5	630·2	501·7
86	169·20	1·77	138·9	631·5	492·6
95	195·80	1·53	149·4	632·6	483·2
104	225·40	1·33	159·9	633·4	473·5

TABLE II.—REFRIGERATING EFFECT OBTAINED PER CUBIC FOOT SWEPT VOLUME OF COMPRESSOR IN B.Th.U.'s WITH DIFFERENT CONDENSER AND EVAPORATOR TEMPERATURES.

Temperature Evaporation. ° F.	Suction Gauge Pressure.	Condensing Temperatures. 68° F.	86° F.	104° F.
		Corresponding gauge pressures. 109·6	154·5	210·7
−22	2·6	19·8	16·9	13·9
−13	7·3	27·8	24·5	21·1
− 4	12·9	36·7	32·5	28·7
5	19·6	46·5	42·2	38·3
14	27·5	58·0	54·5	50·5
23	36·8	71·0	67·0	62·5
32	47·6	87·0	82·5	78·5

TABLE III.—COMPRESSOR I.H.P. PER CUBIC FOOT SWEPT VOLUME PER MINUTE WITH DIFFERENT CONDENSER AND EVAPORATOR TEMPERATURES.

Temperature of Evaporation. ° F.	Suction Gauge Pressure.	Condensing Temperatures. 68° F.	86° F.	104° F.
		Corresponding gauge pressures. 109·6	154·5	210·7
−22	2·6	0·167	0·183	0·205
−13	7·3	0·190	0·220	0·250
− 4	12·9	0·205	0·245	0·282
5	19·6	0·220	0·270	0·316
14	27·5	0·226	0·282	0·347
23	36·8	0·220	0·290	0·363
32	47·6	0·200	0·288	0·377

Ammonia is generally considered to be the most satisfactory and economical refrigerant. It has a high latent heat, and over the normal temperature range the pressures and sizes of parts are comparable to ordinary steam and air compressor practice.

The gas has a highly pungent odour and is irrespirable, so that great care must be exercised in working or in overhauls, to prevent dangerous leakages.

It is exceedingly soluble in water, and one volume of water at 60° F. will absorb 600 volumes of gas.

Ammonia attacks copper and its alloys, so that none of these must be used for parts of the machine with which it comes in contact.

The figures given in Tables II. and III. are for compressors working with dry or practically dry compression. They represent the average results that are obtained with machines of moderate size, but the variations in performance and power naturally vary to some extent with the characteristics of different makes.

With wet compression, both the number of B.Th.U.'s abstracted and compressor I.H.P. are reduced per unit compressor volume, and theoretically the performance, or ratio of $\frac{\text{B.Th.U.'s}}{\text{I.H.P.}}$ is slightly superior, though in practice dry compression gives the best results.

Carbonic Acid Refrigerating Machines.

CO_2 occupies a unique position in the group of fluids used for refrigeration in that its critical temperature (88·4° F.) often comes within the working range; also its specific heat is high, and its latent heat relatively low.

Its efficiency with condensing water at about 50° F. is but little inferior to that of the ammonia machine, but falls away more rapidly with an increasing condenser temperature. There is, however, no break in the curves of capacity at the critical temperature.

CO_2 is inodorous, and it is stated that air containing up to 8 per cent. can be inhaled without danger, though at higher percentages it causes stupefaction and suffocation.

The quantities used in machines are, however, such that even if the whole charge were to escape, in any ordinary situation, it is hardly likely to produce a dangerous concentration, and on this account the Board of Trade regulations permit CO_2 machinery to be installed in the engine-room or similar space on board ship, whereas ammonia machines must be housed in a special deck-house.

CO_2 does not attack any metals, so that condensers can be constructed of copper piping, and these advantages have given it a predominant position for marine refrigeration.

Although the pressures are high, the diameters of all parts are small, so that there are no constructional difficulties.

TABLE IV.—PROPERTIES OF CARBONIC ACID.

Temperature. ° F.	Absolute Pressure in Atmospheres.	Volume Vapour. Cu. ft. per lb.	Total Heat.		Latent Heat. B.Th.U.'s per lb.
			Liquid. B.Th.U.'s per lb.	Vapour. B.Th.U.'s per lb.	
−22	14·48	0·432	−24·78	102·0	126·7
−13	16·92	0·367	−21·03	102·2	123·3
− 4	19·67	0·313	−17·17	102·3	119·5
5	22·75	0·267	−13·16	102·1	115·3
14	26·19	0·228	− 8·99	101·7	110·7
23	30·03	0·195	− 4·62	100·9	105·6
32	34·29	0·167	0·00	99·83	99·83
41	39·01	0·142	4·93	98·3	93·37
50	44·22	0·120	10·28	96·24	85·95
59	49·96	0·101	16·22	93·44	77·22
68	56·26	0·084	23·08	89·56	66·49
77	63·16	0·067	31·62	83·8	52·17
86	70·70	0·047	45·45	72·46	27·00
88·4	72·86	0·035	59·23	59·23	0·00

TABLE V.—REFRIGERATING EFFECT OBTAINED PER CUBIC FOOT SWEPT VOLUME OF COMPRESSOR IN B.TH.U.'S WITH DIFFERENT CONDENSER AND EVAPORATOR TEMPERATURES.

Temperatures of Evaporation. ° F.	Suction Gauge Pressure in Atmospheres.	Condensing Temperatures.		
		68° F.	86° F.	104° F.
		Corresponding Pressure in Atmospheres.		
−22	13·48	132	104	82
−13	15·92	160	134	106
− 4	18·67	196	162	132
5	21·75	236	200	166
14	25·19	282	242	200
23	29·03	334	288	242
32	33·29	396	348	294

TABLE VI.—COMPRESSOR I.H.P. PER CUBIC FOOT SWEPT VOLUME PER MINUTE WITH DIFFERENT CONDENSER AND EVAPORATOR TEMPERATURES.

Temperatures of Evaporation. ° F.	Suction Gauge Pressure in Atmospheres.	Condensing Temperatures.		
		68° F.	86° F.	104° F.
		Corresponding Pressure in Atmospheres.		
−22	13·48	1·33	1·45	1·58
−13	15·92	1·42	1·57	1·73
− 4	18·67	1·46	1·65	1·85
5	21·75	1·47	1·69	1·95
14	25·19	1·43	1·69	1·99
23	29·03	1·34	1·62	1·97
32	33·29	1·22	1·50	1·90

The figures given in Tables V. and VI. are for ordinary CO_2 compressors working with dry compression. They represent the average results that are obtained with compressors of moderate size, but the variations in performance and power naturally vary to some extent with the characteristics of different makes.

To obtain the best results in working, a CO_2 machine should be run with the suction gas in a dry saturated state, or even slightly superheated. When leather piston and gland packings were used this was impracticable, as the leathers were burnt by the temperatures reached with dry compression. All modern CO_2 machines have piston rings and metallic gland packings, so that there is now no difficulty in running a CO_2 machine to give the best results that can be obtained.

With high condensing temperatures the performance of a CO_2 machine can be appreciably improved by permitting the cooling of the liquid by its own partial evaporation to take place in two stages.

The compression also takes place in two stages: in the first the vapour from the liquid that has effected refrigeration, plus that from the second stage of the partial evaporation for liquid cooling, is compressed to the pressure at which the first stage of partial evaporation ends, when the whole of the vapour is compressed to the condensing pressure.

Other Refrigerants.

Both the theoretical and practical performance of other fluids used approximate closely to the results obtained with Ammonia, but the B.Th.U.'s extracted and compressor I.H.P. as shown in the tables should be divided by the following factors:

For Sulphur Dioxide	2·89
For Methyl Chloride	1·94
For Ethyl Chloride	6·57

The principal characteristics of these refrigerants, taken at 32° F. are:

TABLE VII.—REFRIGERANTS.

Refrigerant.	Absolute Pressure. Lbs. per sq. in.	Volume Vapour. Cu. ft. per lb.	Specific Heat of Liquid.	Latent Heat. B.Th.U.'s per lb.
Sulphur Dioxide .	22·45	3·41	0·322	156·8
Methyl Chloride .	36·63	2·68	0·467	174·6
Ethyl Chloride .	8·90	8·88	0·376	168·9

With very small machines, which receive practically no skilled attention, low working pressures are an advantage in reducing the risks of leakage, but pressures below the atmosphere should be avoided, as inward leaks of air cause difficulties in working, and any moisture carried in may combine with SO_2, forming sulphuric acid, which corrodes the parts.

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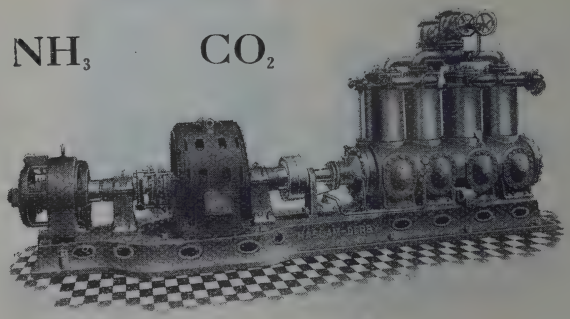

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Compressors.

Both single-acting and double-acting compressors are made in a large variety of designs and sizes, and during the last few years there have been great developments in high-speed forced lubrication machines suitable for direct coupling to electric motors.

With the exception of machines made by Messrs H. J. West & Co., Ltd., who employ a sleeve valve, all valves are of the automatic type, the high-speed compressors using light ring and plate valves of similar character to those developed for air compressors.

Most single-acting ammonia compressors are made of the enclosed type and work with ammonia at the suction pressure in the crankcase. The gland is of the rotary type on the crankshaft, and it is sealed with oil from the pressure lubricating pump. These machines have trunk pistons, the lower portion of which forms the crosshead, and is fitted with oil scraper rings. The upper forms the piston proper, and the suction ports in the cylinder walls lie between the limits of the travel of the upper and lower parts.

The suction valves are placed at the top of the piston, and the delivery valves in a spring-loaded false or safety head.

The arrangement enables the maximum valve port area to be provided with a minimum clearance space; the gas passes through the compressor in one direction, so that the upper portion can be effectively water-jacketed, and it is claimed that the 'Uniflow' principle increases the compressor efficiency.

The safety head is a valuable feature, as it will lift and save any risk of accident in the event of liquid ammonia or oil passing into the compressor.

These machines are always of the vertical type, and are made with from one to four cylinders.

Double-acting compressors are made both in the horizontal and vertical types, and the valves are arranged either in hemispherical end covers or round the circumference at each end of the cylinder.

Double-acting compressors usually have the gland constructed in two portions, with a central space or lantern between them. The lantern space is connected to the suction side of the compressor, so that the outer portion of the gland is subjected to the low and steady suction pressure only, and any gas leaking past the inner portion is retained in the system.

CO_2 compressors are now almost invariably machined from high carbon steel forgings to ensure strength and the necessary gas-tightness, and for the same reasons all stop valves and fittings are of mild steel and machined from the solid.

Double-acting compressors are general except in the smallest sizes; the gland is provided with a lantern which is sealed with oil at a rather higher pressure than the compressor is delivering against.

This higher pressure is obtained by using a differential piston in a cylinder, connecting the greater area to the gas delivery and the lesser area to the oil space in the gland, a small hydraulic pump being used to make up any oil leakage.

In refrigerating machinery, absolute gas tightness is essential, and it is usual to test compressors and all other parts subject to gas pressure by hydraulic test to about three times the normal maximum pressure; also to test them when immersed in water with compressed air to about one and a half times the normal maximum pressure to show up any minute leaks or porosity in materials.

Condensers.

Condensers are made in three general types:

Submerged Condensers consist of a coil, or series of coils, of piping connected to headers, contained in a tank or casing, generally of circular form, through which the water is passed.

Atmospheric Condensers consist of coils in vertical stacks, over which the water flows, erected in the open air and standing over a collecting tank. These are often made of large size, and the water continuously recirculated so that they function also as recooling towers and only require a small make up supply.

Double Pipe Condensers consist of a number of concentric pipes, arranged in series as shown in Fig. 1 (p. 1274); the water passes through the inner pipe and the gas condenses in the annulus between the two pipes. The gas and water traverse the pipes in opposite directions, so that the condenser is counter-current, and on account of the high water velocities the rate of heat transfer is high.

Evaporators.

A refrigerating machine may be used either to cool brine or water that is in turn circulated through the cooling appliances used, or it may be arranged so that the evaporator piping itself forms the cooling appliances, and this method is referred to as direct expansion.

Brine Cooling Evaporators may be either of submerged coil or double pipe construction, or for ammonia or other low pressure refrigerants they may be of shell and tube form, the ammonia evaporating in the shell around the tubes through which the brine is circulated in either one or more passes, depending upon the quantity and velocity required.

Evaporators for Cooling Water are frequently made of the open type where the water trickles over the outside of the coils to avoid the danger of freezing up in any confined spaces.

The Direct Expansion System may be applied for several purposes, but is generally only used for cooling cold storage rooms.

The piping may be fixed directly in the rooms, or nested together to form an air-cooling battery, with a fan to circulate air over it and through the rooms by a system of ducts.

This type of air cooler must have a circulation of brine maintained over the piping to keep the surfaces free from frost where temperatures below freezing-point are required, or otherwise the accumulation of snow and frost would rapidly choke it up.

Heat Transference.

The proportions of the condenser and evaporator are determined by the rates of heat transfer that can be obtained.

The rate of heat transfer is directly proportional to the temperature difference. It varies as a power of the velocity V, and may be generally taken as $V^{0.75}$.

The rate of heat transfer varies with the temperature, viscosity, density, and state of the fluids in contact with the surfaces, and to secure satisfactory operation over a long life it is necessary to allow for deposits on and deterioration of pipe surfaces.

The rate of heat transfer through iron pipe and under the conditions usually prevailing in refrigerating machinery may be taken as being approximately as follows:

	B.Th.U.'s per sq. ft. surface per hour and per 1° F. mean temp. difference.
In submerged condensers	40 to 45
Atmospheric condensers	60 to 70
Double pipe condensers with a water velocity of 3 feet per second	100 to 120
Submerged brine coolers	35 to 40
Double pipe or shell and tube brine coolers with a brine velocity of 3 feet per second	80 to 90
Direct expansion or brine piping in a room with natural air circulation only	2·0 to 2·5
Air coolers with fans and forced air circulation and an air velocity of 10 feet per second	6 to 7

To conform with general practice, pipe surfaces should be so proportioned that the mean temperature difference between the refrigerant and the brine or water is 10° to 15° F., and in the piping for rooms a difference of 15° to 20° between the air and the refrigerant or brine.

Indicator Diagrams.

The indicator diagram gives an exact measure of the indicated horse-power developed in a compressor, and if it is compared with an indicator diagram taken when the machine is new and in good condition, it will disclose any defects in working such as leaky valves or piston rings.

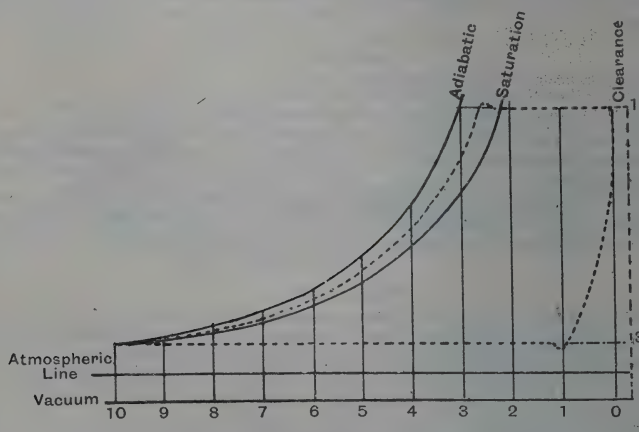

FIG. 2.

In order completely to analyse the indicator diagram, it is necessary to draw on it the curves for adiabatic compression, and for compression at saturation temperatures, as is shown in fig. 2.

With ammonia, the exponent for adiabatic compression is 1·29 and the compression curve follows the formula $P \cdot V^{1.29} = C$.

The saturation curve can easily be plotted from the volumes given in the table of properties.

The actual compression curve will lie between these two, and in the case of dry compression it will be close to the adiabatic line.

The horizontal suction and delivery lines should practically coincide with the gauge pressures. If the gauges read correctly, and the difference is more than one or two pounds, it shows that there is a restriction through the valves which may be due to either too heavy springs, the valves not working freely, or insufficient areas in the ports.

At the points where the valves open, there is always a peak on the pressure line due to the difference in pressure required to lift them from their seats, but these peaks should only be small.

The re-expansion of the gas remaining in the clearance space at the end of the stroke follows approximately the same curve as that formed on the compression stroke.

The effective swept volume of a compressor, which is indicated by the length of the suction line, is thus reduced with the proportion of the clearance volume, but as the power required is correspondingly reduced, a moderate amount of clearance does not seriously affect the performance, though it may make a considerable difference in the output of compressors with otherwise similar dimensions.

If the compression curve approaches or overlaps the adiabatic line, it indicates a leakage from the condenser side, back into the compressor through the delivery valves or the joint rings of their seats.

If the compression curve approaches the saturation line, it indicates a leakage either through the suction valves or past the piston rings.

If the diagrams from each end of a double-acting compressor are compared, and a falling away of the compression line occurs at one end only, it indicates that the leakage is at the suction valve there. If both ends are similar, it may be either the valves, the piston rings, or both that require attention.

Ammonia Absorption Machines.

Ammonia absorption machines are only used in special cases where there is sufficient live or preferably waste steam which can be utilised.

The arrangement is shown diagrammatically in fig. 3, p. 1282.

In place of the compressor the ammonia is absorbed by cool weak liquor, which, being thus enriched, is pumped into a generator or boiler, where it is heated, and the ammonia driven off into the condenser.

An interchanger is provided to heat up the cool rich liquor passing to the generator, and at the same time cool down the hot weak liquor returning to the absorber.

The small 'Electrolux' refrigerator working on the absorption system makes most ingenious use of Dalton's law of partial pressures by introducing an inert gas into what is normally the low pressure side of the system. The total pressure throughout is maintained constant, so that circulation of the liquid can be effected on the thermo-syphon principle without any moving parts. At the same time the partial pressure of the ammonia in the evaporator is low enough to effect refrigeration.

Ice Making.

The manufacture of ice is one of the principal uses of refrigeration, and the method now almost universally employed is the 'can' system, where the ice is made by placing cans or moulds containing water in a tank containing brine cooled to a temperature of 10° F. to 15° F.

When distilled and de-aerated water is used, the ice made is clear and transparent, but if ordinary water is frozen without agitation, the ice is soft and opaque, due to the minute bubbles of air dissolved in the water.

By agitating the water during the time of freezing, these air bubbles are swept off the ice surface, and the block made is clear, with the exception of a central core formed of the dissolved salts, the extent of the core depending on the hardness of the water.

Agitation can be effected by stirrers, but the best system in all except the smallest plants is that of blowing air through the water.

The time required for freezing can ice with brine at 15° F. is approximately :

Thickness of ice in inches .	3	4	6	8	10	12
Time of freezing in hours .	6	10	18	30	46	64

Ice moulds are made in a great variety of sizes to produce blocks of definite weights up to 4 cwts. each, which is a usual size for plants of large capacity, these blocks measuring about 22 in. wide, 11 in. thick, and 60 in. long.

The moulds must be made with a slight taper to enable the ice to slide out freely, and usually a number are secured together in a row, and handled as one unit by a crane.

The ice tank is arranged to contain the evaporator, which may either be of coil piping, or of the shell and tube type, and a vigorous circulation of the brine in the tank is maintained by means of a propellor or centrifugal pump.

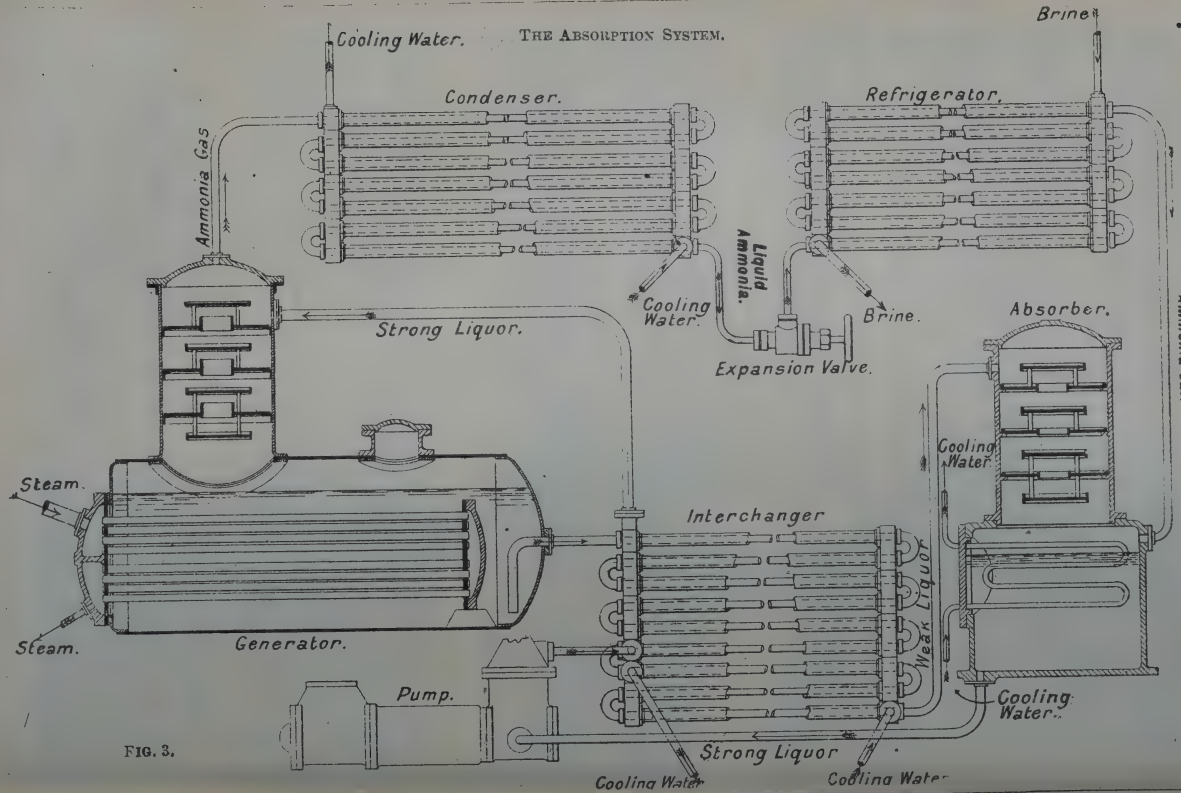
THE ABSORPTION SYSTEM.
Cooling Water.
Condenser.
Brine.
Refrigerator.
Ammonia Gas.
Liquid Ammonia.
Cooling Water.
Brine.
Strong Liquor.
Expansion Valve.
Absorber.
Ammonia Gas.
Cooling Water.
Steam.
Interchanger
Weak Liquor
Steam.
Generator.
Pump.
Cooling Water.
Strong Liquor
Cooling Water
Cooling Water

FIG. 3.

A row of ice moulds when lifted from a tank is dipped into a thawing tank containing warm water to release the blocks of ice from the cans. These are then lifted, placed in a swinging tipping frame, and turned over so that the blocks slide out.

The empty row of moulds is then refilled with the correct quantity of water on one operation by a filling tank. One cubic foot of ice at 32° F. weighs 57·5 lbs., or 30 cubic inches weigh one pound.

In a temperate climate, and with a medium or large plant, about 230 B.Th.U.'s are required to produce one pound of ice from water at 65° F., and about 60 kw. hours are required with a motor-driven plant per ton of ice made. In warmer and tropical climates these figures are considerably increased.

Refrigerating Power.

The output of a refrigerating machine is often stated in Tons Refrigeration, and the standard American rating is then generally referred to.

One ton refrigeration is then equal to 288,000 B.Th.U.'s per day, or 12,000 B.Th.U.'s per hour when working with an evaporator temperature of 5° F. (— 15° C.) and a condensing temperature of 86° F. (30° C.).

Cold Storage.

The average temperatures maintained in cold storage rooms are as follows:

Butter—frozen	10° F. to 12° F.	Hops	28° F.
Butter—short storage	32° F. „ 35° F.	Meat—frozen	15° F. to 16° F.
Cheese	35° F. „ 40° F.	chilled	29° F. „ 30° F.
Eggs	29° F. „ 31° F.	fresh	36° F. „ 38° F.
Furs and Fabrics	30° F.	Fish—frozen	10° F. „ 12° F.
Fruit—Apples	32° F. „ 35° F.	fresh	30° F. „ 32° F.
Pears	35° F. „ 36° F.	Dried Fish—frozen	15° F. „ 16° F.
Peaches	32° F. „ 33° F.	for short storage	32° F. „ 35° F.
Oranges	45° F. „ 50° F.		

Cold storage temperatures should, as far as possible, be maintained constant without variation. Both this and the maintenance of a definite temperature are particularly important where the temperature required is in the neighbourhood of the freezing-point. For produce that is frozen hard, an exact storage temperature is not quite so important, but variations should also be as far as possible eliminated.

The refrigerating power required for cold storage rooms varies very greatly with their size, shape, insulation, quantities of warm goods brought in and methods of working, but for ordinary storage rooms is about:

Capacity of Cold Rooms in Cu. Ft.	Temperature. 30° to 35° F. Tons Refrigeration.	Temperature. 10° to 15° F. Tons Refrigeration.
1,000	0·5	0·8
10,000	2·5	4·0
100,000	12·0	20·0

These figures assume continuous operation, and for reduced hours must be proportionately increased. The surface and extent of the cooling appliances will vary with the refrigerating power required and conditions of working.

The quantity of piping fixed in a room is usually determined by empirical rules based on practical results, which vary somewhat with different makers' and users' experience and give the following averages:

Capacity of Cold Rooms in Cu. Ft.	Temperature. 30° to 35° F. Length of 1¼ in. Piping to be fixed in Stores.	Temperature. 10° to 15° F. Length of 1¼ in. Piping to be fixed in Stores.
1,000	225	450
10,000	1,125	2,250
100,000	6,000	12,000

Where other sizes of piping are used, the length is adjusted to provide a similar surface.

Calcium Brine.

Calcium Chloride Brine of a density ranging from 1·18 to 1·25 is usually employed. In estimating the weight of calcium chloride required to produce brine of a given density regard

must be had to the fact that the commercial calcium chloride contains a large amount of water of crystallisation. An approximate rule is to multiply the density by 20 and subtract 20·1, the remainder gives the number of pounds of commercial calcium chloride required for each gallon of brine of the required density; for example, take the required density at 1·20, then $1{\cdot}20 \times 20 - 20{\cdot}1 = 24 - 20{\cdot}1 = 3{\cdot}9$ lbs. per gallon of brine.

Corrosion by Brines.

An important problem of refrigeration engineers is the corrosion by brines, either sodium chloride or calcium chloride, of copper, steel, or grey cast iron. An investigation by a French authority, M. Pierre, shows that the active element of this corrosion is due to the formation of an electrolytic couple, due to the association of air, brine, and the metal, and thus the dissolution of air should be avoided by submerging the return brine pipe so that it delivers below the level of the fluid in the main container. Strong brines cause more rapid corrosion, and the presence of magnesium chloride increases the activity. Lime or soda should be used with them to neutralise the formation of hydrochloric acid.

Insulation.

The thermal conductivity of the materials used for insulation may vary to some extent with individual samples, and with all loose fillings with the density to which they are packed.

The following figures are taken from the tests made at the National Physical Laboratory for the Food Investigation Board:

Material.	Density in lbs. per cu. ft.	Conductivity in B.Th.U.'s per hour per sq. ft. per 1 in. thickness and 1° F. difference in temperature.
Cork slab	11·3	0·306
" "	12·5	0·331
Granulated cork, fine	—	0·298
" " coarse	5·3	0·326
" " "	7·3	0·345
Silicate cotton	13·0	0·302
" "	21·0	0·290
Dry charcoal	11·5	0·370
Kieselguhr	30·0	0·560
Wood—Pitch pine	42·0	1·036
Concrete	—	8·200

These figures are taken at normal cold storage temperatures. The conductivity increases slightly with an increase in temperature.

To obtain the conductivity of a compound wall, the reciprocals of the conductivities of its components must be added together, and this will give the reciprocal of the whole.

Thus, if a 6-in. concrete wall is insulated with 4-in. compressed cork slabs, the reciprocal of its conductivity

$$= \frac{1}{8{\cdot}2} \times 6 + \frac{1}{0{\cdot}33} \times 4 = 12{\cdot}85;$$

and its conductivity

$$= \frac{1}{12{\cdot}85} = 0{\cdot}078.$$

If, therefore, there is a difference in temperature of 40° F., the heat leakage would be 3·12 B.Th.U.'s per sq. ft. per hour, or about 75 B.Th.U.'s per sq. ft. per day.

It is not advisable to attempt to make any allowance for the rate of heat transfer between the air and the two wall surfaces, as while this may vary very greatly, it is in any case so relatively small an item that it does not appreciably affect the result.

In an insulated wall, the jointing material for cork slabs, the timber studding for loose fillers, and unavoidable inperfections of workmanship will make the conductivity of the material as erected rather greater than the test figures given, and the results should be increased by 10 per cent. to 15 per cent. to allow for this.

The leakage of heat through the insulated walls, floor, and ceiling of a cold store practically always forms the greater proportion of the total refrigerating power required to cool it, so it is necessary that the insulation provided should reduce this leakage to a minimum.

The first essential is that the material used should have a low co-efficient for the transfer of heat; it should have no attraction for moisture, be uninflammable, inodorous, and have a high specific heat.

It should pack well without tendency to settle and leave void spaces, and it should have no tendency to spontaneous combustion under any conditions.

Compressed cork slabs erected in cement or bitumen, and having their surfaces finished in hard-setting cement, provide the most satisfactory and permanent construction, but granulated cork and silicate cotton, or slag wool, are also largely used, and other materials that are employed are pumice stone, charcoal, kieselguhr, sawdust, and shavings.

Loose filling materials are packed between wooden studs and joists, erected against walls, floors, and ceilings, and covered by T. & G. boarding with or without waterproof paper.

An air space is often provided against external walls, the construction then being illustrated in figs. 4, 5, and 6.

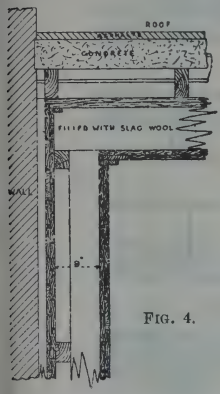

FIG. 4.

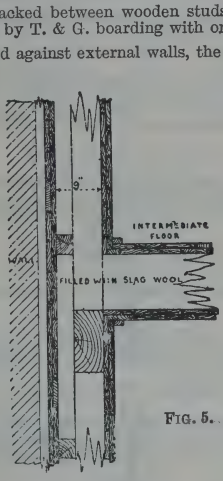

FIG. 5.

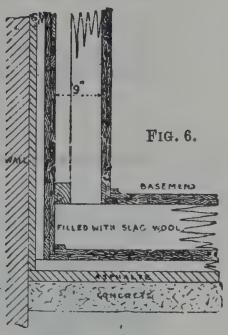

FIG. 6.

If an insulating material is allowed to become damp or sodden with moisture, its value as insulation is enormously reduced; the building or structure containing it should be impermeable to moisture, and brick walls are preferably treated with a coating of pitch or bitumen.

For large refrigerating stores for meat and other purposes the method adopted by Mr. Herbert Birkett, M.I.Mech.E., which is shown by figs. 4, 5, and 6, is one of the best that can be employed, waterproof insulating paper being placed between the matchboarding.

THICKNESS OF INSULATION.

To determine the most economical thickness of any insulating material, the cost of power to drive the refrigerating machine, which falls as the thickness of insulation increases, should be balanced against the interest on the increasing cost, and the decrease in the net or useful storage capacity.

The usual practice is to use a thickness of 4 ins. of compressed cork slabs for chill, and 6 ins. for freezing temperatures, or, alternatively, 6 and 9 ins. of granulated cork or silicate cotton. These figures are largely worked to, not entirely as giving equal insulating value, but as economical standards for the commercial thickness of cork slabs and sizes of timber.

PAPER INSULATION.

(The Willesden Paper and Canvas Works, Ltd., Willesden Junction, London, N.W. 10.)

A special description of paper known as 'Willesden' paper has for many years been largely used in the insulation of cold storage chambers. The usual method of constructing these chambers is to erect vertical studding at certain distances apart, and to cover this on both sides with grooved and tongued matched boarding, then to cover that in its turn with the Willesden paper, and over the paper to again fix another surface of matched boarding. There is then left a space between the two erections of matched boarding and paper equal to the width of the studding used, and this space is filled with some insulating material, such as charcoal, slag wool or rice husks, etc., and the work is done. The main use of the paper is to exclude air, and the Willesden material is preferred because of its durability and strength, and because it is not affected by damp nor liable to harbour fungoid growth.

'Neponset,' 'Ko-sat,' and 'Coted' are special papers of the highest grade, which are impervious to air and moisture under the severest conditions, and are largely used for cold storage insulation. They are made in rolls 36 ins. wide containing 1,000 sq. ft.

Cork Insulation.

The application of compressed cork slabs for insulation purposes is becoming more general, both in the U.S. and in England. Being in the form of slabs which are manufactured in various shapes and dimensions, they are easily fitted to the walls of the chamber. By being built together in various layers, breaking joint and cemented with a waterproof cement, they form an impermeable insulating lining to the chamber.

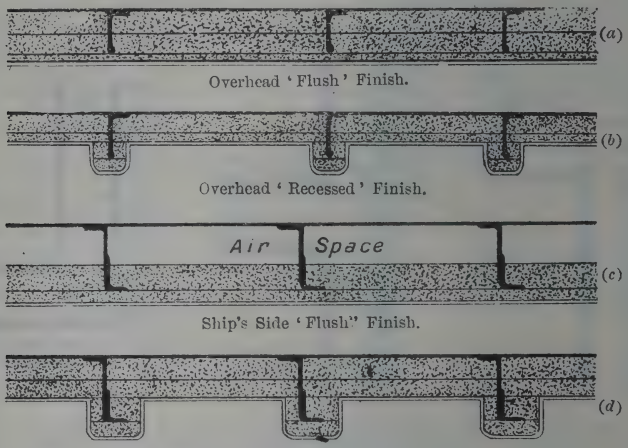

Fig. 7.—'Anderson' Jointless Insulation on Cork Slabs.

The interior facing to the chamber is usually of a special cement, preferably without joint.

With this system of insulation (fig. 7) a less thickness is required as compared with the insulating materials of a loose granular nature, and it has the further advantage of giving an increased capacity to the chamber. *Messrs. Thomas Anderson Ltd., Liverpool*, have had considerable success in its application. The efficacy of their preparation is illustrated by a recent case in which the insulation of a steamship, which had been submerged for weeks, on being raised was found intact, not requiring renewal or repair.

The material '*Fosalsil*' (p. 537) is very suitable for insulation purposes.

Insulation on Board Ship.

The insulation of cold chambers on board ship follows the same general principles and method that apply to insulation work carried out on land.

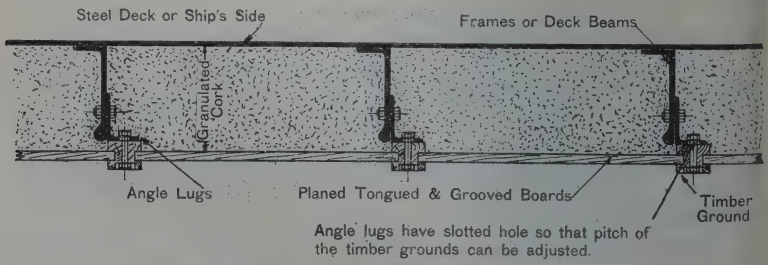

Fig. 8.—Panel System (Thompson's Patent).

ON ADMIRALTY LIST.

'ANDERSON'

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INSULATION.

JOINTLESS AND UNIT SYSTEMS.

For **COLD** Storage and Provision Chambers, Ice Boxes :: :: and all Refrigerated Spaces. :: ::

HEATED Surfaces, Bulkheads and Engine Room Casings.

CORK SECTIONAL COVERING FOR BRINE AND COLD WATER PIPES.

Magnesia Sectional and Plastic Coverings for Steam Pipes, :: :: Boilers, Turbines, etc., etc. :: ::

THOMAS ANDERSON,
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54 to 62 DERBY ROAD, LIVERPOOL.

'Phone : 1070 Bootle. Wires : 'Centrifugal,' Liverpool

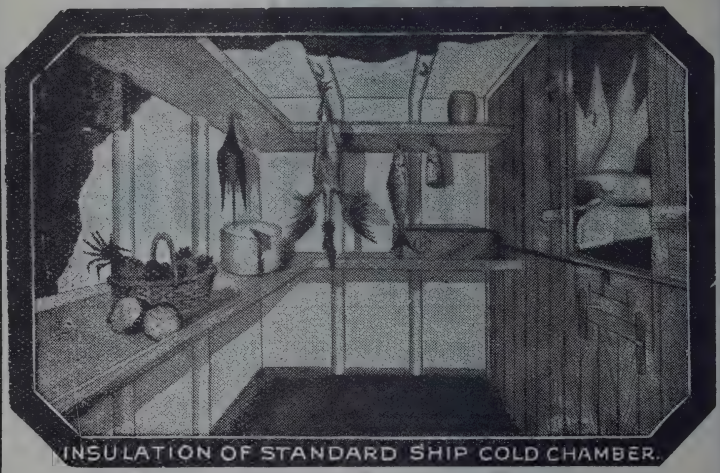
BRANCHES : London, Glasgow, Belfast, Manchester, Southampton, Sheffield and Barrow-in-Furness.

F. 1286

ON ADMIRALTY LIST.

'ANDERSON' INSULATION

JOINTLESS AND UNIT SYSTEMS.



INSULATION OF STANDARD SHIP COLD CHAMBER.

For COLD *Storage and Provision Chambers, Ice Boxes and all Refrigerated Spaces,* HEATED *Surfaces, Bulkheads and Engine Room Casings.*

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Wires: 'Centrifugal, Liverpool.' Phone: 1070 Bootle.
BRANCHES: LONDON, GLASGOW, BELFAST, MANCHESTER, SOUTHAMPTON, SHEFFIELD, BARROW-IN-FURNESS.

F. 1287

Owing to the way in which the ship's side and deck beams break up the surfaces, and to the absence of pure rectangular spaces, cork slabs are not so simple to use as loose filling materials, but there is, nevertheless, an extending use of cork slabs and an elimination of woodwork, inner linings, and air spaces.

One of the latest methods is the panel system of insulation (Thompson's patents), which, while it is particularly adapted to ships, is also applicable to work on land.

The construction is shown by figs. 8 and 9, and the advantages claimed are:

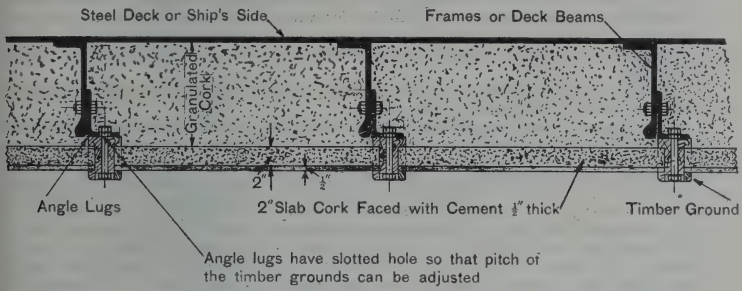

FIG. 9.—Panel System (Thompson's Patent).

(*a*) Any one or more panels can be removed intact without destruction or loss of insulating materials, and can readily be replaced without interfering in any way with the adjacent panel insulation.

(*b*) That the insulation is readily adjustable to the curved surfaces of the ship's plating, and the use of granulated cork, of silicate cotton, or the like, enables the insulation to be thoroughly well packed, no matter how curved or cut up the surface.

(*c*) When cement-faced cork slabs are used, the size of each slab being comparatively small, the liability to surface crack is slight.

(*d*) The wood grounds are exposed on the front faces, their condition can always be examined, and as they are ventilated, the danger of dry rot is greatly reduced.

(*e*) Repairs are easily effected, each panel being separate from all the others.

Operating Refrigerating Machinery.

As refrigerating machinery is solely concerned with temperatures, the gauges connected to the compressor suction and delivery are marked both with a pressure scale and a scale of the equivalent temperatures. The temperature scale should be used for regulating the working of the machine and in making any logs or records, as the differences are then obtained direct without reference to tables of properties.

The gauge on the suction side of the compressor indicates the pressure and temperature of evaporation, and that on the delivery side the pressure and temperature of condensation.

To operate a plant successfully, or analyse its working, it is also necessary to have thermometers to show the temperatures of:

1. The suction gas returning to the compressor from each separate evaporator circuit.
2. The discharge gas leaving the compressor.
3. The liquid refrigerant leaving the condenser.
4. The liquid refrigerant immediately before the regulating valves.
5. The brine leaving the evaporator.
6. The brine returning to the evaporator from each separate brine circuit.
7. The water entering the condenser.
8. The water leaving the condenser.
9. The temperature of the cold storage rooms, or, where a machine is used for special purposes, the temperature of the materials that are cooled.

The first four of these points are frequently omitted in commercial plants, but the second four are essential.

The suction gas thermometer readings should coincide with the evaporator gauge readings unless the suction gas is superheated, and thermometers in this position are particularly useful where there are several separate expansion circuits, as they provide the best indication for the quantity of liquid to be admitted to each, and for the manipulation of the regulating valves.

The discharge gas thermometer readings will be above the condenser gauge readings unless the compressor is run wet compression, and the elevation of the thermometer above the gauge temperature is an index of the dryness of the gas returning to the compressor.

The temperature of the liquid refrigerant will coincide with the condenser gauge reading unless the liquid is sub-cooled either by the use of a counter-current condenser or separate liquid cooler.

Sub-cooling of the liquid, particularly with CO_2, is always an advantage where it is practicable.

The regulation of the quantity of brine flowing through the separate circuits, and consequently of the refrigerating effect, is controlled by the difference between the brine flow and return temperatures.

The quantity of water flowing through the condenser is regulated by the difference in temperature between the inlet and outlet.

It is most important that the machine should be maintained fully charged with its refrigerant, and that supplies should be added from time to time to make good the inevitable small losses that occur with even the most carefully operated plant.

With a proper charge and well-proportioned installation, the condensing temperature should be from 10° to 15° F. above the mean condensing water temperature, and the evaporating temperature from 10° to 15° F. below the mean temperature of the brine, or about 15° to 20° F. below the air temperature when cold storage rooms are cooled by the direct expansion system.

At the same time the suction valve ports on the compressor should be frosted over, and, in the absence of thermometers, the delivery should be as hot as the hand can comfortably bear.

Closing down the regulating valve reduces the evaporating temperature and increases the gas discharge temperature, while opening up the regulating valve increases the evaporating temperature and decreases the discharge gas temperature.

The dryness of the suction gas is indicated by the discharge gas temperature, and while the aim should be to work as nearly as possible dry compression, the conditions of working that best suit individual makes of compressors and proportions of plant can only be determined by experience with them.

An undercharge of refrigerant is indicated by a high delivery temperature, a low condensing gauge temperature, and a low evaporator temperature, which does not rise as it should when the regulating valve is opened.

An overcharge is indicated by a cold delivery temperature, a high condenser gauge temperature, and an evaporator temperature which does not fall at the normal rate when the regulating valve is closed.

Of the two, an undercharge is the more serious, as it results in a reduced refrigerating effect, while an overcharge practically only affects the power required.

The refrigerant should be kept in pure condition by occasionally purging out any air or foreign gases, and the oil separator should be regularly drained to prevent oil passing over into the condenser and evaporator.

Refrigeration on Board Ship.

The use of refrigerating machinery on board ship may be roughly subdivided into three groups:

I. Small plants to cool provision storage rooms and to make small quantities of ice.

II. Large passenger vessels that are arranged to carry refrigerated cargo.

III. Large vessels used primarily for refrigerated cargo.

CO_2 refrigerating machines are almost invariably used for all classes and sizes of machines, and evaporative liquid cooling of the CO_2 is frequently employed.

On steamships the larger machines are practically always steam-driven and incorporate their own steam condensers, but the smaller machines are now generally driven by electric motors, and on motor ships an electric drive is always used.

Compressors running at low and medium speeds are generally preferred, and while direct-coupled sets are sometimes installed, the drive is generally through double helical or other speed-reduction gears.

The third group includes the increasing numbers of vessels used solely for the carriage of tropical fruits, but by far the most valuable and important marine installations are those intended mainly for the carriage of chilled beef.

Some of these have an insulated capacity of upwards of 600,000 cu. ft., and a typical section of such a vessel, together with the arrangement of the refrigerating machinery supplied by *J. & E. Hall, Ltd.*, is shown in figs. 10, 11, and 12.

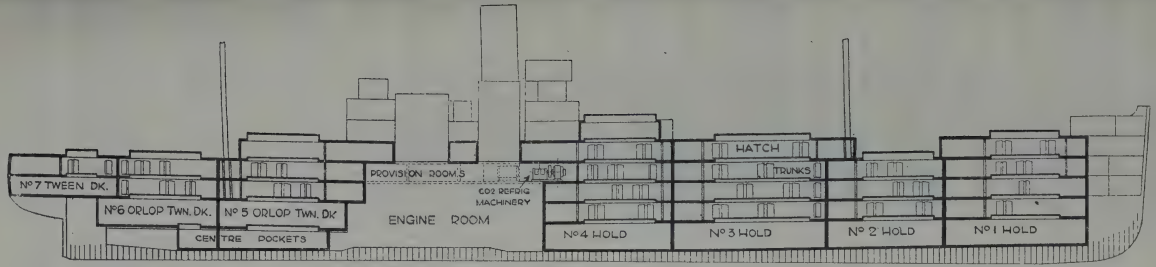

FIG. 10.

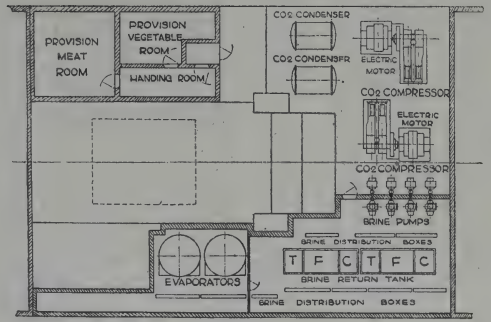

FIG. 11.

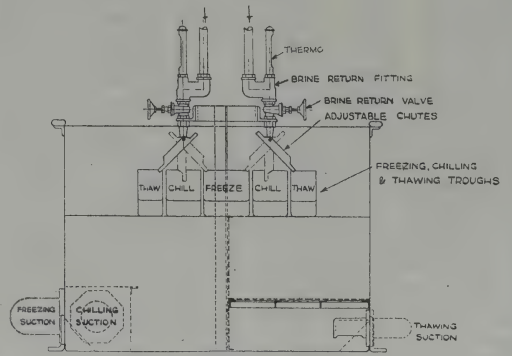

FIG. 12.

In these vessels both chilled and frozen meat can be carried, and the insulated spaces are cooled by piping in them through which cold brine is circulated.

The brine pipes are arranged in a number of circuits of limited length so that the return temperatures shall only show a small rise, and each of these circuits is separately controlled.

In modern practice a number of the spaces are, in many cases, also provided with air-cooling batteries and fans, so that cold air circulation can be used either to supplement the brine piping or as a complete alternative.

The method of cooling by cold air circulation is often preferred for fruit and for other cargoes that are carried at a temperature above the freezing-point.

The carriage of chilled beef calls for very precise regulation of the temperatures to be maintained in the various spaces.

This is effected by what is known as the three-temperature brine system, with mains providing for the delivery of brine at suitable temperatures for freezing, chilling, and thawing service, to enable any temperature from freezing to chilling to be maintained in the various spaces to suit the class of produce carried, and individual requirements of shippers.

The great majority of the large meat-carrying installations are arranged on the open brine circulating system, but the closed system is preferred by several important shipowners.

Both systems have certain advantages; both produce excellent results in practice, and the balance between them may be said to be a matter of individual preference.

The general principle common to both systems is that the brine returning from the piping in the chill spaces is pumped directly back to the chilling delivery header, but the heat absorbed by the brine in its passage through the chilling circuits is eliminated by means of an injection of the freezing brine into the chilling system, there being a corresponding overflow to the freezing system.

When carrying mixed cargoes, it is often an advantage to run one of the evaporators at the chilling and the other at the freezing temperature, instead of having both on the low temperature, and to use the system of brine injection, or attemperating, as it is often termed.

In the open system the brine returns into an open return tank or tanks placed in an insulated space adjoining the machine room, which also contains the headers, valves, cocks, and thermometers required to control the flow of brine.

The arrangement is shown in figs. 11 and 12, and the detailed arrangement of the piping for the same vessel in fig. 13.

An example of the closed brine system is shown diagrammatically in fig. 14, p. 1292, for a vessel fitted up by the *Liverpool Refrigeration Co., Ltd.*

Figs. 15 and 16 (p. 1293) show the form of main attemperating valve and attemperating cock of the Liverpool Refrigeration Co., Ltd.; these, as will be seen, adjust the proportion of chilled or cold brine in such a manner that the one supply is cut off in proportion to the amount the other is opened up.

The flow of brine through the circuits is sometimes controlled by flowmeters placed in them. In other cases no special arrangements are made for measuring quantities, and the control is made entirely on the thermometer readings, but each return has a bye-pass connection, so that the brine may be diverted into an open tank for testing purposes if required.

A large modern installation may involve up to about 200 separate brine circuits, and the control room for a closed brine system fitted up by the *Haslam Foundry & Engineering Company* is shown in fig. 17 (p. 1294).

The refrigerating machinery for these installations always consists of at least two units, each complete with its condenser and evaporator, and capable of independent working, each being of sufficient capacity to maintain the required temperatures in the cargo spaces at sea if the other is out of action.

In some important cases there are three machines, two of which have ample power to maintain the cargo, with one independent unit in reserve.

The machines are often of the Duplex type, with a cross compound engine driving the CO_2 compressors from the tail rods, and arranged so that either side can be used independently. Large single machines are made with tandem compound steam cylinders driving one compressor direct.

There are also a few examples of triple compressor machines with three-cylinder engines, as shown in fig. 18 (p. 1295), illustrating an installation by the *Liverpool Refrigeration Co., Ltd.*

The CO_2 condensers are constructed of solid drawn copper piping contained in cast-iron casings. The evaporators are generally of solid drawn steel piping contained in built steel casings, and in modern practice both brine and water circulating pumps are of the centrifugal type direct coupled to electric motors.

The pump connections to the suction and delivery mains are made to valve boxes, permitting an interchange of duties on the respective chilling and freezing circuits, and for one pump being always available as a standby for either duty.

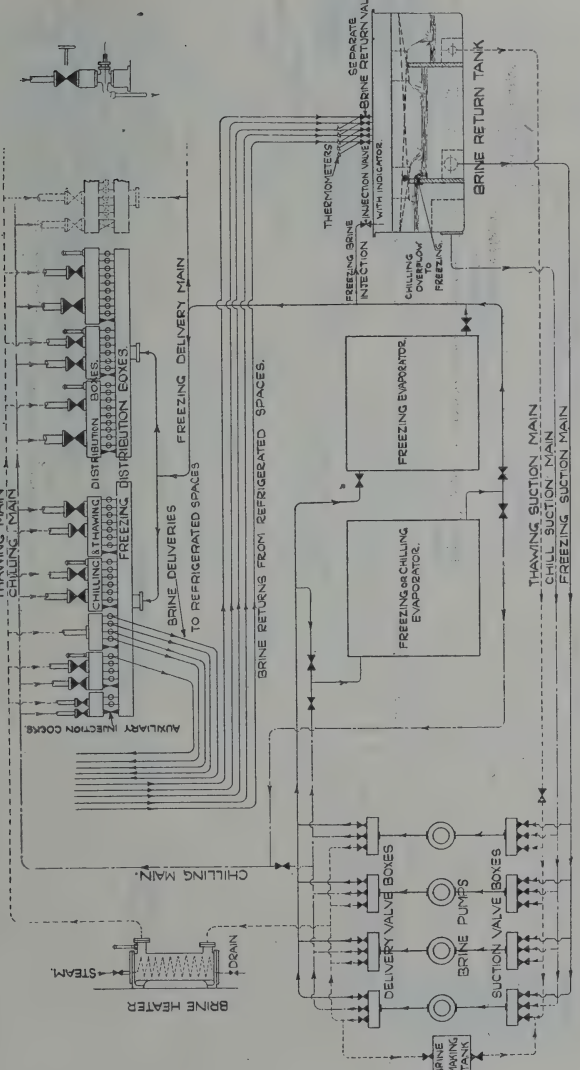
THAWING MAIN
CHILLING MAIN
AUXILIARY INJECTION COCKS
CHILLING & THAWING DISTRIBUTION BOXES
FREEZING DISTRIBUTION BOXES
BRINE DELIVERIES TO REFRIGERATED SPACES
FREEZING DELIVERY MAIN
BRINE RETURNS FROM REFRIGERATED SPACES
THERMOMETERS
SEPARATE BRINE RETURN VALVES
FREEZING BRINE INJECTION
INJECTION VALVE WITH INDICATOR
CHILLING OVERFLOW TO FREEZING
BRINE RETURN TANK
FREEZING EVAPORATOR
FREEZING OR CHILLING EVAPORATOR
THAWING SUCTION MAIN
CHILL SUCTION MAIN
FREEZING SUCTION MAIN
CHILLING MAIN
STEAM
DRAIN
BRINE HEATER
DELIVERY VALVE BOXES
BRINE PUMPS
SUCTION VALVE BOXES
BRINE MAKING TANK

FIG. 13.

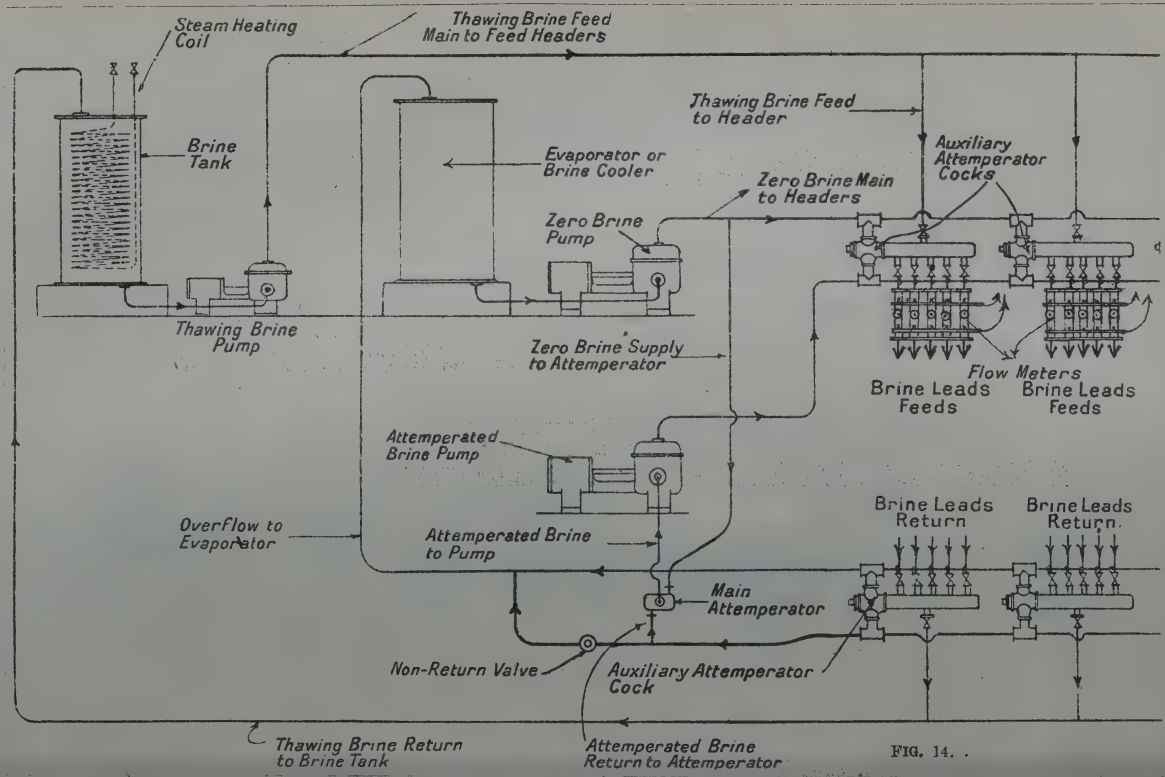
Steam Heating Coil
Thawing Brine Feed Main to Feed Headers
Thawing Brine Feed to Header
Brine Tank
Evaporator or Brine Cooler
Auxiliary Attemperator Cocks
Zero Brine Main to Headers
Zero Brine Pump
Thawing Brine Pump
Zero Brine Supply to Attemperator
Flow Meters
Brine Leads Feeds
Brine Leads Feeds
Attemperated Brine Pump
Brine Leads Return
Brine Leads Return
Overflow to Evaporator
Attemperated Brine to Pump
Main Attemperator
Non-Return Valve
Auxiliary Attemperator Cock
Thawing Brine Return to Brine Tank
Attemperated Brine Return to Attemperator

FIG. 14.

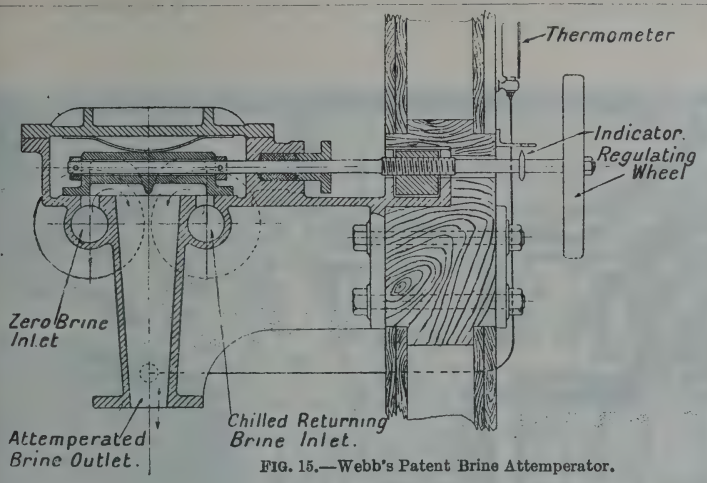

FIG. 15.—Webb's Patent Brine Attemperator.

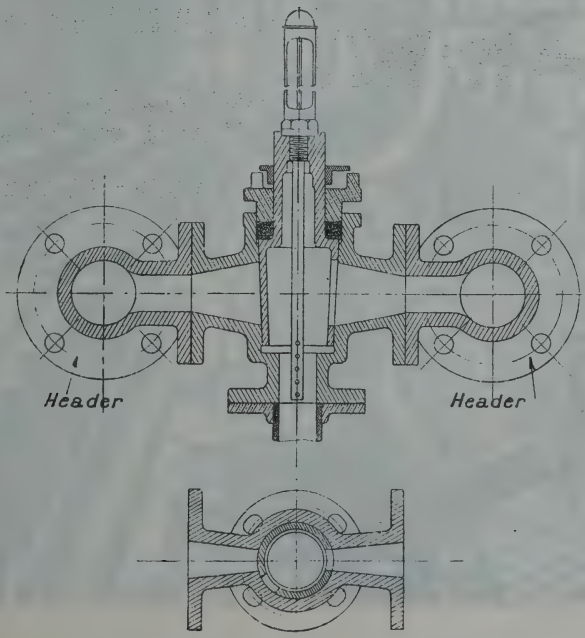

FIG. 16.—Webb's Patent Attemperator Cock (Section).

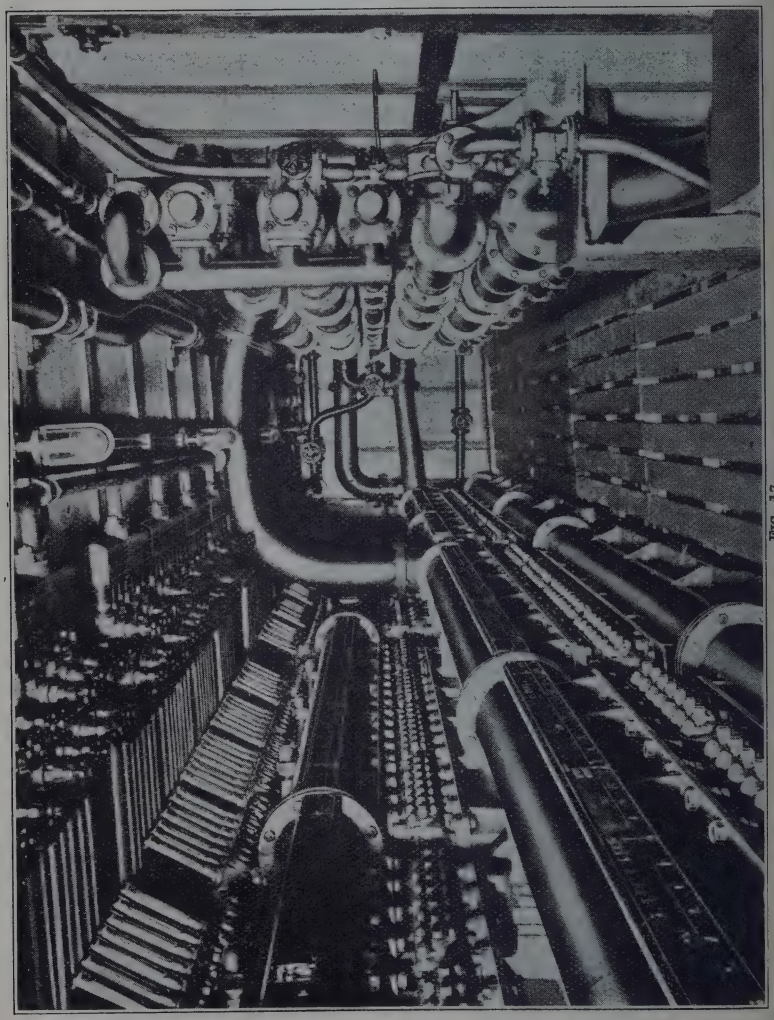

FIG. 17.

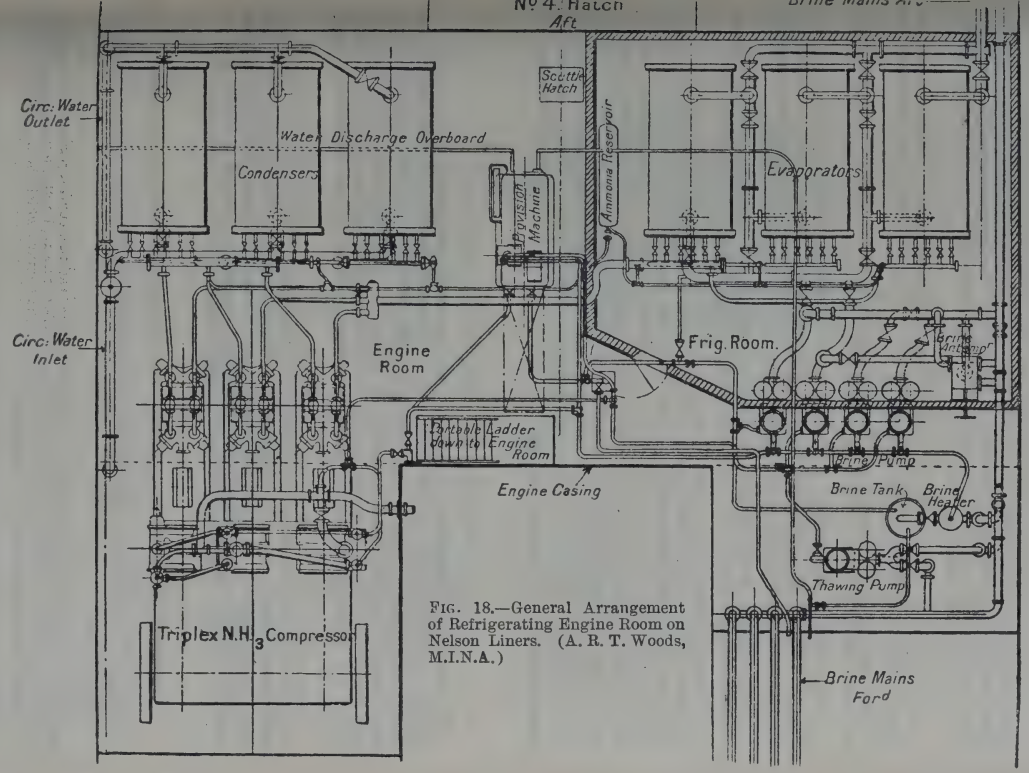

FIG. 18.—General Arrangement of Refrigerating Engine Room on Nelson Liners. (A. R. T. Woods, M.I.N.A.)

Water Coolers.

The 'Heenan' Water Cooler.

The latest type of cooler recently introduced by Messrs. Heenan & Froude, Ltd., Worcester, claims a minimum consumption of water per brake horse-power-hour, and has the advantage of being compact and occupying comparatively small space. The apparatus is also self-contained. It is of the stationary type, and has no moving parts beyond the fan which circulates the air, and the pump which circulates the water.

The apparatus (as shown by fig. 19) consists of an outer casing, which is rectangular in shape, built up of mild steel plates. The base of this casing forms a tank into which the water drains after cooling, and previous to re-circulation.

The cooling effect is obtained by evenly distributing the heated water over a number of screens set up one above the other in the body of the cooler.

The water to be cooled, after passing through a strainer, enters at the top of the cooler and falls on to the screens through nozzles which feed perforated troughs. In its fall through the screens it meets a current of cold air which is forced upward through the casing by a centrifugal fan, the discharge from which is introduced to the underside of the lowest screen.

The screens are formed of phosphor-bronze metallic wool of standard size and thickness, held together between brass wire netting which is attached to galvanised angle-steel frames.

The cooling effect is positive and continuous, the cooling surface being always efficient, and the volume of air being a predetermined quantity which is not dependent on climatic conditions. By suitably proportioning the size of the machine for the duty which it has to undertake, water can be cooled down to a temperature closely approaching that of the prevailing wet bulb thermometer. Thus in hot weather—in temperate as well as in tropical climates—re-cooled water can be provided at a temperature considerably below the dry bulb temperature of the surrounding atmosphere. This feature renders the machine especially suitable for dealing with the circulating water of refrigerating plants, for which purpose large numbers of 'Heenan' coolers have been supplied. The practical value of the cooler is due not only to the saving in water but to the improved efficiency of the refrigerating plant, resulting in lower compression pressures and reduced power consumption.

'Pulsometer' Refrigerating Plants.

The Pulsometer Engineering Co., Ltd., are manufacturers of apparatus for working on both the NH_3 (Ammonia), and CO_2 (Carbon Dioxide) compression systems, and their machines are designed and manufactured on the principle that high efficiency as well as reliable and satisfactory service with a minimum amount of attention is of first importance, and apart from the large number of plants of various capacities they supply for land service both in this country and most countries abroad, they are large suppliers of marine type plants for ordinary ships' stores cooling and icemaking, and also for magazine cooling, refrigerating, and icemaking on board war vessels.

A considerable number of cargo and passenger boats have been equipped with this type, and the manufacturers have recently developed an improved design in the form of an enclosed type quick running splash lubrication machine which is particularly suited for both land and marine use. Though marked by many up-to-date improvements, it retains most of the features for which the early designs were so well known, i.e. simplicity and ease of operation with the minimum amount of attention, freedom from breakdown, and low cost of maintenance.

Negretti & Zambra's Low Temperature Electrical Distance Thermometer.

This Thermometer (which depends upon the variation of an electrical resistance by change of temperature) is specially designed for cold-storage work suitable for dairies, butter factories, and meat storage.

The advantage of its installation is that it is possible to read in a central position the temperatures of a number of different points situated some distance away, i.e. the temperatures of cold chambers can be read in the engine room or the manager's office, which is a great advantage and assists the economical working of the plant.

The elements or thermometer bulbs are placed in the cold chambers, brine pipes, etc., and connected up to the indicator by means of lead-covered wire, the electric current being provided by an accumulator. These elements vary according to the purpose for which they are required, either for air temperatures, or for brine or water temperatures.

'HEENAN' COOLER. TYPE 'V.'

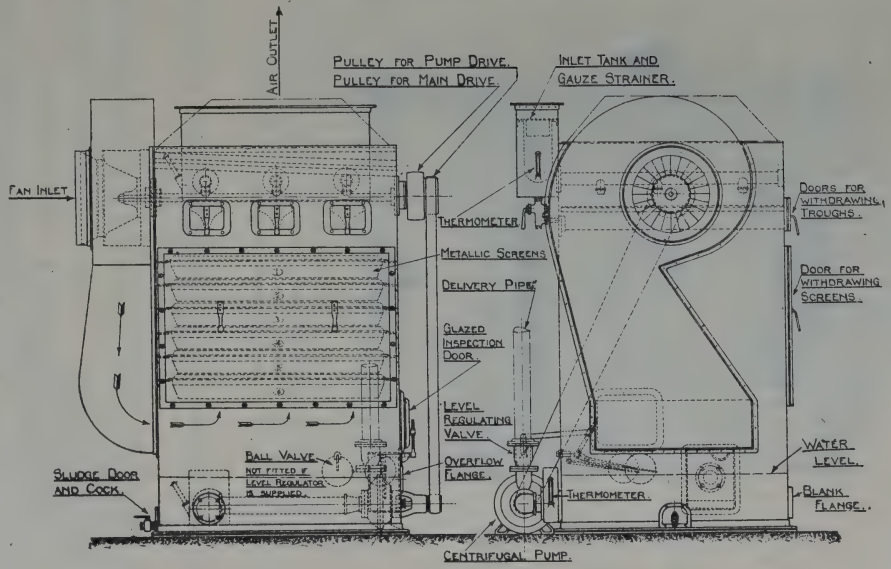

FIG. 19.

The indicator (fig. 20) is mounted in a cast-iron moisture-proof case sprayed and stoved white, the scale being graduated to cover the temperatures required, such as cold stores – 20 to + 100° F., etc. There is a multiple point switchboard incorporated in the case, by means of which the temperature of any point can be read on the indicator as desired.

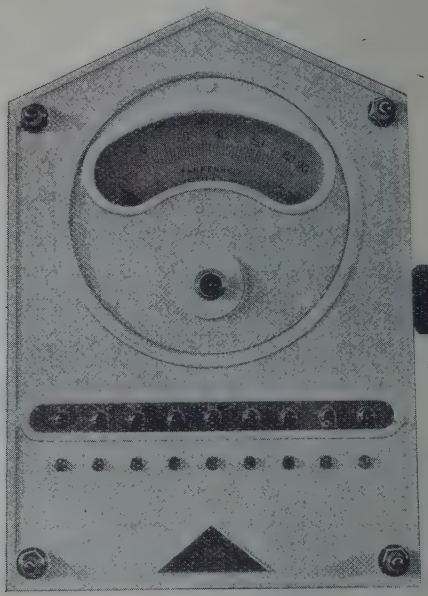

FIG. 20.

All the connections are enclosed in the case, so that they are adequately protected from moisture, dust, etc.

The connecting wire used is a 3-core cable, lead-covered for protection.

LLOYD'S RULES FOR THE SURVEY OF REFRIGERATING MACHINERY AND APPLIANCES OF FROZEN MEAT STORES.

(Abstract.)

Power of Machinery.—The refrigerating machinery is to be of approved construction and of sufficient power to maintain a temperature of 15° F. simultaneously in all insulated chambers when running 18 hours per day.

Motive Power.—Each compressor is to be driven by independent means, or, alternatively, the motive power is to be in duplicate.

Where the compressors are electrically driven, a spare electric generator is to be fitted, unless the power is supplied by a public generating station.

Where electric transformers are installed on the premises, a spare transformer is to be fitted.

Hydraulic and other Tests.—In the case of new refrigerating machinery and appliances, the tests recommended for the various parts are as follows, viz.:

(*a*) CO_2 compressors, separators, condenser and evaporator coils, headers and connections to be tested by hydraulic pressure to 3,000 lbs. per sq. in., and afterwards by air pressure to 1,500 lbs. per sq. in., whilst submerged in water.

(*b*) NH_3 compressors and cast iron or steel connections to be tested by hydraulic pressure to 600 lbs. per sq. in. Where compound compressors are fitted, the low pressure compressor and cast-iron or steel connections to be tested by hydraulic pressure to 200 lbs. per sq. in.

(*c*) NH_3 condenser, evaporator and air cooler coils to be tested by hydraulic pressure to 1,500 lbs. per sq. in., and afterwards by air pressure to 500 lbs. per sq. in., preferably whilst submerged in water.

(*d*) NH_3 plant, after erection in place, to be tested by air pressure; the gas delivery side (*i.e.* from the compressor to the liquid expansion valves) to 200 lbs., and the return side, including the direct expansion piping for the chambers (*i.e.* from the liquid expansion valves to the compressor suction valves) to 150 lbs. per sq. in.

(*e*) Brine piping, after erection in place, to be tested by air or water pressure to 90 lbs. per sq. in.

(*f*) Gas evaporator casings of cast iron and gas condenser casings, whether of cast iron or steel, where of enclosed type, to be tested by hydraulic pressure to 15 lbs. per sq. in., or to double the working pressure, whichever is the greater.

(*g*) Gas evaporator wrought-iron and steel casings, where of enclosed type, to be tested by hydraulic pressure to 30 lbs., if gravitation type, or to 50 lbs. per sq. in. if pressure type, or to double the working pressure, whichever is the greater.

Cooling Tests.—(*a*) Upon completion of the installation under special survey, the refrigerating machinery is to be tested under working conditions, and the insulated chambers are to be cooled down simultaneously to about 15° F.

(*b*) The whole of the refrigerating power may be used in order to reduce the temperature, but the specified temperature is to be maintained in the insulated chambers for a period of 12 hours with the spare compressor unit out of action.

Brine Cooling System.—(*a*) Where the brine system of refrigeration is employed the cooling pipes in each refrigerated chamber of over 5,000 cu. ft. capacity are to be arranged in not less than two sections, and the cooling surface is to be sufficient to maintain the working temperature of the chamber when one of the sections is out of use. Isolating valves or cocks are to be fitted to each section of cooling pipes.

(*b*) The brine circulating pipes and brine tanks should not be galvanised on the inside.

(*c*) In cases where internally galvanised tanks or cooling pipes are fitted, the brine cooling and return tanks, if of closed type, are each to be provided with a ventilating pipe or pipes led to the open air in a situation where no danger will be incurred from the issuing gas, and each ventilating pipe is to be fitted with a wire gauze diaphragm which can easily be removed for renewal.

(*d*) Where the tanks are not closed the compartments in which they are situated are to be efficiently ventilated.

Direct Expansion System.—Where the direct expansion system of refrigeration is employed, the cooling pipes in each refrigerated chamber of over 5,000 cu. ft. capacity are to be arranged in not less than two sections, and the cooling surface is to be sufficient to maintain the working temperature of the chamber when one of the sections is out of use. An expansion valve and a return gas valve or cock are to be fitted to each section of cooling pipes.

SECTION XXV

PART I

HYDRAULICS — GENERAL DATA OF WATER — WATER PRESSURE — HORSE POWER REQUIRED TO PUMP WATER — PRESSURE IN HYDRAULIC MAINS — DIMENSIONS AND STRENGTH OF HYDRAULIC PIPES AND CYLINDERS — PIPE UNIONS AND JOINTS (pp. 1303-1312)

PART II

PUMPS - STEAM PUMPS — PUMP PACKING — CENTRIFUGAL PUMPS—TURBINE PUMPS—AIR LIFT PUMPS (pp. 1313-1344)

PART III

THE DEVELOPMENT OF WATER-POWER

(Partly Contributed by Arthur Surveyer, D. Eng., M.E.I.C., M.Inst.C.E.

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PART IV

WATER PRESSURE ENGINES—PELTON WHEELS—TURBINES
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PART V

HYDROSTATIC PRESS—HYDRAULIC RAMS—HYDRAULIC LIFTS —HYDRAULIC BOLT FORCERS - HYDRAULIC RIVETERS
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SECTION XXV

PART I

HYDRAULICS—GENERAL DATA OF WATER—WATER PRESSURE—HORSE POWER REQUIRED TO PUMP WATER—PRESSURE IN HYDRAULIC MAINS—DIMENSIONS AND STRENGTH OF HYDRAULIC PIPES AND CYLINDERS—PIPE UNIONS AND JOINTS.

General Data Regarding Water.

An imperial gallon of water at 62° F. weighs 10 lbs. avoirdupois. (See also page 236.)

Gallons × 277·420 = cu. ins. (*International Bureau of Standards, Paris*, 1921.)

Gallons × 0·16055 = cu. ft.
Cu. ft. × 6·2288 = gallons.
Cu. in. × 0·0036047 = gallons.
Cu. ft. × 62·288 = lbs. weight.
Lbs. × 0·016053 = cu. ft.

Gallons × 0·004464 = tons.
Tons × 224 = gallons.
Cu. ft. × 0·027807 = tons.
Tons × 35·962 = cu. ft.

A pipe one yard long holds approximately (actually, 1·52 per cent. less) as many lbs. of water as the square of its diameter in inches; thus, a 6-inch pipe holds approximately 36 lbs. of water in each yard length.

VISCOSITY (ν)* OF WATER IN C.G.S. UNITS AT VARIOUS TEMPERATURES.

(Calculated from data in *The Philosophical Transactions of the Royal Society*, A., Vol. 214.—*H. R. K.*)

C.°	8·6	10·2	10·5	10·7	11·1	11·3	11·5	14·3	15·0	16·0	20·5	23·0	25·0
F.°	47·5	50·4	50·9	51·3	51·9	52·3	52·7	57·7	59·0	60·8	68·9	73·4	77·0
ν	0·0136	0·0131	0·0130	0·0129	0·0128	0·0127	0·0126	0·0115	0·0114	0·0110	0·0100	0·0093	0·0090

Approximately the viscosity at 69° F. is 0·01. The viscosity varies approximately 2·06 per cent. for each C.°, or 1·2 per cent. for each F.°

Water-Pressure.

If

H = head of water in feet; P = lbs. pressure per square inch,

$H = P \times 2{\cdot}311$. $P = H \times {\cdot}4326$.

10 feet head of water gives a pressure of 4½ lbs. per square inch, approximately,

27·71 inches of water gives a pressure of 1 lb. per square inch.

* See note p. 1072.

TABLE SHOWING WATER PRESSURE CORRESPONDING TO VARIOUS FEET HEAD.

Feet Head.	Pressure in Lbs. per Square Inch.	Feet Head.	Pressure in Lbs. per Square Inch.	Feet Head.	Pressure in Lbs. per Square Inch.	Feet Head.	Pressure in Lbs. per Square Inch.	Feet Head.	Pressure in Lbs. per Square Inch.	Feet Head.	Pressure in Lbs. per Square Inch.
1	·43	21	9·08	41	17·8	61	26·4	81	35·0	110	47·6
2	·87	22	9·52	42	18·2	62	26·8	82	35·5	120	51·9
3	1·30	23	9·95	43	18·6	63	27·3	83	35·9	130	56·2
4	1·73	24	10·4	44	19·0	64	27·7	84	36·3	140	60·6
5	2·16	25	10·8	45	19·5	65	28·1	85	36·8	150	64·9
6	2·60	26	11·3	46	19·9	66	28·6	86	37·2	160	69·2
7	3·03	27	11·7	47	20·4	67	29·0	87	37·6	170	73·5
8	3·46	28	12·1	48	20·8	68	29·4	88	38·1	180	77·9
9	3·89	29	12·5	49	21·2	69	29·8	89	38·5	190	82·2
10	4·33	30	13·0	50	21·6	70	30·3	90	38·9	200	86·5
11	4·76	31	13·4	51	22·1	71	30·7	91	39·4	210	90·8
12	5·19	32	13·8	52	22·5	72	31·1	92	39·8	220	95·2
13	5·62	33	14·3	53	22·9	73	31·6	93	40·2	230	99·5
14	6·06	34	14·7 *	54	23·4	74	32·0	94	40·7	240	103·8
15	6·49	35	15·2	55	23·8	75	32·4	95	41·1	250	108·1
16	6·92	36	15·6	56	24·2	76	32·9	96	41·5	260	112·2
17	7·35	37	16·0	57	24·7	77	33·3	97	42·0	270	116·8
18	7·79	38	16·4	58	25·1	78	33·7	98	42·4	280	121·1
19	8·22	39	16·9	59	25·5	79	34·2	99	42·8	290	125·5
20	8·65	40	17·3	60	26·0	80	34·6	100	43·3	300	129·8

* Atmospheric pressure.

TABLE SHOWING THEORETICAL HORSE-POWER REQUIRED TO RAISE 1,000 GALLONS (160·6 cubic feet) OF WATER PER HOUR TO VARIOUS HEIGHTS.

Height in Feet.	Horse-power.	Height in Feet.	Horse-power.	Height in Feet.	Horse-power.	Height in Feet.	Horse-power.	Height in Feet.	Horse-power.	Height in Feet.	Horse-power.
1	·005	21	·106	41	·207	61	·308	81	·409	110	·556
2	·010	22	·111	42	·212	62	·313	82	·414	120	·606
3	·015	23	·116	43	·217	63	·318	83	·419	130	·657
4	·020	24	·121	44	·222	64	·323	84	·424	140	·707
5	·025	25	·126	45	·227	65	·328	85	·429	150	·758
6	·030	26	·131	46	·232	66	·333	86	·434	160	·808
7	·035	27	·136	47	·237	67	·338	87	·439	170	·859
8	·040	28	·141	48	·242	68	·343	88	·444	180	·910
9	·045	29	·146	49	·247	69	·348	89	·449	190	·960
10	·051	30	·152	50	·253	70	·354	90	·455	200	1·010
11	·056	31	·157	51	·258	71	·359	91	·460	210	1·061
12	·061	32	·162	52	·263	72	·364	92	·464	220	1·111
13	·066	33	·167	53	·268	73	·369	93	·470	230	1·162
14	·071	34	·172	54	·273	74	·374	94	·475	240	1·212
15	·076	35	·177	55	·278	75	·379	95	·480	250	1·263
16	·081	36	·182	56	·283	76	·384	96	·485	260	1·313
17	·086	37	·187	57	·288	77	·389	97	·490	270	1·364
18	·091	38	·192	58	·293	78	·394	98	·495	280	1·414
19	·096	39	·197	59	·298	79	·399	99	·500	290	1·465
20	·101	40	·202	60	·303	80	·404	100	·505	300	1·515

In practice about 33 per cent. more power than the theoretical may be required.

TABLE SHOWING HORSE-POWER REQUIRED TO PUMP WATER TO GIVEN VERTICAL HEIGHTS.
(Calculated at 33 per cent. above theoretical value.)

Gallons per Hour	Height in Feet.											
	20	30	40	50	60	70	80	90	100	200	300	400
	Horse-power.											
300	·0403	·0605	·0806	·1008	·1209	·1411	·1612	·1814	·2015	·4031	·6046	·8062
350	·0470	·0705	·0941	·1176	·1411	·1646	·1881	·2116	·2351	·4703	·7054	·9405
400	·0537	·0806	·1075	·1344	·1612	·1881	·2150	·2418	·2687	·5374	·8062	1·075
450	·0605	·0907	·1209	·1512	·1814	·2116	·2418	·2721	·3023	·6046	·9069	1·209
500	·0672	·1008	·1344	·1680	·2015	·2351	·2687	·3023	·3359	·6718	1·008	1·344
550	·0739	·1108	·1478	·1847	·2217	·2586	·2956	·3325	·3695	·7390	1·108	1·478
600	·0806	·1209	·1612	·2150	·2418	·2822	·3225	·3628	·4031	·8062	1·209	1·612
650	·0873	·1310	·1747	·2183	·2620	·3057	·3493	·3930	·4367	·8733	1·310	1·747
700	·0940	·1411	·1881	·2351	·2822	·3292	·3762	·4232	·4703	·9405	1·411	1·881
750	·1008	·1512	·2015	·2520	·3023	·3527	·4031	·4535	5039	1·008	1·512	2·015
800	·1075	·1612	·2150	·2687	·3225	·3762	·4300	·4837	·5374	1·075	1·612	2·150
850	·1142	·1713	·2284	·2855	·3426	·3997	·4568	·5139	·5710	1·142	1·713	2·284
900	·1209	·1814	·2418	·3023	·3628	·4232	·4837	·5442	·6046	1·209	1·814	2·418
950	·1276	·1915	·2503	·3191	·3829	·4467	·5106	·5744	·6382	1·276	1·915	2·503
1,000	·1344	·2015	·2687	·3359	·4031	·4703	·5374	·6046	·6718	1·344	2·015	2·687
2,000	·2687	·4031	·5374	·6718	·8062	·9405	1·075	1·209	1·344	2·687	4·031	5·374
3,000	·4031	·6046	·8062	1·008	1·209	1·411	1·612	1·814	2·015	4·031	6·046	8·062
4,000	·5374	·8062	1·075	1·344	1·612	1·881	2·150	2·418	2·687	5·374	8·062	10·75
5,000	·6718	1·008	1·344	1·680	2·015	2·351	2·687	3·023	3·360	6·718	10·08	13·44
6,000	·8062	1·209	1·612	2·015	2·418	2·822	3·225	3·628	4·031	8·062	12·09	16·12
7,000	·9405	1·411	1·881	2·351	2·822	3·292	3·762	4·232	4·703	9·405	14·11	18·81
8,000	1·075	1·612	2·150	2·687	3·225	3·762	4·300	4·837	5·374	10·75	16·12	21·50
9,000	1·209	1·814	2·418	3·023	3·628	4·232	4·837	5·442	6·046	12·09	18·14	24·18
10,000	1·344	2·015	2·687	3·359	4·031	4·703	5·374	6 046	6·718	13·44	20·15	26·87
20,000	2·687	4·031	5·374	6·718	8·062	9·405	10·75	12·05	13·44	26·87	40·31	53·74
30,000	4·031	6·046	8·062	10·08	12·09	14·11	16·12	18·14	20·15	40·31	60·46	80·62
40,000	5·374	7·062	10·75	13·44	14·12	18·81	21·50	24·18	26·87	53·74	70·62	107·5
50,000	6·718	10·08	13·44	16·80	20·15	23·51	26·87	30·23	33·59	67·18	100·8	134·4
60,000	8·062	12·09	16·12	20·15	24·18	28·22	32·25	36·28	40·31	80·62	120·9	161·2
70,000	9·405	14·11	18·81	23·5	28·22	32·92	37·62	42·32	47·03	94·05	141·1	188·1

(*H. R. Kempe.*)

Horse-power required to Pump Water.

1 H.P. indicated will raise about 3,000 gallons of water per hour 50 feet high.

To pump 1 gallon of water per minute against a pressure of p lbs. per square inch requires $p \times \cdot0007$ H.P.

Allowing 40 per cent. for friction, the following shows the H.P. required to pump 1 gallon of water per minute at various pressures :—

Pressure per square inch, in lbs.	500	700	1000	1200	1500	2000	2250	2500	5000
Horse-power	·49	·69	·98	1·18	1·47	1·96	2·21	2·45	4·90

The *cost of lifting* 1 ton 50 feet is, in the case of the London Hydraulic Power Company, sometimes as low as $\frac{1}{4}d$.

Speed of Water should not, as a rule, exceed 100 feet per minute with 700 lbs. pressure. In the mains of the London Hydraulic Power Company the delivery is 1,040 gallons per minute, at a velocity averaging 2·83 feet per second, or 170 feet per minute. The loss of head due to this velocity is 22·896 feet per 1,000 yards, by the formula :—

$$\frac{(\text{Gallons per minute})^2 \times (\text{length of pipe in yards})}{(3 \times \text{diameter of pipe in inches})^5}$$

The most distant point of the main is 5,320 yards, or just over 3 miles, from the accumulators. In a circuit of 5 miles the normal difference of pressure, or loss of head, was 20 feet head.

Pressure in Hydraulic Mains.

The average working pressure is 700 lbs. per square inch with accumulators, but varies from 300 to 1,500 lbs. per square inch. The pressure in the mains of the London Hydraulic Power Company averages 700 lbs., the actual pressure at the accumulators being 750 lbs.

700 lbs. per square inch = 549·78 lbs. per circular inch, equivalent to a head of 1,618 feet.

EFFECTIVE PRESSURE WITH 700 LBS. AT ACCUMULATOR.

Ratio of multiplying power	2 to 1	4 to 1	6 to 1	8 to 1	10 to 1	12 to 1	14 to 1	16 to 1
Multiply by	·8	·6	·72	·67	·63	·59	·54	·5
Effective pressure in lbs.	560	532	504	469	441	413	378	350

Dimensions of Hydraulic Pipes and Cylinders.

TABLE OF THICKNESS OF HYDRAULIC PIPES.

Description.	Wrought Iron, to stand 4,000 Lbs. per Square Inch.										Cast Iron, to stand 700 Lbs. per Square Inch.						
Internal diameter, in inches	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	2	$2\frac{1}{2}$	$2\frac{1}{2}$	3	3
External diameter in inches	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{1}{4}$	$3\frac{9}{16}$	$3\frac{15}{16}$	$4\frac{3}{4}$	$5\frac{1}{4}$
Number of threads per inch	14	14	14	11	11	11	11	11	11	11							

(1)

The external diameter, D, may be calculated from the formula :—

$$D = d\left(\frac{p}{f} + 1\right),$$

where,

d = diameter of bore of pipe, in inches ; p = pressure, in lbs., per square inch ; f = 4,000 for wrought iron, and 1,200 for cast iron.

(2)

$$T = \frac{(P + 100)\,D}{0{\cdot}4\,S} + 0{\cdot}333\left(1 - \frac{D}{100}\right),$$

where,

T = thickness of pipe in ins.; D = interior diameter of pipe in ins.; P = pressure of water in lbs. per sq. in.; S = ultimate tensile strength of cast-iron in lbs. per sq. in. (taken as 18,000 lbs.).

This formula gives the weight and thickness for good, tough, and elastic cast-iron pipes covering the ordinary range of static pressures of public water supplies.

TABLE CALCULATED FROM FOREGOING FORMULA

Head of water in ft. . .	115	150	200	250	300
Pressure in lbs. . . .	50	65	87	109	130
Diameter in Ins.	Thickness in Ins.				
4	—	—	—	0·40	0·45
6	—	—	—	0·46	0·50
8	—	—	—	0·52	0·55
10	—	—	—	0·60	0·63
12	—	0·57	0·61	0·65	0·69
14	—	0·61	0·65	0·70	0·75
16	—	0·65	0·70	0·75	0·81
20	—	0·73	0·79	0·85	0·92
24	—	0·80	0·87	0·95	1·03
30	—	0·92	1·00	1·10	1·20
36	0·93	1·03	1·13	1·25	1·36
42	1·01	1·14	1·27	1·40	—
48	1·15	1·25	1·40	1·55	—
54	1·23	1·35	1·53	—	—
60	1·35	1·50	1·70	—	—

(*R. D. Wood & Co., America.*)

(3)

$$T = \frac{(P + L)\,R}{3{,}300} + 0{\cdot}25.$$

where

T = thickness of pipe in ins.; P = static pressure in lbs. per sq. in.; R = inside radius of pipe in ins.; L = pressure in lbs. allowed for water hammer; 0·25 = a constant allowance for inequality in manufacture, deterioration, and rough handling; 3,300 = one-fifth of the tensile strength of cast-iron, which is taken to be 16,500.

The values of L—the allowance for water hammer—for different sizes of pipe are as follows, the allowance decreasing as the diameter and thickness of pipe increase :—

Diameter of Pipe, Ins.	Value of 'L,' Lbs.	Corresponding Head, Ft.
3, 4, 6, 8, or 10	120	277
12 or 14	110	254
16 or 18	100	231
20	90	208
24	85	196
30	80	185
36	75	173
42, 48, 54 or 60	70	162

For a static pressure of 100 lbs. per sq. in. a 6 in. pipe need be only 0·10 in. thick. Such thin pipe, however, could not well be made or handled, and allowance must be made (as above) for shock due to water hammer, for roughness in handling, for inequality in manufacture, and for deterioration. (*D. Fitzgerald, America.*)

Thickness of Hydraulic Cylinders.

If T = thickness of metal in inches, P = bursting pressure in lbs. per square inch, R = radius of cylinder in inches, and C = constant (16,000 for cast iron, 34,000 for brass, 50,000 for wrought iron, and 70,000 for steel),

$$T = \frac{PR}{C - P}.$$

If D = external diameter of cylinder in inches, and d = internal diameter in inches, P and C being as above, then

$$D = d\sqrt{\frac{C + P}{C - P}}.$$

Strength of Hydraulic Cylinders.

If f = allowable stress in lbs. per sq. in.; P = working pressure in lbs. per sq. in.; d = inside diameter in ins.; D = outside diameter in ins.; then

$$D = d \times \text{anti-log}\left(\frac{P}{p} \cdot 4343\right). \qquad (Clark.)$$

EXAMPLE.—If P = 3,000 lbs. per sq. in.; f = 8,000 lbs. per sq. in.; d = 30 ins.; then

$$\frac{P}{p} \cdot 4343 = \frac{3{,}000}{8{,}000} \cdot 4343 = \cdot 16286$$

anti-log.* of $\cdot 16286 = 1 \cdot 455$ (page 99);

therefore $D = 30 \times 1 \cdot 455 = 43 \cdot 65$ ins.

Size of Hydraulic Mains.

The largest mains used for hydraulic purposes are 7½ inches in diameter. The working stress on the metal due to working pressure is 2,800 lbs. per square inch. The mains are usually tested to a water-pressure of 2,500 lbs. per square inch before laying, and to a pressure of 800 to 1,600 lbs. per square inch after laying.

Pipe Unions and Joints.

For wrought-iron pipes up to 2 inches in diameter, such as are used for the connecting-pipes to hydraulic machines, the unions are generally of brass, and of the form shown by fig. 1. For

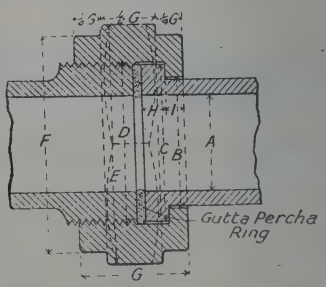


FIG. 1.

main cast-iron pipes the unions are made by means of elliptical flanges (fig. 1) formed on the ends of the pipes, the inner faces of the flanges being turned so that one pipe can enter a little distance into the other; a recess is left between them, to receive a gutta-percha ring, whose outside diameter is about 4 times the inner.

---

* Number corresponding to logarithm.

DIMENSIONS OF PRESSURE UNIONS.

700 Lbs. per Square Inch.									1,500 Lbs. per Square Inch.								
Dimensions of Parts.									Dimensions of Parts.								
A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	In.	In.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	In.	In.
$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{5}{16}b$	$1\frac{23}{64}$	$1\frac{5}{8}$	1	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{5}{16}b$	$1\frac{25}{64}$	$1\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{7}{8}f$	$2\frac{3}{64}$	2	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{7}{8}f$	$2\frac{7}{32}$	$2\frac{1}{8}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
1	$1\frac{3}{8}$	$1\frac{11}{16}$	$1\frac{7}{8}f$	$2\frac{13}{32}$	$2\frac{3}{8}$	$1\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	1	$1\frac{3}{8}$	$1\frac{11}{16}$	$1\frac{7}{8}f$	$2\frac{37}{64}$	$2\frac{7}{16}$	$1\frac{5}{8}$	$\frac{5}{16}$	$\frac{5}{16}$
$1\frac{1}{4}$	$1\frac{11}{16}$	$1\frac{15}{16}$	$2\frac{1}{16}b$	$2\frac{53}{64}$	$2\frac{7}{8}$	$1\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{11}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}b$	$3\frac{1}{64}$	$2\frac{15}{16}$	$1\frac{3}{4}$	$\frac{5}{16}$	$\frac{5}{16}$
$1\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{3}{16}$	$2\frac{3}{8}b$	$3\frac{1}{16}$	$3\frac{1}{8}$	$1\frac{3}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{3}{16}$	$2\frac{3}{8}$	$3\frac{11}{32}$	$3\frac{5}{16}$	2	$\frac{3}{8}$	$\frac{3}{8}$
$1\frac{3}{4}$	$2\frac{3}{16}$	$2\frac{7}{16}$	$2\frac{9}{16}f$	$3\frac{11}{32}$	2	$\frac{5}{16}$	$\frac{5}{16}$		$1\frac{3}{4}$	$2\frac{3}{16}$	$2\frac{7}{16}$	$2\frac{9}{16}f$	$3\frac{35}{64}$	$3\frac{3}{8}$	$2\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
2	$2\frac{7}{16}$	$2\frac{13}{16}$	$3f$	$3\frac{57}{64}$	$3\frac{5}{8}$	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	2	$2\frac{7}{16}$	$2\frac{13}{16}$	$3f$	$4\frac{3}{64}$	$3\frac{7}{8}$	$2\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{16}$

b = bare. f = full.

DIMENSIONS OF CAST-IRON PRESSURE FLANGES, 700 LBS.

Dimensions of Parts.								Dimensions of Parts.							
A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
$2\frac{1}{2}$	$3\frac{5}{8}$	$5\frac{1}{8}$	$8\frac{1}{4}$	$4\frac{3}{4}$	$1\frac{3}{8}$	1	$\frac{7}{8}$	4	$5\frac{3}{4}$	$7\frac{7}{8}$	$10\frac{3}{4}$	7	$1\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$
3	$4\frac{1}{2}$	$6\frac{3}{8}$	$9\frac{1}{2}$	$5\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$4\frac{1}{2}$	$6\frac{3}{8}$	$8\frac{5}{8}$	12	$7\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$
$3\frac{1}{2}$	$5\frac{1}{8}$	$7\frac{1}{4}$	$10\frac{1}{4}$	$6\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	5	7	$9\frac{1}{2}$	13	$8\frac{1}{4}$	2	$1\frac{3}{8}$	$1\frac{1}{4}$

Mains fitted with flanged joints of the description shown by fig. 2 can be made absolutely tight and free from leakage. The flanges are placed in a horizontal position in laying.

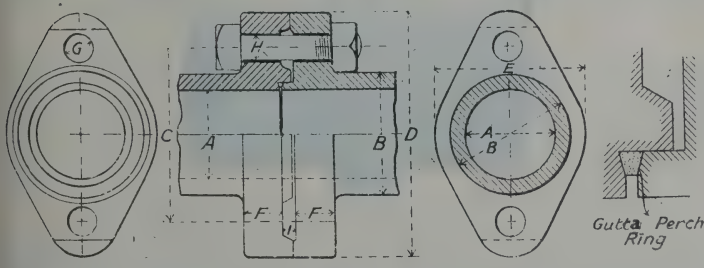


FIG. 2.

Mr. Ellington (engineer of the London Hydraulic Company) found that fractures in the pipes occurred by the breaking off of one of the bolt lugs. By placing the lugs a little farther back on the pipe the strength was found to be greater. It is probable that the slight flexibility of the pipe line which this kind of joint allows is an important element in its success.

On low-pressure hydraulic systems ordinary socket joints can be used.

In the *Philosophical Magazine* the Earl of Berkeley and Dr. Burton have described a simple form of joint packing, which is, they state, tight to start with and maintains this tightness up to the highest pressures they have employed, which have attained 1,500 atmospheres, or

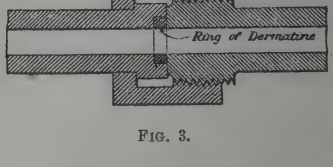


FIG. 3.

say, 10 tons per square inch. The pipe ends (fig. 3) are faced, and a recess is cut in one to take a ring of dermatine; this ring must be slightly thicker than the depth of the recess so that it is slightly compressed when the joint is tightened up. Either red or black dermatine may be used, but the red, being harder, is more easily machined. The joint is said to be equally good for water or oil, and is as suitable for a flanged joint as for a screwed coupling. It is also said to be as satisfactory with large pipes as with small.

THE 'VICTAULIC' SYSTEM OF FLEXIBLE PIPE LINES.

This system (fig. 4) employs pipes with shouldered ends, which are engaged with a certain amount of clearance by the split housing of the joint, which, while coupling the pipes together, permits disalignment or movement due to expansion of the pipes.

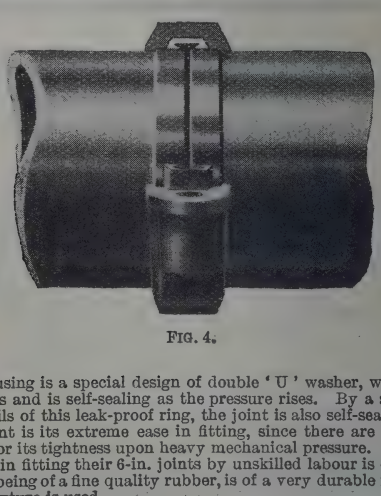


FIG. 4.

Within the split housing is a special design of double 'U' washer, which exercises an initial grip upon the pipe ends and is self-sealing as the pressure rises. By a special proportioning of the buttress-shaped walls of this leak-proof ring, the joint is also self-sealing against a vacuum.

A feature of the joint is its extreme ease in fitting, since there are only two bolts and the joint is not dependent for its tightness upon heavy mechanical pressure. The makers claim that the average time taken in fitting their 6-in. joints by unskilled labour is only two minutes.

The leak-proof ring, being of a fine quality rubber, is of a very durable nature; for oil or gases, acids, etc., a special mixture is used.

The joint is not supplied for use with steam.

Fittings, valves, etc., are all supplied with the ends shouldered or expanded in the same way as the pipe ends, and complete installations can be rapidly built up.

The dimensions of pipe ends are standardised by all the leading tube makers (see table on page 1235), so that all joints and tubes of the same nominal bore will match up together.

Cement Joints for Cast-Iron Water Mains.

(1.)

The pipe is placed and spaced in the usual manner. A thin backing of the best dry jute is used instead of oakum, as the jute is free from oil and grease, which should be avoided. Portland cement is placed dry on a piece of canvas (usually a cement sack ripped open) and moistened so that when thoroughly mixed by hand it will be of such a consistency that when gripped tight it will take the form of the hand and when dropped 12 ins. will crumble. The canvas containing the cement is placed under the bell, and the cement tamped into place by hand with a caulking iron until the bell is about half full. It is then caulked with heavy blows until the cement is thoroughly packed in the back of the socket. The process is continued until the bell is packed solid out to the face. A small bead of neat cement is then put on (this is essential), the caulking iron being used as a trowel, and, as soon as the initial set of the cement in the bead has taken place, the joint is covered with earth to protect it from the air and sun. In back-filling the excavated material is always settled with water, which helps to cure the exposed portion of the joint. The joint is allowed to stand forty-eight hours before the pressure is turned on and the main put into service. At Long Beach, California, there are now sixty miles of cast-iron water mains, ranging from 4 ins. to 24 ins. in diameter, laid with joints of this type. All these pipes are under pressures ranging from 40 lbs. to 80 lbs. per sq. in., and are giving satisfaction.

(*Clark H. Shaw, the American Society of Civil Engineers.*)

(2.)

A method of cement jointing cast-iron water pipes is described by Mr. G. W. Pracy in the *Journal of the American Waterworks Association*. The spigot end of the pipe projects into the bell just the same as for a lead joint, and two rings of jute or yarn are placed round the pipe and driven into the bell in the regular manner. The jute used must be free from oil or tar. Neat cement of standard Portland cement brand is used. The mix is very dry, the proportions being about 13 lbs. to 14 lbs. of cement to 1 lb. of water. The operator takes a handful of cement, and with an ordinary caulking iron forces the cement into the joint until full. He then takes a caulking hammer and caulks the joint until the cement is rammed in as hard as possible. The joint is then again filled and the operation repeated until the joint is completely filled with the rammed cement. At first a bead was put around outside the bell, but this was discontinued as being unnecessary. After the joint is finished it is covered with earth while the cement is hardening. In one case over a mile of piping jointed in this manner has been in use under 175 lbs. per square inch pressure for more than two years without requiring any repairs. It is claimed the method is cheaper than lead joints, and one indirect advantage is that the cement joint is an insulating joint, which tends to reduce damage from electrolytic action.

Pipe Joints for Petrol.

Pipe joints for petrol at ordinary atmospheric temperatures can be made up tight by first filling between the screw threads of the pipe with a thin paste made of gum shellac dissolved in a 10 per cent. solution of ammonia. The screw threads of both pipe and fittings should be thoroughly cleaned of grease before application of the paste.

Concrete-Lined Metal Pipes.

It has been American practice for some years past to line metal pipes with a thin coating of cement, which usually does not exceed three-eighths of an inch in thickness, applied by brush, cement gun, or by hand tamping. The experience gained with such pipes, some of which have now been in continuous service over periods of eight to ten years, showed that no appreciable incrustation had taken place even with bad waters. The iron or steel pipe lined with cement was found to have the further advantage that the interior surface could be rendered perfectly smooth—making its coefficient of friction not appreciably different from that of a new cast-iron pipe.

Stanton Centrifugally Concrete-Lined Pipes.

A rotary motion is imparted to the pipe by four friction wheels driven by chains and operated by a hand-controlled variable-speed motor. The pipe having been trued up, internal rings are placed in position in order to prevent the concrete coming out at the ends of the pipe during the spinning process. During the first spin the pipe is rotated slowly over a period of about ten minutes, during which time the sand and cement concrete is shovelled into each end of the pipe by hand. Owing to the centrifugal force the cement does not fall down, but adheres to the surface of the pipe, and further consolidation is effected by passing a 3-in. diameter rod with a bronze sleeve through the pipe and pressing this by hand against the revolving internal surface. After the correct thickness has been deposited the pipe is spun at a higher speed, which drives the coarser particles of the concrete towards the iron surface of the pipe and gradually expels the water and slurry from the internal surface. During the spin the water and slurry form a thin revolving film, which, as soon as the pipe is brought to rest, falls to the bottom of the pipe. The internal end rings are then removed and the water brushed out. The concrete lining is now quite hard, and after three or four weeks in the open the pipe is ready for service. In the larger pipes the lining is about $\frac{1}{2}$ in. in thickness, but it may be increased up to 1 in. or more if so desired.

Pipes from 4 ins. to 72 ins. diameter may be lined.

The concrete lining is so finished at the socket end that when the joint is made the water in the pipe is only in contact with concrete and does not touch the iron in any part.

A pipe may be drilled and tapped without the concrete unduly breaking away at the edges of the hole, while the operation of running and caulking the joint can be carried out without detrimental effect on the lining. The effect of exposure to the weather has been investigated by leaving a 48-in. diameter pipe in the open for two years, and although subjected to effect of sun and frost no alteration has been detected either in the metal or in the concrete. A modified form of construction is represented by a series of 60-in. diameter pipes made for the Birmingham Corporation. The shells of these pipes are made from $\frac{3}{8}$-in. steel plates bent and welded into a 5-ft. diameter circle. The steel tube is so light that when the finished shell is placed on the ground it takes up a more or less oval form, being distorted in diameter by nearly $\frac{1}{2}$ in. These tubes are filled with a concrete lining $1\frac{1}{4}$ in. in thickness, which, when formed by spinning, is sufficiently strong to prevent all distortion and give to the pipe a perfectly round shape.

The process of centrifugal lining has also been most successfully applied to the new spun cast-iron pipes which are being manufactured at Stanton in sizes from 4 ins. up to 15 ins. in diameter. The spun cast-iron pipe has not only the advantage that it is nearly 25 per cent. lighter than the ordinary vertical sand-cast pipe, but the way in which it is made ensures a perfectly round and true pipe, avoiding the necessity of re-truing before the lining process.

SECTION XXV

PART II

PUMPS — STEAM PUMPS — PUMP PACKING — CENTRIFUGAL PUMPS—TURBINE PUMPS—AIR LIFT PUMPS.

PUMPS.

The surface of the water to be raised should not be more than 25 feet below the movable valve.

Especially for small pumps, the suction pipe of a pump should fall all the way from the pump to the supply well. Any upward bend in the suction pipe introduces an air trap and may seriously diminish the performance of the pump.

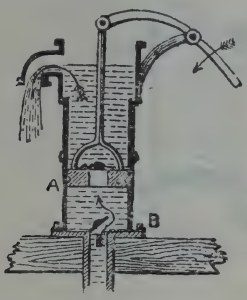


Fig. 1.

Fig 2.

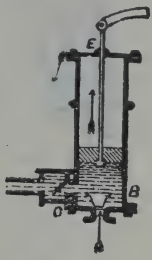


Fig. 3.

The Suction Pump.

This form of pump, which is shown by fig. 1. consists of a cylinder, called 'the barrel,' with valve, B, in which works a piston, A, called 'the box,' with valve in it, both valves opening upwards. The piston is attached to a rod and worked by a handle. When the handle is raised the piston is depressed: the valve A opens upwards, allowing the water or air below it to escape into upper part of cylinder. When the piston is raised the valve in it is closed, the water above is lifted up through the spout, the water from below lifts the valve at B, and rushes up to fill the vacuum caused by the raising of the piston.

If the valves are very dry a little oil should be poured on them. A little water poured on the piston before commencing to work it, makes it air-tight.

Lifting Pump.

The suction pump is converted into a lifting pump by attaching a pipe in place of a spout at C (fig. 2), with a valve in it, opening upwards to prevent the return of the water. A stuffing-box is provided for the piston-rod to work in at E. Each time the piston, A, is raised the water above it is forced up the pipe, and, as the piston descends, the valve C prevents the return of the water from above. It is clear that the man who pumps must exert at each upward stroke of the piston as much strength as is necessary not only to raise a cylinder full from below, but also to lift the column of water in the pipe above.

The valve C is not necessary to the action of the pump, because, the barrel being full, the valve B retains all the water. It is used more as an additional check. The pump would also act if only valve C were in and B removed.

Single-acting Force Pump.

This form of pump, shown by fig. 3, is used to force up water to a height. The piston is made without a valve. The delivery pipe is at bottom of piston: it has a valve opening upwards at C to prevent the return of the water. When the piston is raised the valve B opens and the water rushes into the cylinder: when the piston descends valve B closes, valve C opens, and the water is forced up the pipe. In this pump the force is required for the down stroke. The top of the cylinder E need not be closed; a little water poured in above the piston makes it air-tight.

Plunger Pump.

Sometimes a solid plunger, A (fig. 4), is substituted for the piston, to avoid the expense of turning the cylinder true, and also because it resists better the wear from grease and dirt. At each stroke it raises a volume of water equal to that of the plunger.

Double-acting Force Pump.

This pump (fig. 5) sends up water both at the up and down stroke. At the up stroke the water above the piston is forced through the valve A, while that below enters the piston at the valve D; at the down stroke the water is forced through the valve C, whilst it enters above the piston at the valve B.

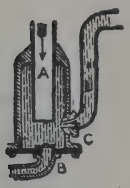


Fig. 4.

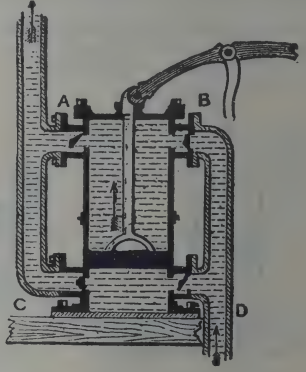


Fig. 5.

In all force pumps the packing of the piston or box is of great importance; it is commonly made of waste tow soaked in tallow and rammed tight; or for great pressures, cup leather packings are used.

Working Barrels, Buckets, and Valves.

These should be made of brass, gun-metal, or phosphor bronze, which metals, although costly in the first instance, will be found more durable, to require less repair, and to be more accurate in their operation than iron, being much less liable to injure the leather attached to the bucket and valve, the parts most frequently in want of repair.

An alloy which will withstand the action of water under pressure in a metal valve, and which is used by one of the largest firms in the country, consists of the following ingredients:—Copper, 10; tin, 1; zinc, $\frac{1}{16}$; lead, $\frac{1}{8}$.

The suction-pipe should be two-thirds the diameter of working barrel.

Pump Balancing.

To ensure equal work on the up and down strokes of a pump, it must be balanced. A complete balance provides for the whole weight of metal hung on the crank pin or beam, and one half the water work. The case of a bucket and plunger pump is perhaps the least simple, as in a bore-hole pump with a plunger at the surface delivering to a height above the surface.

Let A = area of bucket; a = area of plunger; W = weight of moving parts hung on crank pin and immersed in air; w = ditto immersed in water, e.g. the bucket and rods; H = height from water-level when pumping to plunger, in feet; h = height from plunger to point of delivery, in feet; B = balance weight to act at same lever arm as crank pin; then

$$B = W + 0{\cdot}875\, w + 0{\cdot}216 \left\{ [A \times H] + [(A - a) \times h] - [a \times h] \right\}.$$

The coefficient 0·216 represents one half the work, and the relation of pressure to head, or $0{\cdot}5 \times 0{\cdot}43$.

The correction for the different specific gravity of a gun-metal bucket may be neglected. Modern rods ultimately become as heavy as water, but at first have some negative weight. If a balance weight moves through a greater range than the cross-head, it must be correspondingly reduced.

Pumping from Wells.

For wells under 30 feet a 4-inch working barrel with a 9-inch or 10-inch stroke should be used. This size pump will throw 24 gallons per minute from a 20-feet well, and is as large as one man can conveniently work, and the best adapted for general use. For wells above 30 feet and under 70 feet a 3½-inch working barrel with a 9-inch or 10-inch stroke. For wells above 70 feet deep three 3-inch barrels, worked with a three-throw crank wheel and pinion in cast-iron case with fly-wheel, etc.

Artesian Well Pumps.

When the water level in a bore-hole is far below the surface, say 25 to 300 or 400 ft., it is necessary to place the pump barrel down the bore-hole, and it is usually desirable that it shall be lower than the rest level of the water, so as to be charged for starting work.

A bore-hole pump consists of a barrel of gun-metal with a bore at least 1 in. to 1¼ in. less than the diameter of the well lining tube. The barrel is screwed upon a rising main, which must be at least ⅛ in. to ¼ in. bigger than the barrel. The pump bucket and lower valve can thus be drawn up through the rising main for repair or inspection. A 4-in. pump will have a stroke of 1 to 3 ft. as desired, and a speed of 15 to 30 up strokes per minute. For durability it is desirable with very deep pumps to run at slow speeds. The pump rod terminates in a gun-metal rod or plunger, which passes through a stuffing box in the casting which forms the head of the pump. This head is flanged to the lining tube and screwed upon the rising main, and a branch is cast on one side for the water. If the lift above surface is considerable, it is possible partially or wholly to balance the lift of water to the surface by the use of a plunger, which may, if required, be as large in diameter as the bucket. However arranged, in order to equalise the work on the up and down strokes, it is proper to balance half the water lifting, and all the weight hung on the crank pin, so that the duty of the motive power may be evenly distributed in up and down strokes. Comparatively short pumps can be balanced by a weight in the main spur wheel on the crank shaft. When deeper, this is not sufficient, and a weighted lever may be linked to the crosshead pin and fitted with a balance weight on its outer or long end.

Some makers hang a heavy weight upon a pin in the face of the spur wheel, other makers attach wire ropes to the pump crosshead and pass them over a wheel and hang a weight, in guides, upon the ropes. Some engineers prefer to employ wooden pump rods, on account of their large displacement, so as to reduce the balance weights necessary.

A deep-well pump, unless small and slowly driven by a windmill, should be two to three diameters in length, of plain cylindrical form, with alternate grooves, with square-cut corners, and plain body. The grooves should be ¼ in. × $\frac{1}{16}$ in. and the space between, $\frac{5}{16}$ in., the two extreme spaces about ⅝ in. to ¾ in. No rings or packing leathers should be used.

The bucket valve may be mushroom, ball, or flat dermatine, the foot valve the same, in a taper casing, or foot piece which fits in the taper foot piece of the barrel. Under the bucket is a female screw which fits upon the thread projecting above the guard of the lower valve. When it is desired to remove the foot valve for inspection, it is lifted out by the bucket and pump rods, the bucket being lowered upon the valve and screwed to it; the valve then comes up with the bucket.

These pumps are usually driven from a second motion shaft by wheel and pinion, the second motion shaft carrying a fast and loose pulley driven by a belt from the engine or main shaft.

In country house work an oil-engine or an electric motor may be the driving agent, speed being reduced by more pairs of wheels or by larger driven wheels and pulleys. Or an electric motor may be worm-geared to the crank-shaft direct, in which case it is sometimes desirable to interpolate a friction clutch, so that the motor can be started off the load. Larger plants, such as the pumps for small town supplies, are perhaps best driven by gas-engines and suction gas plants.

Steel worms working in phosphor bronze wheels are said to give the best results. The wheel should be hollow faced so as partially to embrace the worm, and the angle of the teeth across the face of the wheel should be about 45°, so that the worm may require to be double or treble threaded to secure this. A thrust collar, or rather several collars, of propeller thrust type, are required on the worm shaft; but it is probably better to employ two worms, right and left, and two wheels connected to the same work, so that the thrusts balance, and no thrust block is required. The wheel should run in oil, which should be not too viscous. If a thrust block is employed, it should not be enclosed too narrowly, especially if near to the worm, as this has been found to prevent free access of oil.

When the water level in a bore-hole is not too deep below the surface, the air lift pump may be used with advantage, but it falls off in efficiency at great depths, and may often necessitate the boring of the well to depths very much greater than would be necessary merely to give the water yield. (*See also* Air Lift Pump, p. 1339.)

Discharge from Reciprocating Pumps.

TABLE OF CONSTANTS WHICH, MULTIPLIED BY EFFECTIVE NUMBER OF STROKES PER MINUTE, GIVE THE DISCHARGE IN GALLONS PER HOUR.

Stroke of Pump, in Inches.	Diameter of Pump, in Inches.												
	2	2½	3	3½	4	4½	5	5½	6	7	8	9	10
1	0·6795	1·061	1·528										
1½	1·019	1·592	2·292	3·120									
2	1·359	2·123	3·057	4·160									
2½	1·698	2·654	3·821	5·200	6·795								
3	2·038	3·185	4·586	6·240	8·154	10·31							
3½	2·378	3·715	5·350	7·280	9·513	12·03	14·86	17·98					
4	2·718	4·247	6·115	8·320	10·87	13·74	16·98	20·54	24·45				
4½	3·057	4·777	6·879	9·360	12·23	15·45	19·11	23·16	27·50				
5	3·397	5·308	7·644	10·40	15·59	17·19	21·23	25·68	30·06	41·60			
5½	3·737	5·839	8·408	11·44	14·95	18·91	23·35	28·25	33·63	45·76			
6	4·077	6·370	9·173	12·48	16·31	20·63	25·48	30·81	36·68	49·92	65·20	82·52	
6½	4·416	6·901	9·937	13·52	17·67	22·35	27·60	33·39	39·73	54 08	70·63	89·40	
7	4·756	7·432	10·70	14·56	19·02	24·07	29·73	35·95	42·79	58·24	76·06	96·27	
7½	5·096	7·962	11·46	15·60	20·38	25·79	31·85	38·52	45·84	62·40	81·49	103·1	
8	5·436	8·494	12·23	16·64	21·74	27·50	33·97	41·09	48·91	66·56	86·93	110·0	135·8
8½	5·778	9·024	12·99	17·68	23·10	29·22	36·10	43·65	51·95	70·72	92·36	116·9	144·3
9	6·115	9·555	13·76	18·72	24·46	30·94	38·22	46·23	55·00	74·98	98·10	123·7	152·9
9½	6·455	10·08	14·52	19·76	25·82	32·66	40·34	48·79	58·50	79·04	103·5	130·6	161 3
10	6·795	10·61	15·28	20·80	27·18	34·38	42·47	51·35	61·12	83·20	108·7	137·5	169·8
10½	7·135	11·14	16·04	21·84	28·54	36·10	44·59	53·90	64·20	87·36	114·1	144·4	178·3
11	7·474	11·67	16·80	22·88	29·89	37·82	46·71	56·50	67·26	91·52	119·5	151·2	186·8
12	8·154	12·74	18·34	24·96	32·60	41·27	50·94	61·63	73·35	99·84	130·4	165·0	203·7
13	8·832	13·80	19·86	27·04	35·32	44·71	55·18	66·77	79·46	108·1	140·2	178·8	220·7
14	9·512	14·86	21·39	29·12	38·04	48·14	59·43	71·90	85·58	116·5	152·1	192·5	237·7
15	10·19	15·92	22·92	31·20	40·75	51·58	63·67	77·04	91·69	124·8	162·9	206·2	254·7
16	10·87	16·99	24·45	33·28	43·47	55·02	67·92	82·17	97·81	133·1	173·8	220·0	271·7
17	11·55	18·05	25·98	35·36	46·19	58·46	72·16	87·31	103·9	141·4	184·7	233·8	288·6
18	12·23	19·11	27·51	37·44	48·90	61·90	76·41	92·45	110·0	149·7	196·2	274·4	305·7

CAPACITY OF PUMP.

If

d = diameter of barrel, in inches; s = stroke, in inches; n = number of acting strokes per minute; g = gallons per hour; then

$$g = d^2sn \div 6, \text{ approximately.}$$

Semi-Rotary Pumps.

THE WILLCOX SEMI-ROTARY WING PUMP.

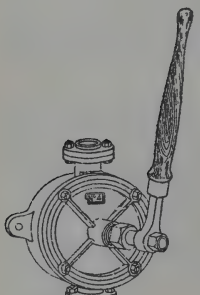


FIG. 6.

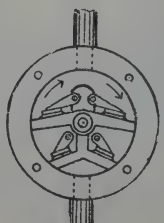


FIG. 7.

These pumps, figs. 6 and 7 (*W. H. Willcox & Co. Ltd.*), are made either double (as shown in the figs.) or quadruple acting. The working parts are of metal, and the wear and tear is reduced to a minimum; they are claimed to be lighter and occupy less space than any other pumps of equal capacity, and are self-contained. Although fig. 6 shows a form for hand-working, these pumps are adapted for being fitted to any kind of motive power and can be employed for all general purposes.

PARTICULARS OF WILLCOX SEMI-ROTARY PUMPS.

No. of Size.	Approximate Capacity per hour, and Price.						Size of Suction and Delivery Pipes (inside).
	Double Acting.			Quadruple Acting.			
	Galls.	Cast Iron.	Brass.	Galls.	Cast Iron.	Brass.	Ins.
0	270	£1 16 0	£2 10 0	360	£1 18 0	£2 12 0	¼
1	420	2 0 0	2 16 0	480	2 4 0	3 0 0	¾
2	540	2 8 0	3 12 0	660	2 10 0	3 16 0	1
3	660	2 18 0	4 13 0	960	3 4 0	4 16 0	1¼
4	900	3 12 0	5 11 0	1,260	3 18 0	6 0 0	1½
5	1,200	4 0 0	6 19 0	1,440	4 10 0	7 4 0	1½
6	1,500	4 16 0	8 7 0	1,740	5 10 0	8 16 0	1½
7	1,860	6 4 0	10 4 0	2,160	6 16 0	11 2 0	2
8	2,460	8 0 0	14 16 0	2,700	9 0 0	15 15 0	2
9	3,300	11 0 0	17 15 0	3,840	11 16 0	18 10 0	2½
10	3,720	15 4 0	24 1 0	4,980	15 16 0	25 0 0	3
11	4,320	18 2 0	29 12 0	6,000	19 0 0	31 10 0	3
12	—	—	—	8,280	38 0 0	69 5 0	4

The capacities in the foregoing table are based on 3 ft. suction, 3 ft. delivery, and on a full stroke; but the pumps will lift 25 ft. and force to a height of about 70 ft., according to size and speed.

Willcox Semi-Rotary Wing Pumps can be supplied with rubber balls for thick liquids, etc., and with phosphor bronze balls for acids, etc.

THE BOULTON WATER ELEVATOR.

This water elevator consists of an endless band to which are fixed a series of open-ended cells, so designed as to retain water by surface tension. The band is shown in fig. 8 and the general arrangement of the apparatus in fig. 8A.

FIG. 8.

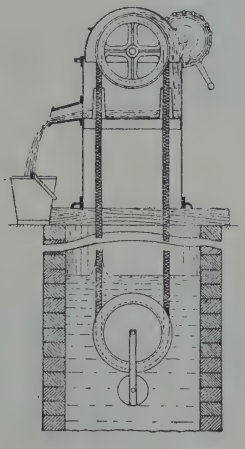


FIG. 8A.

The band passes over a driving pulley at the top, carried in a suitable casing. At the lower end a weighted pulley is carried in the loop formed by the band and is submerged in the water.

When the top pulley is rotated the band is set in motion, carrying on the upward side water which is released in passing over the top pulley by centrifugal force breaking down the surface tension.

The bands are made in various sizes, both single and multi-element, ranging in output for power operation from 284 to 19,500 gals. per hour. For hand use outputs of 2·8 gals. per minute from 220 ft. deep, or 13 gals. per minute from 50 feet, can be obtained by one man.

The Boulton water elevator is suitable for dug wells of practically any depth; installations as deep as 410 ft. having already been successfully undertaken.

The efficiency is very high. From official independent test figures a band efficiency of over 95 per cent. on a well 150 ft. deep was recorded.

The headgears are made in various types to suit most purposes, both with and without force pumps, for delivering to heads above the elevator.

The elevator can also be used for handling sewage, sludge, etc., and the band and elements are practically non-corrodible.

On wells over about 30 ft. the cost is very much lower than ordinary deep-well pumps, and amongst its chief advantages are (1) ease of installation, there being no need to descend, and nothing to fix in the well; (2) simplicity—no valves, buckets, plungers, or pipes in the well; (3) it is unaffected by frost; (4) high efficiency; (5) suitable for wells where there is a big variation in water level; (6) the band is not an articulated construction, and has no pins or knuckles to wear or corrode.

STEAM PUMPS.

The Clarke, Chapman Direct-Acting Feed Pumps.

(*Woodeson's Patent.*)

The single-cylinder direct-acting type of pump, on account of the small number of working parts and consequent small liability to break down, is very largely employed. Figs. 9 and 10, p. 1319, show Woodeson's 'Simple' Patent Direct-acting Pump (*Clarke, Chapman & Co. Ltd., Gateshead-on-Tyne*). This pump, which is extensively used, works with all steam pressures up to 400 lbs. per sq. in.

The steam chest is manufactured of the best hard close-grained cast-iron, of a suitable thickness to withstand any tendency to distort through the temperature of high-pressure steam.

The working parts of the steam chest consist of one auxiliary valve and one main valve, both of piston valve type.

The auxiliary valve is operated by the valve gear, actuated by the piston-rod crosshead. The main valve is partly moved mechanically and partly operated by steam, controlled by the auxiliary valve.

The action of the valves is as follows:—

When the main piston is nearing the end of its stroke, and the auxiliary valve commences to be moved by the valve gear, the first part of the movement closes the port through which the exhaust from one end of the main valve has been passing. The next part of the movement of the auxiliary valve opens steam to this end of the valve, and as the steam to the opposite end has not been closed, the main valve is in equilibrium. By the time that this takes place the auxiliary valve has moved so as to be in contact with the main valve, and further movement of the valve gear causes the auxiliary valve to move the main valve mechanically and so close the ports to the main cylinder. When these ports are nearly closed the auxiliary valve has closed the steam port at the end of the main valve, towards which the valves are moving, and opened an exhaust port, with the result that the main valve is moved by steam to the end of its travel and the steam cylinder ports are opened for the return stroke.

Should the main valve by any chance be delayed in being moved by steam, it would be worked mechanically during the clearance in the steam cylinder to a sufficient extent to open the steam port at the end of the cylinder towards which the piston was moving, and so forming a steam cushion to prevent the possibility of the piston striking the cover.

Advantages of the gear are:—

The main and auxiliary valves can all be mechanically actuated from the outside; this is an advantage if the pump is standing for any length of time, as it keeps the faces from getting rusted up.

During the process of the mechanical movement, the piston to which this movement is imparted is in perfect equilibrium.

Entire absence of valve setting.

These pumps are also made on the Tandem Compound principle. Great economy has been obtained with the pumps, and they are specially applicable for electric power stations and other high-class installations where economy of steam is an important consideration.

Fig. 11, p. 1319, shows a pair of these pumps fitted with automatic controlling gear as used

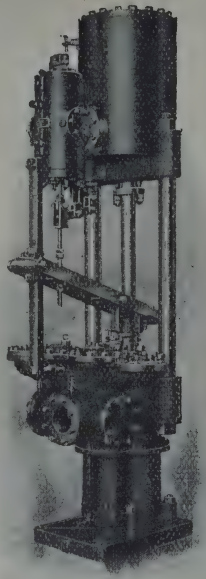


FIG. 9.

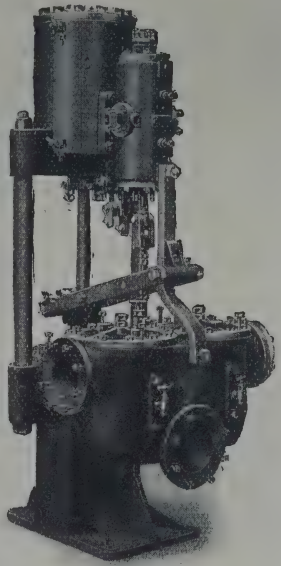


FIG. 10.

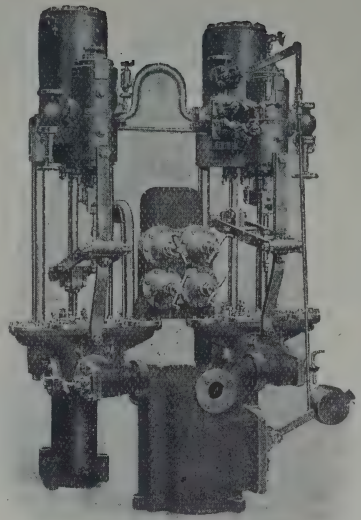


FIG. 11.

for Main Independent Feed-Pumps for Marine Purposes ; with this automatic controlling gear there must be no dead points, and the pump must be able to start from any position, this being a special recommendation for a feed-pump for marine purposes, where, in order to derive all the benefits to be gained by using independent main feed-pumps, the speed of the feed-pumps must be automatically regulated according to the quantity of water to be dealt with, which varies with the speed of the main engines. The 'Woodeson' pump contains all the necessary features for this work.

No flat surfaces exist in any part of the water end exposed to pressure. Both suction and delivery valves are arranged in groups, and are easily accessible for overhauling. The plunger junks are of gunmetal, and are fitted with composition plunger rings, specially manufactured to deal with high pressure and high temperature.

Test taken with Clarke, Chapman Simple Type of Slow Speed Feed-Pump (Woodeson's Patent) :—Diameter of steam cylinder, 10½ ins. ; Diameter of water cylinder, 8 ins.; Length of stroke, 18 ins. ; Water delivered per lb. of steam used, 81 lbs. ; Steam used per water h.p. hour, 59·5 lbs. ; Steam pressure per sq. in., 180 lbs. ; Pressure in discharge pipes per sq. in., 195 lbs. ; Efficiency of pump, 97 per cent.

Test taken with Clarke, Chapman Tandem Compound Type of Slow Speed Feed-Pump (Woodeson's Patent) :—Diameter of h.p. cylinder, 8½ ins. : Diameter of l.p. cylinder, 13 ins. ; Diameter of water cylinder, 8½ ins. ; Length of stroke, 18 ins. ; Water delivered per lb. of steam used, 110·5 lbs. ; Steam used per water h.p. per hour, 36·5 lbs. ; Steam pressure per sq. in., 195 lbs. ; Pressure per square in. in discharge pipes, 215 lbs. ; Efficiency of pump, 97 per cent.

The Caird & Rayner Single-Cylinder Direct-acting Boiler Feed and Service Pump.

The main and auxiliary slide valves of these pumps, figs. 12 and 13 (*Caird & Rayner*), are of the ordinary D type, and have flat wearing surfaces, and are therefore more easily understood and overhauled than those having circular slide valves, and are less liable to leakage. The pistons carrying the main slide valve are subject to end pressure only, so that there is no tendency to sticking, and the wear is practically nil. This obviates the necessity for re-boring worn parts of shuttle casing after working for a period, and the pump does not need to have an extra valve chest supplied as part of the spare gear. Should the water supply be suddenly stopped through any cause, the pump will not unduly race, nor will the piston strike the cylinder ends. The pump is silent in its working.

The main steam-valve admitting the steam to the cylinder ends is the ordinary D type, moving horizontally on a flat face. The auxiliary steam-valve which drives the main steam-valve is of the same type, and moves vertically also on a flat face. The main valve is separate from the small pistons which drive it, so that the pistons are subject to end pressure only, and the wear on them is practically nil. Any little wear on valve faces is taken up by the valves, and, being flat, all easily adjusted and refaced. The auxiliary valve face has ports which lead to the ends of the small cylinder carrying the pistons which drive the main valve. These ports are opened alternately to steam and exhaust, and throw the main valve from side to side. The auxiliary valve is actuated by a lever attached to a crosshead on the pump piston rod. The main steam ports are cast some distance from the cylinder ends, and a small steam port to the extreme end of the cylinder is provided, so that the speed of the pump is reduced when approaching the end of each stroke, thus enabling the pump valves to settle quietly in their seats, and also preventing shock in the feed-pipes. This arrangement of ports also prevents the piston striking the ends of the cylinder should the water supply to the pump for any reason fail, a feature which is of great importance. The pump will start from any point, and the stroke can be adjusted in running by means of the double nuts on the lower valve spindle. The pump valves are arranged in groups, and consist of a number of small valves working on a gunmetal seat. The valves are guided in an overhead frame and have no projections into the seatings, thus permitting a free flow of water and avoiding any side wear in the seatings. The water piston is fitted with ebonite rings, and will run for long periods without adjustment.

The materials of which the various parts are constructed are as follows :—Steam cylinder—close grained cast iron ; steam piston—cast iron or steel, with self-adjusting packing rings ; pump end—close grained cast iron, fitted with gunmetal liner in barrel, or all gunmetal, as required ; piston and pump rods—cold-rolled manganese bronze ; pump bucket—gunmetal, fitted with ebonite packing rings, or as may be desired ; valves and seats—group type of special manganese bronze, working on a gunmetal seat ; columns—mild steel, polished ; valve motion gear—rods and levers of wrought steel, turned bright ; crosshead—gunmetal.

The standard pumps are made suitable for 200 lbs. per square inch boiler pressure.

The Weir Direct-Acting Feed Pump.

The Weir Patent Direct-Acting Feed Pump (*G. & J. Weir, Ltd.*), shown in fig. 14, p. 1323, is the original of a type of pump which is being largely used. Introduced at first for marine boiler feeding, its adoption by the mercantile marine, the British Navy, and numerous foreign navies, caused it afterwards to be placed on the market in a form suitable for land installations, power plants, etc.

The valve gear is positive—*i.e.* the steam valve can never be in such a position that the pump will not start immediately when steam is turned on. The only possible way in which the main valve can rest is at full travel, either for an up or down stroke of the piston. The valve arrangement also ensures constant length of stroke and certainty of action.

THE CAIRD & RAYNER STEAM PUMP.

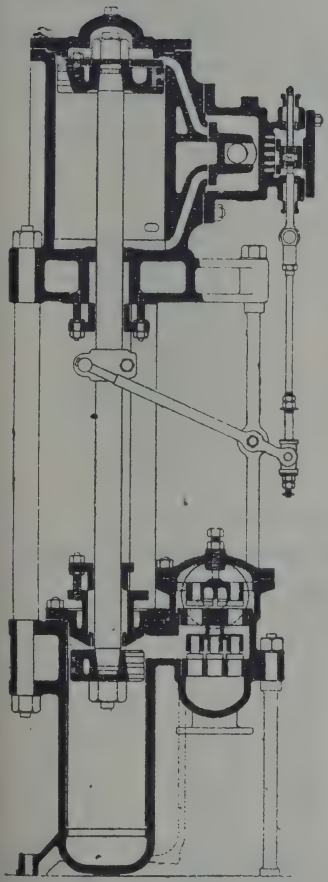


FIG. 12.

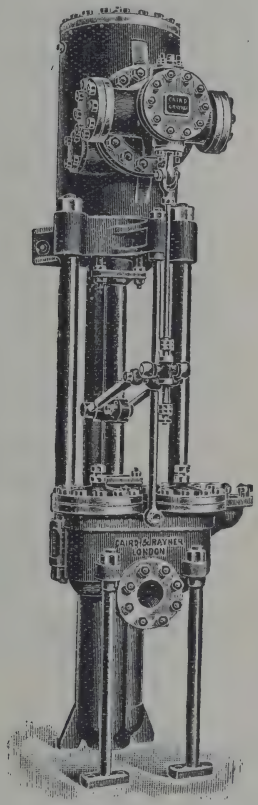


FIG. 13.

The steam valve is practically a D slide-valve, with a small auxiliary valve working on the back, and hence has not the same liability to leak as a piston valve. These are the only two moving parts proper in the steam chest, so that there is little opportunity for wear, and no delicate adjustments to get out of order. The steam is used expansively, and the cut-off can be regulated from the outside while the pump is working.

The water valves are of the Weir group type, providing a large area with only a small lift, thus ensuring easy working and little wear and tear. The pumps are designed to work at a moderate speed and the piston is slowed down towards the end of the stroke enabling the valves to settle quietly in their seats. The working and maintenance of the pumps is therefore much more satisfactory than in pumps running at a high speed. In the matter of steam consumption, numerous tests and comparisons show that the Weir pump is highly economical; this is due to the fact that it has fewer ports and passages than a duplex pump, and the simple expansion arrangement enables it to be built so that the clearance is small.

The parts of each pump are of a standard size, made to gauge and interchangeable, and each complete pump is tested hydraulically and under steam before leaving the works.

Where it is desired to regulate the boiler feed automatically, a special design of float tank and regulating gear is furnished.

The Weir pumps are also supplied of the tandem compound and twin compound types.

Messrs. G. & J. Weir, Ltd., Cathcart, Glasgow, the makers, also list a line of these pumps for light service, tank duty, etc.

List of Parts.—(See fig. 14, page 1323.)

1. Steam slide valve chest.
2. Double joint.
3. Front stay.
4. Bottom spindle.
5. Valve gear levers.
6. Front stay bush.
7. Ball crosshead.
8. Main crosshead.
9. Crosshead pin.
10. Piston rod.
11. Piston body.
12. Piston rings.
13. Cylinder cover.
14. Discharge valve seat.
15. Discharge valve seat ring.
16. Suction valve seat.
17. Suction valve guard.
18. Discharge valve guard.
19. Water valves.
20. Bucket.
21. Pump rod.
22. Pump cover.
23. Valve chest covers.
24. Steam stop valve.
25. Exhaust stop valve.
26. Auxiliary valve spindle.
27. Cylinder neck ring.
28. Cylinder gland.
29. Pump neck ring.
30. Pump gland.

STANDARD SIZES AND CAPACITIES OF WEIR FEED PUMPS.

Size.	Normal Duty.		Maximum Duty.	
	Gallons per Hour.	D.S. per Min.	Gallons per Hour.	D.S. per Min.
Pump. Cyl. Stroke. Ins. Ins. Ins.				
2½ × 3½ × 5	270	30	340	38
3 × 4½ × 6	410	26	535	34
4 × 6 × 7	660	20	810	25
4 × 6 × 12	960	17	1,205	21½
5 × 7 × 12	1,450	16	1,725	19
6 × 8½ × 13	2,000	14	2,350	16½
6 × 8½ × 18	2,700	13½	3,350	16½
7 × 9½ × 21	4,000	13	4,750	15
8 × 10½ × 22	5,500	12½	6,350	14½
9 × 12 × 24	7,200	12	8,100	13½
10 × 13½ × 24	9,000	12	10,000	13½
11½ × 15½ × 24	11,250	11½	12,000	12½
12½ × 17 × 24	13,200	11½	13,800	12
12½ × 17 × 28	14,700	11	15,400	11½
14 × 20 × 27	16,500	10	18,100	11
14 × 20 × 32	19,600	10	21,500	11

THE WEIR DIRECT-ACTING FEED PUMP.

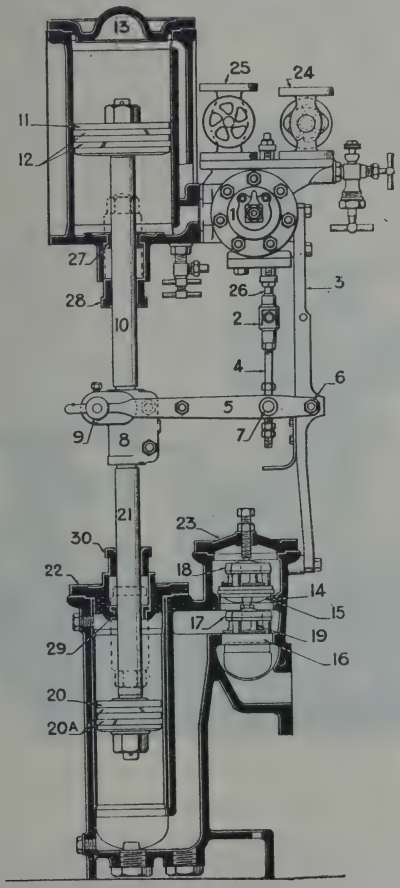


FIG. 14.

The Weir 'Turbo Feed' Pump.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

This pump, fig. 15, consists of a single pressure, multivelocity stage, impulse steam turbine, working in conjunction with a single stage centrifugal pump of special design.

The turbine casing and bearings are divided horizontally, the lower portions being embodied in the general framework or base of the set. This framework is extended at one end to form a flange, to which the pump casing is rigidly secured. By this arrangement the impeller of the pump is carried on the overhanging end of the turbine shaft.

By means of a suitable hydraulic governor, operating a balanced double beat throttle valve, the set is self-regulating for all ordinary changes in both water and steam conditions. When the latter are decidedly adverse, auxiliary nozzles may be brought into play by means of auxi-

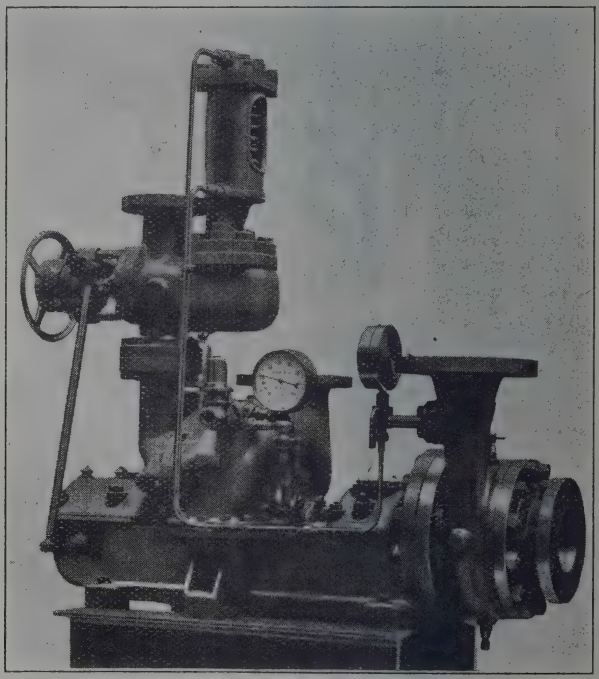


Fig. 15.—The Weir 'Turbo Feed' Pump.

liary valves in the nozzle box and the quantity of steam supplied to the turbine considerably augmented.

An emergency governor of the eccentrically-loaded ring type is provided, which, in the event of the speed of rotation exceeding a predetermined limit, actuates a trip gear which releases a spring and instantaneously closes the stop valve, and steam is completely shut off from the turbine. Thus there is no possibility of the speed of the set reaching unsafe limits in the event of an accidental failure of the supply; and as the discharge pressure depends upon the pump speed only, the set cannot be seriously overstrained by sudden obstruction or closing of the discharge.

The turbine glands are provided with carbon packing, the bearings are of the self-oiling ring type, and the pump impeller is hydraulically balanced.

The Weir Turbo Feed Pumps are of sound mechanical construction and all parts are readily accessible for examination and overhauling. They are entirely automatic in action and are noiseless and free from vibration.

The WEIR TURBO FEED PUMP

Compact—Reliable—Self-regulating.
Suitable for either saturated or superheated steam—Oil-free Exhaust.
Presented in standard sizes capable of dealing with from 7000 to 75,000 gallons per hour to boilers working at pressures varying from 100 to 1200 lbs. per square inch.

Our booklet 'The Weir Turbo Feed Pump' gives you full particulars.

G. & J. WEIR LTD.
CATHCART : GLASGOW :

F. 1324

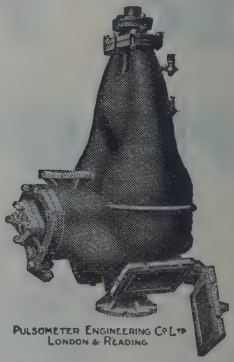
Trade Pulsometer Mark. STEAM PUMP

The "Pulsometer" Symbol.

Will work suspended on a chain.

No moving parts except simple valves.

Will pump almost anything.



No skilled attention required.

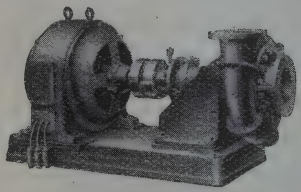
Needs no foundation.

No exhaust steam to heat up the shaft.

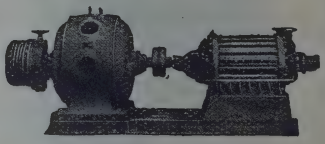
For HEADS up to 150 ft.

(*See Editorial Notice, pages* 1325-1326.)

HIGH EFFICIENCY CENTRIFUGAL & TURBINE PUMPS



SLURRY PUMP,
for pumping water containing grit.



TURBINE PUMPS,
for heads up to 3,500 feet.

Write for List No. 1066.

Pulsometer Engineering Co. Ltd

11 Tothill Street,
LONDON, S.W. 1.

Nine Elms Iron Works,
READING.

The pumps are capable of discharging against the highest boiler pressures and are specially suitable for large units. They can be used to work in conjunction with ordinary reciprocating pumps.

A special feature of the Weir Turbo Feed Pump is its economy in steam consumption. Further, as the exhaust steam contains no oily residue, it is available for heating the feed water by direct contact, thereby utilising all the heat in the steam. In this connection Messrs. Weir have introduced a nozzle heater which has been specially designed for working in conjunction with these pumps.

The Weir Roto-Feed Pump has been adopted by the British Admiralty and the leading Municipalities and Electric Power Corporations, including the Corporations of Cardiff, Glasgow, Greenock, Halifax, Norwich, Poplar, Salford, West Ham, Wolverhampton, Woolwich, the Clyde Valley Electric Power Co., and Treforest Electrical Consumers, Ltd.

The Pulsometer Steam Pump.

In this pump (*The Pulsometer Engineering Co., Ltd.*), figs. 16 and 17 (general view), the neck J contains a gun-metal ball I, above which is a steam pipe K. EE are suction valves placed at the base of two chambers AA. Immediately above the suction valves the two chambers com-

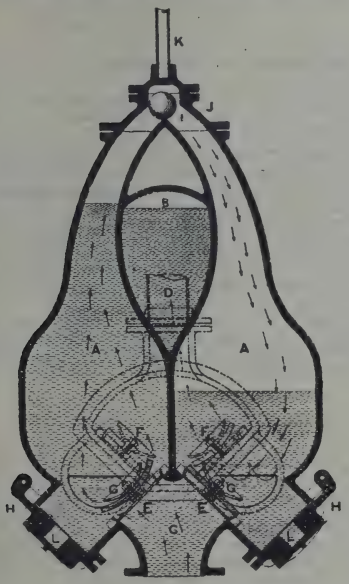


Fig. 16.

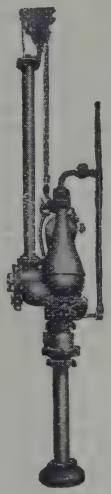


Fig. 17.

The Pulsometer Steam Pump.

municate with a 'discharge box' through two discharge valves FF. The valves in the standard pattern of pump are of the grid type, consisting of a grid, rubber, and guard. In addition to the above valves there are three small gun-metal valves (not shown in the figure) for the admission of air, one of each being screwed into the upper part of the two water chambers and the air vessel.

Action.

Assuming one of the chambers to be open to steam and full of water, the steam entering by the steam pipe and past the ball passes into the chamber and presses upon the small surface of water exposed, depresses it without agitation (and therefore with little condensation), and drives it (as seen in the figure) through the discharge valves FF into the rising main, D. The moment the water in the chamber falls to the level of the opening in the branch leading to the discharge box, the steam blows through with a certain amount of violence, and as it is brought into intimate contact with the water in the discharge box an instantaneous condensation takes

place, and the vacuum thus formed in the emptied chamber immediately pulls the control ball over on to the corresponding seat and cuts off further admission of steam, allowing the vacuum to be completed. Water immediately enters through the suction pipe, and lifting the inlet valve rapidly fills the chamber again. A similar operation has been taking place in the fellow chamber, the period occupied by filling one chamber corresponding to that of emptying the other, and these operations continue alternately in the two chambers so long as the pump is supplied with steam and water. The function of the air valves is to introduce a small quantity of air at each stroke or 'pulsation' for the purpose of cushioning the ball when it changes its position, and for separating the steam from the water by a non-conducting film so as to prevent loss by condensation during the expulsive portion of the cycle.

The 'Pulsometer' Steam Pump will work just as well suspended from a chain or rope as when permanently fixed. Its very small size, in proportion to the quantity of water thrown, makes it available in a great many situations where no other pump can be applied. Another important feature is its ability to pump water heavily charged with mud and sand. For these reasons it is very largely used by contractors for pumping from excavations.

The 'Pulsometer' Steam Pump will, where the conditions remain constant, work day and night without attendance—in fact, as long as steam and water are supplied to it.

Boiler Pressure Required for Pumping.

What boiler pressure would be required to operate a direct-acting steam pump having an 8-in. diameter steam cylinder and a 6-in diameter water cylinder, for pumping water to a height of 100 ft. with the suction water supplied at a pressure of 10 lbs. per sq. in.?

The mechanical efficiency of a pump of the stated size, when in good working order, would be about 65 per cent. The pressure pumped against would be $100 \times 0{\cdot}433 = 43{\cdot}3$ lbs. per sq. in. due to the head, plus the pressure required to overcome friction of the water in the discharge pipe, the latter depending on the rate of pumping, and the diameter, length, and fittings of the discharge pipe. Under ordinary conditions the loss of pressure from pipe friction would be no greater than 10 lbs. per sq. in., and if assumed to be equal to the suction pressure the net resistance to movement of the water piston would be $(6 \times 6 \times 0{\cdot}7854) \times 43{\cdot}3 = 1{,}224$ lbs. With 65 per cent. mechanical efficiency of the pump, the resistance to be overcome by the steam piston would be $1{,}224 \div 0{\cdot}65 = 1{,}883$ lbs., and for overcoming that resistance the effective pressure required to be exerted on a direct-acting 8-in. diameter steam piston would be $1{,}883 \div (8 \times 8 \times 0{\cdot}7854) = 37{\cdot}46$ lbs. per sq. in. The required boiler pressure will need to be equal to the effective pressure plus the back pressure and the reduction of the boiler pressure by throttling in the steam pipe and steam passages of the pump. Allowing a back pressure of 4 lbs. and reduction by throttling of 10 lbs. per sq. in. would require a boiler pressure of $37{\cdot}46 + 4 + 10 = 51{\cdot}46$ or about 52 lbs. per sq. in.

Willcox-Penberthy Cellar Drainer.

This is a Water Pressure Ejector (*W. H. Willcox & Co. Ltd.*) of high capacity, for use in removing water from cellars, inspection pits, stokeholes, lift pits, or wherever it is desired to keep water or other liquids from rising above a certain level. It is automatically operated by a float-controlled, quick opening and closing valve. This valve is never partially opened; it cannot leak, and allows the ejector to give its greatest efficiency by working to full capacity. The float arm is slotted where it connects to the valve lever; this prevents the ejector from operating until the water has raised the float up to the highest point, and, as the water is ejected, the arm travels down the length of these slots before the weight of the float affects the valve.

To facilitate the installation of this drainer in small holes or sumps it is made as compact as possible. The float, instead of being round, is flat on the top; this gives it more buoyancy and occupies less space than would a round float of the same diameter. To further economise space the float is built around the suction pipe. This arrangement (patented) has the advantage of being rigid, and overcomes all the trouble of a loose float. The balance of the drainer is built directly above the float; this not only keeps the whole machine in as small a space as possible, but also keeps all working parts, with the exception of strainer and float, above the water, thus preventing corrosion or the exterior parts becoming clogged up by deposits of slime, dirt, or sediment. The interior parts are prevented from coming into contact with any foreign particles by a special strainer, which is so constructed that instead of the water being drawn directly upward, it is taken in at the sides, allowing all sediment to collect under the strainer without being disturbed by the force of the suction. A foot valve is provided inside the strainer, which closes the instant the drainer ceases operating, holding all water in the pipes, all primed for starting instantly at the next filling of the sump.

The following tables show the capacities at different pressures and elevations, dimensions, pipe sizes, weights, etc.:

TABLE OF CAPACITIES OF WILLCOX-PENBERTHY CELLAR DRAINERS AT DIFFERENT PRESSURES AND ELEVATIONS, PIPE SIZES, ETC., MODEL 'R.'

Size and Model.	Pipe Sizes. Ins.		Working Head in ft.	Maximum Net Capacities from Sump, in Gallons per Hour at 10 to 100 lbs. Water Pressure.								
	Supply	Discharge		10	15	20	25	30	40	60	80	100
No. 1 Model R	¾	1	3	80	*210*	*300*	*340*	*400*	*510*	*700*	*720*	*700*
			6		90	140	*240*	*300*	*390*	*570*	*670*	*690*
			9			90	150	210	*330*	*480*	*620*	*660*
			12				100	150	220	*390*	*550*	*630*
			15					90	190	*300*	*450*	*600*
			18						120	250	*320*	*550*
No. 2 Model R	¾	1¼	3	190	*390*	*550*	*620*	*750*	*910*	*1130*	*1240*	*1220*
			6		210	340	*420*	*600*	*750*	*1020*	*1140*	*1200*
			9			210	300	380	*540*	*900*	*1090*	*1150*
			12				210	300	420	*780*	*1020*	*1110*
			15					210	370	*570*	*940*	*1050*
			18						300	510	*850*	*970*

The model 'R' drainer requires 5 lbs. water pressure or more for each one foot of elevation, while a low-pressure drainer can be supplied which will work on 2 lbs. to 4 lbs. per foot of elevation.

TABLE OF CAPACITIES OF WILLCOX-PENBERTHY CELLAR DRAINERS AT DIFFERENT PRESSURES AND ELEVATIONS, DIMENSIONS AND PIPE SIZES, MODEL 'L.'

Size and Model.	Pipe Sizes. Ins.		Working Head in ft.	Actual Capacities in Gallons of Water per Hour taken from Sump, and Not Total Amount of Discharged Water.			
	Supply.	Discharge and Suction.		At 25 lbs. will elevate	At 40 lbs. will elevate	At 60 lbs. will elevate	At 80 lbs. will elevate
No. 3 Model 'L'	1	1½	3	660	1100	1440	1650
			6	520	860	1230	1440
			9		720	1050	1320
			12			840	1040
			18				760
No. 4 Model 'L'	1¼	2	3	960	1600	2020	2400
			6	760	1240	1880	1980
			9		1040	1600	1800
			12			1280	1440
			18				1050
No. 5 Model 'L'	1½	2½	3	1280	2100	2700	3200
			6	1000	1620	2300	2820
			9		1260	1960	2600
			12			1560	2060
			18				1500

The above capacities are the actual capacities of water taken from sump, and not the combined discharge of operating and drainage water as given in most tables. For higher elevations than shown above, special drainers can be made.

Pump Valve Materials

Dexine.

Dexine (*Dexine, Ltd.*) is a preparation of vulcanised indiarubber and other ingredients manipulated by a special process; it is an exceedingly tough and frictionless material which has been proved to withstand the action of oils and chemicals. It is extensively used for valves, in the place of ordinary indiarubber, and can be obtained in any degree of hardness, suitable for straight or curved guards and pumps of all descriptions and of all dimensions.

Valves made of Dexine are claimed to retain all the resiliency and natural cohesion of pure Para rubber—which enters into its composition to a certain extent—and is, in addition, rendered immune from the detrimental influence of acids, oils, alkalies, or grease. The material can be moulded to any shape, and vulcanised to any degree of hardness or flexibility to suit any particular purpose.

Dexine is also used to form the 'bucket or cup leathers' of pumps, up to 20 ins. diameter. In round or square section, or in the form of U rings, the material makes an efficient packing for compressor rods, and, having a low coefficient of friction, the wear on the material is very slight.

Hydraulic Packings.

Ram or 'U' Leathers.

A cupped leather packing (ram or 'U' leather) forms a self-tightening packing, and is very generally used, although if it is not properly made, and if the cup is not strengthened at the bend (where the greatest friction is), the leather soon wears out and fails.

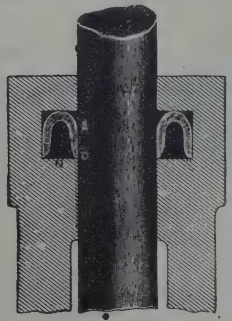


FIG. 18.

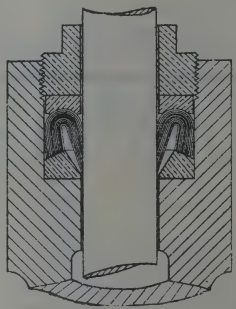


FIG. 19.

Fig. 18 shows a ram leather in its position. The water gets behind the leather and presses it tightly against the ram; the friction occurs mainly at part A, and increases as the pressure of water increases. There is not much friction at the portion between A and B, and the efficiency of the press is but little altered by making AB greater or less. It is, however, asserted by some that the distance AB is of importance, but this is on account of deterioration. The part AB is constantly in states of tension and compression, and if the leather is not good and well made it is liable to crack. Leathers are very frequently made too deep, and this leads to their being more liable to crack and fail; a shallow leather is undoubtedly the best—it works just as well as a deep one, and in making the leather considerably less strain or pull is required to block or mould it than would be the case with a deep one.

Too much stress cannot be laid on the necessity for using leather packings of the best quality and make only. It is equally important to consider the question of tannage. The value of a tannage depends upon its suitability and adaptability for different classes of work. Low pressure work, for example, requires a different tannage and fibre from high pressure and medium pressure a tannage and fibre between the two.

Fig. 19 shows a Patent 'SEA' Ring of compressed cotton layers supplied for packing purposes.

Pump Leathers and Packings.

'SEA' rings are specially designed with a view to a higher efficiency than may be obtained by the use of the ordinary leathers. Fig. 20 shows a double-acting plunger fitted with two 'SEA' ring cups separated by metallic junk-ring, and fig. 21 shows a 'SEA' ring collar fitted to a hydraulic or other ram. It is claimed that these ring packings will wear indefinitely where the ordinary leather would wear out and crack in a very short time. The rings are able to resist high temperatures, and are used with success for extremely high pressures. They are

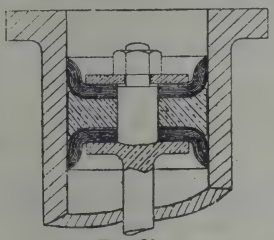


Fig. 20

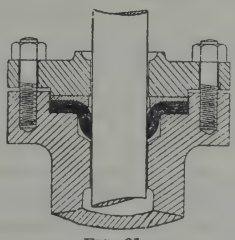


Fig. 21.

obtainable in sizes varying from those suitable for cylinders of 1 in. up to 9½ ins. in diameter and of various sections according to the specific purpose for which they are required.

Notes on Hydraulic Leathers.

Corrosion is one of the principal annoyances of hydraulic power, and bad water is responsible for fully 50 per cent. of wear and tear and repairs. Chalybeate water (that is, water containing iron) is about the worst.

Where dirty or gritty water has to be used the leathers wear away very rapidly. When the leathers are not kept constantly under pressure, if the pressure is taken off, the water gets between the leather and the ram, and as soon as the pressure comes on again, a little gritty or dirty water passes between the leather and the ram and causes the wear of the packing; it also scaives or flutes the ram. A remedy for this consists in putting a relief valve on the pipe that delivers the water to the accumulator from the pump, and in leaving the suction valve always open. The pressure in this way is always kept on the leather, preventing leakage, and at the same time saving considerable wear and tear of the packing.

It is important and essential that a leather should be well rubbed and worked with tallow before putting in. A good plan is to fill the inner space of the leather with neatsfoot oil or sperm, about an hour before putting in. *Never use mineral oil for rams or cylinders*, it runs away quickly, through being thin, and also renders the leathers rotten and pulpy.

For lubrication, Entwistle's patent lubricant (Patent No. 16,292; 1894), which contains 50 parts stearine or tallow, or other similar substance, 20 parts soapstone or powdered mica or talc, 2 parts graphite, 10 parts neatsfoot or other oil, 10 parts powdered zinc, lead, copper, or other soft metals, and 10 parts oil of tar, has given excellent results; the particles of metal, by the motion of the ram up and down, fill up any indentations, pores, or rough surfaces there may be on the ram or in the cylinder, and being of a soft or yielding nature (not gritty) distribute themselves over the rough surfaces.

Friction of Accumulator Cup Leathers.

The loss by friction in pumping into an accumulator is a very doubtful quantity and has not been satisfactorily determined. Various formulæ have been given, but a very wide divergence exists between them, probably due to the fact that the friction varies very greatly with the smoothness of the ram—whether it is rusty or not—the nature of the leather, also as to whether it is clean or sticky, and whether the ram is stationary or sliding, and whether the ram is perfectly centrally loaded—if the load is only a very small amount out of the centre of the ram it tilts it and materially increases the friction.

The formula due to 'Hicks' gives a result which makes the friction but one-sixteenth of that given by another formula due to Professor Goodman, and even the latter formula has been questioned as giving results much too low.

CENTRIFUGAL PUMPS.

V = velocity of the periphery of fan, in feet per second. H = height, in feet, to which water is to be raised. R = revolutions per minute of fan. D = diameter of fan, in inches. W = width of fan at the periphery, in inches. d = diameter of discharge-pipe, in inches. n = number of blades. t = thickness of blades. G = gallons per minute. E.H.P. = effective horse-power required.

$$V = 8{\cdot}8\sqrt{H}, \text{ for small fans, to } 10{\cdot}5\sqrt{H} \text{ for large fans.}$$

Another formula is—

$$V = 8{\cdot}8\sqrt{H} + K, \quad \text{where } K = 5 \text{ to } 10.$$

The last formula gives good results, varying the coefficient K with the height of lift.

$$R = \frac{V \times 230}{D} = \frac{(8{\cdot}8\sqrt{H} + K) \times 230}{D}. \qquad D = \frac{(8{\cdot}8\sqrt{H} + K) \times 230}{R}.$$

$D = 1{\cdot}5d$. to $5d$. $\quad d = \frac{\sqrt{G}}{4}$. $\quad W = \frac{d^2}{4D - 1{\cdot}27nt}$. $\quad E.H.P = \frac{G \times 10 \times H \times \frac{5}{4}}{33000} = G \times H \times {\cdot}00076.$

(The fraction $\frac{5}{4}$ represents 40 per cent. efficiency.)

EXAMPLE.—What size of pump is required to lift 4,000 gallons per minute to a height of 15 feet?

First find velocity, V, of periphery of fan. Taking 6 as a mean value for K, then $V = 8{\cdot}8\sqrt{15} + 6 = 34{\cdot}08 + 6 = 40{\cdot}08$ feet per second, or, say, 40 feet per second.

Diameter, d, of discharge-pipe at 4,000 gallons per minute, G, $= \frac{\sqrt{4000}}{4} = 16$ inches.

Taking $D = 3d$ as a mean value, then $D = 3 \times 16 = 48$ inches.

Number of revolutions per minute, R, $= \frac{8{\cdot}8\ (\sqrt{15} + 6)\ 230}{48} = 192.$

Taking 6 blades (n), each having a thickness, t, of $\frac{1}{2}$ inch, then

$$\text{Width, W, of fan} = \frac{16 \times 16}{(4 \times 48) - (1{\cdot}27 \times 6 \times \frac{1}{2})} = \frac{256}{192 - 3{\cdot}81} = 1{\cdot}36 \text{ inches.}$$

The greater the diameter of the fan, the less number of revolutions it requires to make.

The speed of the water through the pipes should not much exceed 8 feet per second. In many pumps the speed is greater (10 feet per second); but this is too high for good practice.

In all cases the efficiency of a pump will be increased by a tapering enlargement of the discharge pipe to as large a diameter as convenient. Such a taper pipe should be very slowly tapered, say about 1 in 8 times its initial diameter.

PROPORTIONS OF SINGLE-STAGE CENTRIFUGAL PUMPS.

Size of Pump and Diameter of Pipes.	Nominal Horse-power of Engine for each Foot of Vertical Height from Level of Water to Top of Delivery Bend.	Maximum Quantity raised per Minute.	Diameter and Width of Pulley.	Width and Kind of Leather Belt for Lifts up to 20 Feet.	Resistance of each Yard of Pipe for maximum quantity in Ins. of Lift.
Ins.		Gallons.	Inches.		
3	·045	150	8 × 4	2 inch single	3·0
4	·078	260	9 × 4	2 „ „	2·25
5	·121	400	9 × 5	2½ „ „	1·75
6	·175	580	10 × 6	3 „ „	1·5
7	·242	800	11 × 6	3½ „ „	1·26
8	·303	1,000	11 × 7½	4 „ „	1·1
10	·484	1,600	11 × 7	4 inch double	·9
12	·700	2,300	13 × 9½	5 „ „	·75
13	·818	2,700	14 × 10½	6 „ „	·7
16	1·242	4,100	21 × 10½	7 „ „	·58
18	1·606	5,300	24 × 10	9 „ „	·5
20	1·970	6,500	30 × 11	10 „ „	·45
24	2·848	9,400	36 × 15	14 „ „	·37

Speed Table of Centrifugal Pumps.

Giving the Number of Revolutions per Minute (including an allowance for slip of the belt) which the Pumps should make for different Lifts.

Size of Pump in Inches.	Feet Lift.							Size of Pump in Inches.	Feet Lift.						
	3	6	9	12	15	20	25		3	6	9	12	15	20	25
3	463	563	638	709	774	872	960	12	296	353	404	448	487	549	604
4	460	560	634	704	768	864	951	13	276	330	377	418	456	512	563
5	422	505	578	642	700	788	867	16	222	267	304	338	369	414	454
6	388	466	532	592	644	726	798	18	196	236	269	299	325	366	402
7	360	432	493	548	596	672	738	20	178	212	243	270	294	330	363
8	359	432	492	547	596	670	737	24	147	176	201	234	243	273	301
10	359	431	491	546	595	669	736								

The best speed to drive centrifugal pumps is a much debated question. For mine use moderate speed is preferable wherever possible, as less trouble is then experienced with both pump and motor. In other cases the higher speed pumps give good service. For 75 or 100 h.p. and upward 900 r.p.m. is satisfactory; for 30 to 50 or 75 h.p. 1,200 r.p.m., and for smaller pumps 1,500 to 1,800 r.p.m. (*H. Axford in 'Coal Age.'*)

Classification of Centrifugal Pumps.

Generally speaking, centrifugal pumps may be classed in two groups, namely :—(*a*) Without guide wheels; (*b*) with guide wheels.

(*a*) In pumps which are *not provided with guide wheels* (fig. 22), the casing is constructed

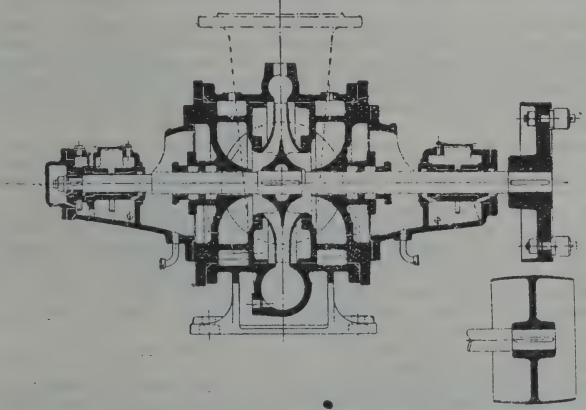


Fig. 22.—Section through Centrifugal Single-stage Pump (Low-lift or Medium).

with a spiral-shaped channel with gradually widening sectional area, which acts as a diffuser These pumps are usually termed low-lift and medium-lift centrifugal pumps, and have, as a rule one—sometimes two—stages. The pressure they produce ranges up to about 300 ft. water column.

(*b*) For pressures above 300 ft., as required for hydraulic service, mine drainage, boiler feeding waterworks, etc., three, four up to ten impellers are arranged in series and all built in the common casing (for extraordinarily high pressures two cases might be used).

With these high-lift pumps (fig. 23) the water passes through each impeller in turn, and is directed from one impeller to the next following and from the last into the delivery branch of the

pump through specially designed *guide wheels*, converting into pressure, without shock, the bulk of the kinetic energy transmitted to the water by the impellers. Each stage of the pump contributes equally to the total pressure. The design of the diffuser guide wheels and the blades of the impellers, i.e. the passages through which the water travels with a high velocity, is mainly responsible for the degree of efficiency attained by a centrifugal turbine pump. The steady flow of water through the pump, with as few changes in velocity as possible, avoiding shocks and eddies with inherent friction loss, is of the greatest importance. The clearance between the rotating and stationary parts in the pump must be so dimensioned that too much water cannot flow back from one stage to the preceding one. The balancing of the axial thrust produced in multi-stage pumps is also important.

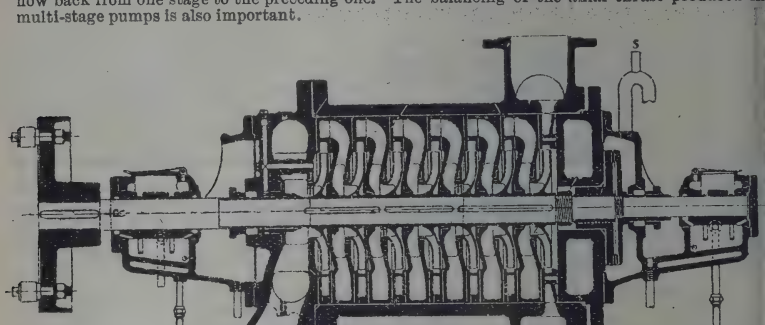


FIG. 23.—Section through Centrifugal High-lift Pump.

There are practically no limits as regards the pressure heads that high-lift centrifugal pumps cannot overcome (some makers, for example, have supplied pumps delivering to 3,500 ft.), as long as the quantity to be delivered is not too small. The manometric suction head should, for hydraulic reasons, not exceed about 18 ft., as otherwise the efficiency may be reduced and wear in the first stage be caused. For hot liquids the suction water should flow from a higher position into the pump, this height being determined by the fact that no evaporation must take place in the suction pipe.

The characteristics of the centrifugal pump are in many respects different, even the reverse, to those of the piston pump. Thus a centrifugal pump can run with the delivery valve shut, producing no dangerous pressure. Generally speaking, at a constant speed with increase in quantity the pressure produced falls, or, in other words, a reduction in the pressure which the pump has to overcome will result in a greater quantity being delivered. Great care should therefore, be taken in ascertaining, as accurately as possible, the head for which a pump is to be built, as otherwise the pump will possibly not come up to expectations as regards capacity or if the head upon which the designer based his calculations is greater than the actual head against which the pump has to work, a larger quantity will be delivered by the pump and the load on the driving motor increased.

No bearings should be permitted inside the pump; they should be carried in brackets outside the casing. Stuffing-boxes should not be used as bearings.

Under specially favourable conditions a centrifugal pump made by a first-class firm should attain efficiencies up to 86 per cent.

Centrifugal pumps sometimes will pick up water for a few seconds, as shown by the discharge gauge, and then lose the suction when the discharge valve is open. The reason for loss of suction generally is a large amount of air which is drawn in through the glands or suction pipe in some way. Air sometimes may be drawn in through the suction pipe, although it is entirely submerged beneath the level of the water. This is due to some extent to the vortex or whirling of the water around the suction pipe, thus forming an open passage to the air above. The cure lies in reducing the velocity of water in the suction pipe, either by adding a bell-mouth or tee, etc., or by drilling a number of holes into this pipe.

SOLID MATTER CENTRIFUGAL PUMPS.

See Vol. COVIII. (Dec. 1920), 'Minutes of the Proceedings of the Institution of Civil Engineers,' pages 275–346, and *Engineering*, Jan. 20, 1922.

The impellers in these pumps have flexible blades.

Packing of Centrifugal Pumps.

About nine-tenths of the trouble with centrifugal pumps is due to improper packing. Square ax is generally used, and this soon wears hard, cuts the shaft, leaks badly, and has to be replaced requently at considerable expense. Soft-flax packing soaked in oil and graphite gives better esults, but it lasts only a short time. A 5 in. double-suction centrifugal pump direct-connected o a 15 horse-power motor running at 1,800 revolutions per minute, supplying a barometric con- enser, experienced considerable trouble owing to the packing wearing out, the pump taking air, osing the water, and the vacuum ; this pump being packed with rawhide packing, after two nonths' continuous running was found not to leak. The rawhide packing is very economical, s the old packing does not have to be pulled out, and a new ring can be put in on top of the ld and kept in the box till it is completely worn out, also the shaft is kept in a good condition.

(*Power.*)

The 'United States' Patent Rotary Packing.

This packing is intended primarily for rotating shafts of centrifugal pumps, etc., and its rincipal feature is that it causes no friction whatever to the shaft, whilst providing an arrange- ient which will run for a considerable period without requiring renewal. It tends to increase he efficiency of the pump, and obviates any wear on the shaft.

The packing is made in two portions, one portion being for attachment to the casing, whilst he other is clamped to the shaft and rotates therewith. In this rotating portion the packing ings proper are fitted, and as these are not subjected to any friction they should last indefinitely. The two portions of the packing are always held in contact, and the friction which arises s restricted to the two surfaces (as between the fixed and the rotating portions) thus affected, ut as one of these surfaces is of anti-friction metal, and provision is made for lubrication at this oint, the wear is slight, and, as above stated, the packing gives considerable service before enewal of the anti-frictional part becomes necessary.

To facilitate the fitting of this patented packing, the component parts can be supplied in isected form, when so required.

A special lubricator is furnished at slight additional cost. This is pressure operated, and naintains a feed of oil to the surfaces in contact all the time the pump is running, but ceases o operate when the pump is stopped.

It is claimed that a 20 per cent. increase in efficiency of centrifugal pumps has resulted from he adoption of this device.

The packing is absolutely air-tight, whilst it causes no friction whatever to the shaft.

The Pulsometer Centrifugal Pump.

(*The Pulsometer Engineering Co., Ltd.*)

This pump, fig. 24, is specially adapted for low lifts at moderate speeds. The suction is central t one side of the pump. The discharge branch can be fixed at various angles to suit the direction f the pipes. The bed, casing, and impeller are of cast iron. Gun-metal impeller, slip rings,

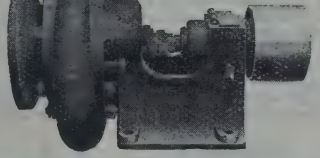


Fig. 24.

enewable bronze sleeve on shaft, or rustless steel shaft can be supplied at an extra price. Sufficient thickness of metal is allowed in the covers where the impeller is in running contact to permit of their being bored out and slip rings fitted when wear takes place. When dealing with dirty water slip rings should be fitted in the first instance. The shaft, which is of high carbon steel and of large diameter, is of ample strength to permit of driving by the overhung pulley. The bearings are of cast iron lined with white metal, the lubrication being continuous by means of a revolving ring dipping into a large reservoir fitted with oil overflow and drain. Creeping of the oil is prevented by collars fixed on the shaft. The stuffing box is fitted with a gun-metal neck bush, and is cooled and lubricated by water. It is sealed with water under pressure, which prevents the ingress of air when the pump is working with a high suction lift, but the stuffing box can be sealed with grease by fitting a lubricator for semi-solid lubricant.

Centrifugal Pumps for Hot Water.

Centrifugal pumps, when designed for pumping hot water, are quite satisfactory for feeding boilers. When used for this purpose, however, the intake pipe must be about three times as large as it would ordinarily be for cold water. Sharp turns and constricted passages, both in the pump

itself and in the connecting pipework, must be avoided in order to prevent the release of steam at the constricted points. This trouble generally occurs when there is a sudden demand for water. In addition the efficiency of the pump is lowered and difficulty is also encountered in maintaining the supply of water. (*W. E. Warner*, '*Cheap Steam*,' July 1927.)

Turbine-Pumps.

The 'Pulsometer' High-Lift Turbine Pump.

(*The Pulsometer Engineering Co., Ltd.*)

In this pump, fig. 25, the axial thrust is taken up inside the pump by a balancing disc fixed on and revolving with the spindle.

The periphery of the disc moves in close contact with a seat fixed to the delivery cover. The space enclosed by the disc and its seat is supplied with water under pressure from the last cell, and this water passes out between the periphery of the disc and the seat into the chamber in which the disc revolves, and then through a connecting pipe back into the suction pipe.

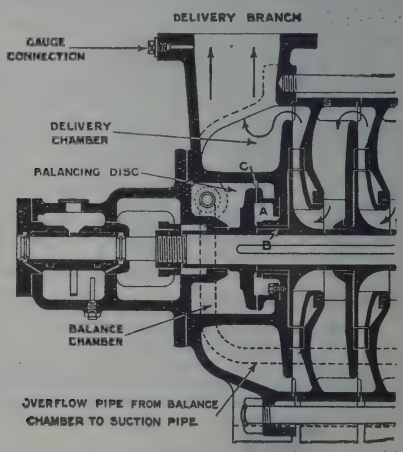


FIG. 25.

There are no collars on the spindle at the bearings, so that it is free to move axially when the pump is not working, but when working the balancing disc keeps it in position. This system of balancing has the further great advantage that the stuffing box at the delivery end is exposed to suction pressure only, no matter what pressure the pump is working against.

The impellers are not balanced, and the unbalanced area of each impeller causes an axial thrust towards the suction cover. It is this thrust that the balancing arrangement successfully overcomes in the following manner:

The chamber A is supplied with water under pressure from the last impeller, through the clearance B between the spindle and the centre bush in the delivery cover.

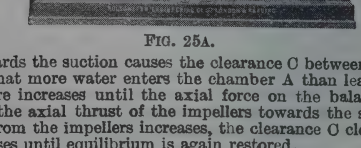


FIG. 25A.

The axial thrust towards the suction causes the clearance C between the balancing disc and its seat to close up, so that more water enters the chamber A than leaves it, and the pressure in this chamber therefore increases until the axial force on the balancing disc towards the delivery cover balances the axial thrust of the impellers towards the suction cover.

As the axial thrust from the impellers increases, the clearance C closes up, and the pressure in the chamber A increases until equilibrium is again restored.

As the pressure in the chamber A increases, the clearance C opens, and the pressure in the chamber A is reduced until equilibrium is restored.

The balancing disc is made so large that there is no danger of its coming into contact with its seat even under the most unfavourable conditions of pumping, such as when the pump is running at full speed with no head.

As there is no metallic contact there is no wear, except when gritty water is pumped, and when from this cause the wear has become excessive, the disc or its seat, or both, can be replaced in a very short time and at small cost, without dismantling the pump, it being only necessary to remove the bearing.

Fig. 25A shows a general view of one of these pumps.

THE 'VSG' MARK III. VARIABLE DELIVERY PRESSURE PUMP.

(*The Variable Speed Gear, Ltd.*, 6, *Broadway, Westminster, S.W.* 1.)

This pump is of the 'Williams-Janney' or horizontal piston type. Fig. 26 shows a vertical section through the latest design (arranged for lever control).

The 'mainshaft' is driven in one direction, and carries a rotating block or 'cylinder barrel' mounted on it by a universal joint and which is free to move axially.

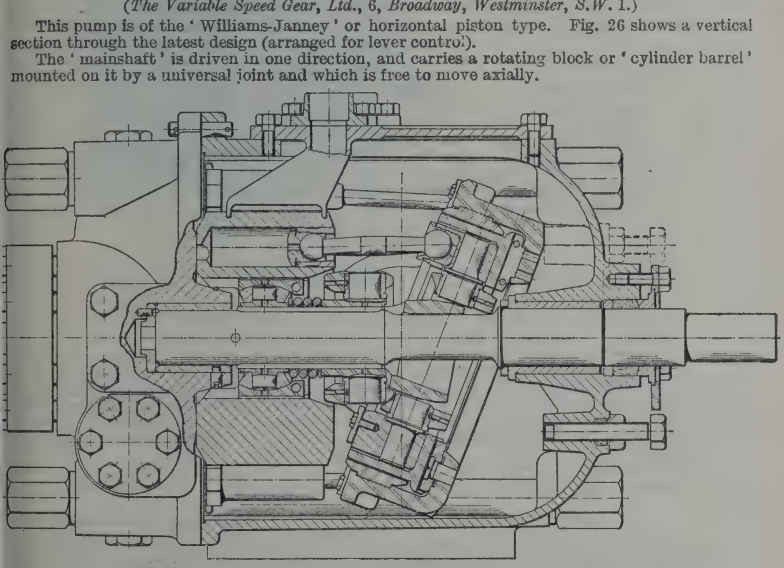


FIG. 26.

This 'cylinder barrel' contains cylinders bored parallel with the mainshaft, having ports of reduced section opposed to two kidney-shaped ports contained in the face of the 'valveplate,' which is stationary.

The 'cylinder barrel' rotates in contact with the 'valveplate' face in a state of hydraulic balance, initial contact being obtained by spring loading.

Each cylinder is fitted with a 'piston' connected by a ball-ended rod to the 'socket ring,' which in turn is connected to the 'mainshaft' by a double universal joint.

The 'socket ring' rotates in a non-rotatable but pivoted member called the 'tilting box,' 'Michell' type bearings being interposed to take the thrust and radial load. When the 'socket ring' is vertical the pump is in the neutral or no-stroke position, but any deviation from the vertical imparts stroke to the 'pistons' and causes delivery through one of the 'valveplate' ports and return through the other.

The greater the tilt the more delivery given, owing to the increased travel of the pistons. By reversing the angle of tilt the flow will also be reversed, and what was previously the delivery port will become the return port.

Lever or wheel controlled pumps can be arranged to give delivery in both directions from zero to maximum, but in the case of pumps fitted with auto-pump control, as applied to operate rams, etc., tilt is usually applied in one direction only, and the flow from these pumps is therefore not reversible.

Two distinct types of pumps can be supplied, viz. :—

Lever or Wheel controlled Pumps.	To give variable delivery at fluid pressures up to the maximum pressure at which the relief valves are set, controlled by hand or mechanical means.
Automatic Pressure controlled Pumps.	To give automatically regulated delivery over a predetermined pressure range, or alternatively at a practically constant pressure. Delivery is controlled by the pressure of the fluid in circulation acting on rams connected to the top of the tilting box opposed to springs acting on the base of the tilting box.

This pump also forms the 'A' end unit of the hydraulic transmission gear manufactured by this Company (*The Variable Speed Gear, Ltd.*), described on pp. 1032-1034.

The Stone Turbine Pump.

(J. Stone & Co., Ltd., Deptford, S.E. 14.)

These pumps are made in seven sizes, varying in capacity from 100 to 1,500 gals. of water per min., the maximum head on the smallest size, with eight stages, being 360 ft., and with the largest size 1,600 ft.

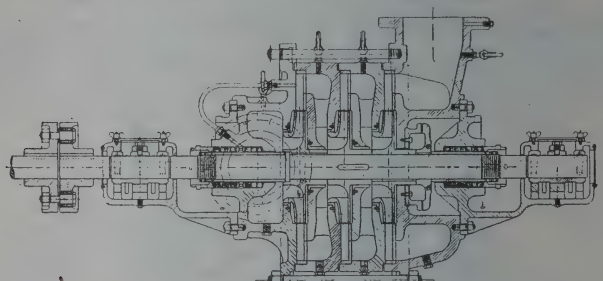


FIG. 27.

The construction adopted is of the sectional type (fig. 27), which enables the pump to be built up to any number of stages up to the maximum. The sectional construction also possesses the very great advantage that leakage between the stages can be at once detected, and the pump can be easily dismantled on site. This construction is usually preferred by mining engineers to the solid-casing type of pump, as with the latter it is impossible to detect leakage between the stages, and also, with the solid-casing type of pump, internal rusting is likely to cause difficulty in dismantling.

The impellers and guide vanes are usually supplied in Stone's special 'No. 1 Bronze,' which is free from zinc and has proved very successful in withstanding the action of gritty and acid

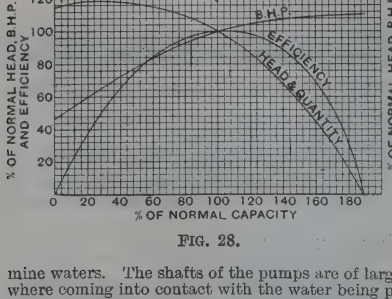


FIG. 28.

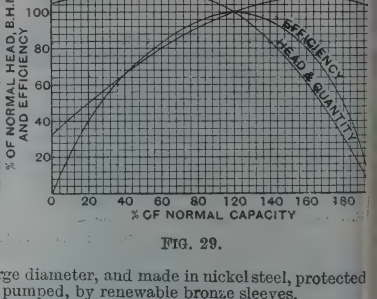


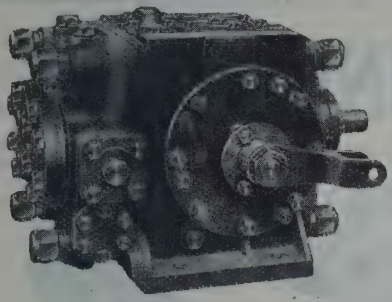
FIG. 29.

mine waters. The shafts of the pumps are of large diameter, and made in nickel steel, protected where coming into contact with the water being pumped, by renewable bronze sleeves.

Curves, figs. 28 and 29, show the characteristic curves of the pumps plotted on a percentag basis, and from which curves the performance of any individual pump, when working on an other duty than normal, can be readily seen.

Example.—An MS. 6-2 stage pump is designed for 550 gals. per min., and 200 ft. head, with a efficiency of 72 per cent., taking 46·5 b.h.p. at coupling to drive. What would be the performanc at a head of 170 ft. ?

170 ft. corresponds to 85 per cent. of the normal head, and referring to the curve marke 'Head Quantity,' for pump sizes 6 ins. and above, the curve shows that the capacity has increase to 119 per cent. of normal, or, say, 655 gals. per min. Referring to the 'Efficiency' curve for thi percentage increase in capacity, the curve shows that the efficiency is 95 per cent. of the norma which is 95 per cent. of 72 per cent., or, say, 68 per cent. efficiency. From the 'Brake-horse power' curve it will be seen that the power required to drive is increased to 106 per cent. of norma or, say, 49·5 b.h.p.



"VSG Mark III" Variable Delivery Pressure Pump fitted with Lever Control.

"VSG"

VARIABLE DELIVERY PRESSURE PUMPS

SUITABLE FOR ALL SYSTEMS EMPLOYING OIL AS THE HYDRAULIC MEDIUM

Two types of Pumps can be supplied :—

1. To give variable delivery at fluid pressures up to pre-determined maximum, controlled by hand or mechanical means.
2. To give delivery over a pre-determined pressure range, controlled automatically.

Extensively applied for operating Gun Mountings, Steering Gears of Naval and Mercantile Vessels, also Hydraulic Presses, Shears, Riveters, Control Systems, Lifts, etc.

THE VARIABLE SPEED GEAR LIMITED
6 BROADWAY, LONDON, S.W.1.

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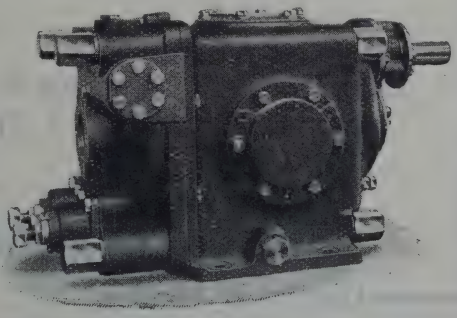
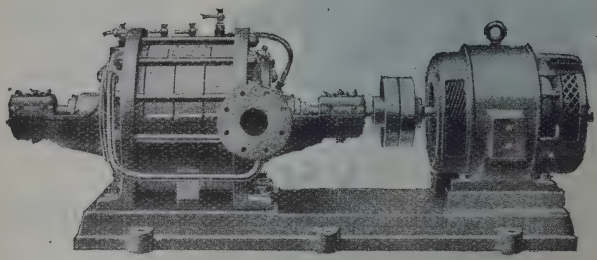
"VSG Mark III" Variable Delivery Pressure Pump fitted with Auto-Control and Internal Reduction Gearing.



HIGH EFFICIENCY

TURBINE PUMPS



Correct Hydraulic Design.

Sound Mechanical Construction.

Best Material and Workmanship.

Impeller and Diffusion Vanes cast in Stone's No. 1 Bronze.

End Thrust Hydraulically Compensated.

Standard Designs up to 3,000 ft. head, from 90 to 1,500 G.P.M.

Full particulars will be sent on request.

J. STONE & COMPANY LTD

Deptford, London S.E. 14.

Makers of Pumps for all Duties.

F. 1337

The pumps have the advantage that neither the suction nor delivery gland is under high-pressure water, the gland at the suction end being water-sealed, and at the delivery end the balance valve reduces the pressure across the gland. By this construction the stuffing-boxes need only be packed lightly, to reduce leakage to the minimum amount; it also means less friction and absence of wear on the shaft sleeves, and consequent higher pump efficiency.

The end thrust is compensated by the standard design of balance valve. Both the balance valve and seating are made in hard bronze, and are easily renewable.

The pumps are designed to give self-regulation and high efficiency over a wide range, as will be seen from the two characteristic curves, figs. 28, 29.

The outputs of the pumps at a speed of 1,450 r.p.m. are given in the 'Table of Outputs,' and in connection with the horse-powers shown, the following allowances for contingencies should be made in fixing the power of the driving unit:

25% up to 3 B.H.P.	15% up to 10 B.H.P.	7½% up to 100 B.H.P.
20% „ „ 7 „	10% „ „ 50 „	5% above „ „

For speeds other than 1,450 r.p.m. the following rules approximately apply:

'Head' varies directly as the square of the speed; 'Capacity' varies directly as the speed B.H.P. varies directly as a product of R.P.M. and head.

TABLE OF OUTPUTS AT 1,450 R.P.M. OF STONE'S HIGH EFFICIENCY TURBINE PUMPS.

Pump Size.	Suction Branch Diameter.	Delivery Branch Diameter.	Quantity. Galls. per Minute.	Head in Feet. / Number of Stages.	2	3	4	5	6	7	8
	Ins.	Ins.									
HS.3	3	3	100	Head in feet.	90	135	180	225	270	315	360
				B.H.P. required.	4·50	6·80	9·00	11·30	13·5	15·80	18·00
HS.4	4	4	220	Head in feet.	126	189	252	315	378	441	504
				B.H.P. required.	13	19·5	26	32·5	39	45·5	52
HS.5	5	5	340	Head in feet.	160	240	320	400	480	560	640
				B.H.P. required.	24·3	36·4	48·6	60·75	73	85	97
HS.6	6	6	550	Head in feet.	200	300	400	500	600	700	800
				B.H.P. required.	46·5	70	93	116	140	163	186
HS.7	7	7	750	Head in feet.	250	375	500	625	750	875	1000
				B.H.P. required.	77·00	115·50	154·00	192·50	231·00	269·50	308·00
HS.8	8	8	1,000	Head in feet.	300	450	600	750	900	1,05.	1,200
				B.H.P. required.	117	175	233	291	349	407	46[illegible]
HS.9	10	9	1,500	Head in feet.	400	600	800	1,000	1,200	1,400	1,600
				B.H.P. required.	227	340	445	568	680	795	910

The outputs given in the above table are based on cold water, with a suction lift not exceeding 20 ft.

Pumps for Oils and Viscous Fluids.

The 'Stone-Paramor' Rotary Pump.

(J. Stone & Co., Ltd., Deptford, S.E. 14.)

This is a rotary pump specially designed for dealing with heavy fuel oils, lubricating oils, and all industrial viscous fluids. A special feature is that sliding contact between the inner and the outer rotor is reduced to a minimum, there being a high degree of rolling action.

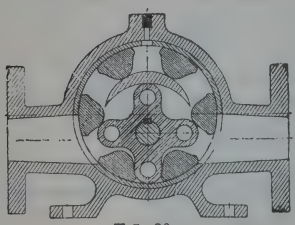


FIG. 30.

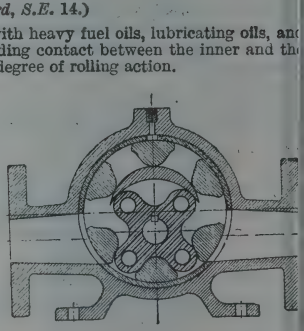


FIG. 31.

Figs. 30 and 31 show the rotors in two different positions. It will be observed that the shap of the teeth being cycloidal (as they are generated in accordance with the relative rolling actio between inner and outer rotors), the teeth of the inner rotor make continuous rolling contact wit the teeth or abutments of the outer rotor.

Particular attention has been given to the prevention of leakage in the suction and discharg when operating under heavy pressure. The figs. show that in any relative position of the tw rotating members this point is amply provided for, so that the volumetric efficiency of the pum is very high.

In all sizes provided with 3-in. branches and above, the pumps are fitted with ball bearing carried in end brackets, so that the inner rotor is always kept in a central position.

TABLE OF CAPACITIES.

Type.	Diameter of Branches.	Capacity. Tons per Hour.	R.P.M.	
			Min.	Max.
P.R.P. 1	1½ ins.	3	500	600
,, 2	2 ,,	7½	400	550
,, 3	2½ ,,	10	350	500
,, 4	3 ,,	15	300	450
,, 5	3½ ,,	20	300	400
,, 6	4 ,,	30	250	350
,, 7	5 ,,	37	250	350
,, 8	6 ,,	50	225	300
,, 9	7 ,,	75	225	300
,, 10	8 ,,	120	200	250
,, 11	9 ,,	150	175	250
,, 12	10 ,,	200	150	200
,, 13	12 ,,	250	150	200
,, 14	14 ,,	300	125	200
,, 15	14 ,,	375	125	200
,, 16	15 ,,	450	100	150
,, 17	15 ,,	550	100	150

NOTE.—The capacities stated above represent the outputs of the pumps at minimum spe when dealing with heavy Mexican fuel oil.

The maximum speed stated can be employed on less viscous fluids and lubricating oils, but molasses, heavy oils, tar, etc., the lower speed should be selected.

When dealing with the lighter liquids the outputs of the pumps can be increased in proport to the speed.

The pumps are in use by many large oil companies for pumping fuel and lubricating oils, and also by many shipowners, as it is particularly adaptable for installing on board ship, also by large industrial concerns where viscous fluids have to be dealt with.

Scoop Wheels.

For raising large bodies of water through a small elevation the scoop wheel is very effective. At Amsterdam the canals are freshened by the drawing of water through them by 8 scoop wheels, discharging to the Zuyder Zee.

Their diameter is 8 m.; breadth, 3·25 m.; capacity, 300 m.³ each per minute; speed about 3 revolutions per minute. Floats inclined so that they enter water nearly horizontally, and leave nearly vertically. Height of lift, about 1·5 m.

The tendency to-day is to substitute the centrifugal pump for the scoop wheel even for small elevations.

Water Raising from Deep Wells by Compressed Air.

(1)

In this system, air under the necessary pressure, and of suitable volume, is admitted to the foot of a pipe immersed in the water to be lifted, as shown by fig. 32, p. 1340. By this means, alternate bands or plugs of air and water are formed in the water pipe or 'rising main,' and the air does not, as might perhaps have been anticipated, pass through the mass of water. The result of this is that the aggregate weight of the water in the rising main is insufficient to balance the column of water in the boring, and the pressure of the latter therefore produces an upward movement of the air and water column in the rising main. As the force lifting this column is the head of water at A, it follows that the height to which the water can be lifted depends upon the depth to which the pipe is immersed below the pumping level of the water in the boring: thus the higher the 'lift' required, the deeper must be the point at which the air is injected relatively to the normal water level therein, and consequently the height to which the water has to be raised determines the minimum depth to which the boring must be driven.

The following table shows the approximate horse-power required to compress 1 cubic foot of free air to different pressures per square inch:—

Locality.	Pressure in Pounds per Sq. Inch.	H.p. required to compress 1 Cub. Ft. of Air.	Locality.	Pressure in Pounds per Sq. Inch.	H.p. required to compress 1 Cub. Ft. of Air.
1. Solvay Works, Saaralben	176	0·434	5. Tunbridge Wells Waterworks	60	0·159
2. Brostowe Estate, near Friedheim	140	0·376	6. Sugar Factory, Glogan	45	0·145
3. Tunbridge Wells Waterworks	100	0·201	7. Yard Works, Zwickau	30	0·121
4. Ditto	80	0·189	8. Rossland Mines, B.C.	95	0·134

With regard to the quantity of air required to lift a given volume of water to any specified height, the following formula has been found to give correct results:—

x = cubic feet of free air per minute; A = gallons of water required per minute; B = 'lift' of water in feet;

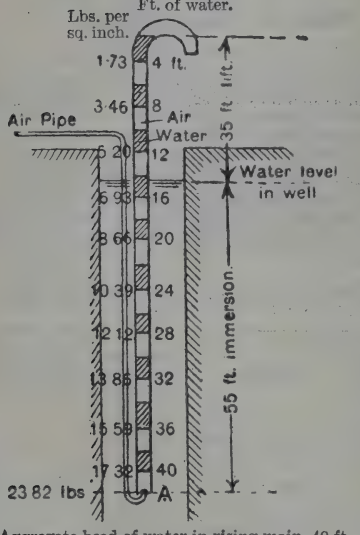
$$x = \frac{A \times B}{125}.$$

The velocity of the air should not exceed about 20 ft. per second.

In considering the design of the compressor, it is obviously important in the interests of economy to provide either 2-stage or 3-stage machines (with intercoolers) according to the amount of compression required; thus for pressures above 60 lbs. per square inch and up to 300 lbs. per square inch 2-stage machines are most suitable, and from this to 1,000 lbs. per square inch 3-stage machines are desirable. The cooling of the air is also of great importance in this respect, and care should be taken to start with an air supply at the lowest temperature obtainable.

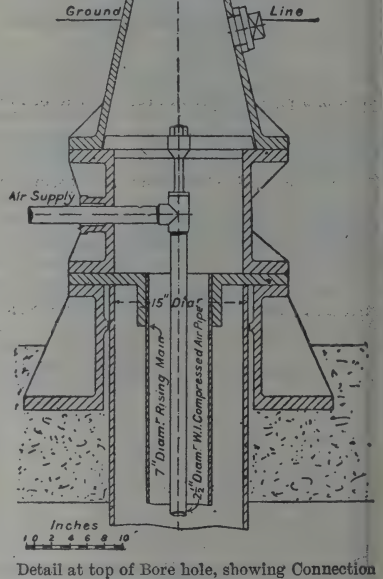
At Tunbridge Wells the compression is carried out in two stages, the first to a pressure of 25 lbs. per square inch, and the second, after intercooling, to the pressure required, which varies from 90 lbs. to 100 lbs. per square inch according to the depth of the water in the boring. The air is delivered into a large steel receiver situated in the engine-house, whence it is conveyed to the wells by means of a 4-inch cast-iron pipe. This main is formed of ordinary spigot and socket pipes with lead joints, which, however, shortly after starting the plant, showed signs of leakage adjacent to the receiver. This was traced to the expansion and contraction of the pipes due to the high temperature of the air, and was effectually prevented by fixing a cooler on the air pipe between the second stage compressor and the receiver.

There are two sets of engines and compressors, designed to deliver a sufficient volume of air to lift the desired quantity of water, if need be, over a standpipe 20 ft. high above ground level.



Aggregate head of water in rising main, 40 ft. = 17·32 lbs. per square inch.
Aggregate head in well = 55 ft. = 23·82 lbs. per square inch.

FIG. 32.



Detail at top of Bore hole, showing Connection of Air Supply.

FIG. 33.

The engines are compound, with cylinders 8 ins. and 12 ins. diameter respectively, the air-compressing cylinders being 10 ins. (first stage) and 6 ins. (second stage) diameter respectively. The stroke in each case is 14 ins. The air cylinders are water-jacketed at sides and covers. The clearance in the air cylinders does not exceed 1 per cent. of the capacity. The air is drawn from outside the building, and is carried in an earthenware pipe under the floor to the inlet valves, so that it enters the compressors at the lowest possible temperature.

An intercooler (between first and second stages of compressors), formed of a series of 'Row' tubes cooled by circulating water, is fixed outside the engine-house.

The boring is 350 ft. deep. The upper portion is lined with 15-inch steel tubes, and the lower portion (150 ft.) with steel perforated tubes, 13½ ins. diameter. The rest level of the water

is about 96 ft. from the surface, and the pumping level, when drawing at the rate of 32,000 gallons per hour, is about 120 ft. from the surface, but on the cessation of pumping the water resumes its rest level very rapidly.

The water pipe or rising main is 7 ins. diameter, and is carried to within a few feet of the bottom of the boring. The air pipe was originally 1½ ins. diameter, but was subsequently increased to 2½ ins. diameter, an alteration which reduced the air pressure required from 105 lbs. to 91 lbs. per square inch, the latter figure corresponding very closely to the head of water above the bottom of the air-pipe, and thus proving the loss by friction to be reduced to a minimum.

In a trial run of 10½ hours made soon after the plant was installed, an average of 31,402 gallons per hour was raised from this boring under a head of 133 ft., whereas an ordinary single-acting pump, such as could be fixed in a boring of this small diameter, would give no more than about 18,300 gallons per hour.

The most favourable result was obtained when the proportion of immersion of air pipe to lift of water was 3 to 1 at the start and 2·2 to 1 at the finish, the volume of air used per volume of water lifted being in the proportion of 2·69 to 1. The efficiency in this case was 36·8 per cent., calculated on the water raised proportionate to the indicated horse-power developed in steam-cylinders, and 46 per cent. calculated from the indicated horse-power shown by air-cylinder diagrams. No record of fuel consumption was made. If the proportion of immersion to lift is reduced the efficiency falls.

From a trial made with a much less immersion of air pipe than in the foregoing, and when the proportion of air used to water lifted was more than double that in the former case, the cost of fuel worked out at 1·073*d.* per 1,000 gallons for a maximum lift of 125 ft. 9 ins., the price of coal being 25*s.* 5*d.* per ton. (*W. H. Maxwell.*)

(2)

In order to enable the well to work successfully and economically, the pipe should be properly proportioned. When the pipe is too large, the water is apt to blow out in a spray and with great force, which is obviously very wasteful both of air and water. When the pipe is too small, the air is apt to rise to the surface of the water in small bubbles, and without producing the desired results. When the air pipe is outside of the water pipe, the proper relation between the diameters of the air and water pipes is as 1½ to 4, which gives a ratio of actual cross-sectional area of 6·24. When the air pipe is situated inside the water pipe, the same ratio of actual cross-sectional areas should obtain, and in this case the diameter of the water pipe is

$$D = \sqrt{\frac{a \times 6{\cdot}24 + A}{{\cdot}7854}},$$

in which a and A represent the actual internal and external areas of the air pipe. The proper areas of the air and water pipes, together with the required depth of submersion and the introduction of the air into the water pipe at the proper point, are the principal factors which determine the success of the air lift.

The water pipe should be submerged to a depth of 18 ins. for each foot lift above the lowest water level in the well; in other words, the best results are obtained when submersion $r = 1{\cdot}5$ the lift, the latter being measured from the lowest, or the working water level, as it is called.

When the well is being worked, the water level falls below the level reached, before water is pumped out. To illustrate the foregoing rule, suppose we wish to elevate water 25 ft. above the surface of the ground, and that when drilling, the well water is obtained at a depth of 40 ft. below the surface. The lift is now 40 ft. + 25 ft. = 65 ft. Applying the foregoing rule for depth of submersion, we have 65 ft. × 1·5 ft. = 97·5 ft., or practically 100 ft., thus giving a total height of 165 ft. from the point where the air enters the water pipe to the point of discharge. After drilling to a depth of 165 ft. − 25 ft. = 140 ft., we are ready to find the working water level in the well. First put the water and air pipes into the well; then drop a float attached to a string into the well. Pass the string over a pulley, and attach a weight to the free end. The weight should be just heavy enough to take up the slack in the string, and at the same time allow the float to descend with the water level as the latter is lowered by pumping. The distance the weight rises will indicate the depth of the working level below the level first obtained in the well, and the latter level should be employed when making calculations involving lift and depth of submersion. A very simple as well as convenient arrangement for measuring the fall of the water level in the well can be made as follows: Take a pulley whose circumference is twelve times the circumference of the shaft upon which the pulley is mounted, then wind the float string around

the pulley, and fasten another string to the shaft, so that it will be wound on the shaft as the float string unwinds from the pulley. It will be seen that this arrangement reduces the travel of the string on the shaft to a convenient length, and one that can easily be measured. Suppose the water level in the well falls 10 ft. The corresponding additional depth of submersion will be 10 ft. × 1·5 ft. = 15 ft., and if the well is not deep enough it should be drilled to a sufficient depth to permit the increased depth of submersion to be obtained, and this is done in order to make the total depth of submersion equal to 1½ times the lift, which proportion, as has been pointed out, is necessary for the best results. If it is not practicable to increase the depth of submersion after finding the working level, the height of the lift may be decreased a corresponding amount; otherwise the efficiency of the lift will be to some extent affected. If the well had been drilled deeper than necessary at the outstart, the increased depth of submersion could readily be obtained by simply lowering the pipes to the required depth. It will be seen that the lower water level in the well also determines the necessary change in the point at which the air should enter the water pipe. With a fall of 10 ft., when pumping, the air should enter the water pipe at from 38 ins. to 40 ins. from the lower end of the pipe; with a fall of 5 ft. the air should enter at from 24 ins. to 26 ins. from the lower end of the water pipe, and with a fall of from 1 ft. to 3 ft. it should enter at a point 18 ins. to 20 ins. from the lower end of the pipe. For other distances the same ratio may be used. A well put down to the depth previously determined and fitted with pipes of the sizes indicated by the rule, can be cemented over, and buildings erected over it, without fear of trouble, because the well will need no further attention, and all that is required is simply to supply it with air as long as the pipes last. A number of wells can, of course, be operated from the same compressor. The necessary machinery can be located in the engine-room, or in any convenient place, and the air pipes run to the different points of distribution.

It is estimated that 1 cub. ft. of air will raise 1 gallon of water, but in wells that are properly proportioned there will be a saving over the amount of from 40 to 47 per cent.; that is to say, the air used will be 60 per cent. of the above estimate as the maximum, and 52 per cent. as the minimum. To illustrate the application of the rule for volume of air required, if we wish to raise 100 gallons of water, we shall need 60 cub. ft. of air as the maximum, and 52 cub. ft. of air as the minimum, the required volume carrying from the maximum to the minimum according to the conditions in each individual case. The average air pressure is 60 lbs. per square inch. When starting to raise water, it requires a somewhat higher pressure, because there is a solid body of water from the surface in the well to the point at which the air enters the water pipe, and this column of water has to be moved by the first discharge of air. When the well has reached its normal working condition, the water pipe will contain a number of short columns of air and short columns of water. These short columns of air and water are discharged alternately, and in the pipe they form a continuous chain, the intermittent discharge continuing as long as the proper amount of air is supplied, and as long as there remains water to be pumped.

TABLE OF SUBMERGENCE AND EFFICIENCY.

Submergence per cent. of Length of Water-pipe.	Efficiency per cent.	Submergence per cent. of Length of Water-pipe.	Efficiency per cent.
60	50	33	25
50	40	30	22
40	30		

TABLE OF LIFT, SUBMERGENCE, AND AIR VOLUME.

Lift in Feet.	Volume of Air to 1 ft. of Water.	Submergence 60 per cent. total Water-pipe.	Submergence for special Lift.	Air-pressure Submergence 60 per cent.	Air Pressure for special Lift Submergence 60 per cent.	Cubic ft. free air per gallon per minute.	Horse-power per gallon per minute.
		Ft.	Ft.	Lbs.	Lbs.		
25	2	38	50	17	20	0·3	·0184
50	3	75	100	33	44	0·4	·0426
75	4·5	113	150	49	65	0·6	·0828
100	6	150	200	65	87	0·8	·1320
125	7·5	188	250	82	109	1·0	·1910
150	9	225	300	98	120	1·2	·2544
175	10·5	263	350	115	152	1·4	·3150
200	12	300	400	130	173	1·4	·3808

'Special submergence' (cols. 4 and 6) should be used where there is a long horizontal discharge or a great number of turns in the discharge-pipe.

TABLE OF CAPACITY AND PIPE SIZES.

Size of Well in Inches.	Water-pipe in Inches.	Air-pipe in Inches.	Gallons of Water per Minute.
4	$1\frac{1}{2}$	$\frac{3}{4}$	25
$4\frac{1}{2}$	2	1	50
5	$2\frac{1}{2}$	1	75
6	3	$1\frac{1}{4}$	100
7	$3\frac{1}{2}$	$1\frac{1}{4}$	150
8	4	$1\frac{1}{2}$	200
9	5	2	300
10	6	2	450

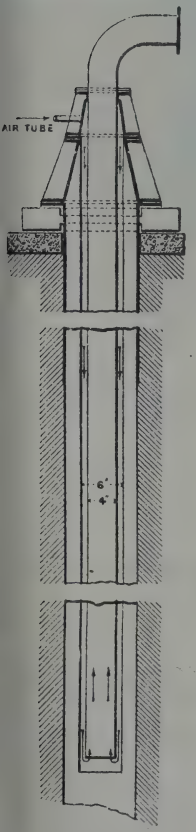


FIG. 34.

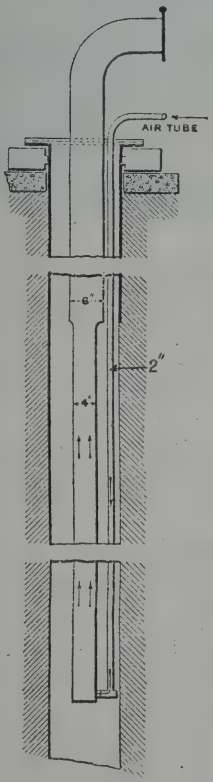


FIG. 35.

(G. C. H. Fredrich.)

At the works of the United Alkali Company, Limited, at Preesall,* a well 450 ft. in depth and 12 ins. in diameter at the bottom is fitted, as shown in figs. 34, 35, with a lining tube going down to the rock-head, and an air tube 6 ins. in diameter, with a delivery tube 4 ins. in diameter inside it, the effective cross-sectional area of the air tube being thus the area of the annulus formed between it and the delivery tube. For working this well a small Ingersoll-Sergeant air compressor was (1906) used.

In another well the delivery and air pipes are arranged on a different plan. In this case the air pipe passes down the well outside the delivery pipe and is connected to it at the bottom, as shown in fig. 35; the air-compressing plant consists (1906) of an Ingersoll-Sergeant cross-compound air compressor, having both the air and the steam cylinders compounded. The speed is regulated by a governor in the usual manner, and also by the pressure of the air as it leaves the high-pressure air cylinder. The air cylinders are water-jacketed, and the air from the low-pressure air cylinder is delivered to an inter-cooler from which it passes to the high-pressure air cylinder. The air suction valves are carried on the piston, the air passing into the piston through a hollow tail-rod working through a stuffing box and gland on the end of the cylinder, and the delivery valves are controlled by suitable spiral springs. The steam cylinders are 20 ins. and 32 ins. in diameter, and the air cylinders 28·25 ins. and 16·75 ins. in diameter, the stroke being 24 ins. The percentage of clearance in the air cylinders is very small. The air is compressed to 35 lbs. per sq. in. in the low-pressure cylinder, and in the high-pressure cylinder to a pressure ranging between 80 lbs. and

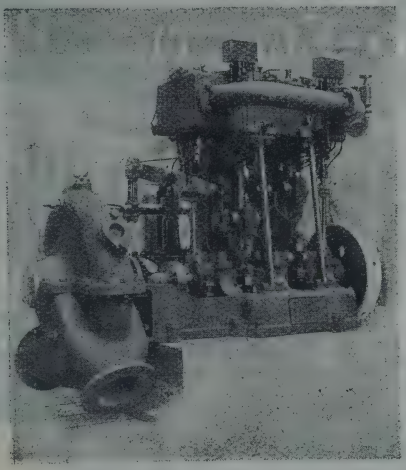
* J. Kelly (*Proceedings of the Institution of Civil Engineers*, vol. clxiii. May 1906).

120 lbs. per sq. in., according to the depth of submersion of the delivery pipes in the well or wells under operation.

Mr. Rix, in a paper read before the Technical Society of San Francisco, concludes that, with lifts not exceeding 20 ft., 1·5 cub. ft. of air will be required for each cub. ft. of water raised; for lifts of 20 ft. to 50 ft., 2 to 3 cub. ft.; and for lifts of 50 ft. to 100 ft., 3 to 4 cub. ft. will be required. He limits the velocity of the water entering the pipes to 4 to 8 ft. per second.

Air-lift pumping systems are not advisable where the submergence is below 35 per cent., and the best condition for this type of pump is from 45 per cent. to 60 per cent. submergence. By submergence is meant the ratio of the depth of the mixing chamber below the pumping water level to the total height pumped.

With air-lift pumps the hotter the liquid to be pumped the higher will be the efficiency of the pump. It has been shown by Prof. Randall that an efficiency of 100 per cent. is possible under certain conditions when pumping water at 200 deg. Fah.



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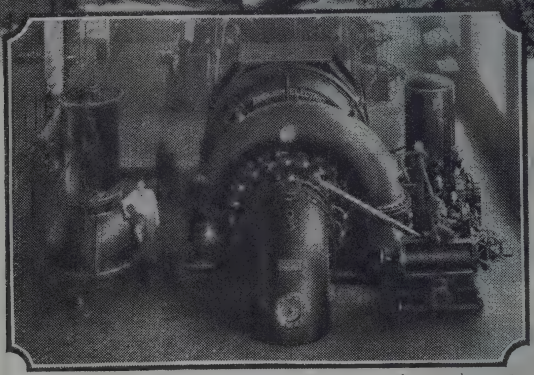

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SECTION XXV

PART III

THE DEVELOPMENT OF WATER-POWER.

(Partly contributed by Arthur Surveyer, D.Eng., M.E.I.C., M.Inst.C.E.)

WATER-POWER.

The theoretical power or effective energy of a fall of water, in ft.-lbs. per min., is equal to the weight in lbs. of the volume of water flowing per min. over the fall, multiplied by the vertical height of the fall in ft.

$$\text{H.P.} = \frac{Q \times h \times W}{550} = \frac{Q \times h \times 62{\cdot}5}{550} = \frac{Q \times h}{8{\cdot}8},$$

where,

Q = discharge in cub. ft. per sec.; W = weight of 1 cub. ft. of water = 62·5 lbs.; h = net head or net fall of water in ft.; H.P. = horse-power (33,000 ft.-lbs. per min. or 550 ft.-lbs. per sec.).

Thus 1 cu. ft. of water per sec. falling through a head of 10 ft. will develop theoretically 1·134 h.p.

For practical purposes, and in order to take into account the losses in the water-wheels, it is better to adopt the following formula, which is based on a water-wheel efficiency of 80 per cent.,

$$\text{Practical H.P.} = Q \times h \div 11.$$

An efficiency of 80 per cent. is now attained even in the medium-priced wheels, and 90 per cent. is frequently reached in the high-priced wheels. Assuming an efficiency of 88 per cent., then

$$\text{Practical H.P.} = Q \times h \div 10.$$

10 tons of water (about 320 cu. ft.) falling 100 ft. develops the energy equivalent to that which can be produced through the burning of one pound of coal. That is, 10 tons, or 20,000 lbs., falling 100 ft., will develop 2,000,000 ft.-lbs. Dividing this by 778 gives 2,570 B.Th.U. of energy. Assuming a hydraulic turbine efficiency of 92 per cent., which is a fair average for a modern hydraulic turbine, the energy actually developed from this water is about 2,370 B.Th.U. This corresponds to the energy made available by the combustion of coal having a heating value of 13,000 B.Th.U. per lb. with an over-all plant thermal efficiency of approximately 18 per cent., which is perhaps fairly representative of good central-station practice although not equal to the best, which approaches 25 per cent.

Tide-Power.

A horse-power for a day of ten hours would require something like 120 tons of water falling from a height of 100 ft., so that a 500 h.p. factory, say, would need 60,000 tons of water at a 100-foot head. On the basis of 36 cub. ft. of water to the ton, there would thus be over 2,000,000 cub. ft. of water, and this would make a fair-sized pond, say, about 1,000 ft. long, 200 ft. wide, and 10 ft. deep.

The possibilities of tidal power, if it can be developed commercially, are very great.

In Great Britain the highest tides are found in the estuary of the Severn, the mean range of the spring tides at Chepstow being 42 ft., and of the neap tides 21 ft. In France the maximum range occurs at St. Malo, where it amounts to 42·5 ft. at spring tides, and about 18 ft. at neap tides. The tidal range in the Dee is 26 ft. at springs, and 12 ft. at neaps, while the mean range of spring tides around the coast of Great Britain is 16·4 ft., and of neap tides 8·6 ft.

Assuming a mean tidal range of only 20 ft. at springs, and 10 ft. at neaps, and adopting the single-basin method of development with operation on both rising and falling tides, each square mile of basin area would be capable, without storage, of giving an average daily output of approximately 110,000 h.p.-hours. In such an estuary as the Severn, where an area of 20 square miles could readily be utilised with a spring tidal range of 42 ft., the average daily output, without storage, would be approximately 10,000,000 h.p.-hours.

(*'Nature,'* June 3, 1920.)

TABLE SHOWING PRACTICAL HORSE-POWERS CORRESPONDING TO HEADS, IN FEET, AND CUBIC FEET USED PER MINUTE, OF WATER.

(1 cu. ft. per min. = 1·7 cu. metres per hr. 1 cu. metre per hr. = 0·59 cu. ft. per min.)

The practical horse-power is taken at 80 per cent. of the theoretical.

Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.
5	76	·57	14	127	2·7	28	180	7·6	42	220	14·0
6	83	·75	16	136	3·3	30	186	8·4	44	226	15·1
7	90	·95	18	144	3·9	32	192	9·3	46	231	16·1
8	96	1·2	20	152	4·6	34	198	10·2	48	236	17·1
9	101	1·4	22	160	5·3	36	204	11·1	50	241	18·2
10	107	1·6	24	167	6·1	38	210	12·1	55	252	21·0
12	118	2·1	26	173	6·8	40	215	13·0	60	264	24·0
5	152	1·15	14	255	5·4	28	360	15·3	42	441	28·0
6	167	1·5	16	272	6·6	30	373	16·9	44	452	30·1
7	180	1·9	18	289	7·9	32	385	18·7	46	462	32·2
8	192	2·3	20	304	9·2	34	397	20·4	48	472	34·3
9	204	2·8	22	320	10·7	36	409	22·3	50	482	36·5
10	215	3·3	24	334	12·1	38	420	24·2	55	505	42·0
12	236	4·3	26	347	13·7	40	431	26·1	60	528	47·9
5	228	1·7	14	383	8·1	28	541	22·9	42	662	42·1
6	251	2·3	16	409	9·9	30	560	25·4	44	678	45·2
7	270	2·9	18	434	11·8	32	578	28·0	46	693	48·3
8	288	3·5	20	457	13·8	34	596	30·7	48	707	51·4
9	307	4·2	22	480	16·0	36	614	33·5	50	721	54·8
10	323	4·9	24	501	18·2	38	630	36·2	55	758	63·1
12	354	6·4	26	521	20·5	40	646	39·1	60	792	72·0
5	342	2·6	14	574	12·2	28	812	34·4	42	993	63·1
6	376	3·4	16	614	14·9	30	840	38·1	44	1,017	67·7
7	405	4·3	18	651	17·7	32	867	42·0	46	1,040	72·4
8	432	5·2	20	686	20·8	34	894	46·0	48	1,061	77·1
9	461	6·3	22	720	24·0	36	921	50·2	50	1,081	81·8
10	484	7·3	24	751	27·3	38	945	54·4	55	1,136	94·6
12	531	9·6	26	782	30·8	40	969	58·7	60	1,188	107·9
5	418	3·2	14	701	14·9	28	992	42·0	42	1,213	77·1
6	459	4·2	16	750	18·2	30	1,026	46·6	44	1,243	82·8
7	495	5·2	18	795	21·7	32	1,059	51·3	46	1,271	88·5
8	528	6·4	20	838	25·4	34	1,092	56·2	48	1,297	94·2
9	563	7·7	22	880	29·3	36	1,125	61·3	50	1,325	100·3
10	591	8·9	24	918	33·3	38	1,155	66·4	55	1,388	115·5
12	649	11·8	26	955	37·6	40	1,184	71·7	60	1,452	132·0
5	609	4·6	14	1,022	21·6	28	1,442	61·1	42	1,766	112·2
6	668	6·1	16	1,090	26·4	30	1,493	67·8	44	1,808	120·4
7	721	7·6	18	1,156	31·5	32	1,542	74·7	46	1,849	128·7
8	771	9·3	20	1,219	36·9	34	1,589	81·8	48	1,889	137·2
9	818	11·2	22	1,278	42·6	36	1,636	89·1	50	1,929	146·0
10	862	13·0	24	1,335	48·5	38	1,680	96·6	55	2,022	168·3
12	944	17·1	26	1,390	54·7	40	1,724	104·3	60	2,142	194·5
5	799	6·1	14	1,340	28·4	28	1,893	80·2	42	2,317	147·3
6	876	8·0	16	1,431	34·6	30	1,959	88·9	44	2,373	158·0
7	956	10·1	18	1,517	41·3	32	2,023	97·9	46	2,427	169·0
8	1,011	12·3	20	1,600	48·4	34	2,085	107·3	48	2,479	180·1
9	1,074	14·7	22	1,678	55·9	36	2,147	117·0	50	2,532	191·6
10	1,130	17·1	24	1,752	63·6	38	2,205	126·8	55	2,652	220·7
12	1,239	22·5	26	1,824	71·8	40	2,252	136·3	60	2,772	251·7
5	1,027	7·8	14	1,723	36·5	28	2,434	103·1	42	2,979	189·3
6	1,127	10·2	16	1,840	44·6	30	2,519	114·3	44	3,051	203·2
7	1,226	13·0	18	1,951	53·1	32	2,610	126·4	46	3,120	217·2
8	1,299	15·7	20	2,057	62·3	34	2,681	137·9	48	3,186	231·4
9	1,381	18·9	22	2,158	71·8	36	2,761	150·4	50	3,253	246·2
10	1,453	22·0	24	2,253	81·8	38	2,835	163·0	55	3,410	283·8
12	1,593	28·9	26	2,345	92·3	40	2,908	176·0	60	3,564	323·6

TABLE SHOWING PRACTICAL HORSE-POWERS CORRESPONDING TO HEADS, IN FEET, AND CUBIC FEET USED PER MINUTE, OF WATER (*continued*).

Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.	Heads, in Feet.	Cubic Feet used per Minute.	Horse-power.
5	1,232	9·3	14	2,067	43·8	28	2,921	123·8	42	3,575	227·2
6	1,352	12·3	16	2,208	53·5	30	3,023	137·2	44	3,661	243·8
7	1,471	15·6	18	2,341	63·8	32	3,132	151·7	46	3,745	260·7
8	1,560	18·9	20	2,469	74·7	34	3,220	165·7	48	3,823	277·7
9	1,657	22·6	22	2,590	86·2	36	3,313	180·5	50	3,905	295·5
10	1,743	26·4	24	2,703	98·2	38	3,402	195·7	55	4,092	340·6
12	1,912	34·7	26	2,815	110·8	40	3,490	211·2	60	4,277	388·8
3	1,389	6·3	10	2,536	38·4	24	3,928	142·7	38	4,944	284·3
4	1,603	9·7	12	2,776	50·4	26	4,089	160·9	40	5,071	307·0
5	1,793	13·6	14	3,000	63·6	28	4,233	179·3	42	5,193	330·0
6	1,963	17·8	16	3,208	77·7	30	4,392	199·4	44	5,316	354·0
7	2,122	22·5	18	3,403	92·7	32	4,536	219·7	46	5,424	377·6
8	2,268	27·5	20	3,588	108·6	34	4,677	240·6	48	5,353	403·3
9	2,408	32·9	22	3,760	125·2	36	4,816	262·4	50	5,665	428·7
3	1,699	7·8	10	3,103	47·0	24	4,806	174·5	38	6,048	347·9
4	1,962	11·9	12	3,398	61·7	26	5,011	197·2	40	6,206	375·6
5	2,192	16·6	14	3,679	77·9	28	5,192	220·0	42	6,357	404·0
6	2,405	21·8	16	3,924	95·0	30	5,364	243·5	44	6,509	433·4
7	2,596	27·5	18	4,161	113·4	32	5,551	268·8	46	6,657	463·5
8	2,776	33·6	20	4,388	132·8	34	5,713	294·0	48	6,801	494·0
9	2,945	40·2	22	4,601	153·2	36	5,887	320·7	50	6,942	525·3
3	2,895	13	9	5,010	68	20	7,475	226	32	9,450	458
4	3,340	20	10	5,285	80	22	7,825	261	34	9,745	501
5	3,735	28	12	5,785	105	24	8,185	297	36	10,025	545
6	4,090	37	14	6,250	132	26	8,520	335	38	10,300	593
7	4,420	47	16	6,685	162	28	8,840	375	40	10,565	640
8	4,725	57	18	7,099	193	30	9,150	415			

GENERAL FEATURES OF A WATER-POWER DEVELOPMENT.

Although the lay-out of hydraulic plants changes with every water-power site, there are certain features which are generally found in all developments, and which can be described as follows :

1. The dam, which impounds the water, regulates the level of the upper pool, and directs the water towards the water wheels.

2. The head gates, which control the supply of water, and by means of racks permit the removal from the water supply of injurious floating and suspended matter.

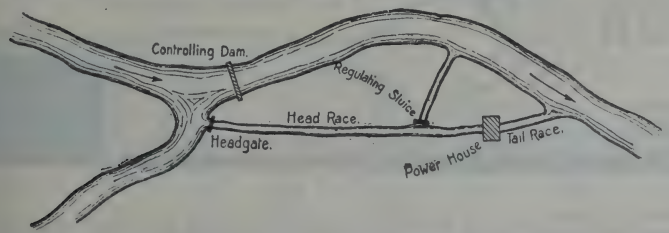

FIG. 1.—Typical General Arrangement of Hydraulic Development.

3. The head race, flume or penstock, which carries the water to the wheels.
4. The power house, which contains the hydraulic machinery.
5. The water wheels, which transform the hydraulic energy.

6. The draft tube, and the tail race, which discharge the water used in the power house into the river.

In some plants the power house forms a part of the dam, and the water is delivered to the wheels without passing through a canal or penstock and discharged back into the river directly through the draft tubes.

Fig. 1 shows a rather complicated lay-out, with a regulating canal for the head race. The regulation of the level of the upper pool is obtained either by a regulating weir, sluices in the dam, or a movable dam.

In approaching the study of any water-power site, the two first things to be determined are the head of water available at all times and the characteristic flow of the river. It is not economical to install machinery which can utilise only the minimum flow of the river, and it is considered good practice to build a plant capable of using the *characteristic flow* of the river, which can be defined as the available dependable flow during at least nine months of a low year.

The available head is determined by levelling and by the daily reading of gauges located in the upper and lower pools of the proposed development.

The *characteristic flow* is found by a series of discharge measurements combined with the daily reading of gauges extending over as long a period as economically possible.

Characteristics of the Flow of Rivers.

The discharge of rivers varies with the precipitation on their drainage basin, the evaporation, the volume of the run off, and the rapidity with which the underground as well as the surface waters reach the river.

The study of drainage basins includes the study of the discharge of streams, of the relations between the stream discharge and the water precipitation, on the drainage basin, on the flood discharges and the rains which cause them, etc.

Discharge of Rivers.

Given a river with an unchangeable bed, there is a fixed relation between the level of this river at a given point and its discharge at that point. Except in the cases of rivers carrying and depositing large quantities of gravel and sand, it is fair to assume that the bed does not change. The discharge curve of a river is obtained from actual measurements, plotted at a suitable scale on cross-section paper. The gauge heights are taken as ordinates and the discharge as abscissæ. The several points thus plotted are connected together by a curve so drawn that the algebraic sum of the squares of the errors is minimum. This curve is a parabola of the form $Q=a+bh+ch^2$. It is often found advisable to develop the discharge equation of a river, and in order to do so the parameters a, b, c can be calculated in each case, from actual measurements, by the method of the least squares.

Measurement of Quantity of Water Flowing in a Stream.

Weir Measurement.

(1)

Rectangular Notch Method.

For small streams a weir dam is used, as shown by fig. 2, consisting of a board long enough to reach across the stream with either end set in the bank. A notch is cut in the board, deep enough

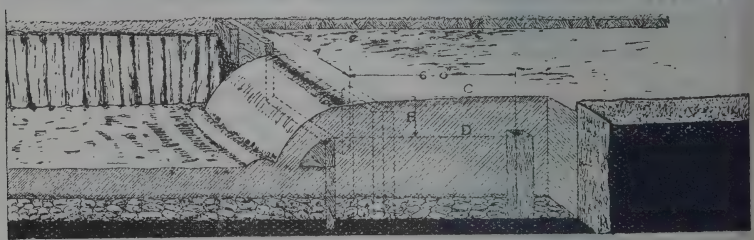

Fig. 2.

to pass all the water, and long enough to reach about two-thirds A, across the stream. The bottom and ends of the notch, D, in the board should be bevelled on the down stream side, leaving the upper edge sharp. The stake, E, should be driven in the bottom of the stream, several feet from the board, on a level with the edge of the notch D. When the water has reached its greatest depth, a measurement, B, can be made of the depth of water over the stake E. The dotted line C represents the top of the running water, and the distance between this line or level of water and the top of the stake gives the true depth or spill over the weir board.

The surface of water below the board should be at least 10 inches lower than the notch D. A part of the stream should be selected where the water can approach the notch quietly.

The weir described above is called a *contracted weir* ; if the sides of the notch are continuous with the sides of the channel it is a *suppressed weir*, or a *weir without end contractions*.

According to the different cases we have the following formulæ giving the discharge in cub. ft. per sec. :

With end contractions and a velocity of approach,

$$Q = 5{\cdot}347\ CL\ \sqrt{(H+1{\cdot}44h)^3}\ ;$$

where water has no velocity of approach,

$$Q = 5{\cdot}347\ CL\ \sqrt{H^3}$$

without end contractions but with velocity of approach,

$$Q = 5{\cdot}347\ CL\ \sqrt{(H+4/3\ h)^3}\ ;$$

where water has no velocity of approach,

$$Q = 5{\cdot}347\ CL\ \sqrt{H^3}\ ;$$

in which

L = Length of weir in ft. ;
H = Head in ft. ;
V = Velocity of approach in ft. per sec. ;
h = Head equivalent of velocity of approach = 0·01555 V^2 ;
C = Coefficient of discharge ;
Q = Discharge in cub. ft. per sec.

VALUES OF 'C.'

For Weirs with Contracted Ends. Length of Weir in ft.

Effective Head in ft.	·66	1	2	3	5	10	19
·10	·632	·639	·646	·652	·653	·655	·656
·15	·619	·625	·634	·638	·640	·641	·642
·20	·611	·618	·626	·630	·631	·633	·634
·25	·605	·612	·621	·624	·626	·628	·629
·30	·601	·608	·616	·619	·621	·624	·625
·40	·595	·601	·609	·613	·615	·618	·620
·50	·590	·596	·605	·608	·611	·615	·617
·60	·587	·593	·601	·605	·608	·613	·615
·70	—	·590	·598	·603	·606	·612	·614
·80	—	—	·595	·600	·604	·611	·613
·90	—	—	·592	·598	·603	·609	·612
1·00	—	—	·590	·595	·601	·608	·611
1·20	—	—	·585	·591	·597	·605	·610
1·40	—	—	·580	·587	·594	·602	·609
1·60	—	—	—	·582	·591	·600	·607

For Weirs without Contracted Ends. Length of Weir in ft.

Effective Head in ft.	19	10	7	5	4	3	2
·10	·657	·658	·658	·659	—	—	—
·15	·643	·644	·645	·645	·647	·649	·652
·20	·635	·637	·637	·638	·641	·642	·645
·25	·630	·632	·633	·634	·636	·638	·641
·30	·626	·628	·629	·631	·633	·636	·639
·40	·621	·623	·625	·628	·630	·633	·636
·50	·619	·621	·624	·627	·630	·633	·637
·60	·618	·620	·623	·627	·630	·634	·638
·70	·618	·620	·624	·628	·631	·635	·640
·80	·618	·621	·625	·629	·633	·637	·643
·90	·619	·622	·627	·631	·635	·639	·645
1·00	·619	·624	·628	·633	·637	·641	·648
1·20	·620	·626	·632	·636	·641	·646	—
1·40	·622	·629	·634	·640	·644	—	—
1·60	·623	·631	·637	·642	·647	—	—

TABLE SHOWING DISCHARGE PER INCH OF LENGTH OVER SHARP-CRESTED, VERTICAL, RECTANGULAR NOTCH WEIRS IN CUBIC FEET PER MINUTE PER INCH OF LENGTH.

Ins.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	Ins.
		·006	·01	·03	·05	·07	·09	·11	·14	·17	·20	·23	·26	·30	·33	·36	
1	·40	·43	·47	·51	·55	·60	·65	·70	·74	·78	·83	·87	·93	·98	1·03	1·08	1
2	1·14	1·19	1·24	1·30	1·36	1·41	1·47	1·52	1·59	1·65	1·71	1·77	1·83	1·89	1·96	2·02	2
3	2·09	2·16	2·23	2·29	2·36	2·43	2·50	2·57	2·63	2·71	2·78	2·85	2·92	2·99	3·07	3·14	3
4	3·22	3·29	3·37	3·44	3·52	3·60	3·68	3·75	3·83	3·91	3·99	4·07	4·16	4·24	4·32	4·41	4
5	4·50	4·58	4·67	4·75	4·84	4·92	5·01	5·10	5·18	5·27	5·36	5·45	5·54	5·63	5·72	5·81	5
6	5·90	6·00	6·09	6·18	6·28	6·37	6·47	6·56	6·65	6·75	6·85	6·95	7·05	7·15	7·25	7·35	6
7	7·44	7·54	7·64	7·74	7·84	7·94	8·05	8·15	8·25	8 35	8·45	8·55	8·66	8·76	8·86	8·97	7
8	9·10	9·20	9·31	9·42	9·52	9·63	9·74	9·85	9·96	10·07	10·18	10·29	10·40	10·51	10·62	10·73	8
9	10·86	10·97	11·08	11·19	11·31	11·42	11·54	11·65	11·77	11·88	12·00	12·12	12·23	12·35	12·47	12·59	9
10	12·71	12·83	12·95	13·08	13·19	13·31	13·43	13·55	13·67	13·80	13·93	14·04	14·16	14·30	14·42	14·55	10
11	14·67	14·79	14·92	15·05	15·18	15·30	15·43	15·56	15·67	15·81	15·96	16·08	16·20	16·34	16·46	16·59	11
12	16·73	16·86	16·99	17·12	17·26	17·39	17·52	17·65	17·78	17·91	18·05	18·18	18·32	18·45	18·58	18·72	12
13	18·87	19·01	19·14	19·28	19·42	19·55	19·69	19·83	19·97	20·10	20·24	20·38	20·52	20·66	20·80	20·94	13
14	21·09	21·23	21·37	21·48	21·65	21·79	21·94	22·08	22·22	22 35	22·51	22·65	22·79	22·94	23·08	23·23	14
15	23·38	23·53	23·67	23·82	23·97	24·11	24·26	24·41	24·56	24·71	24·86	25·01	25·16	25·31	25·46	25·61	15
16	25·76	25·91	26·06	26·21	26·36	26·51	26·66	26·81	26·97	27·12	27·27	27·43	27·58	27·73	27·89	28·04	16
17	28·20	28·35	28·51	28·66	28·82	28·98	29·14	29·29	29·45	29·60	29·76	29·92	30·08	30·23	30·39	30·55	17
18	30·70	30·86	31·02	31·18	31·34	31·50	31·66	31·81	31·98	32·15	32·31	32·47	32·63	32·80	32·96	33·12	18
19	33·29	33·45	33·61	33·78	33·94	34·11	34·27	34·44	34·61	34·77	34·94	35·10	35·27	35·44	35·60	35·77	19
20	35·94	36·10	36·27	36·46	36·60	36·87	36·94	37·11	37·28	37·45	37·62	37·79	37·96	38·14	38·31	38·48	20
21	38·65	38·82	39·00	39·17	39·34	39·52	39·69	39·86	40·04	40·21	40·39	40·56	40·73	40·91	41·09	41·26	21
22	41·43	41·60	41·78	41·96	42·13	42·31	42·49	42·67	42·84	43·02	43·20	43·38	43·56	43·74	43·92	44·10	22
23	44·28	44·46	44·64	44·82	45·00	45·18	45·38	45·53	45·71	45·90	46·08	46·26	46·43	46·63	46·81	47·00	23
24	47·18	47·36	47·55	47·72	47·91	48·09	48·28	48·46	48 65	48·83	49·02	49·20	49·39	49·58	49·76	49·93	24

The readings obtained at the weir dam are used with the weir table, thus :—

The figures 1, 2, 3, etc., in the first vertical column of the weir table are the inches depth of water running over the notch of weir. The top horizontal line shows fractional parts of an inch ; the body of the table shows the cubic feet and the fractional parts of a cubic foot that will pass each minute, for each inch and fractional inch depth of water in notch. Each of these results is for one inch only of weir, as follows :—

EXAMPLE.—Suppose the notch in board is 20 inches wide and the water at the stake E 5½ inches deep. Take the column containing figure 5 and the one containing figure ½, and the square where they meet contains 5·18 cubic feet. This is the quantity of water passing for each inch in width ; but the weir is 20 inches wide, therefore this result, multiplied by 20, gives 103·6 cubic feet per minute. The same method applies to any depth from one to 25 inches, or any width.

The foregoing only applies in cases where the weir or notch is without end contractions, and discharging from still water.

(2)

'V'-Notch Method.

In this method a 'V'-shaped notch, fig. 3, is cut in the sill board, this notch being of sufficient size to allow the full volume of water to discharge through it. When the flow is steady, then

$$Q = \frac{4}{15} kwh \sqrt{2gh}, \text{ cubic feet } \textit{per second},$$

w, h, and g being in *feet*.

The value of k varies from ·59 to ·62, according to the angle α, being ·59 for a right angle (90°).

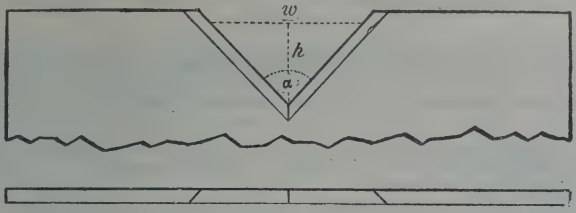

FIG. 3.

When α is a right angle, then $w = 2h$, and formula becomes

$$Q = \cdot 3h^2\sqrt{h}, \text{ cubic feet } \textit{per minute},$$

h being in *inches*.

The advantage of the 'V'-notch method is that the ratio of the wetted perimeter of the notch to the area of outflow is the same for any value of h.

A series of 'V'-notches may be cut in the sill-board if the flow of water is great; these notches should be of equal size, and their apexes should be exactly in line, and this line should be exactly horizontal.

When a series of 'V' notches is used, there is a certain amount of mutual interference between the several jets, and in order to get complete immunity from this the notches should be seven times the head apart. If the notches are $3\frac{1}{2}$ times the head apart, the error may be, but would not exceed, ·5 per cent. (*H. S. Rowell.* '*Engineering*,' *May* 2, 1913.)

WEIR TABLE FOR RIGHT-ANGLED 'V'-NOTCH (FROM ONE INCH TO THIRTY INCHES DEEP) GAUGING, GIVING DISCHARGE (Q) IN CUB. FT. PER MIN. FORMULA :—$Q = \cdot 3h^2\sqrt{h}$.

h Ins.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
1	·300	·339	·403	·461	·522	·591	·665	·742	·827	·916	1·01	1·11	1·22	1·33	1·44	1·57
2	1·70	1·83	1·97	2·12	2·28	2·42	2·61	2·78	2·96	3·15	3·35	3·55	3·76	3·98	4·21	4·44
3	4·68	4·92	5·18	5·44	5·71	5·99	6·28	6·57	6·88	7·19	7·51	7·83	8·17	8·51	8·87	9·23
4	9·60	9·98	10·4	10·8	11·2	11·6	12·0	12·4	12·9	13·3	13·8	14·3	14·8	15·2	15·7	16·3
5	16·8	17·3	17·8	18·4	18·9	19·5	20·1	20·7	21·3	21·9	22·5	23·1	23·8	24·4	25·1	25·8
6	26·5	27·2	27·9	28·6	29·3	30·0	30·8	31·5	32·3	33·1	33·9	34·7	35·5	36·3	37·2	38·0
7	38·9	39·8	40·7	41·6	42·5	43·4	44·3	45·3	46·2	47·2	48·2	49·2	50·2	51·2	52·2	53·3
8	54·3	55·4	56·5	57·5	58·7	59·8	60·9	62·0	63·2	64·4	65·6	66·8	68·0	69·2	70·4	71·6
9	72·9	74·2	75·5	76·8	78·1	79·4	80·7	82·1	83·5	84·8	86·2	87·6	89·0	90·5	91·9	93·4
10	94·9	96·4	97·9	99·4	101	102	104	106	107	109	110	112	114	115	117	119
11	120	122	124	126	127	129	131	133	135	136	138	140	142	144	146	148
12	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	181
13	183	185	187	189	192	194	196	199	201	203	206	208	210	213	215	218
14	220	222	225	227	230	233	235	238	240	243	245	248	251	253	256	259
15	261	264	267	270	273	275	278	281	284	287	290	292	295	297	301	304
16	307	310	313	316	319	323	326	329	332	335	338	341	344	348	351	354
17	358	361	364	368	371	374	377	381	384	388	391	395	398	402	405	409
18	413	416	420	423	427	431	434	438	442	446	449	451	457	461	464	468
19	472	476	480	484	488	492	496	500	504	508	512	516	520	524	528	533
20	537	541	545	550	554	558	563	566	571	575	580	584	589	593	598	602
21	606	611	615	620	625	629	634	638	643	648	653	657	662	667	671	676
22	681	686	691	696	701	706	711	716	721	725	731	736	741	746	751	756
23	761	766	772	777	782	787	793	798	803	809	814	819	825	830	836	841
24	847	852	858	863	869	875	880	886	891	897	903	908	914	920	926	932
25	938	944	950	955	961	967	973	979	985	991	997	1,000	1,010	1,016	1,020	1,028
26	1,030	1,040	1,047	1,050	1,060	1,065	1,070	1,080	1,085	1,090	1,100	1,104	1,110	1,120	1 124	1,130
27	1,136	1,140	1,150	1,156	1,160	1,170	1,176	1,180	1,190	1,196	1,200	1,210	1,220	1,224	1,230	1,240
28	1,240	1,250	1,260	1,266	1,270	1,280	1,287	1,290	1,300	1,310	1,315	1,320	1,330	1,340	1,344	1,350
29	1,360	1,366	1,370	1,380	1,390	1,395	1,400	1,410	1,420	1,426	1,430	1,440	1,450	1,456	1,460	1,470
30	1,480	1,485	1,490	1,500	1,510	1,520	1,530	1,533	1,540	1,550	1,560	1,565	1,570	1,580	1,590	1,600

FLOW OF WATER OVER SHARP-EDGED NOTCHES AND WEIRS.

(1) Flow over a triangular notch.

$$Q = 2{\cdot}48nH^{2{\cdot}47}.$$

Q = cub. ft. per sec.; n = tangent of half-included angle of notch; H = head in feet.

(2) Flow over any trapezoidal notch = flow over a rectangular weir of equal length with two end contractions, plus the flow through a triangular notch of corresponding angle.

(3) Flow over a rectangular weir with end contractions varies as—

$$Q = 3{\cdot}10\,L^{1{\cdot}02}\,H^{1{\cdot}47},$$

for all weirs up to at least 19 ft., and for head up to half length of weir, provided depth of post below sill of weir is not less than twice the head. L = length in feet.

General law for trapezoidal weirs:

$$Q = 3{\cdot}10\,L^{1{\cdot}02}\,H^{1{\cdot}47} + 2{\cdot}48nH^{2{\cdot}47}.$$

(*H. J. F. Gourley and B. Santo Crimp*, '*Proceedings Inst.C.E.*,' vol. cc. p. 388, Nov. 1915.)

See also Dixon & Macauly on 'Measurements of Discharge over a Rock-Faced Dam'; Minutes of Proceedings of the Institution of Civil Engineers, vol. 220, May, 1926; and Hubert Mawson, D.Sc., on 'Applications of the Principles of Dimensional and Dynamical Similarity to the Flow of Liquids through Orifices, Notches, and Weirs'; the Proceedings of the Institution of Mechanical Engineers, No. 2, 1927.

Sluice Measurement.

(*Contributed by J. F. Maryon, M.I.Mech.E.*)

Raise the sluice gate, taking care that the level of the water above the sluice gate is constant, and take the three measurements shown, D being the height from the bottom of the sluice gate to the sill over which the water is flowing, W the width of the opening, and H the distance from

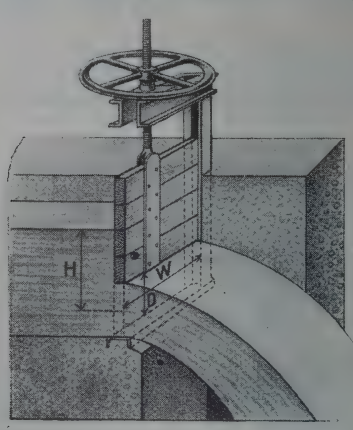

FIG. 4.

the surface of the water above the sluice gate, to a point half-way between the bottom of the sluice gate and the sill. Having obtained these figures in feet, the quantity of water passing in cubic feet per minute is as follows:—

$$Q = W \times D \times 8\sqrt{H} \times 42.$$

Measuring Open Streams.

(*Contributed by J. F. Maryon, M.I.Mech.E.*)

To measure the discharge of a stream it is necessary to obtain by soundings an accurate cross-section of the river at the point of observation. This section is subdivided into a certain number

of sections, A, B, C, D, E (fig. 5), and the mean velocity of flow accurately determined for each sub-section. We have then the relation $Q=AV$; where Q=discharge in cub. ft. per sec., A=total area in sq. ins., and V=mean velocity in ft. per sec., throughout the section.

$$Q=q_1+q_2+q_3+ \ldots = A_1V_1+A_2V_2+A_3V_3+ \ldots$$

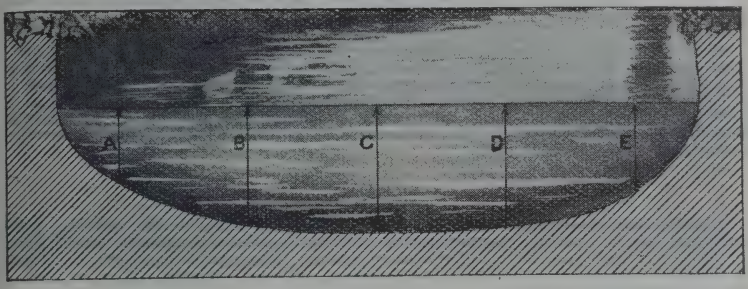

FIG. 5.

The mean velocity occurs at about 0·6 of the depth of a stream, but the mean between the velocities observed at 0·2 and at 0·8 of the depth will also give the mean velocity for the total depth.

MEASUREMENT WITH FLOATS.

In order to measure the velocity of the current in the different sections by means of floats it is necessary to lay out on the shore two parallel ranges perpendicular to the general direction of the current and distant from each other by 200 or 300 ft.

A series of floats are afterwards dropped at a certain distance above the upstream range and their course determined either by transits set up on the shore, or by sextants from a boat kept a few feet distant from each float during its downstream travel.

The passage of each float in line with the upstream and downstream range is recorded with a stopwatch and the mean velocity of the float throughout the distance calculated.

(a) Measurement with Rod Floats.

If a rod float is made to float vertically at a section of the stream so that its lower end is not more than a foot or so above the bed of the river at that point, such a float will be carried downstream by the current at a rate corresponding approximately to the mean velocity of the current at the point considered. It is not always practically possible to fulfil this condition, and even with a complete set of hollow galvanised iron rod floats, which can be sunk at will by loading them with shot, it is found necessary to correct the observed velocity and to reduce it to the mean velocity by using the following formula, due to Francis:

$$V_m = V_r\,(1-0{\cdot}116\,(\sqrt{d}-x)),$$

where

V_m = mean velocity for the vertical section considered;

V_r = observed velocity of the rod float;

$$d = \frac{\text{distance between bottom of rod and river bottom}}{\text{depth of river}};$$

x is a function of $\frac{l}{d}$, l being the length of the rod and d the depth of the water.

The following shows the values of x corresponding to various values of $\frac{l}{d}$:

$\frac{l}{d}$	0·9	0·8	0·7	0·6	0·5
x	0·10	0·05	0·00	−00·5	−0·10

When $\frac{l}{d}$ = 0·9 or more, the formula is that given by Francis:

$$V_m = V_r\,(1-0{\cdot}116\,(\sqrt{D}-0{\cdot}1)).$$

(b) Measurement with Submerged Floats.

It is possible by means of a surface float connected by a string to a submerged float held at a depth equal to about 0·6 of the depth of the stream at that point, to obtain directly without correction the mean velocity in a section. The surface float is generally made very flat so as not to be affected by the wind, and the sub-surface float is generally composed of two pieces of galvanised plate placed cross-wise and terminated at their upper end by hollow tubes in order to give the submerged float the necessary buoyancy.

Measurement by Meters.

The current meters used to measure the velocity of water consist in a wheel of some form so constructed that it is made to revolve by the impact of flowing water, the number of revolutions of this wheel being either recorded, or indicated to the observer. The relation between the velocity of the moving water and the revolutions of the wheel is determined by rating each meter.

Meter Rating.

To rate a meter it is necessary to drive it through still water at a uniform velocity and over a given distance. The distance being known and the time taken to cover it as well as the number of revolutions being noted, it is possible to determine the velocity per second and the number of revolutions per second for this velocity. The experiment must be made at varying speed of translation, so that a complete rating curve can be obtained for each instrument. This curve in all meters is practically a straight line. Meters are not generally reliable for the measurement of velocities of less than 0·3 ft. per sec.

(See also Section XXVII., p. 1497.)

DAMS.

Dams are constructions placed across a stream to impound water, to raise the level of the water upstream, or to divert a part or the whole of the river flow towards the water wheels either by means of a head-race, flumes, or pipes under pressure. Dams can be built with earth, loose stones, timber, masonry, concrete, reinforced concrete, and even with steel. They are fixed or movable according to the needs.

Dams can be built with their crest above the level of the highest waters, and provided with sluiceways, or they can be designed with spillways allowing the water to flow over their crest.

Earth Dams.

Earth dams (fig. 6) can, on account of their large base, be built on less resisting foundations than those constructed of other materials provided of course that the bed of the river is impermeable. The section of these dams varies according to local circumstances, and with the materials used. In general the upstream slope is either 3 to 1 or 2 to 1, and the downstream slope about 2 to 1. The centre part of earth dams is often constituted by a core of impermeable material, generally a mixture of sand and clay (two-thirds of sand and one-third of clay). Sometimes this core puddle is replaced by a concrete core wall driven into the bed of the river to an impermeable strata. In designing these concrete core walls, it is necessary to make them strong enough to resist the stresses induced by the settlement of the earth embankment.

Rock-Fill Dams.

Rock-fill dams (fig. 7) are also used on uncertain foundations, because the loose stones tumble into place when erosions take place. They are generally given a fair width at the top, with slopes varying between 1 in 1 and 2 in 1; they have the disadvantage of not being water-tight, although they can be made practically so by placing on the upstream slope an impermeable layer of sand and clay. It is not advisable to allow the water to discharge over these dams, and like the earth dams they must be provided with sluiceways and waste gates.

Timber Dams.

Timber dams (fig. 8) are either hollow or filled; the hollow dam consists of a wooden frame covered by an apron on the upstream and on the downstream side and held in place by the weight of water. The filled dams or crib dams consist of boxes made of large pieces of timber bolted together and filled with loose stones. These dams have generally a nearly vertical downstream face and an upstream face sloping 1 to 1 or 2 to 1; they are held in place partly by their own weight and partly by the weight of the water on top of them. They can be used either on solid foundations or on medium foundations; in the latter case, the upstream and downstream toes should be protected by loose stone, in order to prevent erosion.

Masonry and Concrete Dams.

These dams are used principally when the foundation is rock or hard pan, and are generally built with a practically vertical upstream face and a downstream slope of 1 to 1.

Masonry is used chiefly in the construction of storage dams provided with sluiceways, but concrete can be used either for storage dams or spillways.

Reinforced Concrete Dams.

The characteristics of these dams (fig. 9) are that they are formed by a series of vertical buttresses upon which is placed a reinforced concrete deck, the buttresses being also connected, underneath the deck, by reinforced concrete beams or slabs. These dams can be used either on a rock foundation or on uncertain ground; in the latter case they are generally built over a reinforced concrete mattress distributing the pressure over the foundation. Their upstream face is inclined at an angle of 45° and the buttresses are practically vertical on the downstream side. In the case of a spillway, the downstream side is formed in the same manner as the upstream side, by a reinforced concrete apron of the shape required by the quantity of water which is expected to flow over the crest. These dams have the advantage of requiring much less material than the

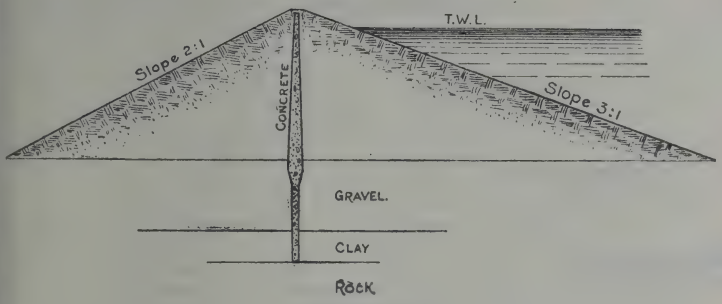

FIG. 6.—Earth Dam.

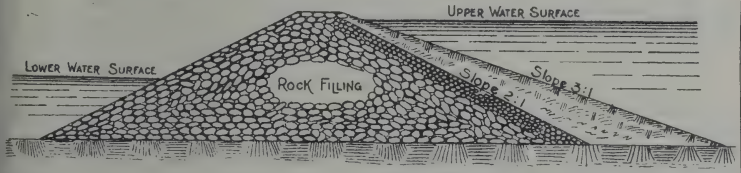

FIG. 7.—Rock-fill Dam.

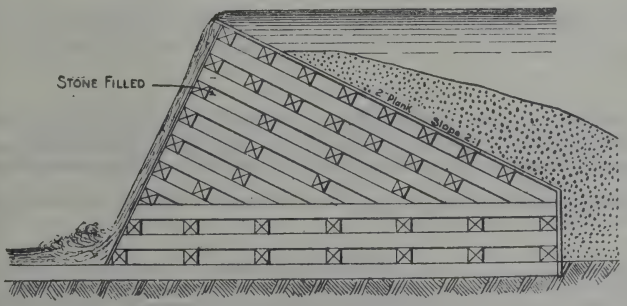

FIG. 8.—Timber Dam.

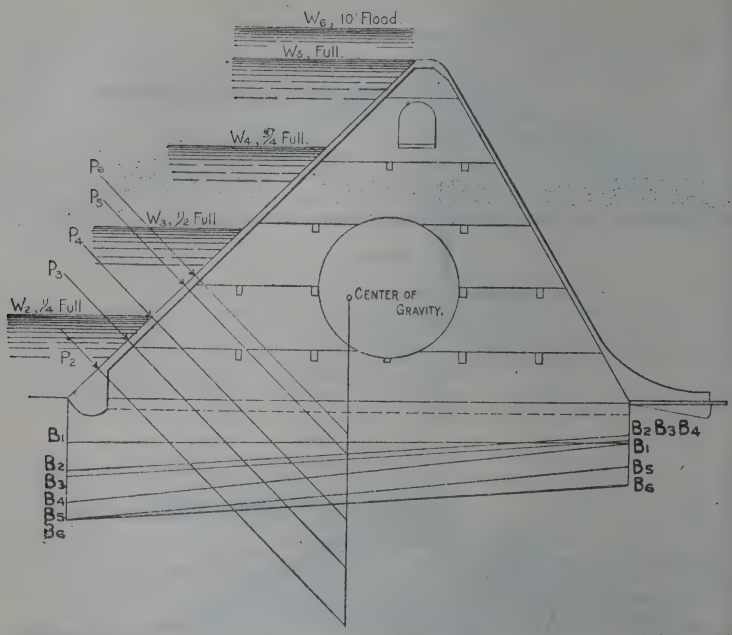

FIG. 9.—Reinforced Concrete Dam.

gravity dams, and are consequently used in places where transportation is difficult. Another advantage also is that their upstream face being inclined at 45° they resist better than the vertical face dams the ice pressures which, on account of their uncertainty, are always difficult to provide for.

Stability of Dams.

When dams are built on rock or solid foundations they can be built up from the bed of the river. If the bed is in hard pan the construction must be started below the bed of the river, and if the bed is composed of sand or gravel the dam generally rests on piles driven into the soil.

CONDITIONS OF STABILITY.

1. The weight of the dam must be sufficient to resist the water thrust tending to overturn it.
2. The dam must be so designed that there is no danger of its sliding upon its base.
3. The pressure on the downstream toe of the dam caused by the overturning moment must not exceed the resistance in compression of either the masonry or the foundations upon which it rests.
4. The resultant of all forces must be such that the upstream face of the dam is not in tension, but rather subject to a compressive stress.

Design of Dams.

Every design of dam must, of course, be tested for the foregoing different conditions, but the following rule will be found useful in arriving at a first tentative determination of the section.

Let h (fig. 10) be the greatest depth of water in the proposed reservoir at the dam. The width of the base B′C′ can be taken as equal to the height h or AB′, and the theoretical section of the dam would then be represented by the triangle B′AC′. In practice, however, it is necessary to give to the crest a certain thickness which can be taken as equal to one-tenth of the height. The portion AH above the highest water in the reservoir is generally made from 3 to 10 ft. When

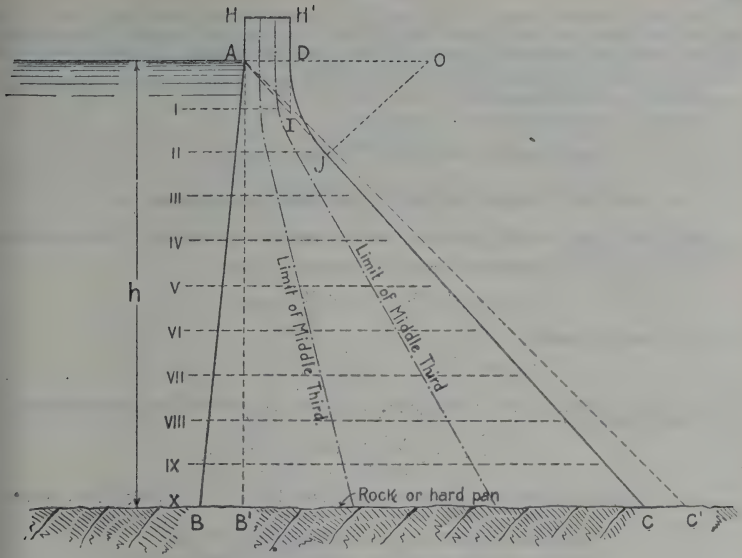

FIG. 10.—Masonry or Concrete Storage Dam.

the dam is very high it is difficult to build the upstream face vertical; it is preferable to give it a batter of 0·10 to 0·20. As it is not necessary to give to the base a greater width than the total height AB′, the point C′ is therefore brought back to C over a distance equal to BB′.

The downstream face is curved at the upper part into an arc tangent to the vertical H′I at D and to the inclined line AC at J. The section of the dam is therefore represented by the polygon BAHH′DJC.

DESIGN OF SPILLWAY DAMS.

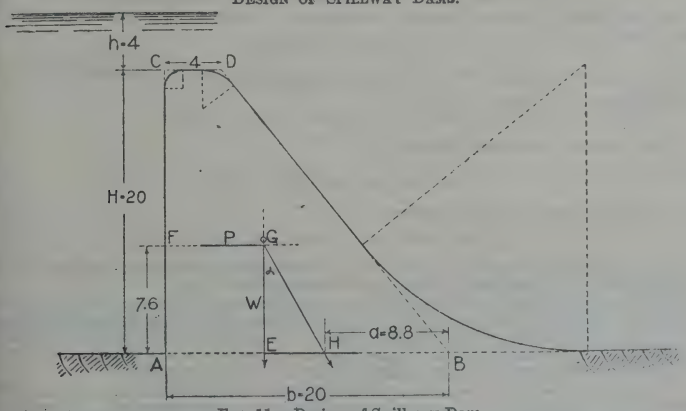

FIG. 11.—Design of Spillway Dam.

Spillway dams, or weir dams, are designed so as to allow the water to flow over their crest. The two first points to decide before beginning the design of such a dam are the elevation of the crest of the dam and the elevation of the highest possible flood.

Assuming that the elevation of the crest is 20 ft. above the bed of the river, and that the greatest flow of the river can be passed over the dam when the water level is 4 ft. above its crest, we can now proceed to design a plain concrete dam to meet these conditions, fulfilling at the same time the requirements as to stability enumerated above.

The width of the crest OD (fig. 11) can be taken as 0·2 of the height of the dam, and the width of the base b equal to the height H.

Referring to the figure we have the following:

$$A = \text{area of section of dam} = \frac{4+20}{2} \times 20 = 240 \text{ sq. ft.};$$

w = weight of 1 cub. ft. of concrete = 130 lbs.;
W = weight of section of dam 1 ft. wide = $240 \times 130 = 31{,}200$ lbs.

This force W acts vertically through the centre of gravity of the section G, whose position is determined graphically.

The water pressure P tending to overturn the dam has for value

$$P = 62{\cdot}5 \times \frac{(H+h)^2 - h^2}{2} = 62{\cdot}5 \frac{H}{2}(H+2h),$$

and in the case in question,

$$P = 62{\cdot}5 \times \frac{20}{2}(20+2\times 4) = 17{,}500 \text{ lbs.}$$

This force P acts horizontally, and is applied at a height AF above the bed of the river given by the following formula:

$$AF = \frac{H}{3} \cdot \frac{H+3h}{H+2h} = \frac{20}{3} \times \frac{20+12}{20+8} = 7{\cdot}6.$$

Taking the moments about the downstream toe of the dam B we have the following results:

$$\text{Resisting moment} = W \times EB = 31{,}300 \times 13 = 405{,}600 \text{ ft. lbs.}$$
$$\text{Overturning moment} = P \times AF = 17{,}500 \times 7{\cdot}6 = 133{,}000 \text{ ft. lbs.}$$
$$\text{Factor of safety} = \frac{\text{Resisting moment}}{\text{Overturning moment}} = \frac{405{,}600}{133{,}000} = 3{\cdot}05.$$

A factor of safety of 3 is considered sufficient to fulfil the first condition of stability.

The second condition is that there should be no danger of the dam sliding upon its base; this condition is fulfilled if we have the following inequality:

$$\text{Weight of dam} \times \text{coefficient of friction} > \text{Total water pressure.}$$

The coefficient of friction of masonry on masonry, or masonry or concrete on rock, is 0·7, so that we have

$$31{,}200 \times 0{\cdot}7 > 17{,}500.$$

The resultant R of the forces P and W can be found graphically or algebraically by the following equation:

$$R = \sqrt{W^2 + P^2} = \sqrt{31{,}200^2 + 17{,}500^2} = 35{,}770.$$

Its direction can be found by the equation

$$\tan \alpha^\circ = \frac{P}{W} = \frac{17{,}500}{31{,}200} = 0{\cdot}56;$$

and the point of application H found thus

$$EH = AF \tan \alpha^\circ = 0{\cdot}56 \times 7{\cdot}6 = 4{\cdot}26.$$

This point of application H must fall within the middle third of the base; this condition must be fulfilled whether the reservoir created by the dam is full or empty.

It is advisable to round up the dam at the upstream corner C to prevent chipping by logs or floating ice. It is also advisable to give to the downstream face a form resembling as much as possible the probable curve of the overfalling water. Corner D should therefore be rounded up and a concave curve built at B, so as to carry the water x away horizontally and without impact. The foregoing method can, of course, be used also in the case of storage dams.

When the proposed dam is over 30 or 40 ft. it is better to subdivide it into a certain number of sections and to test each block separately according to the method described; the resultant in each case must fall within the limits of the middle third. In the example given it has been assumed that there was no upward water pressure at the base; when infiltration and under pressure must be provided for, this new force is subtracted from the weight and combined with it before calculating the resisting moment.

Head Gates.

Head gates (fig. 12) are placed at the entrance of the head race, in order to permit the emptying of the canal and pipes in case of repairs, and in order to be able to stop quickly the admission of water in case of accident to the canal, flumes, pipes, or water wheels.

The head gates are, of course, built differently, according to the size of the opening they have to close.

Head gates for a canal consist of wooden or steel gates moving between concrete, masonry, or crib piers. The weight of the heavy gates is generally partly balanced by a counter weight, and they are raised and lowered by electric or hydraulic motor. The smaller gates are moved by hand with the help of a mechanical hoist.

The piers must be designed to withstand a pressure equal to the total head of water multiplied

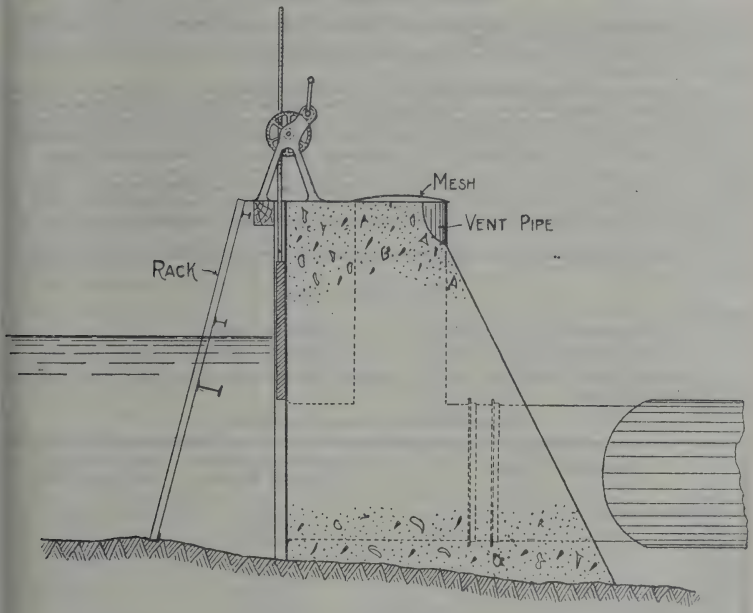

FIG. 12.—Head Gate and Rack.

by the distance between the centres of two adjoining openings. The factor of safety must be at least 3.

When pipes are used to carry the water to the turbines they are generally protected by a concrete head wall designed to resist the full hydrostatic pressure. The gates in this case are much smaller, and are operated by hand.

The force necessary to raise the gate can be calculated as follows:—The total weight of gate in water plus the total water pressure on the gate must be multiplied by a coefficient of friction which varies according to the materials used. To this weight should be added the weights represented by the mechanical losses in the transmission of power, and the grand total increased by about 13 per cent. in order to provide for the extra force necessary to start the gate.

Racks.

Racks are usually made of flat bars having sections from $\frac{5}{16}$ in. by 1 in., to $\frac{1}{2}$ in. by $3\frac{1}{2}$ ins., held together by bolts and separators. These racks may be either of large or small spacing, the former being those in which the bars are from $1\frac{1}{2}$ ins. to 4 ins. apart, and the latter where the bars are from $\frac{1}{2}$ in. to $1\frac{1}{2}$ ins. apart. The spacing is determined by the cross section of the openings of the distributor and runner buckets of the water wheels.

The racks are generally placed at an angle varying from 45° to 60° with the vertical; there should always be an operating platform at least 3 ft. wide, so placed that the attendants can work to best advantage either when cleaning or raising the racks.

The racks should be designed on the assumption that they act as a solid dam, and that all water behind may be drawn off. In such a case the racks and their supports would have to take care of the entire water pressure.

For the purpose of keeping floating *débris* from choking the gratings at the circulating water intakes at an American power station, a pipe has been installed just above water level in front of the grid. The pipe is drilled with ½-in. holes, and is supplied with water at 120 lbs. per square inch. The jets of water issuing from these holes wash away any leaves, sticks, and snow that might clog the grating.

Design of Head Races.

The cross-section area of a head race should be such that the water will rise to about three-quarters to seven-eighths of the height.

Wooden flumes are ordinarily rectangular and designed to carry a depth of water equal to about half the width.

Canal sections are determined by the class of material forming the perimeter and the head which it is found economical to use. The efficiency of a cross-section of a canal is greater with the value of the wetted perimeter minimum, so that a semi-circular section is the most advantageous cross-section that can be used in a channel where resistance to flow is alone considered. When the canal is lined with masonry or concrete walls it is more advantageous to make the face nearly perpendicular, and to place the batter of the wall at the back. When the canal is cut in stone or shales which will not be eroded by the flow of the water, a slope of 90° to 40° may be used. In canals dug through earth the slopes may be from 1 in 1½ to 1 in 1½. With artificial banks of earth and gravels the slope must frequently be made as low as 1 in 2.

According to Bazin, the relation between the bottom and the mean velocities in channels is the following:

$$V_b = V - 10{\cdot}87\sqrt{rs},$$

where,

V_b = bottom velocity in ft. per sec.; r = hydraulic radius;

V = mean velocity in ft. per sec.; s = hydraulic gradient or slope of channel.

The following table, calculated from the foregoing formula, gives the safe bottom velocities for different materials:

TABLE OF SAFE BOTTOM VELOCITIES.

Material of Channel.	Safe Bottom Velocity (V_b) in Ft. per Sec.	Mean Velocity (V) in Ft. per Sec.
Soft brown earth	0·249	0·328
Soft loam	0·499	0·656
Sand	1·000	1·312
Gravel	1·998	2·625
Pebbles	2·999	3·938
Broken stone, flint	4·003	5·570
Conglomerate, soft slate	4·988	6·564
Stratified rock	6·006	8·204
Hard rock	10·009	13·127

Flow of Water in Pipes, Flumes, and Channels.

The principal formula of flow in pipes, flumes and channels, is based on the formula for velocity of flow known as *Chezy's* formula, which is as follows:

$$V = C\sqrt{rs},$$

where,

V = velocity in ft. per sec.;
C = a coefficient of discharge;
A = area of cross section considered, in sq. ft.;
p = wetted perimeter in ft.;

r = hydraulic radius = $\dfrac{\text{area of section}}{\text{wetted perimeter}} = \dfrac{A}{p}$;

s = hydraulic gradient or slope of channel = $\dfrac{\text{difference of level}}{\text{distance}} = \dfrac{h}{l}$.

h = fall in ft. between points considered;
l = distance in ft. between points considered.

The formula for the flow is $Q = AC\sqrt{rs}$,
where

Q = discharge in cub. ft. per sec.

The value of the coefficient C can be determined either by Kutter's formula or Bazin's formula.

Kutter's formula is as follows :

$$C = \frac{41{\cdot}65 + \frac{0{\cdot}00281}{s} + \frac{1{\cdot}811}{n}}{1 + \left(41{\cdot}65 + \frac{0{\cdot}00281}{s}\right)\frac{n}{\sqrt{r}}},$$

where,
n = the coefficient of roughness.

Robt. E. Horton gives in 'Engineering News,' of February 24, 1916, the following category of coefficients of roughness for use in Kutter's formula :

TABLE OF 'n' FOR KUTTER'S FORMULA.

(*R. E. Horton.*)

Surface.	Perfect.	Good.	Fair.	Bad.
Uncoated cast iron pipe	0·012	0·013	0·014	0·015
Coated cast iron pipe	0·011	0·012*	0·013*	—
Commercial wrought iron pipe, black	0·012	0·013	0·014	0·015
Commercial wrought iron pipe, galvanised	0·013	0·014	0·015	0·017
Smooth brass and glass pipe	0·009	0·010	0·011	0·013
Smooth lockbar and welded 'OD' pipe	0·010	0·011*	0·013*	
Riveted and spiral steel pipe	0·013	0·015*	0·017*	—
Vitrified sewer pipe	0·010 0·011	0·013*	0·015	0·017
Glazed brickwork	0·011	0·012	0·013*	0·015
Brick in cement mortar; brick sewers	0·012	0·013	0·015*	0·017
Neat cement surfaces	0·010	0·011	0·012	0·013
Cement mortar surfaces	0·011	0·012	0·013*	0·015
Concrete pipe	0·012	0·013	0·015	0·016
Wood-stave pipe	0·010	0·011	0·012	0·013
Plank flumes :				
Planed	0·010	0·012	0·013	0·014
Unplaned	0·011	0·013	0·014	0·015
With battens	0·012	0·015	0·016	—
Concrete lined channels	0·012	0·014*	0·016*	0·018
Cement-rubble surface	0·017	0·020	0·025	0·030
Dry-rubble surface	0·025	0·030	0·033	0·035
Dressed-ashlar surface	0·013	0·014	0·015	0·017
Semi-circular metal flumes, smooth	0·011	0·012	0·013	0·015
Semi-circular metal flumes, corrugated	0·0225	0·025	0·0275	0·030
Canals and ditches :				
Earth, straight and uniform	0·017	0·020	0·0225*	0·025
Rock cuts, smooth and uniform	0·025	0·030	0·033*	0·035
Rock cuts, jagged and irregular	0·035	0·040	0·045	—
Winding sluggish canals	0·0225	0·025*	0·0275	0·030
Dredged earth channels	0·025	0·0275*	0·030	0·033
Canals with rough stony beds, weeds on earth banks	0·025	0·030	0·035*	0·040
Earth bottom, rubble sides	0·028	0·030*	0·033*	0·035
Natural stream channels :				
(1) Clean, straight bank, full stage, no rifts or deep pools	0·025	0·0275	0·030	0·033
(2) Same as (1), but some weeds and stones	0·030	0·033	0·035	0·040
(3) Winding, some pools and shoals, clean	0·035	0·040	0·045	0·050
(4) Same as (3), lower stages, more ineffective slope and sections	0·040	0·045	0·050	0·055
(5) Same as (3), some weeds and stones	0·033	0·035	0·040	0·045
(6) Same as (4), stony sections	0·045	0·050	0·055	0·060
(7) Sluggish river reaches, rather weedy or with very deep pools	0·050	0·060	0·070	0·080
(8) Very weedy reaches	0·075	0·100	0·125	0·150

* Values commonly used in designing.

TABLE OF COEFFICIENTS C FOR VARIOUS HYDRAULIC RADII (r), ACCORDING TO KUTTER'S FORMULA.

(For the same *actual* r (such as 3·28 ft., or 1 metre) the coefficient for metric units is the coefficient for British units $\times \frac{100}{181}$, or $\frac{5}{9}$, nearly.)

Slope S = ·000025 per Unit of Length, = 1 in 40,000, = ·132 Foot per Mile.

Hydraulic Radius, r, in Feet.	Coefficients n of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040
	Coefficients C.											
·1	65	57	50	44	40	33	28	23	17	14	12	10
·2	87	75	67	59	53	45	38	31	24	19	16	14
·4	111	97	87	78	70	59	51	42	32	26	22	19
·6	127	112	100	90	81	69	60	49	38	31	26	22
·8	138	122	109	99	90	77	66	55	43	35	30	25
1	148	131	118	106	97	83	72	60	47	38	32	28
1·5	166	148	133	121	111	95	83	69	55	45	38	33
2	179	160	144	131	121	104	91	77	61	50	43	37
3	197	177	160	147	135	117	103	88	70	59	50	44
4	209	188	172	158	146	127	113	96	78	65	56	49
6	226	206	188	174	161	142	126	108	88	74	64	57
8	238	216	199	184	171	151	135	117	96	82	71	63
10	246	225	207	192	179	159	142	124	102	87	76	68
12	253	231	214	198	186	165	149	129	107	92	81	72
16	263	242	223	208	195	174	157	138	115	100	88	79
20	271	249	231	215	202	181	164	144	121	106	94	84
30	283	261	243	228	215	193	176	157	133	117	104	95
50	297	274	257	241	228	207	190	170	147	130	117	107
75	306	284	267	251	238	217	200	180	157	140	127	117
100	312	290	273	257	244	223	207	187	163	147	134	124

Slope S = ·00005 per Unit of Length, = 1 in 20,000, = ·264 Foot per Mile.

Hydraulic Radius, r, in Feet.	Coefficients n of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·04
	Coefficients C.											
·1	78	67	59	52	47	39	33	26	20	16	13	1
·2	100	87	77	68	62	51	44	35	26	21	18	1
·4	124	109	97	88	79	66	57	46	35	28	24	2
·6	139	122	109	98	90	76	65	53	41	33	28	2
·8	150	133	119	107	98	83	71	59	46	37	31	2
1	158	140	126	114	104	89	77	64	49	40	34	2
1·5	173	154	139	126	116	99	87	72	57	47	40	3
2	184	164	148	135	124	107	94	79	62	51	44	3
3	198	178	161	148	136	118	104	88	71	59	50	4
4	207	187	170	156	145	126	111	95	77	64	56	4
6	220	199	182	168	156	137	122	105	85	72	63	5
8	228	206	189	175	163	144	129	111	91	78	68	6
10	234	212	195	181	169	149	134	116	96	82	72	6
12	238	217	200	185	173	153	138	120	99	86	75	6
16	245	223	206	191	180	160	144	126	106	91	81	7
20	250	228	211	196	184	165	149	131	110	96	85	7
30	257	236	219	204	192	172	157	139	118	103	92	8
50	266	245	228	213	201	181	165	148	127	112	101	9
75	272	250	233	218	207	187	171	153	133	119	108	9
100	275	254	237	222	210	190	175	158	137	123	112	10

Slope S = ·00001 per Unit of Length, = 1 in 10,000, = ·528 Foot per Mile.

Hydraulic Radius, r, in Feet.	Coefficients n of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040
	Coefficients C.											
·1	90	78	68	60	54	44	37	30	22	17	14	12
·2	112	98	86	76	69	57	48	39	29	23	19	16
·4	136	119	106	95	86	72	62	50	38	31	25	22
·6	149	131	118	105	96	81	70	57	44	35	30	25
·8	158	140	126	114	103	88	76	63	48	39	33	28
1	166	147	132	120	109	93	81	67	52	42	35	31
1·5	178	159	144	130	120	103	89	75	59	48	41	35
2	187	168	151	138	127	109	96	81	64	53	45	39
3	198	178	162	149	137	119	104	89	71	59	51	45
4	206	186	169	155	143	125	111	94	76	64	55	49
6	215	195	178	164	152	134	119	102	84	71	61	54
8	221	201	184	170	158	139	124	107	88	75	66	59
10	226	205	188	174	162	143	128	111	92	78	69	62
15	233	212	195	181	169	150	135	118	98	85	75	68
20	237	216	200	185	173	154	139	122	102	89	79	71
30	243	222	206	191	179	160	145	128	108	95	84	77
50	249	227	211	197	185	166	151	134	114	100	91	83
100	255	234	218	204	191	172	158	140	121	108	98	91

Slope S = ·0002 per Unit of Length, = 1 in 5,000, = 1·056 Feet per Mile.

Hydraulic Radius, r, in Feet.	Coefficients n of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·0
	Coefficients C.											
·1	99	85	74	65	59	48	41	32	24	18	15	1
·2	121	105	93	83	74	61	52	42	31	25	21	1
·4	143	125	112	100	91	76	65	53	40	32	27	2
·6	155	138	122	111	100	85	73	60	46	37	31	2
·8	164	145	131	118	107	91	79	65	50	41	34	2
1	170	151	136	123	113	96	83	69	54	44	37	3
1·5	181	162	146	133	122	105	91	77	60	49	42	3
2	188	170	154	140	129	111	97	82	64	54	45	3
3	200	179	163	149	137	119	105	89	72	59	51	4
4	205	185	168	155	143	125	111	94	76	63	55	4
6	213	193	176	162	150	132	117	100	82	69	60	5
8	218	198	181	167	155	137	122	105	87	73	64	5
10	222	201	185	170	158	140	125	108	89	76	67	6
15	228	207	190	176	164	145	131	113	95	82	72	6
20	231	210	194	180	168	149	134	117	98	85	76	6
30	235	215	198	184	172	154	139	122	103	89	80	7
50	240	220	203	189	177	158	143	126	108	94	85	7
100	245	224	208	194	182	163	148	131	113	99	90	8

TABLE OF COEFFICIENTS C FOR VARIOUS HYDRAULIC RADII (*continued*).

Slope S = ·0004 per Unit of Length, = 1 in 2,500, = 2·112 Feet per Mile.

Hydraulic Radius, *r*, in Feet.	Coefficients *n* of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040
	Coefficients C.											
·1	104	89	78	69	62	50	43	34	25	19	16	13
·2	126	110	97	87	78	65	54	44	32	25	21	18
·3	138	120	107	96	87	73	62	50	37	30	24	21
·4	148	129	115	104	94	79	68	55	42	33	27	23
·6	157	140	126	113	103	87	75	62	47	38	31	27
·8	166	148	133	121	110	93	81	67	51	42	35	30
1	172	154	138	125	115	98	85	70	55	45	37	32
1·5	188	164	148	135	124	106	93	78	61	50	42	37
2	190	170	154	141	130	112	98	83	65	54	45	40
3	199	179	162	149	138	119	105	89	71	59	51	45
4	204	184	168	154	142	124	110	94	76	63	55	48
6	211	191	175	161	149	130	116	99	81	69	60	53
10	219	199	183	168	157	138	123	107	88	75	66	59
20	227	207	190	176	164	146	131	115	96	83	73	66
50	235	215	198	184	173	154	139	123	104	91	82	75
100	239	219	203	189	177	158	143	127	108	96	87	80

Slope S = ·0010 per Unit of Length, = 1 in 1,000, = 5·28 Feet per Mile.

Hydraulic Radius, *r*, in Feet.	Coefficients *n* of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040
	Coefficients C.											
·1	110	94	83	73	65	54	45	36	27	21	17	14
·2	129	113	99	89	81	66	57	45	34	27	22	18
·3	141	124	109	98	89	74	63	51	39	30	25	21
·4	150	131	117	105	96	80	69	56	43	34	28	24
·6	161	142	127	115	104	88	76	63	48	39	32	27
·8	169	150	134	122	111	94	82	68	52	42	35	30
1	175	155	139	127	116	99	86	71	56	45	38	33
1·5	184	165	149	136	124	108	93	78	62	50	43	37
2	191	171	155	142	130	112	98	83	66	54	46	40
3	199	179	163	149	138	119	105	89	71	59	51	45
4	204	184	168	154	142	124	110	93	75	63	54	48
6	211	190	174	160	149	130	116	99	81	68	59	52
10	218	197	181	167	155	136	122	105	87	74	65	58
20	225	205	188	175	163	144	129	113	94	81	72	65
50	232	212	196	182	170	151	137	120	101	89	79	72
100	236	216	200	186	174	155	141	124	105	94	85	77

Slope S = ·01 per Unit of Length, = 1 in 100 = 52·8 Feet per Mile.

Hydraulic Radius, *r*, in Feet.	Coefficients *n* of Roughness.											
	·009	·010	·011	·012	·013	·015	·017	·020	·025	·030	·035	·040
	Coefficients C.											
·1	110	95	83	74	66	54	46	36	27	21	17	14
·2	130	114	100	90	81	67	57	46	34	27	22	19
·3	143	125	111	100	90	76	64	52	39	31	25	22
·4	151	133	119	107	98	82	70	57	44	35	29	24
·6	162	143	129	116	106	90	77	64	49	39	33	28
·8	170	151	135	123	112	95	82	68	53	43	35	31
1	175	156	141	128	117	99	87	72	56	45	38	33
1·5	185	165	149	136	125	107	94	79	62	51	43	37
2	191	171	155	142	130	112	98	83	66	54	46	40
3	199	179	163	149	138	119	105	89	71	59	51	45
4	204	184	168	154	142	124	110	94	76	63	55	48
6	211	191	175	161	149	130	116	99	81	69	60	53
10	218	197	181	167	155	136	122	105	87	74	65	58
20	225	204	187	173	161	143	128	112	93	80	71	64
50	231	210	194	181	168	150	135	119	100	87	78	71
100	235	214	197	184	172	153	139	122	104	91	82	75

To find the coefficient C, having the slope S, the hydraulic radius, *r*, and the degree *n* of roughness. Turn to the division of the Table corresponding to the given slope, S. In the first column find the given hydraulic radius, *r*. In the same line with this *r*, and under the given *n*, is the proper value of C.

To find the actual, or the greatest permissible, degree n of roughness of channel, having the slope S, the hydraulic radius *r*, and either C, or the actual or required velocity, *v*.

If the velocity is given, and not C, first find $C = \frac{\text{velocity}}{\sqrt{\text{slope} \times \text{hydraulic radius}}}$. Turn to the division of the Table corresponding to the given S, and in the first column find the given *r*. In the same line find the value given, or just obtained, for C; over which will be found the required *n*.

To find the actual or necessary hydraulic radius, *r*, having the slope S, the degree *n* of roughness, and the actual or required velocity, *v*. Assume an hydraulic radius; and from the division of the Table corresponding to the given S take out the value of C corresponding to the given *n* and the assumed *r*. Then say

$$v = \text{C so found} \times \sqrt{\text{assumed hydraulic radius} \times \text{slope}}.$$

If this *v* is the same as the given velocity or near enough to it, take the assumed *r* as the proper one. Otherwise, repeat the whole process, assuming a new *r*, *greater* than the former one if *v* is *less* than the given velocity, and *vice versa*.

To find the actual or necessary slope, S, having the dimensions of the wetted portion of the channel, the degree n of roughness, and the actual or required velocity.

$$\text{Find the hydraulic radius, } r = \frac{\text{area of wet cross-section}}{\text{length of wet perimeter.}}$$

Assume one of the four slopes of the Tables to be the proper one. From the corresponding division of the Table take out the value of C corresponding to the given r and n.

For slopes steeper than ·01 per unit of length, = 1 in 100 = 52·8 ft. per mile, C remains practically the same as at that slope. But the *velocity* (being = C × $\sqrt{\text{hydraulic radius} \times \textit{slope}}$) of course continues to increase as the slope becomes steeper.

Bazin's formula for the determination of C is as follows:

$$C = \frac{157{\cdot}6}{1 + \frac{y}{\sqrt{r}}},$$

where,

y = a coefficient of roughness, whose value Bazin gives as follows for different classes of channels.

Class I. y=0·109 for smoothed cement, or planed wood.
„ II. y=0·290 for planks, bricks, and cut stone.
„ III. y=0·833 for rubble masonry.
„ IV. y=1·54 for earth channels of very regular surface or reveted with stone.
„ V. y=2·35 for ordinary earth channels.
„ VI. y=3·17 for exceptionally rough earth channels (bed covered with boulders) or weed-grown sides.

See also ' A New Hydraulic Formula,' by F. W. Woods, C.I.E., *The Engineer*, June 17, 1927.

Design of Pipes.

Pressure in Pipes.

The interior pressure in a pipe due to the presence of water, and tending to burst this pipe is larger transversely than longitudinally.

The pressure in pounds per sq. in. p, determined by a head of water H expressed in feet, is:

$$p = \text{pressure in lbs. per sq. in.} = \text{head in ft.} \times 0{\cdot}44,$$

and the diametral pressure P, tending to burst the pipe, is represented by the equation

$$P = p \times \frac{d}{2},$$

where,

d = diameter of pipe in ins.

The longitudinal tension P in the pipe is equal to

$$P' = p \times \frac{d}{4}.$$

This explains why steel riveted pipes have generally a single row of rivets at the circumferential joints and two rows of rivets along the longitudinal joints.

Design of Steel Pipes.

The thickness of metal t (expressed in ins.) required to carry a certain pressure can be determined by the following formula:

$$t = \frac{(p + p')d}{2fe} + c,$$

where,

t = thickness of steel shell in ins.;
d = inside diameter of pipe in ins.;
p = pressure of water in lbs. per sq. in.;
p' = allowance for water hammer in lbs. per sq. in.;
f = allowable tensile stress of steel in lbs. per sq. in.;
e = efficiency of riveted joint
c = thickness to be added to plate for corrosion.

The permissible unit tensile stress with ordinary open-hearth steel is assumed at 16,000 lbs. The efficiency of the joint may be taken at 55 per cent. for single riveted pipe, and at 70 per cent. for double riveted pipe. The thickness to be added to compensate for the weakening of the pipe due to corrosion is about $\frac{1}{16}$ in. In large pipes under small pressure, the thickness of metal computed with the above assumptions must still be increased to give the pipe the necessary stiffness.

Design of Reinforced Concrete Pipes.

Reinforced concrete pipes are designed under the assumption that the steel takes care of all longitudinal or transversal stresses in the pipe whilst the concrete acts as a waterproof shell. It is evident that, in this case, the steel can be reduced to the minimum thickness required.

The permissible stress per sq. in. of metal can also be taken at 16,000 lbs. per sq. in.

The area of the circles forming the transversal reinforcement can be determined as follows:

Let p = total internal pressure in lbs. per sq. in.;
d = diameter of pipe in ins.;
A_s = area of steel reinforcement per lineal foot, expressed in sq. ins.;
f = permissible stress in steel in lbs. per sq. in.;

then assuming that the concrete is to take no part of the tensile stresses, we have

$$A_s = \frac{p\,d \times 12}{2 \times f}.$$

The longitudinal reinforcement is taken with an area per lineal foot of circumference equal to half the area per lineal foot of pipe as determined above.

Spacing of Pipe Supports.

Steel and concrete pipes are not always built resting on the ground, and very often they have to be carried on concrete or masonry piers resting preferably on rock, or having a bearing surface in proportion to the load carried and to the resistance of the foundations.

The spacing of the piers is determined by considering the pipe as a circular beam resting freely on supports and carrying a uniformly distributed load consisting of the weight of the pipe plus the weight of the water. This load determines a longitudinal tension in the lower side of the pipe, and this stress added to the longitudinal tension of the pressure of water caused by the static head, plus the extra head due to water hammer, should not be allowed to exceed f, the safe tensile strength of the material.

The stress, f_b, due to bending is

$$f_b = \frac{3}{2} \cdot \frac{WL^2}{S},$$

where

L = distance between supports in ft.;
W = total load in lbs. per ft. of length;
S = section modulus of the pipe.

The longitudinal fibre stress, f_t, due to water pressure is

$$f_t = \frac{pd}{4t},$$

where,

p = pressure in lbs. per sq. in.;
d = nominal inside diameter of pipe in ins.;
t = thickness of pipe in ins.

This formula applies to steel pipe, but can be utilised in the calculation of a reinforced concrete pipe, by reducing the total area of steel reinforcement per foot length to a continuous pipe of uniform thickness. This method, however, would not take into account the resistance in compression of the concrete on the upper side of the pipe.

Adding together the stress due to bending f_b and the stress due to water pressure f_t we have a total stress,

$$f = \frac{3}{2} \cdot \frac{WL^2}{S} + \frac{pd}{4t};$$

from this we can get the distance between the supports

$$L = \sqrt{\frac{2}{3} \cdot \frac{S}{W} \left(f - \frac{pd}{4t} \right)}.$$

The permissible value of f, in a steel riveted pipe, can be taken from 8,000 to 11,000 lbs. per sq. in. according to the efficiency of the joint; in a reinforced concrete pipe 16,000 lbs. per sq. in. could safely be assumed.

Design of Wood Stave Pipes.

In Canada and in the United States extensive use is made of pipes composed of wooden staves held in place by steel wires wound continuously around the pipe, or by separate steel bands or rods connected by malleable iron shoes.

The steel is designed to take care of all the stresses and the wood forms only the shell. These pipes are very cheap, and have a greater carrying capacity than either steel or reinforced concrete pipes; they have been used for heads as high as 200 ft.

The following information has been compiled from the writings of Robert E. Horton and of Andrew Swickard.

The staves are made of California redwood, Douglas fir, and Canadian red pine. Practice varies somewhat as to the thickness of staves to be used under given pressure for a pipe of given diameter. The following considerations should govern the thickness of staves to be adopted in a given case.

1. The thicker the staves the greater stability of pipe against deformation by its own weight, and accordingly the staves must be thicker for large than for small diameter of pipes.

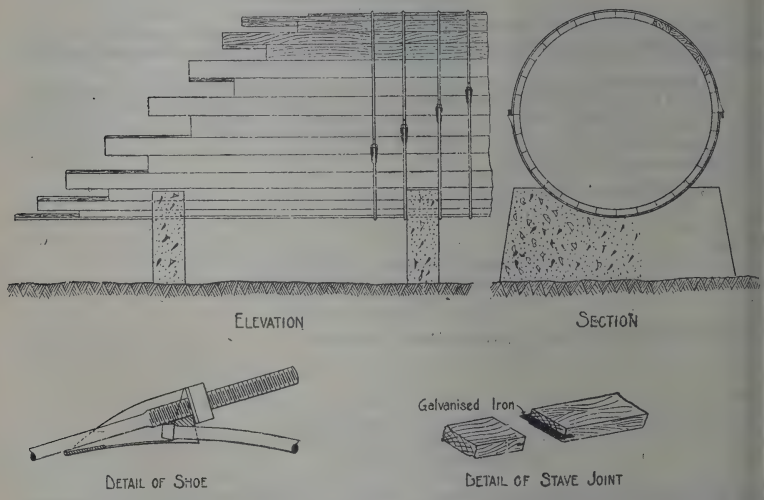

Fig. 13.—Details of Wood Stave Pipe.

2. The staves should be thick enough to prevent material loss by percolation, and accordingly should be thicker for heavy than for lighter pressures.

3. The staves should not be so thick as to prevent their being thoroughly saturated. This and considerations of economy require the use of as thin a stave as is compatible with the first two conditions named.

The following rule serves as a general guide for determining the approximate thickness of staves to be used in any case; the actual thickness of staves may be made equal to the nearest $\frac{1}{8}$ in. or $\frac{1}{4}$ in. greater thickness than shown by the rule:

$$t = 1 \text{ in.} + \frac{\text{Head in ft.} + \text{Diameter of pipe in ins.}}{100}.$$

The minimum radius of bends which may be made with continuous pipe increases with the diameter of the pipe and with the thickness of the staves. An approximate rule is

$$\text{Minimum radius, in ft.} = 4 \text{ to } 5 \times (d+4t^2)$$

where,

d = inside diameter of pipe, in ins.;

t = thickness of staves, in ins.

Wood stave pipes should be supported through an arc extending about 55° each side of the vertical axis, in order to prevent deformation of the pipe by its weight and that of the water it contains.

Stave pipes (fig. 13) are generally carried on wooden or on concrete cradles, concrete being preferable for large pipes. Joseph P. Frizell says that wooden cradles are best made of 6 in. × 8 in. or 8 in. × 8 in. timbers, spiked or drift-bolted together, of a length somewhat greater than the diameter of the pipe, and at distance apart about equal to their length. Robert E. Horton is of the opinion that the spacing of the supports is about the same for wood stave and steel pipes.

The abutting end joints of the staves are connected together by iron plates inserted in a slot sawn in for that purpose. This iron tongue should be about $\frac{3}{32}$ in. wider than twice the depth of the slot and about $\frac{1}{8}$ in. longer than the slot, allowing a projection of $\frac{1}{16}$ in. into the adjoining staves.

Creosoted wood-stave pipes put in place twenty-eight years ago were said, at the recent convention of the American Wood Preservers' Association, to be still in perfect condition. The best method of treatment for the staves was described as being the empty-cell process with 50 lbs. initial air pressure, following the creosote pressure period with several minutes' reheating at about 25° F. in excess of any previous temperature, then a vacuum of not less than 20 ins. maintained for from 30 mins. to 1 hour. By this process a satisfactory creosote penetration is obtained, and the staves come out thoroughly clean, and so dry as scarcely to soil the hand.

Area of Bands and their Spacing.

The two principal considerations governing the size and spacing of bands are as follows:—

(1) The area of section of the band per ft. length of pipe must be such as to safely withstand the water pressure plus the stress in the band due to swelling of wood when saturated.

(2) The size and spacing of bands must be such as not to produce crushing of the wood.

Taking into account both the stress due to water pressure and that due to swelling of the staves, the following formula has been derived for determining the necessary area of cross-section of metal in the bands per in. length of pipe.

$$a = \frac{pd + 200t}{2f},$$

where,

a = required area of band section per in. length of pipe;

p = pressure in lbs. per sq. in.;

d = inside diameter of pipe in ins.;

t = thickness of stave in ins.;

f = permissible unit stress in lbs. per sq. in., taken generally as 16,000 lbs.

In order to avoid dangerous crushing of the wood, the bearing pressure between bands and staves should not exceed about 800 lbs. per sq. in. of contact between the band and stave. For round bands the width of contact between the band and stave should be about equal to the radius of the band.

From these data the following formula is obtained for determining the maximum permissible spacing S in ins. between bands of given size under a given pressure.

$$S = \frac{400 \times \text{diameter of round bands in ins.}}{\text{Pressure in lbs. per sq. in.}}.$$

Shoes or Band Couplings.

The band couplings should be made of malleable iron. The weight of these shoes will vary with the size of the band and the diameter of the pipe, but the following table gives average weights for various sizes of bands, which are accurate enough for estimating purposes:

Diameter of Band, ins.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Weight of Shoe, lbs.	0·35	0·40	0·65	1·00	1·75	2·75	4·00	6·00

Length of Bands.

Before the length of a band can be determined it is necessary to know how much lap-over of the rod there is in the shoe. This differs in shoes for different sizes of pipe, increasing with the increase in size of rod. However, this quantity will average about as follows for various sizes of bands :

Diameter of Band, ins.	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Lap-over of Band in Shoe, ins.	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{5}{8}$

The end of the rods should be upset and threaded over a length of not less than $4\frac{1}{2}$ ins. for $\frac{3}{8}$ in., 5 ins. for $\frac{7}{16}$ in., and 6 ins. for other sizes. There are three types of head in use—button, square, and tee heads. The tee head has the advantage of keeping both ends of the rod closer to the staves, and shortens the space over which the rod is raised from the staves ; it also permits the use of a shorter shoe. The length of rods under the head should be such that, after the pipe is finally tightened, at least $1\frac{1}{2}$ ins. of thread will remain ahead of the nut. The length of the rod, excluding the head, is determined in the following manner, where the rod is in one part and 6 ins. of thread is being used :

$$\text{Total length} = (d+2t+r)\pi+k+4\tfrac{1}{2} \text{ ins.}$$

where,

d = nominal inside diameter of pipe in ins. ;
t = thickness of staves in ins. ;
r = diameter of rod in ins. ;
k = lap of rod in shoe in ins.

If the rod is in two parts, the following formula applies :

$$\text{Total length} = (d+2t+r)\pi+2k+9 \text{ ins.}$$

From 68 tests on wood-stave pipe lines with diameters from 4 to 162 ins., and velocities ranging from 1 ft. to 8 ft. per sec., it was found that with diameters from 4 to 24 ins. the average value of n in Kutter's formula (p. 1319) was 0·0109, and w th diameters from 31 to 162 ins. the average value of n was 0·0124.

(*Mallett ; Flow of Water in Pipes, Vol. CCVIII, April* 1921), *Proceedings Inst. C.E.*)

Discharge of Water through Orifices.

The theoretical velocity, v, with which water flows from an orifice in the side of a vessel at a depth h from surface is the same as that of a body falling freely by gravity from height, h, viz.

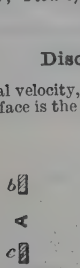

FIG. 14.

FIG. 15.

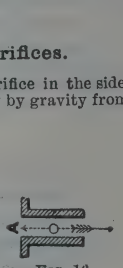
FIG. 16.

$v = \sqrt{2gh}$, but practically the converging currents produce a contraction of the jet, which assumes the form of the vena contracta, d, e, f, g, fig. 15.

h = height from surface of water to centre of orifice, in feet. v = velocity of issuing water

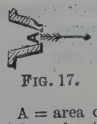
FIG. 17.

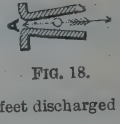
FIG. 18.

in feet per second. A = area of orifice, in feet. Q = cubic feet discharged per second. g = coefficient of terrestrial acceleration.

$$v = m\sqrt{2gh}. \qquad Q = mA\sqrt{2gh}. \qquad 2g = 64{\cdot}4 \qquad \sqrt{2g} = 8 \text{ practically}$$

m.	
·625.	Where the orifice is a thin plate, bc (fig. 14), with thickness less than $\frac{1}{2}$ smallest dimension of orifice.
·97.	Orifice shape of vena contracta, d, e, f, g (fig. 15) ; A is measured at f, g.
·82	Orifice with an adjutage (fig. 16) ; O = $2\frac{1}{2}$ to 3 times least dimension at A.

m.	
·95.	Sides converging at angle of 13½° (fig. 17). m depends on diameter and angle of convergence.
1·46.	Sides diverging at angle of 5° 6′ (fig. 18). C = 9 times least dimension at A, which is of form of vena contracta. (Seldom used.)
·548.	Where 2 sluices in thin plates are so close as to interfere with each other; m being reduced from ·625.
·62.	For sluices of moderate size in lock gates, etc.
·82.	For narrow-bridge openings.
·92.	For very large sluices and bridge openings.

The conclusions drawn from investigations made by Messrs. *Dempster Smith* and *J. W. Walker* * are:—

(1) That above a certain critical head (about 2 ft. of water) and a critical orifice diameter (2½ ins.), the experimental values of the coefficient of contraction for different types of orifice agree closely with the values deduced from hydrodynamical theory.

(2) That the coefficient of contraction varies with the head and orifice diameter in a manner closely represented by the formula

$$C = 1 - \frac{a}{e^x} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a is a constant and x a function of the head and orifice diameter.

(3) That in the case of the coefficient of contraction for sharp-edged orifices

$$a = 0{\cdot}39;$$
$$x = \frac{0{\cdot}15}{a^3\, h^{0{\cdot}125}},$$

where h is the head causing the flow.

(4) That formula (1) may be extended to include the effect of a variation in the pipe or reservoir area. The formula for C then becomes

$$C = \frac{1}{1 + \left\{\frac{a}{e^x - a}\right\}(1 - a^2} \quad . \quad . \quad . \quad . \quad (2)$$

where x and a have the same significance as before and a = ratio $\frac{\text{orifice area}}{\text{pipe area}}$.

To raise a River a certain Height by a Weir.

Q = discharge of river in cubic feet per second; h_1 = height by which river is to be raised in feet; h_2 = depth of top of weir below original surface of water necessary to raise surface by height h_1; h_a = head corresponding to velocity of approach; l = length of weir in feet; m = coefficient of contraction = ·628; $2g = 64{\cdot}4$.

$$h_2 = \frac{Q}{ml\sqrt{2g(h_1 + h_a)}} - \tfrac{2}{3}\frac{(h_1 + h_a)^{\frac{3}{2}} - h_a^{\frac{3}{2}}}{\sqrt{h_1 + h_a}}.$$

If h_a is not taken into account, then

$$h_2 = \frac{Q}{ml\sqrt{2gh_1}} - \tfrac{2}{3}h_1.$$

* *Proceedings of the Institution of Mechanical Engineers*, 1923.

SECTION XXV

PART IV

WATER-PRESSURE ENGINES—PELTON WHEELS—TURBINES

Water-pressure Engines.

SINGLE-ACTING ENGINES

consist of single cylinder and piston. The water is admitted under the piston, raises it, is allowed to escape, and the piston falls by its own weight. Average velocity of piston should not exceed 140 feet per minute. Stroke should be as long as possible, generally from 6 to 10 feet.

Water-pressure engines are also made rotatory with single or double acting cylinders, and single and double acting rams are extensively used for working cranes, dock gates, etc., the stroke of the ram being multiplied by gearing or chain tackle. The pressure generally used is 700 lbs. per square inch.

POWER OF WATER-PRESSURE ENGINES.

$P = 62{\cdot}42Qh \times {\cdot}66$ to ${\cdot}8$ ft. lbs. per sec.; $\quad$ H.P. $= Qh \times {\cdot}07491$ to ${\cdot}09080$,

where,

Q = cub. ft. of water per sec., h = height of fall, in ft.

Diameter of supply-pipe = diameter of cylinder $\times$ ·41 for single cylinder engines, = diameter of cylinder $\times$ ·68 for double cylinder engines.

EXAMPLE.—A single-acting pressure engine has a pressure cylinder 50 ins. in diameter, a head of water of 132 ft., a stroke of 10 ft., and is worked 4 to 7 strokes per min.

$$Q = \frac{25^2 \times 3{\cdot}14}{144} \times 10 \times \frac{4}{60} = 9{\cdot}1 \text{ cub. ft. per sec.}$$

H.P. $= 9{\cdot}1 \times 127 \times {\cdot}09080 = 105$ horse-power, with 4 strokes per min., or 184 with 7 strokes The actual work was about 168 horse-power.

PELTON WHEELS

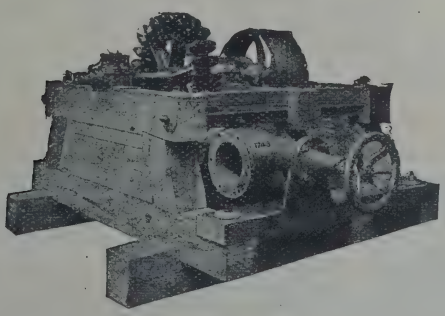

FIG. 1.

In these wheels, fig. 1, the water striking the buckets in the middle is deflected to both sides equally, and in such a way that the discharge from one bucket clears the one following. The

construction of the buckets is shown in fig. 2. An improvement of the Pelton semi-cylindrical bucket is the Doble bucket, fig. 3, each half of which is ellipsoidal in form, and has a part of the outer lip cut away, so as to avoid hitting the jet when moving under it.

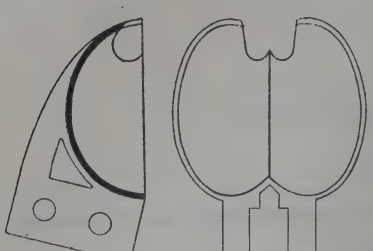

FIG. 2.—Pelton Bucket.

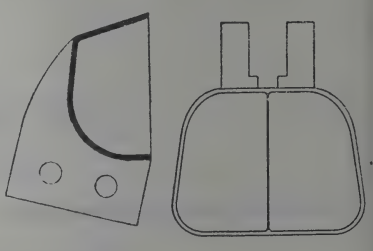

FIG. 3.—Doble Bucket.

THE ENGLISH ELECTRIC BUCKET ATTACHMENT FOR IMPULSE WATER TURBINES.

(The English Electric Co., Ltd.)

Fig. 4 shows the method of attachment in detail. For each bucket it consists of one tapered forged-steel bolt passing through a bush of chrome nickel steel, the external surface of which is cylindrical, whilst the interior is reamered to a taper. The bush is split longitudinally along its whole length. The holes through the disc and the lugs of the bucket are, therefore, cylindrical, so that spare buckets can be completely finished in the shops, and are interchangeable without difficulty; no reamering is necessary on site, and prolonged stoppage of the plant is obviated.

The tapered bolt is provided with nuts which, on being tightened, cause the bush to expand and tighten against the wall of the cylindrical hole; the force due to this taper is considerably greater than that exerted by the jet. At the same time, the lugs of the bucket are tightened by the nuts with absolute security against the two faces of the disc. These nuts are secured by locking washers, which are bent over both the boss of the lug and the face of the nut.

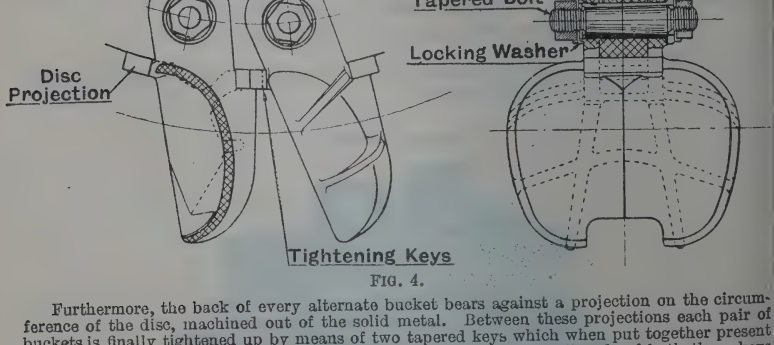

FIG. 4.

Furthermore, the back of every alternate bucket bears against a projection on the circumference of the disc, machined out of the solid metal. Between these projections each pair of buckets is finally tightened up by means of two tapered keys which when put together present parallel faces to the bucket surfaces. After final assembly the small ends of both these keys are bent to prevent any movement. By this means, the buckets are tightened under great pressure against the disc projections and the circle of buckets resists the blows of the jet as rigidly as a solid mass.

Not only is the attachment remarkably strong, but the one-bolt fastening works under better conditions than the two-bolt attachment generally used. It is extremely difficult to drill a series of pairs of holes in the cast-steel disc and buckets with the necessary accuracy to render the buckets interchangeable, and to ensure that the stresses are shared equally by each bolt. There is always the danger of one bolt bearing nothing whilst the other takes the whole of the

strain. With one bolt and one key this danger is overcome; the bolt bears the shearing, and the key the compressive stresses, thus the forces are transmitted to the disc in the best possible manner.

Proportion of Parts of Pelton Wheels.

(1.)

The area of the jet should not exceed 0·1 the projected area of the bucket, or the diameter of the jet should not exceed 0·3 the width of the bucket. The ratio of the wheel diameter to jet diameter should not be lower than 9, 12 being a common value, so that the diameter of the wheel in feet should about equal the diameter of the jet in inches.

The size of the jet depends on the amount of power desired, per unit, under the given head; the peripheral speed of the wheel varies between 0·43 and 0·47 of the theoretical jet velocity. Two and three jets are sometimes used upon one wheel, but a single jet is preferable. Sometimes two wheels are used to drive a single generator mounted between them.

The efficiency of the Pelton wheel has been found to exceed 86 per cent. Since this wheel operates by utilising the kinetic energy of the water, it is best adapted to a small discharge under a high head: its range of usefulness varies from 50 foot heads to 3,000 and even 5,000 foot heads.

A recent Gunther Pelton wheel, installed in India for electric power and lighting, develops 100 b.h.p. under 600 ft. head, and the oil-pressure governor works on to the jet deflector, the spear rod regulator being hand-controlled.

The majority of impulse wheels are now equipped with steel buckets, as the average of steel castings has been greatly improved, so that the present steel bucket will outwear the bronze bucket.

(2.)

(Contributed by W. Gunther & Sons, Oldham.)

The diameter of a Pelton wheel is fixed by the speed required. Theoretically and practically the most efficient wheel velocity is one-half the jet velocity.

$$\text{Velocity of jet in ft.-sec.} = 0{\cdot}95 \text{ to } 0{\cdot}97 \sqrt{2gH}.$$

where,

$$\text{Velocity of wheel in ft.-sec.} = V = 0{\cdot}47 \sqrt{2gH},$$

H = head in feet.

When the speed required is known or can be fixed, the diameter, D, of the wheel is given by—

where,

$$D = \frac{V\ 60}{n\ \pi}$$

V = velocity of wheel in ft.-sec.; n = revolutions per min.

This is the diameter of an imaginary circle having as a tangent the line of action of the centre of the jet.

The diameter of jet required may be found as follows:—

$$\text{Diam. of jet in inches} = \sqrt{\frac{Q \times 0{\cdot}401}{\sqrt{H}}};$$

where,

Q = quantity of water in cu. ft. per *minute*; H = head in *feet*.

The ratio of the diameter of the jet to the diameter of the wheel should not normally be below 1 : 12.

The proportions of the wheel buckets are given in terms of the jet diameter, and may generally be taken as follows:—

width of bucket, 3·2 to 3·5 × jet diam.; height of bucket, 2·7 × jet diam.; depth of bucket, 1·2 × jet diam.

When two jets are used on one wheel the size of the buckets will be materially less than if one jet were used, and this often means a considerable saving. Various combinations of jets and wheels are sometimes used, e.g. two wheels keyed to one shaft, each with either one or more jets, and so on, but not more than four jets, at intervals of 90 degs., should play on one wheel, or interference takes place. In actual practice it is rarely found advisable to use more than two jets per wheel.

Pelton Wheel Regulators.

General.

The section of the nozzle is either square or circular, but more generally circular, with a needle, fig. 5, to secure a more uniform velocity in all parts of the jet; this needle can be moved back or forward by the governor, varying the area of the opening and regulating the amount of water discharged. For very high heads, where the interruption or partial suppression of flow by such an arrangement might involve danger to the pipe-line, deflecting nozzles of various kinds are employed. The movement of a regulating nozzle of this description is accomplished with comparatively little expenditure of energy, and thus the control of Pelton wheels is simple unless affected

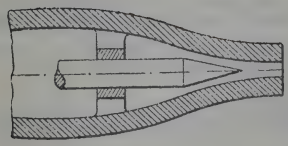

Fig. 5.

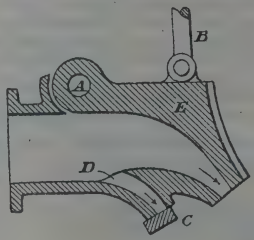

Fig. 6.

by irregularities. A deflecting nozzle, as used by Messrs. Theodor Bell & Co., is shown in fig. 6. This nozzle is rectangular in section, the upper side being formed by the piece E pivoted at A. This is moved by the governor attachment B, so as to increase or diminish the area of the nozzle at the mouth. A secondary nozzle D is closed by a cap C, which also rotates about the pivot A, and is moved through the same angle as E. As the two nozzles have the same width, a partial closure of the larger nozzle is compensated by an opening of the smaller, so that the spouting area is always a constant, and the flow through the pipe is steady, while the wheel receives that fraction of it which is required to maintain the speed constant at all loads.

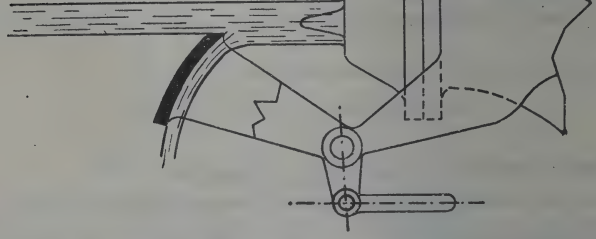

Fig. 7.—Needle Nozzle with Deflector.

The foregoing device, however, is wasteful of water even with the best of attention. Since the water hammer caused in the pipe by a sudden opening of the nozzle is less dangerous than the hammer due to the sudden interruption of the flow, a device, fig. 7, has been perfected, consisting of an automatic jet deflector and an ordinary nozzle needle, which causes the governor to act on the deflector only in case of closing, the needle being afterwards slowly closed by means of a dash-pot mechanism, whilst the deflector becomes tangential to the reduced jet. When the governor moves to increase the discharge of the nozzle, it controls simultaneously and rapidly the deflector and the needle.

Combined Spear and Deflector Regulator Controlled by Shaft Governor.

(Gilbert Gilkes & Co. Ltd., Sole Makers and Patentees.)

For high-falls (100 ft. and upwards), Pelton wheels or other impulse turbines may be controlled by an arrangement similar to that shown in fig. 8, as made by *Gilbert Gilkes & Co. Ltd.*, of Kendal.

The arrangement consists of a pendulum mounted upon the turbine shaft and coupled direct to the deflector shaft, the design of the deflector being such as to impose the least resistance to the passage of the water through the jet.

Movement to the spear is given by a piston moving in a hydraulic or oil-pressure cylinder fixed to the end of the branch pipe.

The position of the spear is dictated by a poppet valve controlled by levers and links connected to the deflector shaft, and so arranged that if the load be thrown off the deflector

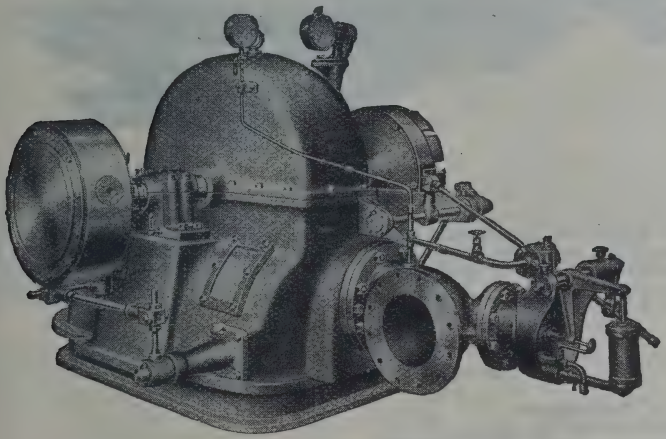

Fig. 8.

is brought instantaneously into the jet, the spear slowly following and the deflector finally taking up a position just clear of the jet. If the load is thrown on, the spear is drawn rapidly back.

When economy of water on reduced loads is immaterial, as in the case where the supply is from a stream without storage, the automatic spear-following combination is dispensed with, a hand-regulated spear being substituted.

The pendulum being mounted directly on to the shaft ensures a perfectly steady drive, saves space, and is immune from all risks due to breaking of chains, belts, etc.

As the pendulum is connected directly to the deflector without the intermission of servo-motors, etc., extreme rapidity of action is obtained, the movements being instantaneous and dead time eliminated, the results showing a momentary variation of less than 1 per cent. with full load thrown off.

The 'Seewer' Impulse Wheel Regulator

(The English Electric Co., Ltd.)

The design of this governing device for impulse turbines is based on the principle of the rapid destruction of the energy of the jet. This is obtained by placing blades in the nozzle at a slight angle to the normal direction of the water stream, so that the jet issuing from the nozzle no longer remains cylindrical, but is dispersed in a hollow conical form, thus diverting the energy of the jet from the buckets.

The blades, normally withdrawn into the hollow spearhead, fig. 9, are carried by a movable ring which is connected to the speed governor by a rod passing through the spindle of the spear. When a sudden drop in load occurs and the speed rises, the blades are pushed forward into the water stream, giving it a whirling movement which makes it lose its useful energy. Fig. 9 shows the blades advanced into the position for dispersing the jet.

Fig. 10 is a diagrammatic arrangement of this governing device for a single-jet impulse turbine.

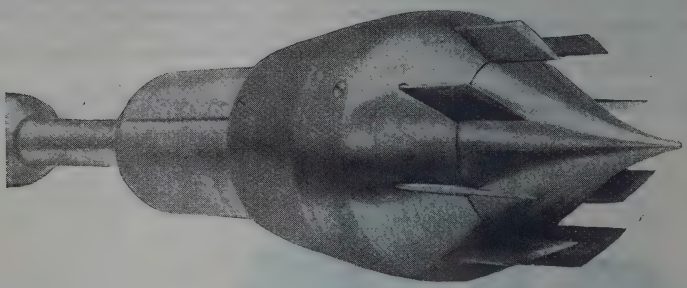

FIG. 9.

On a sudden drop in load with its attendant rise in speed, the governor pendulum rises; point 1 being a momentary fulcrum, point 2 must fall, depressing the plunger in the distributing valve and thus allowing the oil to flow from the pump to the right-hand piston chamber of the guide-blade servomotor, and at the same time opening the exhaust from the left-hand chamber. The resultant oil pressure in the right-hand chamber, in conjunction with a spring, pushes the piston to the left and the guide blades are moved forward into the water stream by the action

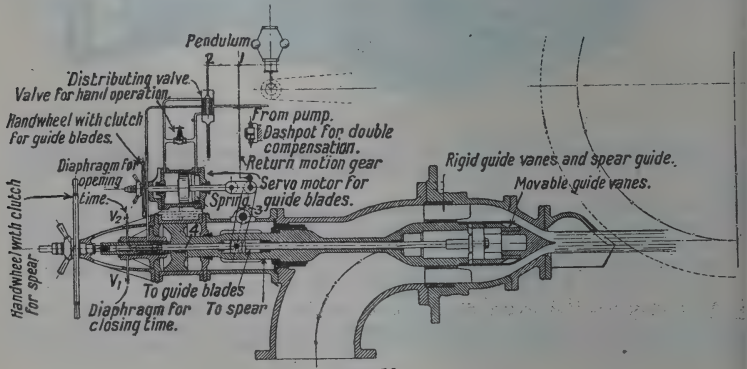

FIG. 10.

of the lever 3 on the spindle attached to the movable ring. At the same instant the rear end of the spindle 4 acts as a distributing rod and allows oil under pressure to pass into the left-hand chamber of the spear servomotor and connects the right-hand chamber to the exhaust; the spear is thereupon closed. The closing movement is controlled by the diaphragm V_1, which prevents the oil from flowing too quickly to the exhaust and thus obviates any undue pressure rise in the pipe-line.

For an increase in load the reverse operation takes place, and in this case the diaphragm V_2 controls the speed with which the spear is withdrawn and the normal operation of the jet is resumed.

In the arrangement, the strokes of the primary and secondary mechanisms—*i.e.* the blades and the spear—being always identical, no sort of cam device is required, which avoids troubles in the adjustment of governing apparatus. The spear shaft, together with the rear part of the guide blade rod, forms the distributing apparatus of the spear servomotor, thus simplifying the whole apparatus; and, being rigidly controlled by the servomotors, any danger of its getting out of order is obviated.

As the blades have no important force to sustain, they are light in design, and this fact, in conjunction with their small stroke, enables them to destroy the energy of the jet very quickly—in fact, almost instantaneously. This advantage is of the utmost importance as regards the speed variation .and stabilises the running of the set considerably.

Another advantage of the governing device is the small amount of energy required, as the only effort to be overcome is that due to friction; this friction is due chiefly to the reaction of the whirling water, but is only a small percentage of the force exerted by it. Owing to this fact, the governing device requires a governor of small dimensions only, taking up less space than usual in the power house.

In case of breakdown of the governor, the governing mechanism acts as a security device, the dispersing blades being automatically pushed forward by the spring of the servomotor, thus spreading the jet and avoiding accidents.

The sensitiveness of the governing device is such that good regulation is obtained without adding to the moment of inertia found in a generator of normal design; this is a consequence of considerable significance, as it is frequently found that with ordinary methods of jet control either an abnormal design of generator is called for or else a separate flywheel has to be provided.

As the results of tests taken on a 3,300 b.h.p. turbine at the Kinlochleven Power Station, running under 900 ft. pressure, it was noticed that when the full load was suddenly thrown off, the maximum speed variation was only 3·45 per cent. for a permanent speed variation adjusted at 0. When operating at fractions of full load, the speed variations on removing the load were still smaller, these qualities conducing to remarkably steady running. The pressure rise was also very low, amounting in the tests to a maximum of only 2½ per cent. for the combined movement of both the dispersing blades and the spear. For the blades alone the corresponding rise in pressure would, of course .be still less, and in fact for all practicable purposes negligible.

Notes on Regulators.

The best makes of hydraulic regulators for medium and high falls will govern within the following limits, the per cent. being that of the mean speed:

For a sudden variation of load of 25 per cent.	4 per cent.
„ „ „ 50 „	6 „
From no load to full load	10 „

The relative speed with which gates may be closed by hydraulic and mechanical regulators is greater for the hydraulic, the ratio being generally about 5 to 1 in favour of the hydraulic.

TURBINES.*

Classification of Turbines.

Action, Impulse, Tangential, or Pressureless Turbines.

In these turbines the passages are never completely filled with water and the flow of water is always under atmospheric pressure. During flow through the wheel the absolute velocity of the water is reduced as the water gives up its kinetic energy.

Reaction, or Pressure Turbines.

In these turbines the wheel passages are completely filled with water under a pressure which varies throughout the flow. During this flow through the runner, both the pressure and the absolute velocity of the water are reduced as the water gives up the energy to the wheel.

---

* The following books have been consulted and quoted: *Hydraulic Turbines*, by R. L. Daugherty; *Elements of Hydraulics*, by S. E. Slocum; *Water-Power Engineering*, by Daniel W. Mead; *Water-Power Plants and the Type Characteristic of Turbines*, by W. Basshuus; and *La technique de la houille blanche*, by Etienne Pacoret.

Direction of the Flow of Water.

In the radial outward flow, or centrifugal turbines (Fourneyron type, fig. 11), the guide-vanes ring is contiguous to the runner, and the water passes through the runner whilst moving away from the axis of rotation but in the plane perpendicular to it.

In the parallel, or axial flow turbines (Jonval type, fig. 12), the guide-vanes ring is superposed to the runner, and the water passes through the runner buckets whilst moving along a circular cylindrical surface having for axis the shaft of the turbine.

In the radial inward flow, or centripetal turbines (Francis type, fig. 13), the guide-vanes ring is contiguous to the runner, and the water moves towards the axis of rotation in a plane perpendicular to it.

In the mixed (radial, inward, and axial) flow turbines (American type, fig. 14) the water enters the wheel radially, in the direction of the axis, and, during its flow through the runner buckets, turns and discharges axially.

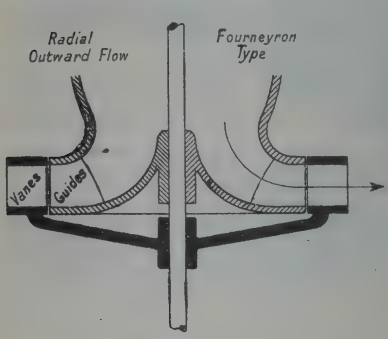

Fig. 11.

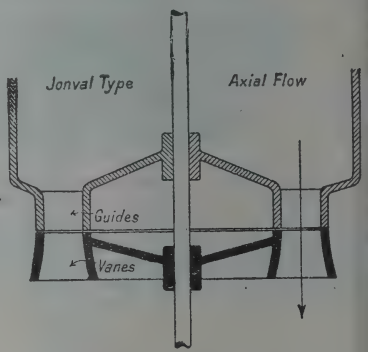

Fig. 12.

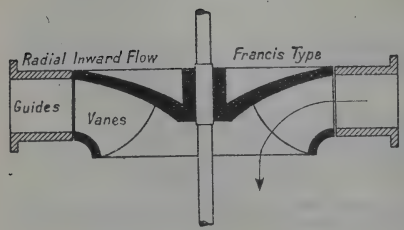

Fig. 13.

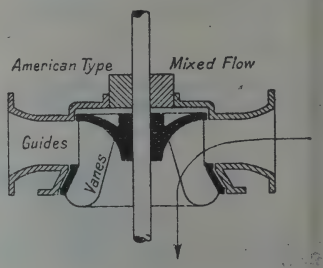

Fig. 14.

Position of the Shaft.

Turbines have either (*a*) an horizontal shaft, or (*b*) a vertical shaft; the latter are further classified as right-hand or left-hand turbines according to the direction of their rotation. If in looking down upon the wheel from above the rotation appears clockwise it is called a right-hand turbine. The reverse of this is a left-hand turbine.

Turbine builders have now reduced their production to three types, viz. the tangential or Pelton wheel, the centripetal flow or Francis turbine, and the helico-centripetal or American turbine, each of which satisfies special conditions.

Types of Turbines.

The Francis and the American turbines (both of which are of the reaction type) have superseded all the others, because they are cheaper to build, smaller, more easily regulated, and have a higher speed than the turbines of the Fourneyron or Jonval type.

The Francis Turbine.

Some of the main reasons for the pre-eminence of the Francis turbine over all other types of low and medium head turbines lie in its adaptability, since it can be designed either to pass large or small volumes of water for a given diameter of wheel, and can be constructed for low or fairly high heads, and in the relative ease with which it may be governed owing to the short stroke of its regulating apparatus, thus rendering it particularly suited for electrical work. Francis turbines may be used with either horizontal or vertical shafts, and with one, two, three, four, or even more wheels upon one shaft. The regulating device consists of a number of pivoted guide blades spaced round the circumference of the runner, and simultaneously moved to open or to close by means of a floating ring to which they are attached and which is connected to the governor by a lever and rocking shaft.

As a basis of comparison between Francis turbines, the specific speed of the runner is used. This term 'specific speed,' which was evolved by Prof. Camerer, is the speed of a runner which, operating under a fall of 1 ft. (or 1 metre), produces 1 h.p. The formula for specific speed, n_s, is given by—

$$n_s = \frac{n}{H} \sqrt{\frac{N}{\sqrt{H}}}, \text{ or, } n_s = \frac{n\sqrt{N}}{H^{\frac{5}{4}}}$$

where,

n = revs. per minute; H = head in ft. (or metres); N = horse-power.

H may be in ft. or metres, and the result gives respectively the specific speed in English or metric denominations.

The speed classification, according to Camerer, is as follows:

n_s (metric) 50–120 : slow speed runner; 120–250 : normal speed runner; 250–400 : high speed runner.

n_s = over 400 is known as an 'express' runner.

Recent progress has resulted in the construction of runners having still higher specific speeds, but these are mainly of interest in the case of very large powers under low heads, and also are only in the early stages of development. Slow-speed runners are always narrow wheels, and are largely used in spiral Francis turbines; high-speed runners have wide entrance and discharge areas.

Runners of Francis turbines are mostly made in series, geometrically identical for the same specific speed, all the dimensions varying in proportion to the diameter of the wheel.

All possible arrangements of Francis turbines may be considered under two heads—viz. 'Open-flume' and 'Cased' turbines.

Open-flume Francis Turbines.

On relatively low falls, up to about 30 ft., in dealing with large quantities of water, the Francis turbine is frequently made without casing and placed in an open flume or pit, the turbine shaft being carried through the end or retaining wall of the head water chamber. The runner is usually of a high specific speed type. This arrangement proves to be a very convenient one for direct coupling to an electric generator. Either a single runner, or two or more, may be carried on the same shaft. Fig. 15 shows a section through a twin turbine of this type, as made by Messrs. W Gunther & Sons, Oldham, for direct coupling to an electric generator. On smaller plants the bearing farthest from the driving side is usually submerged, but in the plant shown this bearing is placed in a water-tight casing accessible from above the head water level, so that the bearing may at all times be examined.

Cased Francis Turbines.

Circumstances do not always permit of low-fall Francis turbines being placed in an open flume—*e.g.* when they are to be installed in existing buildings, or when the lay of the ground is more suited to a pipe conduit. Such turbines are then enclosed in steel or cast-iron casings, cylindrical or spiral. In fig. 15 a 500 h.p. twin turbine of Messrs. Gunther is shown, in which

GUNTHER & SONS' TURBINES.

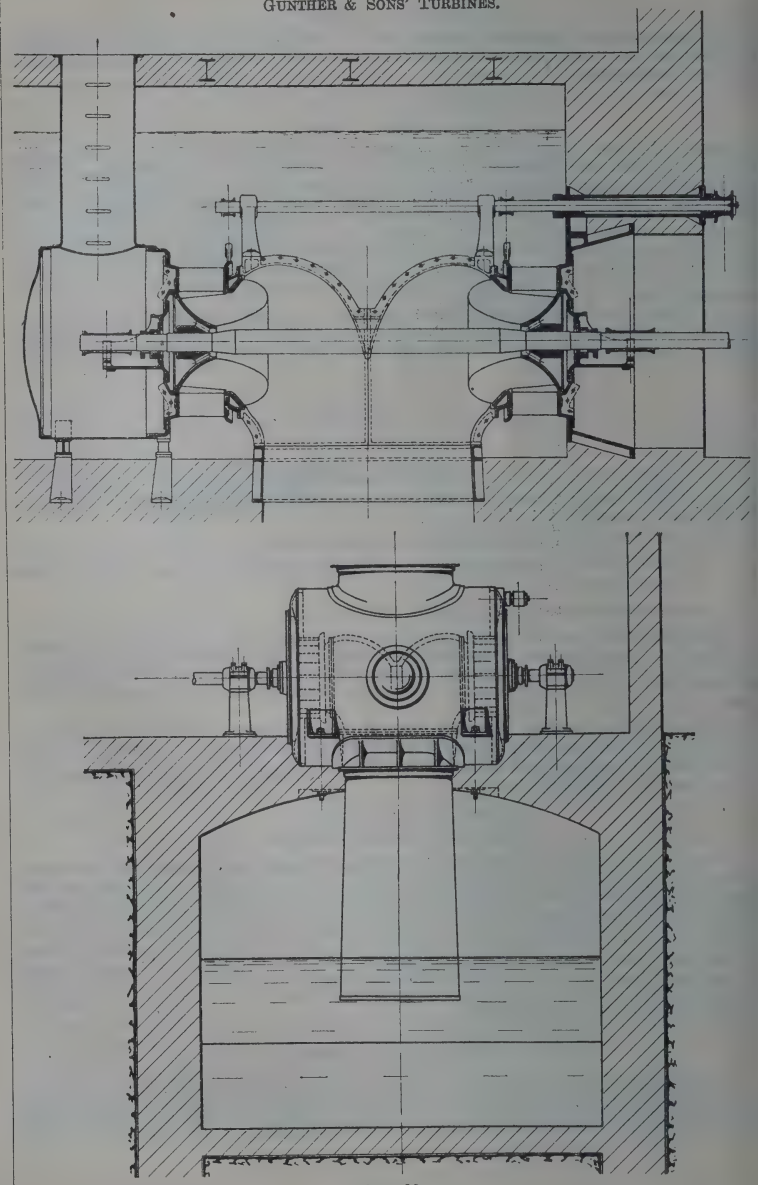

FIG. 15.

the water discharged from the two runners passes into a suction chamber formed by a double bend, and is discharged centrally into the suction tube, the whole being enclosed in a steel casing. The ring regulation of the guide ports for this arrangement of turbine may be inside or outside the casing, the more modern but more costly way being to have the regulating gear outside, and thus out of contact with the water.

One of the most valuable modern developments of the Francis turbine has been in the solution of the problem of dealing with medium heads, i.e. between about 50 ft. to 200 ft. For this range the high-speed runner would have an inconveniently high number of revolutions per minute, and a Pelton wheel may be unsuitable for several reasons—the speed may be too slow, or in order to deal with the quantity of water the Pelton wheel may become very large and heavy, or requiring perhaps two wheels on one shaft, with two or more nozzles to each. For such cases a slow specific speed Francis runner with a spiral casing of cast iron or steel may be used to advantage. In a spiral casing much higher velocities of the water may be taken, thus reducing the size and cost of the installation. The regulating arrangements are placed outside the spiral casing, and are easily accessible. A spiral Francis turbine (fig. 15, p. 1380), made by Messrs. W. Gunther & Sons, of Oldham, for driving a textile mill by means of a rope drive, has a head of 62 ft., with an output of 500 b.h.p. Regulation is effected by an oil-pressure governor.

The range of usefulness of the spiral Francis turbine naturally overlaps that of the Pelton wheel in many cases, spiral turbines having been used up to 800 ft. head or more, and the choice of a Pelton or a spiral Francis turbine is not always a rigid one.

American Turbines.

The American turbine, or mixed flow turbine, fig. 14 (p. 1378), is a modification of the Francis turbine, resulting from a demand for higher speed and power under low heads. Higher speed is obtained by reducing the diameter of the runner, greater power by increasing the capacity of the runner, making the buckets deeper and reducing the number of vanes. Since this decreased the discharge area, the vanes were curved so as to discharge axially; combined together these alterations have produced the high-speed high-capacity mixed-flow runner of to-day.

The best peripheral wheel speed for a reaction turbine varies between 0·57 to 0·87 of the theoretical spouting velocity of the water under the head considered. The efficiency of the modern reaction turbines is high, ranging between 80 and 85 per cent. under average conditions, and going up to 90 and 92 per cent. under the most favourable conditions.

(1) Crown Plate.
(2) Curb Plate.
(3) Shifting Ring.
(4) Speed Gate.
(5) Gate Bushing.
(6) Fulcrum Bolt.
(7) Link.
(8) Link Bushing.
(9) Gate Pin.
(10) Shifting Ring Pin.
(11) Hub.
(12) Rim.
(13) Bucket Vane.
(14) Main Shaft Key.
(15) Keeper Ring.
(16) Lignum - Vitæ Block.
(17) Block Holder.
(18) Adjusting Plate.
(19) Bearing Casing.
(20) Casing Head.
(21) Main Shaft.
(22) Regulating Shaft.
(23) Lever or Bell Crank.
(24) Bearing.
(25) Connecting Rod.
(26) Connecting Rod Pin.
(27) Cover Plate.
(28) Base Ring.

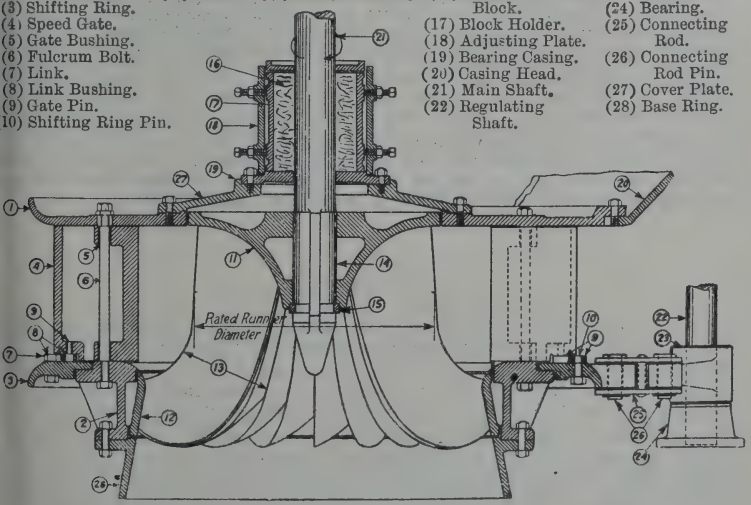

FIG. 16.—American Turbine Nomenclature.

British Turbines.

The Little Giant Double Turbine.

(*S Howes, London.*)

The form of the wheel of this turbine is shown by fig. 17, and general views of vertical forms of complete turbines by figs. 18 and 19.

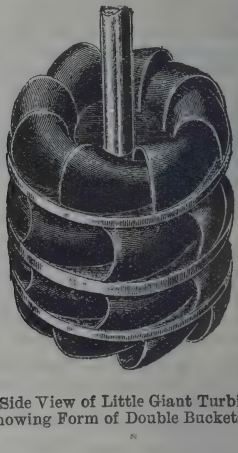

Fig. 17.—Side View of Little Giant Turbine Wheel, showing Form of Double Buckets.

The Little Giant is a double turbine having two tiers of buckets, or, strictly speaking, two turbines keyed to the same shaft, one above the other, and both running in the same case, the upper tier discharging at the top, and the lower one under the bottom of the case. The shaft is supported at the bottom end, and revolves upon an adjustable lignum-vitæ step in the bottom bridge-tree. The case is made of iron in the form of a scroll. This scroll, for larger sizes, is made of boiler-plate, which is planed parallel on the sides, and is held firmly between the cast-iron top and bottom plates by bolts. The case is supported by the bottom bridge-tree, which is bolted firmly to it. The bridge-tree is bolted firmly to the bottom of wheel-pit, upon which it rests. The gate box is made of cast iron and bolted to the case. The gate is also made of cast iron, and the surface of it, as also the ways or seat upon which it slides, are planed, thus forming a perfectly watertight joint. The pressure of water always holds the gate to its place, and the joint remains tight as the gate wears. The gates for the larger sizes of turbines, particularly if to be used under high heads, are mounted upon friction rollers.

The Division Plate.

Figs. 18 and 19 each show an iron plate passing horizontally through the turbine case, and dividing it into two compartments corresponding to the two tiers of buckets, one set being above this plate, discharging at the top of the case, the other below the plate and discharging at the bottom; in fig. 18 the plate is shown as shut down, and in fig. 19 the plate is raised. Referring to fig. 19, the gate is shown raised clear up, or at 'full gate,' admitting the water to both tiers of buckets with the full pressure due to the head, giving the full power of both parts, or of the whole turbine. If but one-half of the power of the turbine were required, the gate could be dropped or closed down to the division plate, thus shutting the water off from the upper tier, but maintaining the full pressure on the lower buckets, which would give one-half the full power with half the quantity of water, thus obtaining as high a percentage of power at half-gate as at full-gate, which could not be done if there was only one set of buckets. If no division plates were used, the full pressure of water due to the head would be on the turbine only when the gate was full open, but when used

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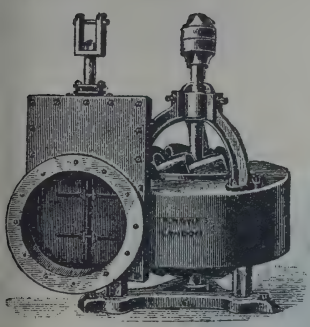


FIG. 18.—Vertical Little Giant Turbine, for joining to Iron Pipe.

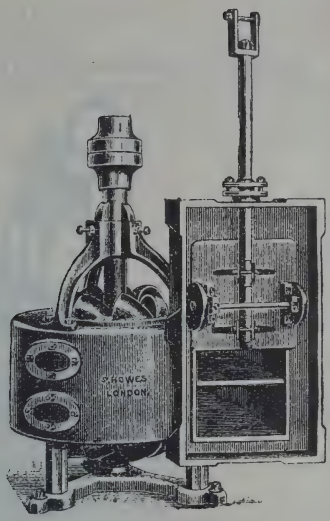


FIG. 19.—Vertical Little Giant Turbine, for joining to Wooden Pipe.

at half-gate the water, after passing through the gate-opening, would pass to both tiers of buckets but with less pressure; consequently the turbine would lose from 20 to 25 per cent. of the power in the water used.

DIMENSIONS OF VERTICAL LITTLE GIANT DOUBLE TURBINES.

Diameter of Turbine.	Diameter of Turbine Shaft.	Distance from Centre of Shaft to Centre of Gate Shaft.	Distance from Floor of Turbine Pit to Centre of Coupling on Turbine Shaft.	Distance from Floor of Pit to top of Turbine Buckets.	Space the Turbine occupies in Turbine Pit.	Size of Gate Frame for Wooden Spout.	Inside Diameter of Round Flange Gate Box for Iron Pipe.	Net Weight of Turbine.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Lbs.
4	—	—	—	$8\frac{3}{4}$	—	—	—	—
6	$1\frac{7}{16}$	$7\frac{1}{2}$	$22\frac{1}{2}$	$12\frac{1}{4}$	$17\frac{1}{2} \times 17\frac{1}{2}$	$13\frac{1}{2} \times 9$	8	265
8	$1\frac{5}{8}$	$9\frac{3}{4}$	$26\frac{1}{2}$	15	$20 \times 18\frac{1}{2}$	$16\frac{1}{2} \times 10$	10	380
10	$1\frac{11}{16}$	$8\frac{7}{8}$	$29\frac{1}{2}$	$16\frac{3}{4}$	$22 \times 21\frac{1}{2}$	$17\frac{1}{2} \times 11\frac{1}{2}$	12	485
12	$1\frac{15}{16}$	$9\frac{5}{8}$	$33\frac{1}{2}$	$18\frac{3}{4}$	$25 \times 25\frac{1}{2}$	$20 \times 13\frac{1}{2}$	14	655
14	$2\frac{3}{16}$	$12\frac{1}{2}$	39	$22\frac{3}{4}$	$29 \times 28\frac{1}{2}$	$24\frac{1}{2} \times 15\frac{1}{2}$	18	760
16	$2\frac{7}{16}$	$13\frac{1}{2}$	$42\frac{1}{2}$	$25\frac{1}{2}$	$35 \times 33\frac{1}{2}$	$27 \times 16\frac{1}{2}$	20	1,140
18	$2\frac{15}{16}$	$15\frac{1}{2}$	$48\frac{1}{2}$	30	$42\frac{1}{2} \times 38$	32×20	22	1,820
18*	$2\frac{15}{16}$	$15\frac{1}{2}$	$48\frac{1}{2}$	30	$42\frac{1}{2} \times 38$	32×20	22	1,820
21	$3\frac{1}{8}$	18	$56\frac{1}{2}$	$32\frac{1}{4}$	$45 \times 42\frac{1}{2}$	$36\frac{1}{2} \times 22\frac{1}{2}$	24	2,190
21*	$3\frac{1}{8}$	18	$56\frac{1}{2}$	$32\frac{1}{4}$	$45 \times 42\frac{1}{2}$	$36\frac{1}{2} \times 22\frac{1}{2}$	24	2,190
24	$3\frac{7}{16}$	18	62	$37\frac{1}{2}$	$53\frac{1}{2} \times 46\frac{1}{2}$	$38\frac{1}{2} \times 26$	30	2,890
24*	$3\frac{7}{16}$	18	62	$37\frac{1}{2}$	$53\frac{1}{2} \times 46\frac{1}{2}$	$38\frac{1}{2} \times 26$	30	2,890
28	$3\frac{15}{16}$	$20\frac{3}{4}$	78	48	54×58	$52\frac{1}{2} \times 28$	32	4,600
33	$4\frac{15}{16}$	$22\frac{5}{8}$	84	54	$66\frac{1}{2} \times 61$	$55\frac{1}{2} \times 33\frac{1}{2}$	34	5,550
33*	$4\frac{15}{16}$	$22\frac{5}{8}$	84	54	$66\frac{1}{2} \times 61$	$55\frac{1}{2} \times 33\frac{1}{2}$	34	6,775
38	$5\frac{1}{2}$	25	100	$67\frac{1}{2}$	78×71	69×42	37	8,000
44	6	$32\frac{1}{2}$	112	75	93×78	76×66	60	14,600

* Deep bucket.

Horizontal Little Giant Double Turbine.

(S. Howes, London.)

There may be many situations where a turbine placed upon a horizontal shaft can be used to better advantage than one on a vertical shaft. By using a horizontal turbine and placing it

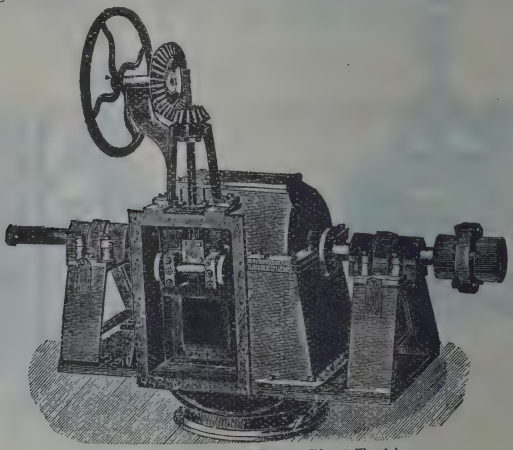


Fig. 20.—Horizontal Little Giant Turbine.

some distance above tail water, nearly the whole effect due to the head can be obtained with an air-tight discharge tube. This mode of setting a turbine (fig. 20) admits of placing a pulley directly on the turbine shaft, and belting to the line shaft.

Dimensions of Horizontal Little Giant Double Turbines.

Diameter of Turbine.	Diameter of Shaft.	Inside Diameter of Inlet Flange.	Outside Diameter of Inlet Flange.	Inside Diameter of Outlet Flange.	Outside Diameter of Outlet Flange.	Height to Centre of Shaft.	Length of Shaft (overall).	Height to top of Case.	Size of Bed Plate.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
4	$1\frac{1}{16}$	8	$11\frac{1}{4}$	8	$11\frac{1}{2}$	$8\frac{1}{4}$	50	12	40×14
6	$1\frac{7}{16}$	$7\frac{7}{8}$	12	9	13	$10\frac{3}{4}$	$55\frac{1}{2}$	$15\frac{3}{4}$	$44\times15\frac{1}{2}$
8	$1\frac{15}{16}$	$9\frac{3}{8}$	14	14	18	13	65	$18\frac{1}{2}$	$50\times16\frac{1}{2}$
10	$1\frac{15}{16}$	$12\frac{1}{2}$	$16\frac{1}{2}$	18	23	16	70	23	$52\times22\frac{1}{4}$
12	$2\frac{3}{16}$	14	$18\frac{7}{8}$	22	26	19	75	28	$58\times27\frac{1}{2}$
14	$2\frac{7}{16}$	$17\frac{3}{4}$	$22\frac{1}{4}$	25	30	$21\frac{1}{2}$	90	$30\frac{1}{4}$	71×31
16	$2\frac{11}{16}$	20	$24\frac{1}{7}$	24×31	28×35	$22\frac{3}{4}$	94	31	$73\times33\frac{1}{4}$
18	$2\frac{15}{16}$	22	$27\frac{1}{4}$	28	33	$26\frac{1}{4}$	108	$36\frac{1}{2}$	$83\times37\frac{1}{4}$
21	$3\frac{7}{16}$	$23\frac{3}{4}$	29	26×34	31×39	30	114	$36\frac{3}{4}$	92×48
24	$3\frac{11}{16}$	$30\frac{1}{4}$	$35\frac{7}{8}$	30×38	35×43	$35\frac{1}{2}$	132	43	$110\times52\frac{1}{2}$
28	$4\frac{3}{16}$	$31\frac{3}{4}$	$36\frac{3}{4}$	34×44	40×50	$37\frac{3}{4}$	144	$56\frac{1}{2}$	118×57
33	$4\frac{15}{16}$	34	39	2×32	2×37	$43\frac{1}{2}$	149	69	121×62

Size of Pipe for Little Giant Double Turbine.

Turbine		Pipe	
Turbine	4 ins. dia.	Pipe	6 ins. dia.
,,	6 ins. ,,	,,	9 ins. ,,
,,	8 ins. ,,	,,	12 ins. ,,
,,	10 ins. ,,	,,	14 ins. ,,
,,	12 ins. ,,	,,	16 ins. ,,
,,	14 ins. ,,	,,	20 ins. ,,
,,	16 ins. ,,	,,	22 ins. ,,
Turbine	18 ins. dia.	Pipe	24 ins. dia.
,,	21 ins. ,,	,,	28 ins. ,,
,,	24 ins. ,,	,,	32 ins. ,,
,,	28 ins. ,,	,,	36 ins. ,,
,,	33 ins. ,,	,,	44 ins. ,,
,,	38 ins. ,,	,,	48 ins. ,,
,,	44 ins. ,,	,,	60 ins. ,,

Low Fall 'Gilkes-Francis' Turbines.

(Gilbert Gilkes & Co. Ltd., Kendal.)

The type of Francis turbine shown in fig. 21 is a medium-speed wheel (specific speed 63·0 r.p.m. in ft.-lbs. sec. units) which has been found a very useful type for small and medium powered installations. This turbine can be arranged with its shaft vertical, as shown in fig. 21, or can be fixed as a horizontal shaft turbine.

The connection of the movable guide vanes by a chain of links (as shown in the fig.) is

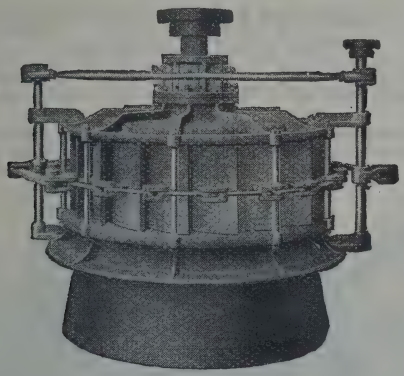


Fig. 21.

found to have a long life under ordinary working conditions, and is found to require less power than by any other method.

The vanes are so pivoted that they are as nearly as possible balanced in all positions. This fact is of great importance when it is required to control the turbine speed automatically by a governor.

Fig. 22.

All the wearing parts of the guides themselves and their connecting links are bushed with bronze and the pins are made of hard steel.

The wheel shown in fig. 22 is made of steel buckets bent to mathematically accurate curves, and then cast into an iron boss and outer skirt.

The wheel discharges to the tailwater through a cast iron flume or tail pipe, and when the turbine is arranged for a horizontal setting a cast iron discharge bend and tapered tail pipe is fitted.

For the vertical setting it is strongly recommended that the weight of the rotating parts be carried on a suitably designed ball thrust bearing arranged above the head water level. This type of bearing is much to be preferred to the lignum vitae pivot bearing under the water. The latter though very simple and cheaper than the above water suspension bearing, may give trouble, especially if the water contains much sand or grit in suspension. The pivot is in any case difficult to inspect and costly to renew.

Medium Fall 'Gilkes-Francis' Turbine.

(Gilbert Gilkes & Co. Ltd., Kendal.)

Fig. 23 shows a turbine installed at San Juan Mines, in the Argentine. It is designed to develop 750 h.p. when using 7,270 cub. ft. of water per minute under a head of 70 ft. and running at 500 r.p.m.

Owing to the comparatively high speed in relation to the head, two runners are employed, each with its own casing but discharging into a central suction flume common to the two

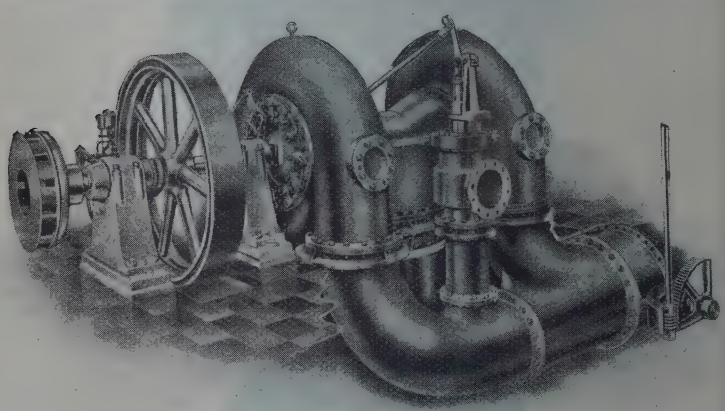


Fig. 23.

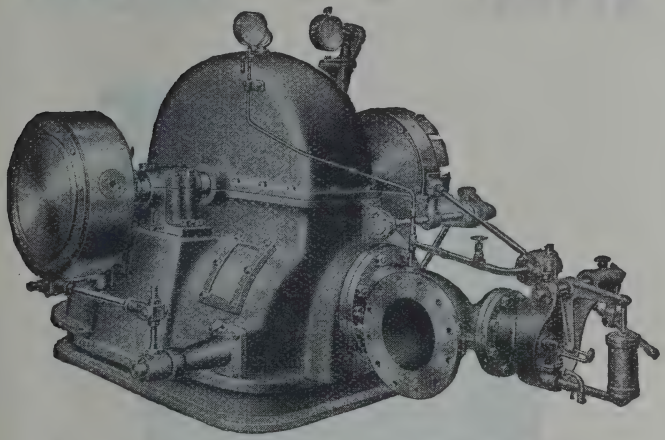
wheels, thus putting both wheels into balance and avoiding the necessity of thrust bearings. The casings are of the spiral form, which allows the kinetic energy of the water flowing through the pipes and casing to be utilised with a minimum of loss. The runners and guide blades are of the Francis type, the former being constructed with steel buckets cast into a c.i. boss and skirt.

The guide blades are of cast steel, working in phosphor-bronze bushes, and have a stem cast on which is accurately turned and carried through glands to the outside of the casing; on the end of each stem is keyed a c.i. lever, the lower being coupled together by means of bronze bushed links. Two of the stems are coupled by means of special levers to the governor. By this means all pins, joints, etc., are placed outside the turbine, where they are not affected by the action of the water and can easily be lubricated. Although this method of outside gate mechanism is rather more costly in the first place, its extra cost is soon compensated for by smoothness in running and absence of repairs. It has been known that pins acted upon by the water, assisted sometimes by electrolytic action, have required renewing after a few months' wear, entailing the shutting down of the plant for a considerable time to gain access to the inside of the turbine.

The speed of the set is controlled by a Gilkes oil pressure governor, assisted by a cast steel flywheel. In order to prevent shock on the pipe line due to the rapid shutting off of the water, an automatic by-pass valve is provided. The valve is connected direct to the governor and is so arranged that, directly any water is shut off the turbine, the valve lifts immediately, allowing

WATER POWER.

FRANCIS TURBINES FOR LOW AND MEDIUM FALLS



375 H.P. PELTON WHEEL FOR GREAT BRAK RIVER SCHEME IN SOUTH AFRICA.

PELTON WHEELS AND IMPULSE TURBINES FOR HIGH FALLS.

CENTRIFUGAL PUMPS.

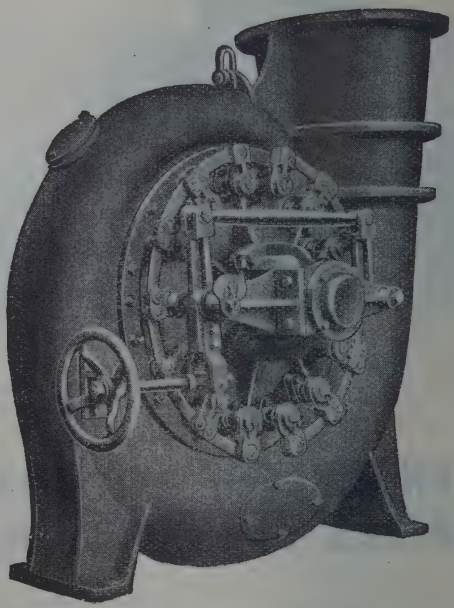
GILBERT GILKES & CO., Ltd., KENDAL, ENGLAND.

F. 1386

GILBERT GILKES

AND CO. LTD.

KENDAL - - ENGLAND



Spiral Cased Francis Turbine showing the guide blade mechanism out of contact with the water

F. 1387

an equal quantity of water to pass through the valve, but immediately the movement of the gate ceases the valve slowly closes without shock on the pipe line. By the arrangement, the valve anticipates any rise in pressure in the pipe line. The speed of closing is regulated by an oil cataract which can be regulated to close at any desired speed.

This type of turbine is commonly adopted for falls varying from 30 ft. to 300 ft. On the higher falls a single spiral is used, discharging its water either from one side of the wheel or from both sides.

Spiral Turbines for Small Outputs.

With a view to meet the increasing demand for small but high efficiency water turbines, *Boving & Co., Ltd.*, have designed and recently placed on the market a machine which, although low in cost, nevertheless possesses a high efficiency.

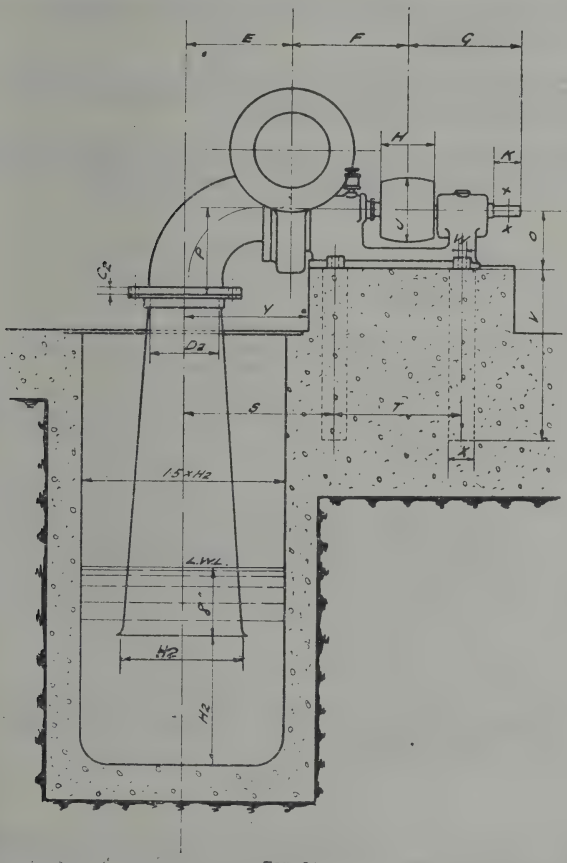


Fig. 24.

From fig. 24 it will be seen that the turbine is self-contained on its own bedplate, and consists of a specially designed spiral casing enclosing a runner of the Francis type, which is mounted on the end of the turbine shaft. The turbine is also provided with a belt pulley.

The shaft, extended at one end to accommodate a coupling, is supported on two metallic bearings, oil lubricated, and with the runner overhung; the bearings do not sustain damage should the water contain abrasive matter.

The discharge water from the runner passes through a specially designed suction bend and suction pipe into the tail race.

The foundations present no difficulties, and may be of timber blocks, steel girders, or concrete. Timber beams are frequently used with good results, as the rigid bedplate prevents the bearings from becoming out of alignment.

Another noteworthy feature is the inlet flange, which can be turned in various positions, thus simplifying the pipe line connection.

The turbine is normally arranged for the control of its speed by means of a hand-operated inlet sluice valve, but where necessary it can be equipped with the Boving patent automatic governor of the oil pressure type.

The machine described is manufactured for heads up to 60 ft., and the largest size for that head has an approximate output of 53 b.h.p. at a speed of 1,175 r.p.m. and a full-load efficiency of 82 per cent. This high efficiency was only obtained by careful design of the casing which has been evolved after a long series of tests in the laboratory.

This turbine is eminently suitable for the economical driving of mining, dairying, and similar machinery, and, owing to its unique and compact design, it can be dismantled into suitable small packages for conveyance by mule or other means where transport is difficult.

Selection of a Turbine Runner.

There are a certain number of commercial constants which are of great help to the engineer who is not a turbine designer, when attempting to select the best type of turbine to adopt for a given development and a chosen capacity per electro-generating unit.

The **Specific Speed** (N_s) is a theoretical characteristic which gives the means of comparing the relation between the conditions of speed, head and power of a runner in one installation with the same conditions relative to a runner in a totally different installation. This comparison is made after the conditions governing the design of both runners have been reduced to a common base, viz. the specific speed.

The specific speed of a runner may be defined as the speed at which any runner will run when it is reduced to such a size that it will develop one horse-power when operating under a head of unity. The numerical value, expressed in the metric system, of the specific speed of any runner may be found by first calculating the speed and power output of the runner under consideration for one metre head, and then mathematically reducing the runner in size until it will deliver one horse-power. The speed of this reduced runner when operating at its point of maximum efficiency is its rated specific speed; this speed is generally expressed in the metric system in order to adhere to an international standard. The formula is

$$N_s = 4{\cdot}45 \text{ r.p.m.} \frac{\sqrt{\text{h.p.}}}{h^{\frac{5}{4}}}$$

in which the horse-power and head are expressed in the foot-pounds system, while N_s remains in the metric system. The equivalent given in the foot-pounds system is called the 'unit speeds' or 'type characteristics.'

$$N_u = \text{r.p.m.} \frac{\sqrt{\text{h.p.}}}{h^{\frac{5}{4}}}$$

In figuring the specific speed of any reaction turbine having more than one runner, or an impulse wheel having more than one nozzle, the horse-power used in the formula, of course is the power developed by one runner only, or one nozzle only.

For a given number of revolutions per minute (r.p.m.), and head (h), the h.p. output is proportional to the square of the specific speed; also for a given head and h.p. the r.p.m. of a turbine is proportional to the specific speed.

In applying the formula for the specific speed to turbines already built it will be found that the data of an impulse wheel will give a low specific speed, between 5 and 25, while the data on the radial inward-flow turbine and on the radial inward axial flow turbine will give a high specific speed between 40 and 450. It will be noticed that there is a gap between the impulse wheel and the reaction turbine, as values of N_s between 25 and 40 do not exist with either type; but by using more than one nozzle on one impulse wheel it is possible to increase the value of N_s, so as to cover the entire field.

The formula for the specific speed contains only the two quantities, 'speed' and 'capacity for a certain head,' but as these quantities determine the areas and angles of the turbine, and thereby again the losses which take place during the passage of the water through the turbine, it will be understood that the specific speed is inherently related to the efficiency which can be expected from the turbine.

EFFICIENCY AT THREE-QUARTER POWER OF IMPULSE WHEELS.

Specific Speed.	Efficiency.
	Per cent.
5	80
9	79
13	78
18	77
22	76

EFFICIENCY OF RADIAL INWARD-FLOW TURBINES.

Type.	Specific Speed.	Maximum Efficiency.	Efficiency at half power.
		Per cent.	Per cent.
Low speed . . .	40—100	82 at 0·75 power	76
Medium speed . .	130—220	82 at 0·75 ,,	75
High speed . . .	260—360	80 at 0·80 ,,	70
Very high speed . .	400—450	73 at 0·90 ,,	53

This table shows that the different types of radial inward turbines are of different qualities. The low-speed turbines are very favourable as to efficiency over a wide range of loads, but they are practically limited to high heads. Medium-speed turbines are also very favourable as to efficiency over a wide range of loads. High-speed turbines are favourable as to efficiency at about 0·8 load, but show a marked decrease at about half load. The extreme high-speed turbines may in some cases be tolerable as to efficiency at about 0·9 load, but at about half load the efficiency is below the limit of rational utilisation of the water. The use of such turbines is only justified for low heads, with a supply of water ample in all seasons, and where the head remains rather constant.

The curve (fig. 25, p. 1390), based on tests of higher grade turbines, shows that if one desires the best efficiency possible a specific speed should be chosen between 110 and 220.

The modern practice is towards the use of large units running at the highest speed compatible with the exigencies of economical and prudent operation, so that, although the choice of a turbine depends on the power and speed desired as well as on the head available, it would seem as if the head was in most cases the deciding factor. The following table, based on this assumption, gives the type of runner desirable in function of the head.

Heads from 500′ up.	Specific speed 5 to 25.	Type of Runner Impulse Wheel.
For heads up to 500′ . .	40 to 100	Low speed, reaction.
,, ,, ,, 300′ . .	100 to 150	
,, ,, ,, 150′ . .	130 to 180	Medium speed.
,, ,, ,, 60′ . .	175 to 250	
,, ,, ,, 30′ . .	260 to 360	High speed.
,, ,, ,, 15′ . .	400 to 450	Very high speed.

EFFICIENCY CURVE.

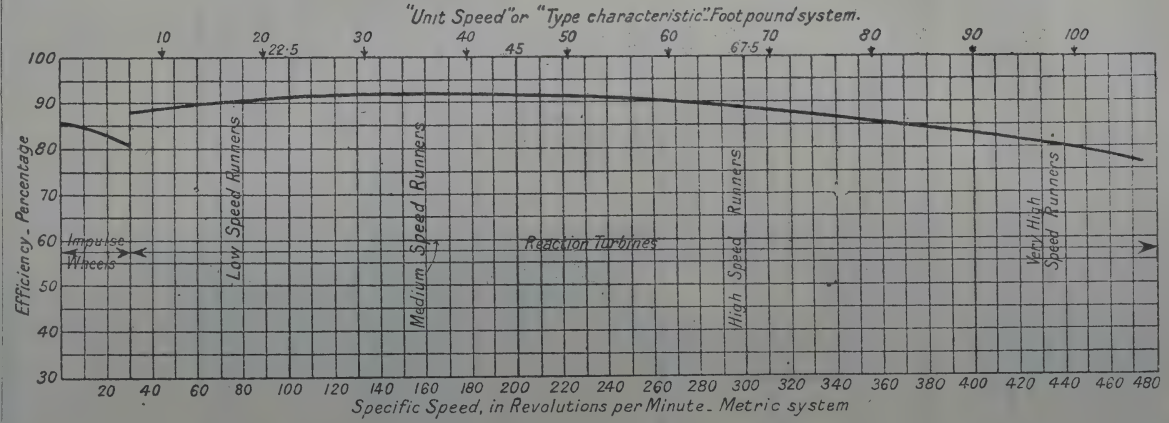


FIG. 25.

Relation between the Speed and the Discharge of a Turbine and the Head.

For maximum efficiency the peripheral speed (U_1) of any runner is a definite fraction of the spouting velocity under the given head,

$$U_1 = \phi \sqrt{2gh};$$

the best wheel speed is given by values ranging from

0·43 to 0·47 for impulse wheels,
and 0·53 to 0·57 for reaction turbines.

The discharge through a turbine is like the discharge through any orifice and varies as the square root of the head, and the coefficient of discharge has a definite value for the best value of ϕ; it follows that *the best speed and the discharge of a given turbine vary as the square root of the head* ($h^{\frac{1}{2}}$).

Relation between the Input and the Output of a Turbine and the Head.

The power available in each unit volume of water is proportional to the head, and since the quantity of water discharged varies as the square root of the head, then *the power input varies as the three-halves power of the head* ($h^{\frac{3}{2}}$).

The losses of head in any turbine vary as the squares of the various velocities concerned. Since these velocities vary as the square root of the head, their squares will vary as the first power of the head. The amount of water varies as the square root of the head, and since the power lost is the product of these two items, it follows that the *various hydraulic losses vary as the three-halves power of the head.* As the hydraulic losses vary in just the same proportion as the power input, *the hydraulic efficiency will be independent of the value of the head.*

The power output of a given turbine varies as the three-halves power of the head.

Relation between the Diameters of Stock Runners of the same Type.

When a certain type of runner has been perfected, a whole line of stock runners of that type may then be built with diameters ranging from 10 to 70 inches. All of these runners will be homologous in design, that is to say, they will have the same specific speed and each runner will simply be an enlargement or reduction of another. Having the same characteristics, that is, the same value of ϕ and c (coefficient of discharge), they will therefore follow certain laws of proportion, which can be summed up as follows for a series of runners of homologous design :

1. The best r.p.m. will be inversely proportional to the diameter.
2. The discharge of any turbine of the series will be proportional to the square of the diameter.
3. The power of any turbine of the series is proportional to the square of the diameter.

These relations are of practical value, because if the speed, discharge, and power of any runner is known by accurate test, predictions may then be made regarding the performance of any other runner of the series.

Relation between the Diameter of a Runner and its Discharge.

Since the discharge of any runner is proportional to the square of its diameter and to the square root of the head, we may write

$$q = K_1 D^2 \sqrt{h} = \text{cub. ft. per sec.}$$

The value of K_1 depends upon the velocity of the water entering the runner and the area of the passages in the runner. The velocity depends upon the value of the coefficient of discharge c, which varies from 0·6 to 0·8, and the area depends upon the diameter, the height of the runner, the angle, and also the number of buckets and guides. To summarise, the values of K_1 vary

for the tangential water wheel, from 0·0002 to 0·0005;
for the reaction turbine, from 0·0014 to 0·0360.

Relation between the Diameter of a Runner and its Power.

Since the power of any runner is proportional to the square of the diameter and to the three halves of the head, we may write,

$$\text{h.p.} = K_2 D^2 h^{\frac{3}{2}}$$

for the tangential water wheel, $K_2 = 0{\cdot}000018$ to $0{\cdot}000045$;
for the reaction turbine, $K_2 = 0{\cdot}00012$ to $0{\cdot}0033$.

Determination of the Constants.

The constants given may be computed from theory, but for practical use they should be secured from test data. The engineer who has to select a type of turbine can determine these factors by taking the information given in the catalogues of the turbine manufacturers. The tables contained in these catalogues are supposed to be made from actual tests, and give the discharge, power, and speed of runners of various diameters under various heads. Of course, as each manufacturer usually makes several lines of runners, there will be as many distinct values of the constants as he makes types of runners.

The Draft Tube.

It is generally found advantageous to install the turbine at an elevation above the elevation of the water in the tail race, but in order to do this without any loss of head it is necessary to connect the turbine discharge with the tail race water by means of an air-tight steel or concrete tube whose efflux is below the water level. This tube was formerly known as the Jonval device, but now generally called a 'Draft Tube.'

In considering the effect of the draft tube it should be remembered that a given static head may exist either wholly in the form of pressure or pressure head, or wholly in the form of vacuum or suction or draft head, or part of the head may be in the form of pressure head and the remainder in the form of draft head.

Also, a given head may exist wholly in form of pressure or static head, or wholly in the form of velocity, or part of the head may be in form of pressure and the remainder in the form of velocity, and pressure can be converted into velocity or velocity into pressure.

The effect of a draft tube on a turbine is to remove a part of the back or counter pressure due to the pressure or weight of the atmosphere, by a hanging water-column creating a partial vacuum. This water column being held in equilibrium by the pressure of the atmosphere, its height or head cannot be greater than 34 feet.

The draft head is the vertical distance between the centre of the shaft and the tail water for horizontal wheels, and between an horizontal line passing through the centre of the runner buckets and the elevation of the tail water for vertical turbines.

It is never possible to realise an effective draft head of 34 feet, as it is necessary to subtract the various losses due to the friction of the water in the draft tube, to the change in the speed of the water between the turbine runner and the lower end of the draft tube, and to the momentum or velocity still contained in the water while leaving the draft tube.

The absolute velocity in feet per second with which the water issues from the runner buckets and enters into the draft tube, assuming its diameter to be that of the outside of the runner should be from $\cdot 30\sqrt{2gh}$ to $\cdot 15\sqrt{2gh}$, and the velocity at the outlet of the draft tube may be $\cdot 1\sqrt{2gh}$, especially if the discharge is in the direction of the flow.

When no draft tube is used, the heads corresponding to the velocities of discharge from the turbine are completely lost, whilst with a properly designed draft tube it is possible to recover about 75 per cent. of the gain in head, due to the difference between the velocity head at the turbine and the velocity head at the outlet of the draft tube.

The following table gives the greatest draft-head permissible in practice, under average conditions, and for different diameters of draft tube.

Draft Head Permissible in Practice.

Diameter in feet.	Draft Head in feet.	Diameter in feet.	Draft Head in feet.
0·5	31·0	6	17·0
1·0	29·5	7	15·4
1·5	28·1	8	14·2
2·0	26·7	9	13·2
2·5	25·3	10	12·3
3·0	23·9	11	11·4
3·5	22·6	12	10·6
4·0	21·4	13	9·8
4·5	20·2	14	9·0
5·0	19·0		

The draft head given in this table is equal to the difference of elevation between the turbine and the tail water plus the velocity head corresponding to the speed with which the water leaves the draft tube.

The draft tube should be calculated to resist the atmospheric pressure, which tends to make it collapse.

Seal Rings of Hydraulic Turbines.

Water leakage between the turbine runner and the stationary casing is an important item of loss, especially where units operate at high heads. Ordinarily, labyrinth packing is employed, which causes the water to take a very circuitous path and be subjected to close clearances. Abrasive material contained in the water, however, has a disastrous effect on such metallic packing, and is the cause of objectionable repairs. Solid matter jamming in such clearances may cause the revolving parts to bind or run out of centre.

Rubber seal rings being flexible, eliminate a great deal of the trouble encountered, reducing the wear almost to a negligible amount. They are fitted to give material contact with the shaft, the water film acting as a lubricant. Rubber of the consistency of that found in the outer casing of an automobile tire has proved the most satisfactory, after a year of experimenting by the Pelton Water Wheel Co. (America).

In most cases of putting the rings in old units, the change is quite simple and involves only the removal of the existing all-metal wearing rings or sealing rings and the substitution of the rubber rings. Usually, this is done without other modification of the unit. The present construction of the seal rings, particularly for high-head turbines, requires that the rubber shall be vulcanised directly into the metal rings. When the rubber becomes worn, however, it is unnecessary to renew the metal ring section, as it can be again used for vulcanising a new rubber facing to restore the ring to its original condition. This results in a considerable saving in cost of the seal rings over that for the initial installation.

The highest head under which rubber seal rings are now used is 350 ft., but similar rings, in process of construction for the Oak Grove turbines, will operate under a head of 850 ft. The largest rubber seal rings thus far made are 5½ ft. in diameter, but plans are being developed for making seals of this type commercially for the very large diameter low-head turbines used extensively in the eastern part of the United States. This plan contemplates the manufacturing of the rubber seals in strips, which are then secured to their ring containers.

For corrosion-proof centrifugal pumps used for pumping acids and other corrosive fluids, a material called 'ceratherm,' invented by Mr. W. Hayhurst, M.Sc., has been introduced as a lining; it is stronger than fused silica or stoneware, and does not crack even when heated to redness and plunged in cold water. It is inert as porcelain to all chemicals and acids, and pumps of this material have been used for elevating nitric, hydrochloric, and sulphuric acids, hot and cold, hot ferric chloride, copper chloride, acetic acid, and various corrosive materials used in connection with explosives, collodion manufactures, and munition recovery plant. The material is homogeneous, and can be moulded to any shape required. It contains no soluble material, and is not brittle.

A great deal of benefit is said to be derived from an installation in a turbine plant of a Western industrial concern, whereby the lubricating oil in use in three 1875 k.v.a. turbo-generators is passed through 100 ft. of 2-in. copper coil, the latter being immersed in circulating cooling water from the ocean. The effect is a decrease in temperature of this oil of 40° F.

REGULATION OF TURBINES.

In many hydraulic plants, and notably in the hydro-electric plants, it is necessary that the rotating speed of the turbines should be constant, regardless of the power developed. This can be done either by a hand or by an automatic regulation of the water openings, in proportion to the power utilised. The automatic regulation is adopted in preference to the hand regulation in all important plants.

The water wheel governors are controlled by a centrifugal ball mechanism just as in the case of the steam engines, with the difference that, as the force required to move the turbine gates is large, it cannot be supplied by the centrifugal ball governors, but must be borrowed either from the hydraulic motor itself or from an exterior source.

The gates are therefore moved by a 'relay,' which is a device for transmitting energy from a source of energy independent—as to quantity—of the centrifugal governor balls but controlled by them in its application. If the relay is of 'mechanical type' the power required to operate the gates is transmitted, when needed, from the wheel by means of shafts, gears, friction-clutches, belts and pulleys, or other mechanical devices. In mechanical governors the flyballs may actuate pawls, friction gears, or other mechanical devices which will bring the relay into action.

If the relay is of the hydraulic type, it usually consists of a piston connected by some mechanical device to the gate rigging and moved by means of the hydraulic pressure of water taken from the penstock, or other source, or by oil supplied under high pressure from a reservoir. The pressure of the oil in the reservoir is maintained by compressed air supplied by power taken from the wheel itself. The oil thus used in moving the piston is exhausted into a receiver, from which it is pumped back into the supply reservoir. The hydraulic relay is commonly controlled by the ball governor through the medium of a small valve, which by its motion either admits the actuating water (or oil) directly to the cylinder or to a secondary piston controlling a larger admission valve.

Electrical methods of actuating the relays controlled by means of governor balls have been used to some extent but are not nearly so common as mechanical or hydraulic devices.

The best makes of hydraulic governors for medium and high falls will regulate the speed within the following limits, the percentage of variation being that of the mean speed :—

	Speed Variation. Per Cent.
For sudden variation of load of 25 per cent.	4
" " " 50 per cent.	6
From no load to full load	10

Regulation due to Flywheel Effect.*

Flywheel effect is the capacity of a rotating mass to store or supply energy. This effect is expressed at 1 ft. radius and is equal to the moment of inertia of a mass, that is the weight by the square of the radius of gyration, or pounds feet squared. Modern alternating current generator rotors are built in the shape of a common flywheel and usually have sufficient flywheel effect to obtain satisfactory regulation. The flywheel effect of the rotating parts of a turbine varies with different types and usually is not considered, but it should be carefully considered for large low-head multiplex and large diameter impulse turbines. In smaller turbines it may be regarded simply as introducing a factor of safety.

The regulation due to any given flywheel effect can be computed by means of the formula

$$d = \frac{800{,}000 \times \text{h.p.} \times \text{T}}{\text{r.p.m.} \times \text{r.p.m.} \times \text{W}_r^2}$$

where,

d = percentage of variation in speed allowed ;
T = time of closure of governor in secs. ;
W = weight of rotating masses in lbs. ;
r = radius of gyration in ft. ;
W_r^2 = moment of inertia of the rotating masses in lbs. ft. squared.

Actually the relative change of speed (d) on account of the friction load of the turbine and generator is smaller than that given by the above formula. The effect of this friction load will vary according to the various types of turbines used, but the original formula may be modified safely as follows :—

$$d = 0{\cdot}8d.$$

Another cause which should be taken into consideration, providing the turbine is properly designed so as to give its maximum efficiency at normal or synchronous speed, is that the efficiency is reduced with either increasing or decreasing speed, which has the tendency to reduce further the relative change of speed (d).

The amount reduced varies with the type of runner, being greatest for a high-speed, high power runner, and least for a low-speed, low-power runner, since if correctly designed, and therefore following the laws of hydraulics, the change in efficiency will be greater for a high-speed than for a low-speed runner for the same per cent. of variation in speed. The formula modifying d, for this cause, is as follows :—

$$d \text{ eff.} = \frac{d_1}{1 + \frac{d_1}{\frac{n_2}{n_0} - 1}}.$$

The value of $\frac{n_2}{n_0}$ varies with the specific speed, and we have

Specific speed	60	90	130	180	220 to 280	310 to 370	400 to 460
Value of $\frac{n_2}{n_0}$	1·8	1·7	1·6	1·5	1·4	1·3	1·2

For impulse turbines 1·8 can be used as the value of $\frac{n_2}{n_0}$. To find the speed variation for any other than a full load change, the following must be considered : If T is the regulating time for the total governor stroke or 100 per cent. load of the turbine, it would appear that for 50 per cent. load or stroke, the regulating time would be $\frac{\text{T}}{2}$, and for 25 per cent, $\frac{\text{T}}{4}$, etc.

* Adapted from *Speed Regulation of Hydro-electric Plants*, by Wm. F. Uhl.

The regulating time for the total governor stroke or the governor closing time should be adopted only after a thorough study. Sensitive governing means severe wear and tear on the gates as well as increased shocks in the penstocks, and should be avoided where possible. Many lighting plants are successfully operated where it requires 20 seconds to close the gates, and while 20 seconds may be extreme, a closing time of 5 seconds is quite satisfactory for all but the most important or special plants.

Regulation of Turbines.

(Contributed by W. Gunther & Sons, Oldham.)

Regulation of turbines is of the utmost importance with electric power stations, where two or more generators have to run in parallel. Every change of load on a turbine is accompanied at the same moment by a change in speed, Z_{off}, when load is thrown off, and Z_{on}, when load is thrown on. These momentary changes of speed are disturbing to the smooth running of the plant, and it is in the greatest interest of the buyer of a turbine that the values of Z_{off} and Z_{on} should be as small as possible. In many cases certain conditions in regard to these values are asked from the turbine maker. The *momentary* changes of speed Z_{off} and Z_{on}, and the corresponding *remaining* changes in the revolutions Y_{off} and Y_{on}, which also must be as small as possible, are generally given in per cent. of the normal revolutions. If X_{off} and X_{on} denote the respective changes of load in per cent., the following conditions are suitable for average plants:—

$$\left.\begin{matrix} X_{off} \\ X_{on} \end{matrix}\right\} \text{25 per cent.,} \qquad \left.\begin{matrix} Z_{off} \\ Z_{on} \end{matrix}\right\} \text{not more than } 3\tfrac{1}{2} \text{ per cent.,}$$

if the corresponding values of Y are

$$\left.\begin{matrix} Y_{off} \\ Y_{on} \end{matrix}\right\} \text{1 per cent. at the most.}$$

Regulating stipulations can be made more or less severe according to the value of Z required. The *desired* speed change percentages are considerations for the power consumer; for the practically *obtainable* percentages the relative pipe length is, in the first instance, the deciding factor. The term 'relative pipe length' expresses the ratio: length of pipe line / head. The greater the relative pipe length, the more difficult it is to obtain satisfactory governing, and in many cases a compromise between the desired and the practically obtainable regulating percentages is the only solution.

As a general guide, the following percentages of speed variation should be obtainable:

Plant with a Good Relative Pipe Length (2 to 3).

X_{off} per cent.	X_{on} per cent.	Z_{off} per cent.		Z_{on} per cent.		Y_{off} per cent.		Y_{on} per cent.	
		Francis.	Pelton.	Francis.	Pelton.	Francis.	Pelton.	Francis.	Pelton.
25	25	2	3	2½	2½	1	1	1	1
50	50	5	5	6	6	2	2	2	2
100	100	10	12	13	—	3	3	3	3

Plant with Unfavourable Relative Pipe Length (over 3).

X_{off} per cent.	X_{on} per cent.	Z_{off} per cent.		Z_{on} per cent.		Y_{off} per cent.		Y_{on} per cent.	
		Francis.	Pelton.	Francis.	Pelton.	Francis.	Pelton.	Francis.	Pelton.
25	25	5	4½	6	5	1	1	1	1
50	50	9	8	12	9½	2	2	2½	2½
100	100	18	15	—	—	3½	3½	4	4

With respect to the current consumer two distinctions may be made:—

(1) Electric power stations which supply current for public purposes (street lighting, trams, etc.).

(2) Private industries or private power-distributing stations with mechanical or electrical power transmission between turbine and driven machinery.

In power stations of order (1) considerable instantaneous changes of load may be experienced at any time. It is therefore necessary that the turbines driving electric generators which supply current for public purposes (especially if trams or electric railways are being supplied) be so designed that they can withstand severe working conditions imposed by load changes. In plants of order (2), similar though less severe conditions obtain, and only if an accident happens is full load thrown off suddenly.

A very close relationship exists between the pipe line and the amount of flywheel effect (ΣGD^2) of the turbine, a point not often sufficiently realised by the intending purchaser. In governed plants it is important that sufficient flywheel effect be provided, and a portion at least of the necessary flywheel effect may be incorporated in the rotor of the generator. The amount of flywheel effect required is in proportion to the horse-power, the length of pipe line, and the closing time of the governor, and is inversely proportional to the square of the number of revolutions per minute of the turbine, turbine makers having their own formulæ. If a water turbine is regulated by an automatic governor, and satisfactory regulating conditions are expected, the whole mass of the rotating system must have a minimum mass moment with respect to the axis of rotation. The necessary amount of the GD^2 required is a matter to be decided by the turbine maker, because not only is the flywheel a heavy addition to the cost, but the characteristics of the governor and the efficiency of the turbine at different loads play an important part, details of which the maker only has at his disposal.

Control of Admission of Water into Reaction Turbines.

There are three different systems of regulating the amount of water supplied to the turbine in case of a variation of the load; these are (1) the cylinder gate, (2) the register gate, (3) the wicket gate.

(1) The **Cylinder Gate**, fig. 26, as its name indicates, consists of a cylinder closely fitting the guides and moving in a direction parallel to the axis of the turbine, thus decreasing or increasing

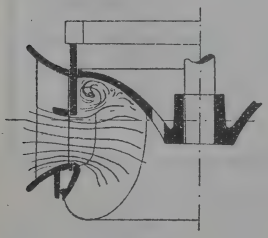


Fig. 26.—Cylinder Gate.

Fig. 27.—Register Gate.

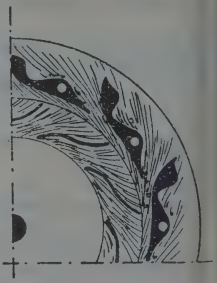


Fig. 28.—Wicket Gate.

the area left between the guide-vanes for the passage of the water. This type of gate is the simplest and cheapest but also the poorest, as the sudden contraction of the vein when passing under the partially closed cylinder gate and the sudden expansion that must take place in the bucket, produces eddying which results in decreased efficiency.

(2) In the **Register Gate**, fig. 27, the guide-vanes are made in two parts. The inner portion next to the runner is stationary, the outer portion is on a ring which may be rotated far enough

to shut the water off entirely if necessary. While this is more efficient than the preceding type, there is still a certain amount of eddying when the register gate is partially closed, with a consequent decrease in part gate efficiency.

(3) The **Wicket Gate**, fig. 28, also called the pivoted guide-vane, consists of a connection rod from the governor operating a shifting ring, which, by means of links, causes the vanes to rotate about their pivots, thus altering the area of the passages through them. This system has the working parts outside the case, which is a great advantage; its maximum efficiency is obtained before the gates are opened to the greatest extent.

Turbine Governors.

The sole efficient survivor of all the various types of governors made in the past is practically represented now by the latest forms of oil-pressure types. Oil-pressure governors as now designed are capable of giving extremely close speed regulation, the degree of regulation obtainable depending in a large measure on the hydraulic conditions under which the plant has to operate, as, although governors can be constructed which will entirely close or open the turbine gates in even as short a time as 1 second, it has been found in practice that from 2 to 3 seconds is about the maximum rate of operation which can be adopted, and even this rate is often not possible on turbines supplied through long pipe lines, owing to the dangerous water-hammer effects which would be set up. In installations of this description, relief valves can be used and quick rate of action of the governor maintained, and, on high falls, Pelton wheels provided with combined spear and deflector regulation can be successfully operated without any danger of water-hammer effects.

In practically every case it is necessary that a certain amount of flywheel effect should be provided in the plant, to assist in speed regulation and to give up or absorb power as required during the time taken by the governor to operate.

Owing to the quick rate of governor action generally adopted, it is of extreme importance that the turbine guide blades and operating gear should be of heavy and solid construction, as otherwise considerable lost motion and excessive wear will soon be set up in the gate operating gear when worked in connection with a quick-acting governor. The light construction of guide vanes and operating gear in turbines, generally known as the American type, is not suitable for obtaining efficient results and long life of working parts when used in connection with quick-acting governors.

Theoretically, speed regulation with modern quick-acting governors can be obtained to within 1 per cent. or 2 per cent. of normal with full load suddenly thrown on or off, but practical consideration of regulating gear design, governor capacity, and weight of flywheel renders such close regulation impracticable for all types of re-action turbines, although impulse turbines of the Pelton type with deflector regulation could be controlled, if necessary, within such close limits. Under ordinary conditions of power-station running, however, it is usually quite unnecessary for such fine speed regulation, and the general standard practice of governor design is to arrange for speed regulation to within 2 per cent. to 3 per cent. of normal under all ordinary working conditions, with a maximum momentary variation of 12 per cent. to 15 per cent. in the unlikely event of the whole load being suddenly thrown off.

In most standard forms of oil-pressure governors relatively small capacity oil-pumps have been used, with a reserve of power provided in the form of compressed air in the oil-receiver. This type of governor was often a source of trouble, owing to the difficulty sometimes experienced in maintaining a sufficient quantity of compressed air in the receiver, and in a number of cases to the compressed air having a detrimental effect on the oil used for operating the governor. The modern tendency is to adopt direct pumping governors without a compressed air chamber, provided with a pump of ample capacity for supplying oil to the operating cylinders at the maximum rate required.

Gilkes Oil Pressure Governor.

(Gilbert Gilkes & Co. Ltd., Kendal.)

This oil pressure governor (fig. 29) is the type constructed by Messrs. Gilkes for use on small and medium-size turbines, or in the larger sizes for controlling turbines of any power; it can equally be used for controlling Pelton wheels, but in Messrs. Gilkes' opinion the most suitable form of governor for controlling impulse wheels of any type is their patent shaft governor, with which much closer speed regulation can be obtained than is possible with the oil pressure type. The power of the shaft governor, however, is not enough to operate the gates on a reaction turbine.

The oil pressure governor is self-contained with its oil reservoir, oil pump, and speed-control mechanism. The base casting forms a reservoir for the oil, and a rotary pump is provided in this base which is driven directly from the turbine shaft.

This oil pump provides the oil pressure by means of which the governor operates the turbine gates. A separate drive is taken from the turbine shaft to operate the governor pendulum, which is of the Pickering type, and has great advantages in simplicity and sensitiveness over other types of pendulum. The pendulum operates upon a relay distributing valve which controls the direction in which the oil pressure provided by the pump will act.

In the upper part of the governor base casting a differential piston is fitted in the cylinder, so arranged that it can be operated in either direction according to whether the oil pressure from the pump is supplied to one side or the other of the cylinder. The piston is mounted on a piston rod which projects through the governor base at both ends. At one end it is fitted with a large hand wheel; the other end carries an eye and is arranged to operate the lever for moving the turbine gates. To this end of the piston rod is also secured the lever which controls the compensation mechanism of the governor. This mechanism is of the floating lever type; by a suitable adjustment the governor can be arranged to give either a small percentage drop of speed as the load comes on or a constant speed at all loads, or even a small percentage of rise in speed as the load increases.

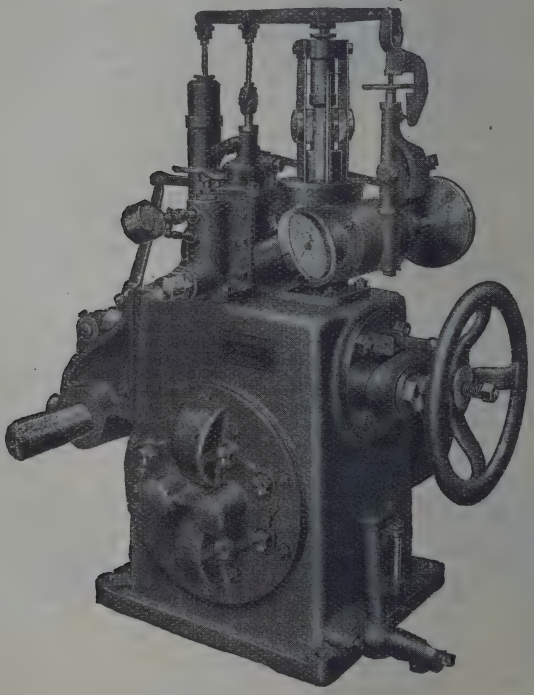


FIG. 29.

Where turbine plants have to work in parallel, the most convenient arrangement is to arrang the governor for a small drop in speed, as the load comes on, to ensure parallelism.

For isolated plants the constant speed or rise in speed characteristic is the most useful.

The governor mechanism is so arranged that the permanent speed may be varied by 5 per cent above or below normal at will while the plant is at work. The whole governor is very accessible and all bearings are of the continuously lubricated type, so that the governor may be run for long periods without stoppage.

Turgo Impulse Wheel.

(Gilbert Gilkes & Co., Ltd., Kendal, Sole Makers and Patentees.)

One of the most important developments of recent years in impulse wheel design has been the introduction by *Messrs. Gilkes* of their Turgo Impulse type. Fig. 30 shows an outside view of this wheel mounted in cast iron casing and arranged for control by Messrs. Gilkes Patent Shaft

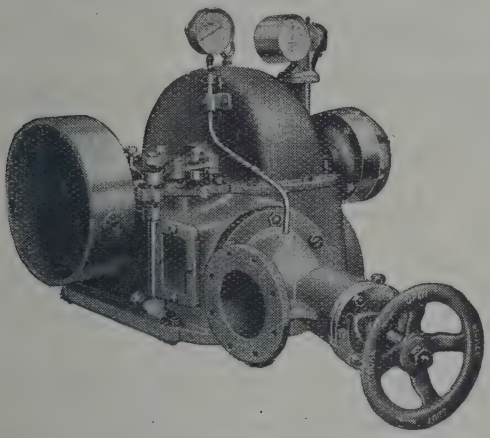


Fig. 30.—Turgo Impulse Wheel with patent Shaft Governor.

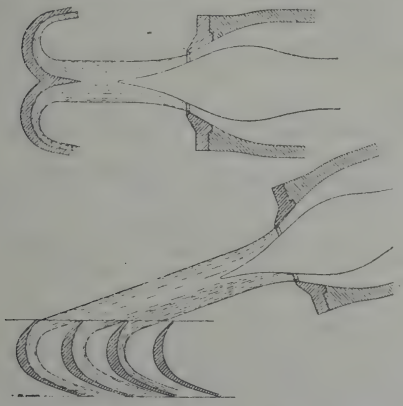


Fig. 31.—Diagram showing the difference between the principle of the Pelton and Turgo Impulse Wheels.

Governor (see p. 1375). The principle of this wheel is identical with that of the Pelton wheel in that the water gives up its power to the wheel by being freely deviated during its passage over the wheel vanes. There is no pressure in the wheel casing, and a branch pipe and nozzle piece exactly similar to that now standard with the Pelton wheel is adopted.

TURGO IMPULSE WHEELS CAPACITY TABLE (*Abbreviated*).

Mean Diam. of Wheel in Inches.	Fall in Feet.	40	50	60	70	90	110	130	150	170	200	250	300	400	500	750
	Fall in Metres.	12·2	15·25	18·3	21·3	27·4	33·6	39·7	45·8	51·9	61·0	76·3	91·5	122·0	152·5	228
12	Horse-power	2·56	3·58	4·71	5·93	8·65	11·7	15·0	18·6	22·4	28·7	40·1	52·7	81·1	113·2	—
	Cub. ft. per min.	45·2	50·6	55·3	59·8	67·8	75·0	81·5	87·6	93·2	101·1	113·1	124	143·1	160	—
	Litres per sec.	21·3	24	26·1	28·3	32·0	35·4	38·5	41·4	44·2	47·9	53·5	58·6	67·5	75·5	—
	Revs. per min.	428	479	524	566	642	710	771	828	882	956	1070	1172	1352	1513	—
13½	Horse-power	4·01	5·62	7·38	9·3	13·5	18·4	23·5	29·2	35·2	45·0	62·9	82·7	127	178	—
	Cub. ft. per min.	69·5	77·8	85·1	92	104·1	115·4	125·4	134·8	143·4	155·6	174	191	220	246	—
	Litres per sec.	32·8	36·7	40·1	43·4	49·1	54·5	59·1	63·6	67·6	73·4	82·1	90	104	116	—
	Revs. per min.	380	425	465	503	569	630	684	735	782	848	948	1040	1200	1342	—
15	Horse-power	5·66	7·92	10·41	13·1	19·1	25·9	33·3	41·3	49·8	63·5	88·8	116·5	180	251	—
	Cub. ft. per min.	96·0	107·2	117·6	127	144	159·3	173·2	186·1	198·1	215	240·4	263·2	304	340	—
	Litres per sec.	45·3	50·6	55·5	60	68	75·2	81·6	87·9	93·5	101·5	113·5	124	143·5	160·5	—
	Revs. per min.	343	383	419	453	513	568	617	663	706	765	855	937	1082	1210	—
18	Horse-power	9·71	13·6	17·8	22·5	32·4	44·4	57	70·7	85·1	109	152	200	308	430	790
	Cub. ft. per min.	165	184	201	218	247	273	297	319	339	368	411	451	521	582	713
	Litres per sec.	77·9	87	95	103	116·7	129	140	150·5	160	174	194	214	246	275	337
	Revs. per min.	285	319	349	377	427	473	514	553	588	638	714	781	902	1008	1234
21	Horse-power	14·6	20·3	26·7	33·6	48·9	66·1	85·2	105·1	127	162	227	298	458	641	1177
	Cub. ft. per min.	246	275	301	325	368	407	443	476	506	549	614	672	776	868	1061
	Litres per sec.	116	130	142	153·5	174	193	209·5	225	239	295·5	290	318	367	410·5	501
	Revs. per min.	243	273	299	323	366	405	441	473	504	546	611	669	772	864	1056
24	Horse-power	21·4	30	39·5	49·7	72·4	97·8	126	156	188	240	335	441	678	948	1741
	Cub. ft. per min.	354	396	434	468	531	587	638	686	730	792	885	970	1119	1251	1532
	Litres per sec.	167	187	204·5	222	250	276	300	323	344	373	417	456	527	590	722
	Revs. per min.	214	239	262	283	321	355	386	414	441	478	535	586	676	756	926
30	Horse-power	33·4	46·8	61·5	77·5	113	153	196	243	293	375	523	689	1060	1480	2720
	Cub. ft. per min.	552	617	676	730	828	917	996	1070	1139	1236	1381	1513	1750	1953	2394
	Litres per sec.	261	292	319	345	391	432	470	507	540	585	655	716	829	925	1129
	Revs. per min.	171	193	212	228	259	287	312	335	357	387	432	473	546	611	748
36	Horse-power	48·2	67·4	88·6	111·4	163	220	283	351	423	540	754	991	1524	2130	3920
	Cub. ft. per min.	797	890	975	1051	1193	1320	1435	1543	1642	1780	1991	2180	2516	2816	3450
	Litres per sec.	376	420	460	498	565	625	680	731	778	842	940	1030	1190	1335	1628
	Revs. per min.	142	159	174	188	213	236	257	276	294	319	356	390	450	504	616

The difference in principle between the Turgo wheel and the Pelton wheel is clearly shown in fig. 31 (p. 1399). In the Pelton wheel the water is divided and discharged on both sides of the wheel, whereas in the Turgo wheel the water enters on one side and passes completely through the wheel and out at the other side.

The advantages claimed for the Turgo wheel are as follows :—

1. The specific speed is much higher than that of the Pelton wheel—that is to say, under given conditions of head and water quantity the Turgo wheel will run at a much faster speed than a Pelton wheel. The reason for this is that with a Pelton wheel the diameter of the jet must for best efficiency be not larger than about $\frac{1}{11}$th to $\frac{1}{12}$th of the mean diameter of the wheel. With the Turgo wheel a jet as large as $\frac{1}{5}$th of the diameter of the wheel can be efficiently applied to it.

2. The Turgo wheel is cast all in one piece with its central boss, wheel vanes, and external shrouding. It is, therefore, a strong type of construction and much more robust than the usual type of Pelton wheel with loose buckets separately bolted to a central disc. Moreover, owing to the fact that the wheel is shrouded externally, the windage and friction loss of the wheel is claimed to be very much less than that of the Pelton wheel.

TYPICAL HYDRO-ELECTRIC PLANTS.

St. Jérôme Hydro-Electric Municipal Plant on the North River, Canada.

This plant (fig. 32) was constructed in 1913 by the town of St. Jérôme to supply electricity to its population of 3,500 ; it is built on the North River, which carries the waters from the Laurentian Mountains to the Ottawa River and thence to the St. Lawrence River.

The chief features of this plant are a concrete weir, a needle dam with three openings, and a reinforced concrete pipe 8½ ft. in diameter, bringing down the water to a power house 1,000 ft. distant from the head gate. The power house consists of a semi-circular forebay of reinforced concrete communicating, by means of sluices, to the three turbine pits. These turbines are of the twin open flume type, designed to have each a maximum output of 270 h.p. at 277 r.p.m. and operating under 20-foot head. The setting of the wheels is horizontal, and they are provided each with a concrete draft tube discharging under the power house proper. The building contains the generators, which are directly connected to the turbines through a cast iron wall plate provided with a stuffing box. Two of the generating units are now installed, and their electrical equipment consists of two 150 kw., 3-phase, 60-cycle, 6,600-volt alternators. The exciters are two 10 kw. units, 120 volts, 1,150 r.p.m. belt connected to the end of the generator shaft. The power is transmitted at 6,600 volts over a transmission line 4 miles long, to a sub-station in St. Jérôme and distributed through the town on a 2,200-volt primary circuit and a 110-volt secondary circuit.

The Cedars Rapids Manufacturing and Power Co.'s Development on the St. Lawrence River, Canada.

The plant (fig. 33) of the Cedars Rapids Manufacturing and Power Co. is situated on the St. Lawrence River about 27 miles from the city of Montreal. The low water flow of the river at that point is about 170,000 cub. ft. per second, and the company has been authorised by the Government to utilise 56,000 cub. ft. per second.

The Cedars Rapids have a fall of 32 ft. in two miles, and the river is approximately 3,000 ft. wide at that point. The development consists of a head-race canal about two miles in length, formed by an outer embankment built up in the river, parallel to the flow, and an inner bank placed back from the original shore line. This head-race is from 700 to 1,200 ft. wide, and is dammed at the lower end by the power house substructure.

The present length of the power house is 667 ft., extending from the outer bank towards the shore and connected to the present shore line by a rock-filled crib dam. This crib is 48 ft. high, and so placed that the work of extending the power house for the remaining 513 ft. to the new shore line for the final development may be carried on without disturbing the crib. When the power house is ready for the final development the crib and fill may be removed by dredging.

The turbines for this development have the largest dimensions of any in the world to date (although not the highest capacity output). In the design are seen all the features of recent advances, such as (1) volute casing and draft tube moulded in the concrete substructure, (2) cast iron speed ring with the vanes serving as columns to support the concrete floor, generator and thrust-bearing loads from above, (3) lignum vitæ guide bearing, (4) Kingsbury thrust bearing located above the generator, and (5) pneumatic brakes acting on the generator rotor to bring the revolving parts quickly to a standstill.

ST. JÉRÔME HYDRO-ELECTRIC PLANT, NORTH RIVER, CANADA.

(Designed by Messrs. Surveyer & Frigon.)

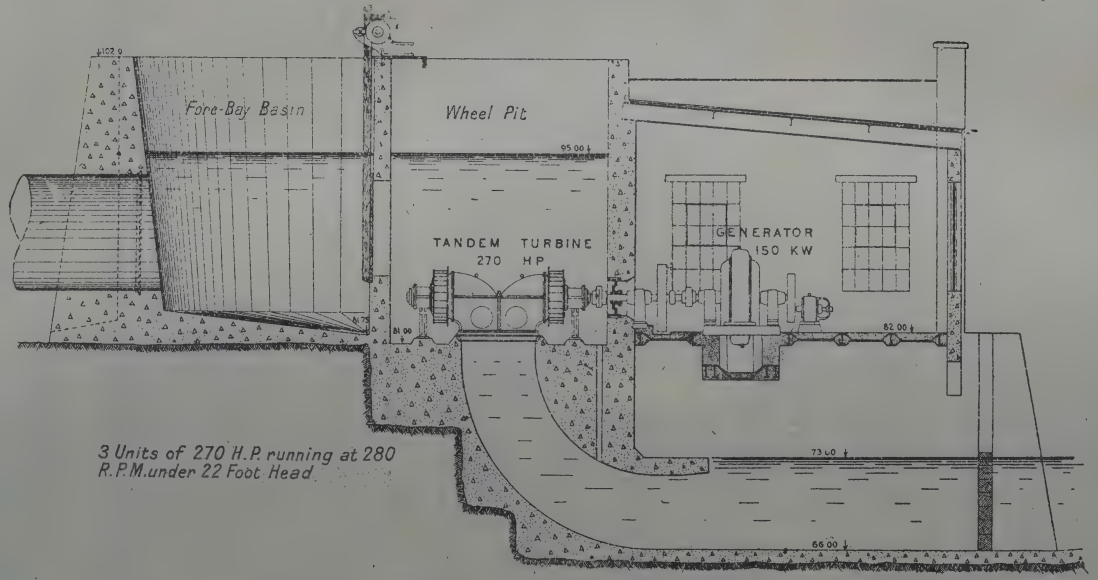


FIG 32.—Three Units of 270 h.p. running at 280 r.p.m. under 22-foot head.

The present construction provides for ten units of 10,000 h.p. each, but 160,000 h.p. will ultimately be developed.

Each generating unit consists of a vertical American turbine guaranteed to have a maximum efficiency of at least 87 per cent. when operating under an effective head of 30 ft. running

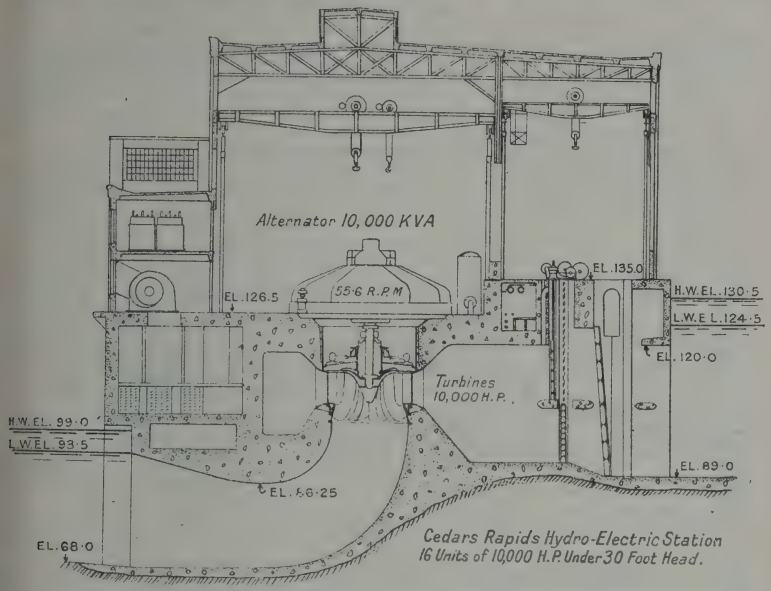


FIG. 33.—160,000 h.p. Plant on the St. Lawrence River (*Cedars Rapids Manufacturing and Power Co.*).

at a speed of 55·6 and developing between 10,000 h.p. and the maximum figure corresponding to wide open gate, provided, however, that the maximum power does not exceed 10,800 h.p. by more than 5 per cent. To each of the main turbines is connected a 10,000 kv.-a. 3-phase 6,600-volt 60-cycle generator of revolving field type.

In the transformer house on shore are the high-tension switches and feeders between transformers and transmission lines. Provision has been made for four transformer banks, two to be of 24,000 kv.-a. capacity and made up of 8,000 kv.-a. single-phase 6,600/110,000-volt units; the other two banks will be of 15,000 kv.-a. capacity, each bank having three 5,000 kv.-a single-phase 6,600/66,000-volt units. The 110,000-volt banks feed transmission lines running to Messina, N.Y., where 60,000 h.p. will be taken by the Aluminium Co. of America. The remainder of the power is transmitted at 66,000 to Montreal, from the 15,000 kv.-a. bank.

THE GRAND'MÈRE MUNICIPAL HYDRO-ELECTRIC PLANT ON THE SHAWENEGAN RIVER, CANADA.

This plant (fig. 34) was built in 1913 by the town of Grand'Mère to supply electricity to its 5,000 inhabitants. It is located at eight miles from Grand'Mère on the Shawenegan River.

The fall utilised is a hundred feet high, and the water is carried to the power house through a four-foot wood stave penstock, 1,100 ft. long.

The equipment consists of two 500 h.p. spiral casing water turbines, running at 600 r.p.m. and each directly connected to an alternating current generator and a direct current exciter. The generators are of 300 kw. capacity, producing electricity at 60 cycles and 2,200 volts. The current is stepped up, by transformers in the power house, to 10,000 volts, transmitted to a substation in Grand'Mère and distributed through the town on 2,200 volts primary circuit and a 110-volt secondary. The power-house floor is situated very high above the low water elevation of the Shawenegan River on account of the extreme high water level, due to the backing up of the St. Maurice River in the spring.

MUNICIPAL HYDRO-ELECTRIC PLANT AT GRAND'MÈRE, SHAWENEGAN RIVER, CANADA.

(Designed by Messrs. Surveyer & Frigon.)

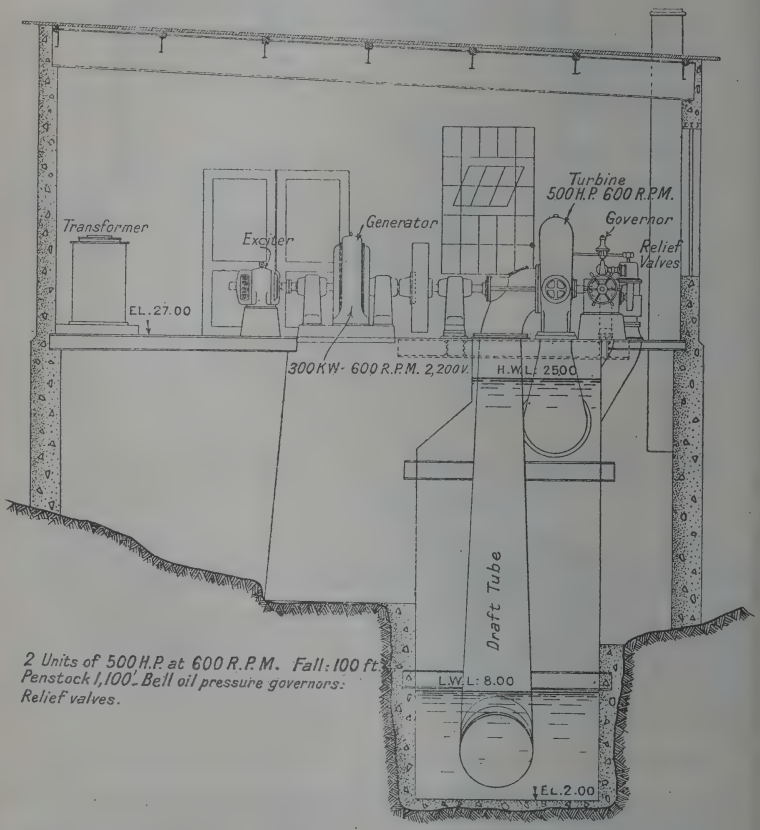


FIG. 34.

Jordan River Development of the Vancouver Island Power Company, Ltd.

The Jordan River plant (fig. 35) of the Vancouver Island Power Company, Limited, is situated at the mouth of Jordan River, which flows into the Straits of San Juan de Fuca about 40 miles west of the City of Victoria, Vancouver Island, Canada.

This development is of particular interest on account of the high head utilised, the static head at the power house being 1,145 ft. The power house is situated on the beach near the mouth of the Jordan River, with the main floor 7 ft. 6 ins. above high tide level. Water is conveyed to the water wheels in the power house from a forebay reservoir through steel pipe lines 9,290 ft. long. The forebay, which is a small equalising reservoir formed by two earth fill dams, is about 1,152 ft. above sea level, giving a static head of 1,145 ft. at the nozzles in the power house.

The power house is composed of two buildings. The first one, completed in 1911, contains two generating units of 4,000 kw. Each of these units consists of a 4,000 kw., 2,200-volt, 3-phase, 60-cycle Allis-Chalmers-Bullcok generator, driven at 400 r.p.m. by a single Doble tangential water wheel of 6,000 h.p. which is mounted on one end of the shaft and overhangs the bearing at the end of the unit.

Water is conveyed from the terminal end of the pressure pipe through a cast-steel flanged taper pipe, which is bolted to the flanged end of the pipe. This taper pipe decreases in diameter from 30 ins. to 24 ins. at the outlet end, where it is bolted to a hand-operated, 24-in., single disc, steel body, rising stem gate valve, which is provided with a by-pass. The steel nozzle casting is bolted to this valve. The jet of water is projected on to the wheel through a Doble needle regulating nozzle, and the governing is done by a type 'Q' Lombard governor, operating the needle gear by means of an oil pressure cylinder. Surges or rams in the pipe line, caused by the quick closing of the main nozzle, are prevented by the Doble relief nozzle. This nozzle is similar to the main nozzle, but is located below it, and the stream does not hit the buckets on the wheel but discharges freely down the tailrace.

The second power house was completed in 1914; it contains a third generating unit composed of an 8,000 kw., 2,200-volt, 60-cycle, 3-phase Canadian General Electric generator, driven at 400 r.p.m. by two Doble tangential water wheels, one mounted on each end of the shaft and overhanging the bearings. The water wheels are rated at 13,000 h.p.

A separate exciter unit is provided for each main generator unit. No. 1 and No. 2 exciters are 100 kw., 125-volt, direct current generators on the same shaft with a 100-h.p. water wheel and a 150-h.p., 2,200-volt induction motor. No. 3 exciter is a 200 kw. generator direct connected to a 200-h.p. water wheel and a 300-h.p., 2,200-volt induction motor.

The transformer equipment consists of two banks of 1,450 kw. transformers (with one spare) and one bank of 3,000 kw. transformers; all of the oil-insulated, water-cooled type. They step the voltage up from 2,200 to 60,000 volts, at which pressure the current is transmitted to Victoria. The transformers are set in compartments along the back wall of the generator room.

Sluice Gates, Strainer Racks, etc.

(James Gordon & Co., Ltd.)

The type of sluice-gate shown by fig. 36 is usually adopted for medium or large size head races, and is made with framing and gearing suitable for single gates up to 8 to 10 ft. wide, and for wider races, frames designed for two or more gates, according to the width of the water channel.

The frames for these gates are constructed of rolled steel joists or channels, making a very simple, cheap, and extremely strong arrangement. For smaller channels the same design and arrangement can be adopted with somewhat lighter construction, or cast-iron frames fitted with cast-iron gates and suitable lifting screws or racks can be used. Strainer racks are usually constructed of flat wrought-iron bars threaded on to rods with pipe distance-pieces placed between each bar to ensure proper spacing, the wider racks being made in s nall sections to facilitate handling.

The water channel between strainer-rack and turbine-pit should be completely covered in, in order to prevent any possibility of foreign matter getting into the channel on the turbine side of the strainer racks.

In streams which are liable to heavy floods, and contain at times a lot of drift wood and foreign matter, it is usually advisable to put down two strainer racks, the first one protecting the intake to the head race, and being made of heavy bars with wide spaces between so as to stop all the larger material, and a fine one to protect the turbines themselves at the lower end of the race close to turbine pits or pipe intakes.

In designing head and tail races for water-power installation, special attention should be paid to their cross-sectional area, which should be ample for the quantity of water to be carried, in order to guard against loss of head when the water is running at full velocity.

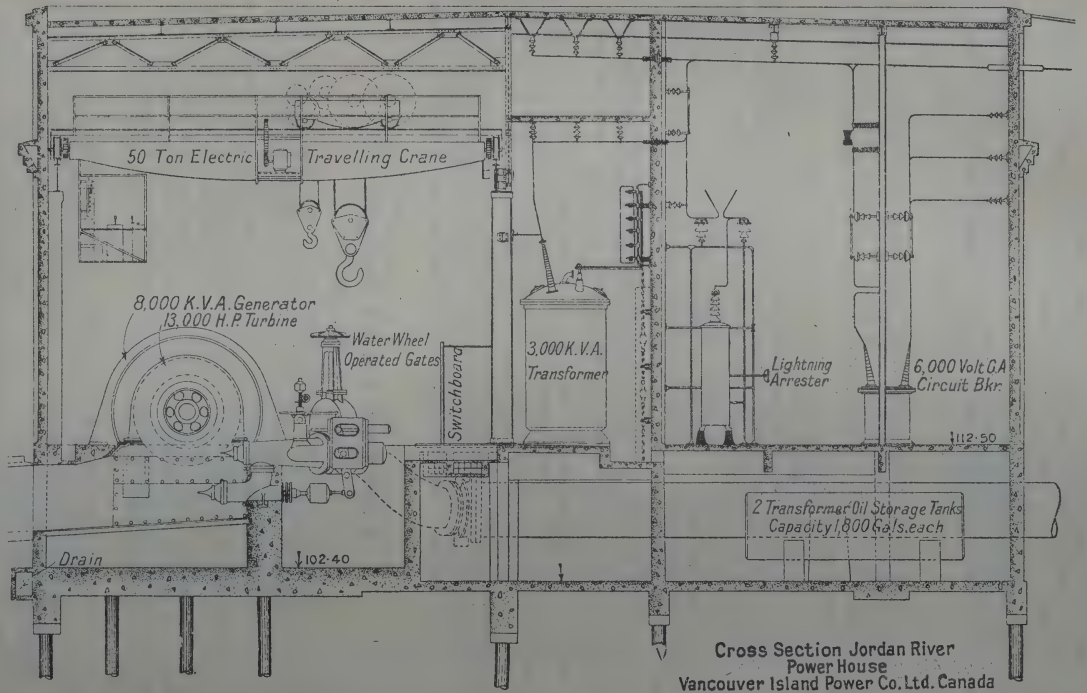
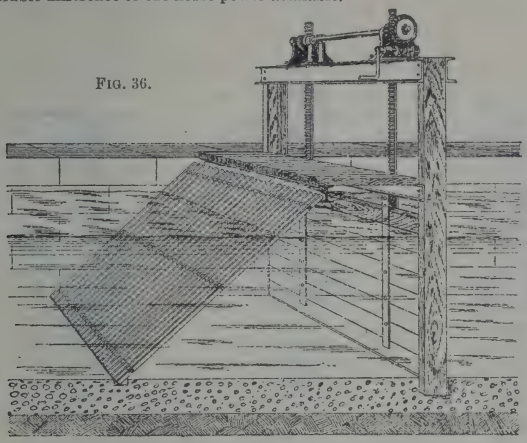

50 Ton Electric Travelling Crane
8,000 K.V.A. Generator
13,000 H.P. Turbine
Water Wheel Operated Gates
Switchboard
3,000 K.V.A. Transformer
Lightning Arrester
6,000 Volt C.B. Circuit Bkr.
112·50
2 Transformer Oil Storage Tanks Capacity 1,800 Gals. each
Drain
102·40
Cross Section Jordan River Power House
Vancouver Island Power Co. Ltd. Canada

FIG. 35.

This is extremely important on plants for low falls, where only a few inches of head will make quite a considerable difference to the horse-power available.

FIG. 36.



The velocity in channels of this kind for low-fall turbine work should not exceed 2 ft. per second, and if possible should be even less than this.

For higher falls, where a slight amount of loss is not very material, velocities as high as 3 ft. or 4 ft. per second can be adopted, but care should then be taken that the banks of the channels are properly protected to prevent erosion.

NIAGARA FALLS INSTALLATION.

The cost of power supplied from the Niagara Falls is 3*l.* 6*s.* per horse-power per annum. The capital outlay on the plant was 45*l.* per horse-power.

GENERATION OF ELECTRICITY BY WATER POWER IN GREAT BRITAIN.

In the Annual Report of the Electricity Commission * it is stated that the total units generated by water power during the year ending March 31st, 1926, was 45,431,048 (from 28 stations), as against 51,093,237 (from 28 stations) in 1925.

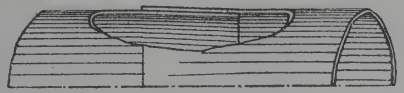
Pipe Lines.

The following table gives thicknesses for different sizes of pipes under varying pressures. The figures are based on a factor of safety of 5, which is a fair average limit to work to for all ordinary work, but in the lower end of high-pressure pipe lines the factor of safety may run up to 8, or even sometimes 9. The working pressures are given in pounds per sq. in., and are for double-riveted or welded steel pipes; the strength of single-riveted pipes is about 30 per cent. less.

Dia. Pipes in Ins.	8	10	12	14	16	18	20	22	24	27	30	33	36	42	48
Thickness.															
$\frac{1}{8}$	240	192	160	137	120	107	96	87	80	71	64	58	53	46	40
$\frac{3}{16}$	360	288	240	206	180	160	144	131	120	106	96	87	80	68	60
$\frac{1}{4}$	480	384	320	274	240	213	192	174	160	142	128	116	106	91	80
$\frac{5}{16}$	600	480	400	343	300	267	240	218	200	177	160	145	133	114	100
$\frac{3}{8}$	720	576	480	412	360	320	288	262	240	213	192	174	160	137	120
$\frac{7}{16}$	840	672	560	480	420	373	336	305	280	248	224	203	186	160	140
$\frac{1}{2}$	960	768	640	549	480	427	384	349	320	283	256	232	213	182	160

In practically every case with modern hydraulic power plants, steel piping, either riveted or welded, is used. Fig. 37, page 1408, shows types of joints which can be adopted for this class of piping. The slip joint (*a*) is suitable for low head pressures and for pipes constructed of thin

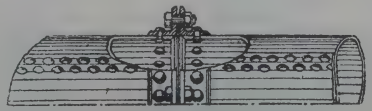
* *Generation of Electricity in Great Britain, year ending March 31st*, 1926. H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.



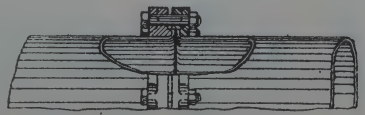
(*a*) Tapered Slip Joint for low pressures.

(*b*) Socket and Spigot Joint, packed with lead and yarn.

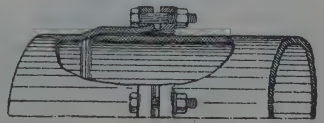
(*c*) Loose Collar Joint, packed with lead and yarn.



(*d*) Flanged Joint for riveted pipes.



(*e*) Flanged Joints for welded pipes.



(*f*) Patent Muff Joint for high pressures.

FIG. 37.

plates. The joint is made by one pipe being tapered slightly outwards and the other slightly inwards, the tapers being coated with paint, cement grout, or some similar composition, and driven into each other until they form a water-tight joint.

The socket and spigot joint (*b*) for lead and yarn packing is a very useful one for low or medium head pressures, as it has some amount of flexibility, and also allows under all ordinary conditions for any expansion or contraction in the pipes being taken up in the joints.

The collar joint (*c*) is another type of lead joint to which the same conditions practically apply.

For higher pressures ordinary forms of lead joints do not always prove satisfactory, owing to the danger of the jointing material being blown out by the pressure of the water. In these cases some form of flanged joint must be used, two of which are shown—one (*d*) with the flanges riveted on to the pipes, and the second (*e*) with the pipe ends turned up and fitted with loose flanges bolted together. The patent muff joint (*f*) is of a special type and allows for a large amount of expansion and contraction in the pipe line, and can be constructed to keep perfectly tight under the heaviest pressures which have to be dealt with.

Anchorage.—One of the most important points in the design of pipe lines is the provision for anchorage on the line itself, and especially at the foot of the line near to the power house, in order to prevent any possibility of pipe line movement being transmitted to the turbines or Pelton wheels. The pipes can be efficiently anchored in several ways, the more common forms of anchorages being to provide cast iron or steel thrust blocks, forming a foot or base on the pipe itself, which are firmly secured to heavy concrete or rock foundations; or special anchoring pipes can be provided with thrust flanges and solidly set into heavy blocks of masonry or concrete.

Expansion and *Contraction* of long lines of piping also require careful attention, and it is necessary in long straight runs of pipe to provide either a type of joint capable of taking up expansion and contraction, or to fit the pipe line with special expansion joints, which are usually constructed of cast iron or steel and of the sliding socket and spigot type.

Relief Valves.—Where the length of a pipe line is excessive in proportion to the head of water, and the plant has to deal with heavy and sudden load changes, it is necessary for the safety of the plant and pipe line to provide efficient relief valves to prevent serious water-hammer effects. These, however, should be of special design, as the ordinary forms of spring-loaded relief or safety valves are worse than useless under conditions of this kind, as if they are set to open with only a small rise in pressure the reaction of the discharging water will nearly always prevent them closing again, and if they are adjusted in the ordinary manner the pressure rises too high before they open, and the sudden closing of the valve by means of the heavy spring employed often causes worse water-hammer effects than there would be with no relief valve at all.

Relief valves for hydraulic power work should be so designed that they will open immediately with a very small rise in pressure, and in proportion to the pressure increase, the closing being effected by some form of oil cataract or dashpot which can be adjusted so that the time of closing will coincide with the time required for slowing up the moving column of water.

The best form of relief valve, however, is one which is directly connected to the gate or nozzle-operating mechanism of the power unit, and adjusted so that it will open in proportion to the decrease of gate or nozzle opening, and be closed again slowly by means of an oil dashpot or cataract. With a relief valve of this form the pressure rise is anticipated, and therefore very good results can be obtained. With a relief valve independent of the Pelton wheel or turbine rise in pressure must take place before it can come into operation.

Where Pelton wheels fitted with deflecting nozzles are used, no relief valve is generally necessary, as the quantity of water discharged remains the same for any load, or is slowly cut off by hand.

(*James Gordon & Co., Ltd.*)

Water Hammer in Pipes.

In the design of pipes (p. 1364) it was pointed out that the pipes had to be designed to resist the static head plus the head due to water hammer. The magnitude of this extra pressure depends, among other things, upon the rate of change of the velocity of the water in the pipe, and in some cases also upon the length of the pipe.

It is shown in treatises on Hydraulics that when a valve is *suddenly* closed the pressure set up due to water hammer is independent of the length of the pipe and it only depends upon the velocity of flow just before closing takes place.

Let

V = velocity of flow of water in ft. per sec.;

P = pressure set up in lb. per sq. in. due to water hammer,

then,

$$P = 63 \cdot 5\, V,$$

where the elasticity of the pipe is neglected; if the elasticity is taken into account the problem becomes rather more complicated. (See Goodman's 'Mechanics Applied to Engineering," vol. i. pp. 699–703, and vol. ii. pp. 411–413.)

The question arises—What is meant by *sudden* closing? In the references given, it is shown that when a valve is rapidly closed a compression wave traverses the pipe with a velocity of 4,720 ft. per sec., *i.e.* the velocity of sound in water. The closing is termed *sudden* if the time taken in closing the valve is equal to, or less than, the time taken by this compression wave to make the return trip of the pipe, or to traverse a distance equal to twice the length of the pipe. Thus if the length of the pipe is 6,000 ft., the time taken by the wave in traversing the pipe and returning is

$\frac{2 \times 6{,}000}{4720} = 2{\cdot}54$ seconds. The pressure due to water hammer for a velocity of 5 ft. per sec. will therefore be 317 lb. per sq. in. if the time of closing be 2·54 secs. or less.

When the valve is closed more slowly than this the pressure due to water hammer will always be less than when the closing is sudden. Many expressions have been put forward to cover this case of gradual closing, but some obviously give absurd results since they give a higher pressure for gradual than for sudden closing. Even the expressions which do not err in this particular way do not all agree, and unfortunately there are no reliable experimental data on record to act as a guide; many experiments have been made, but in every case there have been disturbing causes which have marred the value of the results. The following expression is believed to give reasonably accurate results; it being assumed that the pressure set up by gradual closing is less than that with sudden closing in the ratio:

$$\frac{\text{Pressure with gradual closing}}{\text{Pressure with sudden closing}} = \frac{Pg}{P} = \frac{Tr}{\text{Time taken in closing the valve } (Tg)},$$

where

$$Tr = \frac{2L}{4720}, \text{ L being the length of pipe in ft.};$$

then,

$$Pg = 63{\cdot}5\ V \frac{Tr}{Tg}, \text{ provided } Tg \text{ is equal to or greater than } Tr.$$

In the example given above, L = 6,000 ft.; V = 5 ft. per sec.; $Tr = 2{\cdot}54$ secs.

The pressure set up due to water hammer will be 317 lb. per sq. in. for any time of closing less than 2·54 secs.; if the valve be uniformly closed in, say, 4 secs. the pressure due to water hammer will be, approximately, $Pg = 63{\cdot}5 \times 5 \times \frac{2{\cdot}54}{4} = 200$ lbs. per sq. in., and if closed in 5 secs. it will be 160 lbs. per sq. in., and so on.

These pressures are over and above the static pressure of the water in the pipe. As a rule the pressure due to water hammer should not exceed 25 per cent. of the static pressure.

(*John Goodman, M.I.C.E.*)

SECTION XXV

PART V

HYDROSTATIC PRESS—HYDRAULIC RAMS—HYDRAULIC LIFTS—HYDRAULIC BOLT FORCERS—HYDRAULIC RIVETERS.

The Hydrostatic Press.

P = Power or pressure applied. W = the weight or resistance, in lbs.
l = length of lever, in inches or feet. l' = length of fulcrum, in inches or feet.
A = Area of ram, in square inches. a = Area of piston, in square inches.

$$\frac{Pl\,A}{l'a} = W. \qquad \frac{Wl'a}{Pl} = A. \qquad \frac{Wl'a}{Al} = P. \qquad \frac{PAl}{Wl'} = a.$$

Designing Ram Cylinders.

TO COMPUTE THE THICKNESS OF THE METAL TO RESIST A GIVEN PRESSURE.

(1.)

RULE.—Multiply the pressure per square inch in pounds by the diameter of the cylinder in inches, and divide the product by twice the estimated practical tensile resistance or *value* of the metal in pounds per square inch, and the quotient will give the thickness of the metal required.

EXAMPLE.—The pressure required is 9,000 lbs. per square inch, and the diameter of the cylinder 5·3 inches; what is the required thickness of the metal or cast iron?

$$\frac{9000 \times 5{\cdot}3}{6000 \times 2} = \frac{47700}{12000} = 3{\cdot}975 \text{ ins.}$$ The *value* of the metal is here taken at 6,000.

(2.)

The following formulæ, due to F. B. Kleinhans (*Engineering News*), will be found convenient in determining the proportions of the ram cylinders:—

$$T = \frac{P\pi D_1^2}{2000 \times 4} = 0{\cdot}0003927\,PD_1^2; \qquad T_1 = \frac{PD_2}{2(S-P)};$$

$$T_2 = \frac{D_2}{2}\sqrt{\frac{P}{S}}; \qquad T_3 = \frac{D_2}{2}\sqrt{\frac{3P}{4S}}.$$

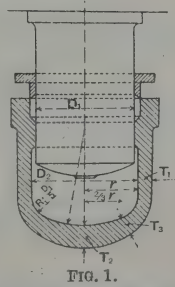


FIG. 1.

where,

T = load on rams in tons; P = water pressure in lbs. per sq. in.; S = safe fibre stress of material; D_1 = diameter of ram in inches; D_2 = diameter of cylinder in inches; T_1, T_2, T_3 = thickness of cylinder walls.

(3.)

A steel containing 0·4 per cent. of carbon is perfectly satisfactory for press, accumulator, and intensifier rams, while for pump rams a steel with a carbon content of 0·6 per cent. is generally preferred, on account of its greater hardness and durability. Stainless steel is now being extensively employed for pump rams.

Wear on the packings is considerably reduced when the ram is electro-coppered or fitted with a bronze liner, and, in consequence, the rams of machines operating at high pressures are invariably protected in this way.

In short-stroke presses the liner is carried up to a point just beyond the top of the packing—that is, almost the full length of the ram. But on long-stroke machines for baling and similar operations, where the greater part of the stroke is made at a low pressure, it is sufficient if the ram is cased for a short length only—from the end to the point at which high pressure is developed. The thickness of bronze liners varies, from $\frac{1}{4}$-in. for small rams to about $\frac{5}{8}$-in. for a ram 30 ins. diameter. The alternative to a liner is electro-coppering, the thickness of which may be anything from $\frac{1}{32}$ to $\frac{1}{8}$-in., but average requirements are met by a coating $\frac{1}{16}$-in. thick. The copper may extend just over the end of the ram or finish in a recessed joint on the wall close to the bottom. The bottom should not be coppered.

The following formula, due to Bach, for determining the thickness of the wall of a ram subjected to external pressure is in common use:

$$T = \frac{D}{2}\left(1 - \sqrt{\frac{f_c - 1{\cdot}7P}{f_c}}\right),$$

where,

T = thickness of wall in ins.; D = external diameter of ram in ins.; P = pressure in tons per sq. in.; f_c = compressive strength of material in tons per sq. in.

From this formula, a cast-iron ram 16 ins. diameter for a pressure of 2 tons per sq. in., assuming a stress of 6 tons per sq. in., gives a thickness of $2\frac{5}{8}$ ins., which is in agreement with practice.

For a ram under internal pressure the formula devised by Lamé is considered to be the most reliable.

$$T = \frac{D}{2}\left(\sqrt{\frac{f_t + P}{f_t - P}} - 1\right)$$

where,

T = thickness of wall in ins.; D = internal diameter of ram in ins.; P = pressure in tons per sq. in.; f_t = tensile strength of material in tons per square inch.

For a 16-in. ram, assuming a core diameter of 8 ins. and a stress of 2 tons per sq. in., the required thickness is 4 ins.

For low pressures and rams of small sizes the thickness of the wall as determined by the above rules, will need to be increased in order to ensure the production of generally sound and reliable castings.

A rough rule for small rams is to make the bottom flat, the end of the core semi-spherical, and the thickness at the centre equal to that of the wall. Another rule, applicable to larger rams, consists in dishing the end slightly, making the radius the same as the diameter of the ram, and the thickness about 25 per cent. greater than that of the wall.

(*Abstract of Article by H. S. C., "Machinery," January* 22, 1925.)

The Hydraulic Ram.

The water working the ram is supplied through the pipe S (fig. 2), and escapes through an opening at *o*, until it has gained a velocity sufficient to raise the valve or ball, B, which

suddenly stops the current, and causes an excessive pressure in the ram, R, which opens the valve or ball, C; the water is forced into the vessel and air-chamber, A, and finally through the delivery-pipe, *d*, to its destination. When equilibrium of pressure is restored between S and R, the ball, B, falls, and the operation is repeated. The ram can make as many as 200 strokes per minute, depending upon its size.

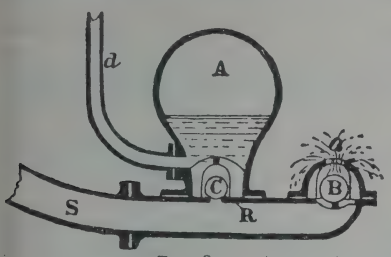


FIG. 2.

The length of the supply-pipe, S, should not be less than 5 times the height of the fall. But the pipe may be made 10 times, or more, the height of the fall.

In ordinary cases the hydraulic ram returns about 50 per cent. of the natural effect. That is, the quantity of water, *q*, multiplied by the height, *h*, of the delivery above the ram will be about 50 per cent. of the quantity of water, Q, working the ram, multiplied by the head of fall, H, in the same unit of time.

$$qh = 0{\cdot}5QF. \qquad q = \frac{0{\cdot}5QH}{h}. \qquad Q = \frac{2qh}{H}.$$

Q and *q* can be expressed in any unit of volume or weight. F and *h* can be expressed in any unit of length.

If

Q and *q* = cubic feet per minute;
F and *h* = fall and height in feet;
L = length in feet, and D = diameter in inches of the supply-pipe, S;
l = length, and *d* = diameter of the delivery-pipe, *d*,

then,

$$D = \sqrt[5]{\frac{2Q^2(L + 5D)}{F}}, \qquad d = \sqrt[5]{\frac{4q^2(l + 5d)}{h}}.$$

TABLE OF RESULTS OF OPERATIONS OF HYDRAULIC RAMS.

Number of Strokes.	Height of Fall.	Height of Elevation.	Water Expended.	Water Raised.	Useful Effect.
Min.	Feet.	Feet.	Cubic Feet.	Cubic Feet.	
66	10·06	26·3	1·71	·543	·9
50	9·93	38·6	1·93	·421	·85
36	6·05	38·6	1·43	·169	·75
31	5·06	38·6	1·29	·113	·67
15	3·22	38·6	1·98	·058	·35
10	1·97	38·6	1·58	·014	·18
—	22·8	196·8	·38	·029	·67

NOTES ON HYDRAULIC RAMS.

Working Fall.—Any working fall, from say, 18 ins. up to 100 ft., will do to work a ram, but the more the working fall obtained (up to about one-third of the total height the water has to be raised above the ram), the less the ram will cost to raise a given quantity, and the less driving water will be required to lift that quantity.

In sluggish streams where it is inadmissible to put a dam in the stream, it is sometimes necessary to carry the driving water several hundred yards down stream, in earthenware pipes running nearly level, before a few feet fall can be obtained; but where driving water is plentiful

It is often less costly to be content with a small working fall and have a more powerful ram, than to go to the expense of obtaining the greater fall, for the sake of enabling a smaller ram to do the work required.

Height to Force.—The height to force must be estimated from the level of the ram or bottom of the working fall.

Rising Main Pipe.—Rams will force to a distance of several miles. In one case a ram is in use forcing to a distance of three miles and to an elevation of 340 ft., with a working fall of only 10 ft.

Driving Water.—The quantity of driving water required to work a ram depends upon the amount of working fall available, the height to raise the water, and the quantity of water it is desired to raise. Rams can be made to work under favourable conditions with less than one gallon of water per minute.

In giving the quantity of water available to work a ram, it is useless to say there is 'sufficient to fill a pipe of certain size,' unless the gradient of the pipe be given at the same time, in order that the velocity of the water in the pipe may be ascertained. Unless the water be practically unlimited for the purpose required, it is preferable to make a positive measurement of the water. A ready method of measuring the flow of very small streams is to dam up the stream with a little puddle, and insert a pipe in the dam to form a spout. Then let the water flow into a bucket for, say, exactly 15, 30, or 60 seconds, and carefully measure out the contents of the bucket in pints, when the total flow in gallons per minute or hour can be calculated. If the stream be too large to measure with one spout, two or more spouts can be inserted in the dam, and each of them measured separately. If the ram required be a large one, and the volume of driving water available be too great to measure in this way, it should be gauged by means of a weir board.

Modern Hydraulic Rams.

Fig. 3 shows a modern form of ram.

There is a minimum ratio of lift to fall at which an ordinary ram will not work. This ratio is usually somewhere about 4 to 1.

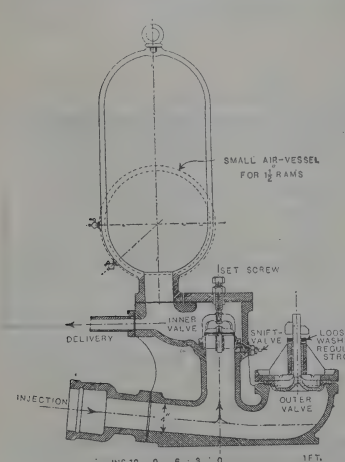


Fig. 3.

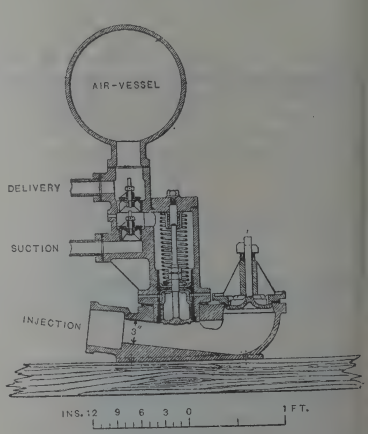


Fig. 5.

Increasing the stroke of the outer valve increases the quantity of water delivered, but reduces the efficiency, and *vice versa*.

If a ram is required to give the largest possible delivery with a limited supply of water, it is an advantage to use a large ram and give its valve a short stroke; if there is an abundance of water, it is cheaper to use a small ram with a long stroke.

A mushroom is better than a ball valve.

It has been found good practice to allow 1 sq. in. of area through the inner valve for every gallon of water to be delivered per minute. In practice a ram will not work without an air-vessel, and it must be kept properly charged with air. Certain waters in passing through the ram are found to give off air in sufficient quantity to keep the vessel charged: where, however, water has to be used which does not possess such a property, some method of supplying air must be adopted, such as a 'Snifting Valve' (p. 1265).

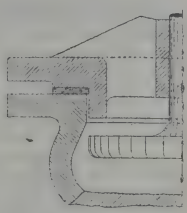


FIG. 4.

The area of the annulus between the edge of the outer valve and the body should be made rather less than that through the valve itself, so that the water should have a high speed locally and thus tend to close the valve rapidly. Fig. 4 shows the half-section of the ram body and valve, showing this contracted area.

The longer the fall pipe in relation to the fall, the better for both efficiency and capability of functioning of the ram under all ratios of lift to fall up to 24 to 1; and the shorter the pipe, the smaller the ratio above 4 to 1 at which it will work. In general it may be said that the best results are obtainable with fall pipes having a length of from 6 to 10 times the fall.

(*Anderson.*)

HYDRAULIC RAM FOR WORKING WITH DIRTY WATER.

In this type, fig. 5, water from one source of supply may be pumped by using water under a small head from another source. It is usually employed to pump clean water from a well or spring by means of dirty or contaminated water from some other source. The efficiency of the arrangement is rather low—*i.e.* from 35 to 56 per cent.

(*Anderson.*)

Hydraulic Lifts.

A speed of 200 to 400 feet per minute is usual.

For packing the ram, hat-shaped packing is preferable to the U-shaped, as it causes less friction and lasts longer. Leather packing is the best, but the most usual form is 'hydraulic' flax or hemp in stuffing boxes.

The cylinder of the lift should be absolutely plumb.

In well-constructed direct-action lifts the total friction should not be more than 5 per cent. In suspended lifts the friction varies from 15 to 20 per cent.

An air-vessel placed between the valve-box and ram cylinder will prevent any shock in the cage from the passing of the water when the valve is opened or closed, or when the water is turned into the waste-pipe.

The gear rod or rope for high-speed lifts should have a range of from 5 to 6 feet (from full pressure to full exhaust), so that the man working the lift may have proper control over it.

The cam motion opening the valve should open the latter very gradually.

The high pressure system of working hydraulic lifts is the most economical in every way, and it enables high working speed to be obtained.

Public supplies of high pressure hydraulic power are available in London, Liverpool, Hull, Manchester, Birmingham, and Glasgow.

Direct acting ram lifts are usually adopted in this country for moderate heights; the machine consists of a hydraulic cylinder having a flange cast on its upper end resting on the foundation at the top of the well bored to receive it, and a simple platform or cage moving between guides firmly screwed to the upper end of the ram working in the cylinder. The valve controlling the action of the lift is worked by a rope, or rod passing through the platform. Tappet gear automatically stops the lift at the top of its stroke, and permanent stops are also fitted to prevent overtravel. Alternative rams can be fitted to meet varying loads.

The suspended type of lift is less expensive than the direct-acting lift when the height of travel is considerable, or where there are difficulties in boring the well for the cylinder. A factor of safety of 10 to 15, to 1, on all ropes (collectively) is ample; very high factors mean, in most ordinary cases, that ropes become too large in diameter to ensure long life. The ram can be placed in the lift shaft or in the roof, or basement, either vertically, horizontally, or on an incline. Safety gear should be fitted to come into immediate action in case the ropes break. The valves are similar to those used for the direct-acting type.

The direct ram lift is becoming usual in America even in the highest buildings on account of its safety. The cylinder consists of a bored well lined with stout Artesian tubing, and failure can hardly occur, for the pipes fit closely in the bored rock. The outlet piece if well made and attached to the lining tube is not apt to fail. Balances are employed so that the long rams when out are under tension.

The guide-bars of lift should preferably be fixed to stone templates with bolts let in and secured by lead, and the bars fixed by nuts. This is preferable to wooden bricks, which are liable to shrink. The V guide-bar is the best form.

Electric push button control of lift and gates can be fitted to either type of lift.

Each elevator shaft of the 'Empire Building,' in New York, is walled up independently as high as the third floor, and is made a close fit for the car, the last 50 feet of the drop of each elevator thus forming an air-cushion. If the car fall, the air is confined in the bottom of the shaft, and, by its gradual escape, lets the elevator down easily without shock. It is stated that a car has been dropped from the twentieth floor of the building without breaking eggs placed in the car. The pressure of the air caused by a fall from the top floor, a height of 290 feet, is calculated to be about 3½ lbs. per sq. in. The estimated proportion between the depth of the air-cushion and the length of the drop is as 1 to 6. The only precaution necessary seems to be to make the doors of the lower-floor entrances air-tight.

In hydraulic lifts trouble sometimes arises owing to water leaking from the ram glands and falling on to the ropes. Where this possibility exists the ropes should be well protected with a coating of tallow and blacklead well mixed together, otherwise the water will find its way into the interior of the rope, and by rusting the wires will rapidly weaken them. The danger in such cases lies in the fact that there is often no external evidence to show that the ropes are unsafe. In one instance the two supporting ropes of a lift broke without warning near to their anchorage to the cylinder, causing the lift car to fall the full height of the lift well, wrecking the lift and killing the attendant. On examination of the broken ropes it was found that the internal wires had been damaged by the water to such an extent that they were quite brittle and without strength, but no broken wires were noticeable at the point of failure, before the accident. The best way to prevent such failures is to design the lift so that water cannot possibly fall on the ropes, or, if this be not feasible, to fit drip trays or other appliances to keep the water off the ropes if leakage should occur.

Danish Regulations concerning the Arrangement and Working of Lifts and Hoists driven by Machinery.

The lift cage must be closed in all round, except at the entrance, either with solid sides and roof or with trellis-work having openings not exceeding 1 in. It must be lit up inside, and must contain a notice of the number of passengers allowed. From any point in its travel there must be the means of signalling if in difficulty. Except where their adoption would be attended with serious inconvenience, entrance-doors must be fitted inside the cage itself; these must not open outwards, and must be kept locked while travelling. Where they are dispensed with, at every landing the lift well must be fenced to the full height on the entrance side, with no inward projection; and the clearance between the cage and the well must nowhere exceed 2 ins. In ram lifts the cage and ram must be securely joined together. A hanging cage must be suspended by at least two ropes or chains, each of which must alone be strong enough to carry ten times the weight of the cage fully loaded. Each must also be connected with either a stopping apparatus or a brake, so arranged that the cage shall either be stopped in a fall of not more than 1 ft. or else shall be let down at a speed not exceeding 3 ft. a second. Lifts worked by a winding drum must be provided with a contrivance for preventing the rope from becoming slack in the event of the cage sticking in its descent, and at the same time for stopping the drum. Every counterbalance weight is likewise to be hung by at least two ropes or chains, each having ten times the strength necessary to carry the weight. The counterbalance weights must be securely guided, and the space in which they work must be securely fenced, so as to guard against all possible risk of accident.

See also page 928.

Hydraulic Bolt Forcers.

Fig. 6 represents Young's Hollow-ram Portable Hydraulic Bolt Forcer, constructed principally for forcing in and out coupling bolts, though it is also suitable for forcing pins, etc., in and out of machines. The apparatus consists of a hollow steel sliding ram, the ends or tails of which project through the front and back respectively of the cylinder. Inserted in this hollow ram is a steel drift, which passes right through the centre of ram; a head is forged on one end of the steel drift, and a shoe for the bolt is fitted on the other. The method of working is the same as in any ordinary hydraulic pump, viz. the fluid is forced by the pump from the reservoir into the cylinder, and the ram is gradually forced forward until it presses the shoe, on the end of the steel drift, against the bolt to be forced out. Should the bolt show no sign of moving out of coupling when the maximum hydraulic pressure has been obtained, a sharp blow is given with a hammer on the head of the drift, which transmits a shock or 'jar' to the bolt and starts it from its position, and it can then be ejected, either by pumping the ram forward or knocking it out by

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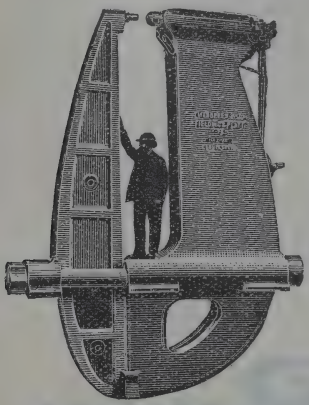

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hammering on the head of the steel drift; this is a valuable feature, as the bolts are generally rusted in their seats, and a sharp blow is very efficacious in starting a bolt or pin under powerful and steady pressure.

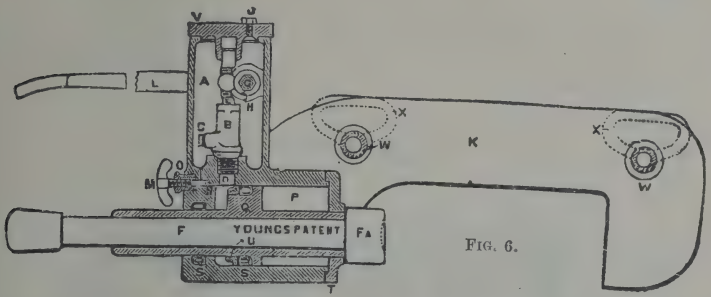

FIG. 6.

A, cistern; B, pump; C, suction valve, spring, stopper, and gauze strainer; D, delivery valve spring, and stopper; E, pump plunger; F, steel drift; F A, drift shoe; G, pump shaft; H, pump tumbler with set screw; J, air screw; K, arms; L, working pump lever; M, stop and release valve; N, stop and release seat; O, stop and release valve gland; P, cylinder; Q, hollow ram; SS, U leather for packing; T, cylinder cover; U, packing ring; V, cistern lid; W, distance pieces; X, handles.

This machine, fitted with crosshead instead of arms as shown, is largely used for forcing winch drums from their shafts.

DETAILS OF HYDRAULIC FORCERS.

Power	tons	20	20	30	40	50	75
Width of gap	inches	9	15	12	14	16	18
Run out	inches	3	3	4	5	5½	6½
Height	inches	15½	15½	16½	17	18	18½
Suitable for bolts approx. .	inches diam.	2	2	2½	3	4	5
Approx. weight	cwts.	1¾	2	3	4	4½	6¼

The body of the apparatus can be separated from the arms or claws by withdrawing two small sliding bolts, when the machine can then be carried in two separate pieces, the body placed first in position on the shaft, and the claws lifted up afterwards and fixed, without having to screw and unscrew any bolts. A gauge supplied with each machine indicates the pressure.

Hydraulic Riveters.

Fig. 7 represents the Tweddell hydraulic riveter (manufactured by Fielding & Platt, Ltd. Atlas Works, Gloucester), a tool which is very largely used for riveting purposes.

In this machine, by means of two rams, one inside the other, a pressure, in the first place, is brought to bear on the plates by means of an annular tool, A, encasing the moving capping die, B. When the plates are thus brought together, the capping tool heads the rivet; and after this operation is performed, the combined power of both rams (C and D) is applied on the head of the rivet, and through the shoulders of same on to the plate surrounding it. The size of work is only limited by the power of the machine, but some very good work in cold riveting, up to 1 inch diameter, has been done by these machines. An advantage of the machine is that by substituting a riveting die for the annular closing tool, A, a second and smaller power is available. This adds very much to the general use of the tool, for it is impossible to keep such a powerful machine in constant work. Excellent work had been done by this machine when using plain bolts—*i.e.*, making both heads of the rivet in the act of closing it. This machine is capable of exerting three different powers, which is a great advantage. Although these machines are made

up to 200 tons power, very little more high-pressure water is required, owing to the use of the auxiliary piston, E, which draws forward by means of the lug, F, the two main rams, C and D, the space left behind being filled with low-pressure water through check-valves, G and H, from a tank, J.

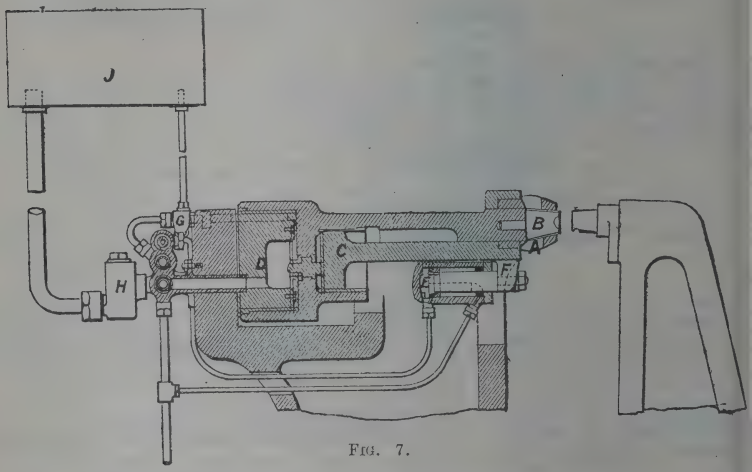

FIG. 7.

In cases where boiler-ends are placed with their flanges inwards, the machine shown by Fig. 8 is used. In this machine there is a hinged arm, A, which is first of all lowered into the boiler, and when restored to its proper position, A′, the riveting is proceeded with.

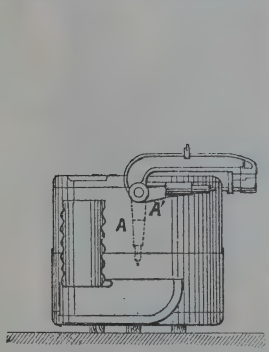

FIG. 8.

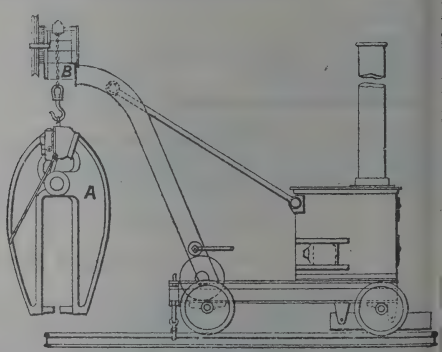

FIG. 9.

Fig. 9 shows a portable riveter, A, slung from a travelling crane. By means of the iron girder, B, this riveter is moved across the work to be riveted, whilst the crane with its rivet heating oil or reverberatory furnace is traversed along. Riveters of this type were largely used in the construction of the Forth Bridge.

SECTION XXVI

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SANITARY ENGINEERING—SEWERS—SEWERAGE—FLUSHING AND VENTILATING SEWERS AND DRAINS—SEWAGE TREATMENT AND DISPOSAL – LOCAL GOVERNMENT BOARD'S REQUIREMENTS—HOUSE DRAINAGE (pp. 1421-1444)

(Contributed by E. J. Silcock, M.Inst.C.E., F.G.S., F.S.I.)

PART II

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(Contributed by Reginald Ryves, Assoc.M.Inst.C.E., M.Cons.E.)

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(With Contributions by Reginald Ryves, Assoc.M.Inst.C.E., M.Cons.E., W. H. Booth, F.G.S., J. H. Horobin, R. Fairfax Middleton, Assoc.M.Inst.C.E., and H. F. Rutter, M.Inst.C.E.)

SECTION XXVI

PART I

SEWERS — SEWERAGE — FLUSHING AND VENTILATING SEWERS AND DRAINS — SEWAGE TREATMENT AND DISPOSAL — LOCAL GOVERNMENT BOARD'S REQUIREMENTS — STANDARDS OF PURITY—HOUSE DRAINAGE

Contributed by E. J. Silcock, M.Inst.C.E., F.G.S., F.S.I.
(Joint author of Moore and Silcock's 'Practical Treatise on Sanitary Engineering.')

SEWERS

Rate at which Rainfall Reaches a Sewer.

C = cubic feet per second per acre reaching sewer; c = average cubic feet of rainfall per second per acre during heaviest fall; S = average slope of ground in feet per 1,000 ft.; a = number of acres drained; K = ·75 for paved streets, ·625 for ordinary cases, ·31 for suburbs with gardens, lawns, and macadamised streets.

$$C = Kc\sqrt[4]{\frac{S}{a}}$$ (*Burkli-Zeigler.*)

(For other formulæ see 'Rainfall,' p. 1461.)

Discharging Capacity of Sewers.

R = hydraulic mean depth in feet; S = sine of angle of inclination; v = velocity in feet per second.

$$v = 124\sqrt[3]{R^2}\sqrt{S}$$ (*Crimp and Bruges.*)

Discharge from the Submerged Orifice of a Culvert.

D = diameter of orifice in inches; L = length of out-fall culvert in feet; W = quantity discharged in cubic feet per minute; H = head in feet.

$$D = \cdot 531\sqrt[6]{\frac{LW^2}{H}}$$ (*Eytelwein.*)

Discharge from Culverts.

The important road improvement works now in progress in the United States have shown the need for further information regarding the capacity of culverts; the more particularly because pre-existing data have been derived almost exclusively from experiments on ordinary straight-walled metal, stoneware, or concrete ducts. Of recent years, however, considerable use has been made of corrugated metal pipes, which offer a much greater resistance to the flow than straight-walled conduits. With a view, therefore, to fix the relative merits of different types of culvert, the Bureau of Public Roads of the U.S. Department of Agriculture arranged for a very comprehensive series of tests to be made at the hydraulic laboratory of the State University of Iowa, where an ample supply of water was available, as well as facilities for the accurate measurement of heads and discharges. The work was carried out under the direction of Mr. D. L. Yarnell and Professors F. A. Nagler and S. M. Woodward, and is described in detail in Bulletin No. 1 issued by the University, Iowa City, Iowa, U.S.A. (the cost of the report is one dollar). In all,

over 3,000 experiments were made, in part on pipe culverts, of concrete, vitrified clay, and corrugated metal, and in part on concrete box culverts. The pipe culverts ranged in size from 12 in. to 30 in. in diameter, and the box culverts from 2 ft. square to 4 ft. square, and, in addition, further tests were made with rectangular box culverts of other than square section. As the result of their observations the authors propose the following formulae for the discharge from pipe culverts 30·6 ft. long, with straight endwall entrances :—

Concrete pipe with bevelled lip upstream, $Q = 4{\cdot}61\ D^{2.18}\ H^{0.50}$

Vitrified clay pipe with bell end up-stream, $Q = 5{\cdot}07\ D^{2.05}\ H^{0.50}$

Concrete pipe with square-cornered entrance, $Q = 4{\cdot}40\ D^{2.09}\ H^{0.50}$

Corrugated metal pipe, $Q = 3{\cdot}10\ D^{2.31}\ H^{0.50}$

where Q = discharge in cubic feet per second ; D = diameter of pipe in ft. ; H = difference in ft. of water level between the two ends.

More general formulæ applicable to culverts of any size and length when flowing full bore are :—

Concrete pipe with bevelled lip entrance,

$$Q = \frac{A\sqrt{2gH}}{\sqrt{1{\cdot}1 + \frac{0{\cdot}026\ L}{D^{1.2}}}}$$

Vitrified clay pipe, regular bell-end upstream,

$$Q = \frac{A\sqrt{2gH}}{\sqrt{1 + 0{\cdot}023\ D^{1.0} + \frac{0{\cdot}022\ L}{D^{1.0}}}}$$

Concrete pipe, square-cornered entrance,

$$Q = \frac{A\sqrt{2gH}}{\sqrt{1 + 0{\cdot}31\ D^{0.5} + \frac{0{\cdot}026\ L}{D^{1.2}}}}$$

Corrugated metal pipe,

$$Q = \frac{A\sqrt{2gH}}{\sqrt{1 + 0{\cdot}16\ D^{0.6} + \frac{0{\cdot}106\ L}{D^{1.2}}}}$$

where A = cross-sectional area of pipe in sq. ft. ; L = length of culvert in ft.

For concrete box culverts the following formulae are proposed, in which R denotes the mean hydraulic radius :

Box culverts with rounded entrance,

$$Q = \frac{A\sqrt{2gH}}{\sqrt{1{\cdot}05 + \frac{0{\cdot}0045\ L}{R^{1.25}}}}$$

Box culverts with square-cornered entrance,

$$Q = \frac{A\sqrt{AgH}}{\sqrt{1 + 0{\cdot}4\ R^{0.3} + \frac{0{\cdot}0045\ L}{R^{1.25}}}}$$

(*Engineering*, Nov. 26th, 1926.)

Circular Sewers.

x = area of sewer ÷ the wetted perimeter ; f = inclination in feet per mile ; v = velocity of flow, in feet per minute ; a = area of flow, in square feet ; V = volume of discharge, in cubic feet per minute.

$$v = 55\sqrt{x \times 2f} \qquad V = va.$$

American Rule.

(Large Sewers.)

The following formula is used by Mr. H. R. Asserson, chief engineer of the Sewer Department of Brooklyn, for proportioning the sizes of large sewers :—

$$D = \frac{3\ \log.\ A + \log.\ N + 8}{10},$$

where,

D = diameter of sewer in inches ; A = the area drained in acres ; N = the distance in feet in which the sewer falls 1 ft.

(Small Sewers.)

For small sewers up to 18 ins. in diameter the formula is—

$$D = \frac{3\ \log.\ A + \log.\ N + 6{\cdot}8}{10}$$

Salt-Glazed Ware Pipes

Salt-glazed ware pipes may be used up to 36 ins. diameter, but above 24 ins. they are difficult to manufacture of a cylindrical shape, and brickwork or concrete is usually adopted.

British Standard Salt-Glazed Ware Pipes.*

(No. 65—1914.) (*Abstract.*)

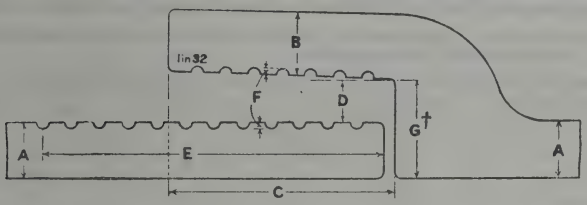
The specification divides pipes manufactured in accordance with the specification into two classes, viz. :—

British standard pipes. British standard tested pipes.

British standard pipes are pipes subject in every respect to the requirements of the specification, and a percentage are to be subjected to a hydraulic test.

British standard tested pipes are subject in every respect to the requirements of the specification, and every pipe has to withstand a hydraulic test.

The specification provides that the dimensions of pipes shall be not less than those set out in the following table, except as provided in the section dealing with permissible variation.



1	2	3	4	5	6	7
Int. Dia. of Pipe.	Minimum Mean Thickness of Barrel. A.	Minimum Mean Thickness of Socket. B.	Minimum Internal Depth of Socket. C.	Minimum Jointing Space. D.	Length of Grooving on Spigot. E=1½C.	Minimum Depth of Grooving. F.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	In.
3	7/16	7/16	2	5/16	3	1/16
4	1/2	1/2	2	3/8	3	1/16
5	9/16	9/16	2¼	7/16	3⅜	1/16
6	5/8	5/8	2¼	7/16	3⅜	1/16
7	11/16	11/16	2¼	7/16	3⅜	1/16
8	11/16	11/16	2½	1/2	3¾	1/16
9	3/4	3/4	2½	1/2	3¾	1/16
10	13/16	13/16	2¾	5/8	4⅛	1/16
12	1	1	2¾	5/8	4⅛	1/16
13	1 1/16	1 1/16	3	5/8	4½	1/16
14	1 3/16	1 3/16	3	5/8	4½	1/16
15	1½	1½	3	5/8	4½	1/16
18	1⅝	1⅝	3	5/8	4½	1/16
21	1⅝	1⅝	3¼	3/4	4⅞	1/16
24	1¾	1¾	3¼	3/4	5¼	1/16
27	1⅞	1⅞	3¼	3/4	5¼	1/16
30	2	2	3½	3/4	5¼	1/16
36	2½	2½	3½	1	5½	1/16

† Width of shoulder of socket, which must exceed the mean thickness of the barrel of the pipe by not less than the values for D given in column 5.

The sockets of pipes shall be conical, having a taper of one-sixteenth of an inch measured on the diameter per inch of length.

The length of the barrels of straight pipes shall be as follows :—

Up to and including 6 ins., 2 ft.

7 ins. to 10 ins. inclusive, 2 ft. and 2 ft. 6 ins.

12 ins. to 36 ins. inclusive, 2 ft., 2 ft. 6 ins., and 3 ft.

* By permission of the British Engineering Standards Association.

The interior of the sockets and exterior of the spigots shall have groove one-sixteenth inch deep for a length equalling one and a half times depth of socket.

The glazing shall be attained by the action of the fumes of volatilised common salt on the material of the pipes during the process of burning.

Subject to the mean thickness of the barrel and socket of a pipe being not less than that specified in columns 2 and 3 of the above table, a variation in the thickness of the barrel or socket may be allowed at any two points not exceeding the following :—

Diameter of Pipe.	Permissible Variation of Thickness.
Not exceeding 12 ins.	$\frac{1}{16}$ in.
13 ins. to 18 ins. inclusive	$\frac{3}{32}$ in.
28 ins. to 36 ins. inclusive	$\frac{1}{8}$ in.

The internal diameter of the barrel shall nowhere deviate from the standard diameter by more than the figure given in the following table :—

Standard Internal Diameter of Pipe.	Permissible Variation from Diameter.	Standard Internal Diameter of Pipe.	Permissible Variation from Diameter.
3 ins. and 4 ins.	$\frac{1}{8}$ in.	15 ins. and 18 ins.	$\frac{3}{16}$ in.
5 „ to 7 „	$\frac{3}{16}$ in.	21 „ and 24 „	$\frac{1}{4}$ in.
8 „ and 9 „	$\frac{1}{4}$ in.	27 „	$\frac{5}{16}$ in.
10 „ to 14 „	$\frac{5}{16}$ in.	30 „ and 36 ins.	$\frac{3}{8}$ in.
			1 in.

The permissible deviation of straightness of the barrels measured on the inside of the curve for all diameters of pipes shall be as follows :—

Length of Pipe.	Permissible Deviation from Straightness.
2 ft.	$\frac{3}{16}$ in.
2 ft. 6 ins.	$\frac{1}{4}$ in.
3 ft.	$\frac{5}{16}$ in.

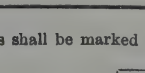
The hydraulic test shall be an internal pressure of 20 lbs. per square inch without showing signs of injury or leakage.

The pipes shall also be tested for absorption by testing pieces of the body of the pipe taken at more than 6 ins. from the end of the pipe. The test pieces shall be of whole thickness of pipe, and shall have two glazed surfaces each of which shall be not less than 8 ins. super or more than 20 ins. super. The test pieces shall be thoroughly dried at a temperature of 150°C., and shall then be immersed in cold water which shall be raised to boiling point and there maintained for one hour. The percentage of increase of weight shall not exceed the following :—

Thickness of Pipe.	Percentage of Increase of Weight.
$\frac{3}{4}$ in. and under	5 per cent.
Over $\frac{3}{4}$ in. and up to 1 in.	6 „
Over 1 in. and up to $1\frac{1}{2}$ in.	8 „
Over $1\frac{1}{2}$ in.	10 „

British standard pipes shall be marked with indelible black with the following :—

British standard tested pipes shall be marked :—



Concrete Pipes.

Sewer pipes constructed of concrete, either with or without steel reinforcement, are gaining favour amongst engineers, especially for the larger sizes of pipes and for sewers where numerous junctions are not required.

These pipes are made by several firms, and are constructed of a rich mixture of concrete with granite aggregate and the highest quality of cement. They are mostly made in moulds as plain cylinders with a curved joint made in the thickness of the concrete.

Recently the Stanton Iron Company have produced concrete pipes made by the Hume process, which is in essence a centrifugal system (see p. 1311) in which the ingredients are passed into rapidly revolving cylinders and are spread out into a uniform pipe of great density and strength. If desired, steel reinforcement can be placed in the revolving cylinders and be buried in the thickness of the concrete pipe. By this means the pipes can be greatly strengthened and can be made to carry high internal pressures.

The Hume Spun Pipes can be made in six and eight feet lengths, thus saving joints and labour in laying as compared with salt-glazed ware or ordinary moulded concrete pipes. The joints are made either by sockets spun on the pipe itself, or by loose collars used with plain cylindrical pipes. Square junctions and junctions inclined at 45° for branch drains can be supplied.

All concrete pipes above 18-in. diameter are best laid on a bed of concrete haunched up to the semi-diameter. This precaution is essential except in special circumstances with pipes of 24-inch diameter and upwards, whether the pipes are made of concrete or salt-glazed ware. Even allowing for the concrete bed, pipes made of concrete are less costly than salt-glazed ware pipes of the best qualities.

Egg-shaped Sewers.

The general form of the section of this class of sewers is shown by fig. 1.

When full.		$\frac{3}{4}$ths full.	$\frac{2}{3}$rds full.	$\frac{1}{2}$ full.	$\frac{1}{3}$rd full.	$\frac{1}{4}$ full.
Area of whole section .	$1{\cdot}1485\ d^2$	$\cdot8795\ d^2$	$\cdot7558\ d^2$	$\cdot5091\ d^2$	$\cdot2840\ d^2$	$\cdot1862\ d^2$
Perimeter of wetted surface	$3{\cdot}9649\ d$	$2{\cdot}6455\ d$	$2{\cdot}39415\ d$	$1{\cdot}8915\ d$	$1{\cdot}3746\ d$	$1{\cdot}1055\ d$
Hydraulic radius . .	$\cdot2897\ d$	$\cdot3325\ d$	$\cdot3157\ d$	$\cdot269\ d$	$\cdot2066\ d$	$\cdot1685\ d$

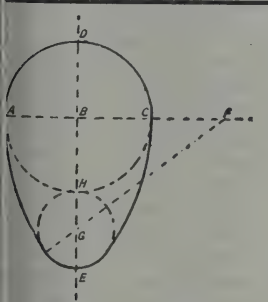


Fig. 1.

This form of sewer gives a fair hydraulic mean depth for flows varying greatly in volume. In a town sewered upon the combined system this is an advantage over the circular section, especially in the case of sewers laid in undeveloped areas where it is frequently necessary to make provision largely in excess of present requirements.

Diameter of Upper Circle = AC = d.
Conjugate Diameter = DE = $1\frac{1}{2}d$.
Radius of Invert = $\frac{1}{4}d$.
Radius of Side = FA = $1\frac{1}{2}d$.

Another advantage possessed by egg-shaped sewers is that for equal sectional areas this form is more easily entered by workmen than the circular section.

On the other hand, the egg-shaped section is not so strong to resist external pressure as the circular, and consequently if used in bad ground special precautions must be taken.

In ordinary practice, egg-shaped sewers are used for those sizes of culvert which fall between the largest circular stoneware-pipe sewers and the smallest size of circular brick culvert in which men can conveniently work.

These limits fix the maximum and minimum sizes of egg-shaped sewers at 3 ft. 6 ins. × 2 ft. 4 ins. and 2 ft. 3 ins. × 1 ft. 6 ins., respectively.

For ordinary depths the smaller sizes of egg-shaped sewers are constructed of one ring of brickwork half-a-brick thick; for the large sizes a second ring of brickwork may be introduced or, preferably, the sewer may be strengthened by placing concrete outside the brickwork.

The following table gives particulars of the ordinary sizes of egg-shaped sewers :—

Dimensions.	Sectional Area in Square Feet.		Wetted Perimeter. Lineal Feet.		Brickwork in superficial yards of half-brick thick per Lineal Yard of Culvert.	
	Total.	Up to $\frac{2}{3}$rds of top circle.	When full.	When full to $\frac{2}{3}$rds top circle.	One half-brick ring.	Two half-brick rings
Ft. Ins. Ft. Ins.						
2 3 × 1 6	2·58	1·70	5·95	3·59	2·72	—
2 6 × 1 8	3·19	2·09	6·61	3·99	2·99	—
2 9 × 1 10	3·86	2·54	7·27	4·39	3·24	7·33
3 0 × 2 0	4·59	3·02	7·93	4·79	3·42	7·65
3 3 × 2 2	5·39	3·54	8·59	5·19	3·54	8·06
3 6 × 2 4	6·25	4·11	9·25	5·59	—	8·60

DISCHARGE OF WATER IN CUBIC FEET PER MINUTE, IN PIPES OR SEWERS, FOR ANY LENGTH AND HEAD, AND FOR DIAMETERS FROM 1 IN. TO 10 FT.

Diameter.	Tabular No.	Diameter.	Tabular No.	Diameter.	Tabular No.	Diameter.	Tabular No.
Ins.		Ft. Ins.		Ft. Ins.		Ft. Ins.	
1	4·71	1 1	2876·7	2 7	25270·	4 1	79380·
$1\frac{1}{4}$	8·48	1 2	3463·3	2 8	27358·	4 2	83492·
$1\frac{1}{2}$	13·02	1 3	4115·9	2 9	29547·	4 3	87730·
$1\frac{3}{4}$	19·15	1 4	4836·9	2 10	31834·	4 6	101207·
2	26·69	1 5	5628·5	2 11	34228·	4 9	115854·
$2\frac{1}{2}$	46·67	1 6	6493·1	3 0	36725·	5 0	131703·
3	73·5	1 7	7433·	3 1	32329·	5 3	148791·
$3\frac{1}{2}$	108·14	1 8	8449·	3 2	42040·	5 6	167139·
4	151·02	1 9	9544·	3 3	44863·	5 9	186786·
$4\frac{1}{2}$	194·84	1 10	10722·	3 4	47794·	6 0	207754·
5	263·87	1 11	11983·	3 5	50835·	6 6	253781·
6	416·54	2 0	13328·	3 6	53995·	7 0	305437·
7	612·32	2 1	14758·	3 7	57265·	7 6	362935·
8	854·99	2 2	16278·	3 8	60648·	8 0	426481·
9	1147·6	2 3	17889·	3 9	64156·	8 6	496275·
10	1493·5	2 4	19592·	3 10	67782·	9 0	572508·
11	1894·9	2 5	21390·	3 11	71526·	9 6	655369·
12	2356·	2 6	23282·	4 0	75392·	10 0	745038·

The last table is applicable to sewers and drains by taking the same proportion of the tabular numbers that the cross-section of the water in the sewer or drain bears to the area of the whole area of the sewer or drain.

The formula upon which the table is constructed is :—

$$Q = 2356 \frac{\sqrt{d^5}}{\sqrt{\frac{l}{h}}},$$

where,

Q = volume of discharge, in cubic feet per minute;
d = diameter of pipe in feet;
h = height of fall of the water in feet;
l = length of pipe in feet.

Application of the Table.

To compute the volume of fluid discharged, the length of the pipe or sewer, the height or fall, and the diameter being given.

Rule.—Divide the tabular number opposite the diameter of the pipe by the square root of the rate of inclination (length ÷ height); and the quotient will give the volume required.

Example.—A pipe has a diameter of 9 ins. and a length of 4,750 feet; what is its discharge under a head of 17·5 feet?

Tabular number for 9 ins. = 1147·6, and

$$\sqrt{\frac{4750}{17{\cdot}5}} = \sqrt{271{\cdot}4} = 16{\cdot}47;$$

then,

$$\text{Discharge} = \frac{1147{\cdot}6}{16{\cdot}47} = 69{\cdot}67 \text{ cubic ft. per minute.}$$

Sewerage Systems.

There are two principal systems of sewerage, known respectively as the 'combined' and the 'separate' systems. In the former, one set of sewers is provided for the removal of both the sewage proper, and also the rainwater; in the separate system two sewers are provided in every street, one for sewage and the other for rainwater. Both systems have their advantages, but these are counterbalanced by certain disadvantages.

The combined system has the advantage of simplicity, but it involves large and deep sewers with small volumes of sewage flowing in them in dry weather, and where the sewage has to be pumped and purified this system produces a larger volume of sewage than the separate system.

On the other hand, a separate system of sewers becomes very complicated, especially in large towns, and there is great risk of sewage drains being connected to the surface water sewers. The latter discharge direct into the nearest river or stream, and can therefore be made of smaller size than in the combined sewerage system, which concentrates all liquid upon one point. The drainage of all streets and yards is taken direct into the surface-water sewers. As the first washings of these surfaces are very foul, there is danger of pollution of the streams into which the surface-water sewers discharge.

In most cases neither system is carried out in its entirety, but a combination is effected with a view to adopting the best points of both.

The quantity of sewage in a strictly separate system should, if the sewers were watertight, be measured by the water consumed, and it is usually taken at from 20 to 40 gallons per head of the population draining, and the rate of flow in the middle of the day is from one and a half times to twice the mean.

Where a partially-separate system is adopted, the back roofs and back yards of the houses are usually drained to the sewage sewers, and the impervious area per head of the population varies from 10 square yards to 20 square yards.

The rainfall on this area, at the rate of from $\frac{1}{4}$ in. to 1 in. per hour, depending upon the area of the district (being smaller for large areas than for small), must be added to the sewage, to find the discharging capacity of the sewers.

In a combined system of sewers the main factor is rainfall, and the rate of fall and proportion of impervious area and size of district must be taken into consideration in determining the dimensions of the sewers.

The proportion of rainfall flowing off an urban area probably never exceeds 75 per cent. of the gross fall, and usually 30 per cent. to 50 per cent. is sufficient to provide for in ordinary circumstances.

For discharges of catchments, including sewered areas, see 'Rainfall,' page 1461.)

As an example of practical working, the following table may be quoted, giving the basis on which sewers have for many years been designed in a North Country city with an average rainfall of 36 ins., and nearly all streets being covered with impervious paving:—

Drainage Area in Acres.	Inches of Rainfall per Hour.	Drainage Area in Acres.	Inches of Rainfall per Hour.	Drainage Area in Acres.	Inches of Rainfall per Hour.
20	1·00	75	0·47	350	0·35
23	0·95	100	0·45	375	0·34
26	0·90	125	0·44	400	0·33
29	0·85	150	0·43	425	0·32
32	0·80	175	0·42	450	0·31
35	0·75	200	0·41	475	0·30
38	0·70	225	0·40	500	0·29
41	0·65	250	0·39	525	0·28
44	0·60	275	0·38	550	0·27
47	0·55	300	0·37	575	0·26
50	0·50	325	0·36	600	0·25

Flushing Sewers and Drains.

All sewers and house drains should be laid at sufficiently good gradients to secure self-cleansing. To prevent deposit, 4-inch diameter drains should have a fall of not less than 1 in 40, 6-inch drains 1 in 60, and 9-inch drains 1 in 100. Whenever these gradients cannot be obtained special facilities should be provided for flushing, and this operation should be regularly attended to once or twice per week.

The water supply to closets, slop-sinks, etc., should be obtained from cisterns specially provided for the purpose, and not direct from the water-main, nor yet from cisterns in which the water for other domestic uses, such as cooking and drinking, is stored.

The best material for the cisterns is galvanised wrought-iron of No. 14 s.w.g. thickness.

The following table gives the capacities of flushing chambers for drains:—

Capacity of Flushing Chamber Required for Pipes of Different Sizes.

Size of Pipe. Diameter in Inches.	Gradient of Pipe.	Capacity of Chamber in Gallons.
4	1 in 40	30
	„ 50	40
6	„ 60	60
	„ 100	100
	„ 200	160
9	„ 100	200
	„ 150	250
	„ 200	300
	„ 300	400
12	„ 100	300
	„ 200	400
	„ 300	500
	„ 400	750
	„ 500	1,000
	„ 600	1,500

Sewers as distinguished from drains may be laid at flatter gradients than those quoted without special flushing arrangements, but this depends upon the quantity of sewage flowing down the pipe. A sewer flowing half full will maintain itself in good order at a much flatter gradient than one flowing quarter full. It is usually found that a velocity of 2 feet to 2½ feet per second will produce self-cleansing conditions.

In practical sewage works sewers with a small flow should have the following minimum gradients :—

8 ins. diam. 1 in 75.	12 ins. diam. 1 in 150.	18 ins. diam. 1 in 250.
9 ins. diam. 1 in 100.	15 ins. diam. 1 in 200.	

Where, however, the sewers have a goodly flow of sewage the following gradients will be found to be self-cleansing :—

8 ins. diam. 1 in 175.	12 ins. diam. 1 in 400.	18 ins. diam. 1 in 800.
9 ins. diam. 1 in 250.	15 ins. diam. 1 in 600.	21 ins. diam. 1 in 1,000.

Ventilation of Sewers.

The object of the ventilation of sewers is to remove the foul emanations arising from the sewage and the fouled surfaces of the sewers above the actual liquid and to discharge them at points where they will easily become diluted with fresh air and not cause a nuisance.

Until comparatively recently it was thought that sewer air was harmful in itself and was likely, not only to impair the vitality of the subject, but also to be the direct cause of infectious disease.

Now, however, it is more generally conceded that sewer air is at least as free from bacteria as the air near the surface of a road, and that apart from any offensiveness to the sense of smell it is not dangerous to persons breathing it. The degree of offensiveness of sewer air depends more largely upon the condition of the sewer than upon the effectiveness of the ventilation.

Fresh sewage does not produce a bad smell, and modern sewers constructed with the best materials and gradients and regularly flushed do not give off foul emanations. On the other hand, sewers constructed of absorbent materials, laid to bad gradients, containing deposits of sewage solids, and in which flushing is absent or carried on at very long intervals, the sewer air becomes very foul and is liable to produce nuisance.

Formerly, the generally accepted theory was that 'sewer gas,' being lighter than air, would tend to rise up the gradient of the sewer and would be discharged at its summit.

This idea has now been demonstrated to be erroneous : there are many factors which affect the motion of air in sewers such as temperature, humidity, ebb and flow of sewage, the drag of the flowing sewage, the natural diffusion of gases, friction on the periphery of the sewer, and the action of the wind.

Of all these, by far the most important is the latter, and it dominates the other factors except on very calm days.

The system of ventilation of sewers introduced on the advice of the late Sir Robert Rawlinson many years ago, was to relieve the pressure of sewer air by means of gratings in manhole covers at ground level.

These open ventilators were fixed at intervals of about 100 yds., and if it was found that some of the ventilators were a nuisance, additional openings were to be made at shorter intervals.

It has been the almost universal experience in most towns that at certain times these surface grids caused nuisance by allowing the sewer air to escape and bad smells resulted.

A modification of the system has been effected by the introduction of tall shafts connected with the sewers alternating with openings at street level.

The tall shafts theoretically act as outlets and the openings at ground level as fresh-air inlets. It is found, however, in practice, that this order is under varying conditions reversed and it is never certain which will be the inlet and which the outlet.

The general practice now is to have all manhole covers sealed where they are situated in narrow streets near the doors and windows of houses or in other situations likely to cause nuisance, and to have vertical steel or iron columns 20 to 25 ft. in height and 6 ins. to 12 ins. diameter, fixed in the line of curb and connected to the manholes to act either as inlets or outlets : the tops of the columns are fitted with wire guards.

In some cases the shafts consist of iron socketed pipes fixed against a building and carried up above the eaves or roof ridges in such a way as to be clear of all windows, skylights, or chimneys.

In broad suburban roads or where the sewers cross agricultural land, the manhole covers are still left open for ventilation purposes.

Connecting the sewers to the flues of factory chimneys has been tried but the draught is confined to a very small area and is not nearly so effective as one would anticipate. Numerous proprietary systems of sewer ventilation by means of fans, special cowls, gas destructors, antiseptic sprays and deodorants have been put on the market from time to time, but these are generally successful only in very favourable circumstances and cannot be recommended for general use.

SEWAGE TREATMENT.

Quantity of Sewage to be dealt with.

The quantity of sewage per head of the population drained, and the effect of the admission of rainwater, have been dealt with in the preceding matter dealing with sewers.

It has now become fairly well established in practice that in towns where the sewers are upon the combined system, and where the sewage is purified, the works shall be capable of providing full treatment for a quantity equal to three times the mean dry weather flow, and that in addition to this there shall be means of partially treating a further quantity equal to three times the mean dry weather flow, any surplus beyond this to be discharged untreated into the streams.

In towns sewered on the separate system the full treatment can be restricted to a volume of twice the mean dry weather flow, and partial treatment must in that case be provided for four times the dry weather flow.

Apart from the fluctuations in volume due to the admission of storm water, the quantity varies from hour to hour during the day, and in different days of the week, owing to the greater or lesser discharge of liquid from the houses in the district.

The following diagram represents the rate at which sewage is received on an average day in dry weather at the Leeds Sewage Purification Works :—

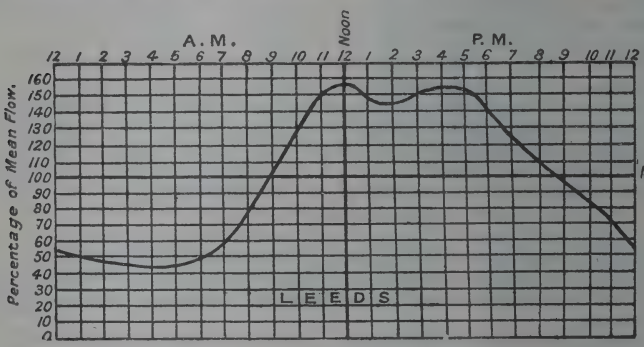


FIG. 2.

It will follow from what has been said that there are continual fluctuations in the volume of liquid to be dealt with at a sewage purification works, and such works must therefore be capable of adapting themselves to all the conditions under which they may be called upon to act.

General Outline of Treatment.

The object of all sewage purification processes is to convert the organic substances in the sewage into harmless inorganic matter. The organic matter may be in suspension or in solution, and it is not sufficient to eliminate the former, as was the case in some of the older processes, and leave the matters in solution, as these will subsequently putrefy and cause nuisance.

In average sewage of a domestic character—i.e. free from trade refuse—there are usually about 100 grains of solid matter per gallon, of which 40 grains are organic.

Grains per Gallon.	Organic.	Mineral.	Total.
Solid matter in suspension	20	10	30
Solid matter in solution	20	50	70
Total	40	60	100

The solids in suspension can be reduced by subsidence, but the matter in solution must be oxidised, and this is effected by the action of bacteria.

In all cases the first step is to remove the largest and heaviest of the suspended matters, and this is done in detritus and screening tanks.

Such tanks should have a capacity of from 2 per cent. to 5 per cent. of the daily sewage flow, and should contain iron gratings for the removal of floating matters, scum boards to arrest the scum ; and they should be so designed as to reduce the velocity of flow of sewage sufficiently to allow the heaviest of the road grit, etc., to settle to the bottom of the tank.

The next step is usually to remove the lighter matters in suspension, and this is generally effected by providing tanks of suitable design : (*a*) to allow the particles to settle by gravity ; (*b*) this process is sometimes expedited by the addition of chemicals known as precipitants; (*c*) for iquefaction of the solids in suspension by bacterial action and settlement combined, as

in septic tanks; (*d*) assisting the action by presenting large surface, to attract floating matter, as in the Travis tank or Dibdin slate filter.

Having freed the liquid as far as possible of the suspended solids with their organic contents the effluent from the first part of the process must be subjected to a further treatment, which has for its object the oxidisation of the matters in solution and their conversion into harmless inorganic compounds which will not putrefy or take up oxygen from the stream into which it may be intended to discharge them.

This part of the process may be effected by application to land or to some form of bacterial filter; but if the latter it is usually necessary to have a further process for the removal of the solids in suspension which are evacuated by the filter. This can be effected either by land treatment, filtration, or settlement in tanks or lagoons.

The capacity of the tanks necessary for the removal of the suspended solids depends upon the strength of the sewage and a variety of circumstances.

If the tank can be used for quiescent settlement—i.e. filled with sewage, allowed to stand, and then emptied by decanting—a capacity of two hours to four hours' sewage flow will usually be sufficient provision. The usual method of using such tanks, however, is to use them continuously by drawing off over a long weir in a thin film at the same rate as the filling; in such a case the tanks should have from six to twelve hours' capacity.

If, however, the settlement be assisted by the addition of precipitants, and the tanks are used for continuous precipitation, their capacity may be reduced by one-half.

Septic tanks vary in capacity from fifteen hours to twenty-four hours' flow, and there is a tendency towards the smaller limit in present practice.

Precipitation by the use of chemicals has some effect upon the organic matter in solution as well as that in suspension, and by a sufficiently large expenditure it is possible to reduce the impurity in solution by as much as 50 per cent. The cost of doing this, however, would be prohibitive in actual practice. (See table, pages 1432 and 1433.)

The precipitants chiefly used are lime in a caustic state, 10 to 12 grains per gallon of sewage; lime and sulphate of iron or green copperas in the proportion of 6 grains to 3 grains of lime with 3 grains to 1 grain of copperas; lime and alumina in the proportion of 2 of the former to 1 of the latter, usually about 8 and 4 grains respectively; alumino-ferric, either with or without lime, proportion 10 to 7 grains lime and 5 to 3 grains alumino-ferric—if used without lime, up to 8½ grains per gallon.

Sludge.

The solid matters precipitated in the tanks produce what is known as sewage sludge, containing about 90 per cent. of water.

The final disposal of the sludge resulting from sewage purification has always been one of the chief difficulties of the problem of sewage treatment. The manurial value of the material is small, and it is a waste product of the process which must be got rid of as cheaply and as expeditiously as possible.

The methods of doing this may be briefly summarised as:—

1. Removal to sea.
2. Earth burial.
3. Cremation.
4. Drying in lagoons.
5. Drying in prepared beds.
6. Filter pressing.

The quantity of sludge per million gallons of sewage varies with the quality of the sewage, and the process adopted for the separation of the solid matter therein.

The method of estimating the quantity of sludge from a given process is as follows:—

To the average number of grains per gallon of solids in suspension in the sewage add the grains of precipitant applied, and deduct from the total the grains of solids in suspension in the tank effluent; this gives the grains of solid matter deposited from each gallon of sewage.

If

G = grains per gallon as above determined;
M = sewage per day in million gallons;
T = tons of wet sludge per day (30 per cent. water);
P = percentage of water in pressed cake;
C = tons of cake containing P per cent. water;

then,

$$T = \frac{100\,M \times G}{154} \qquad C = \frac{T}{100 - P}$$

Pressed sludge cake containing 50 to 55 per cent. of water weighs about 14 cwts. per cubic yard.

SHOWING THE PERCENTAGE REDUCTION OF OXIDISABLE ORGANIC MATTER

(All quantities are stated

Liquid used for Experiment.	Percentage reduction of dissolved Oxidisable										
	1	2	3	4	5	6	7	8	9	10	11
Raw Sewage from	Lime in solution . 3·7	Lime in solution . 5·0	Lime in solution . 10·0	Lime in solution . 15·0	Lime as Milk . 15·0	Lime in solution . 3·7 Iron sulphate . 0·3	Lime in solution . 3·7 Iron sulphate . 1·0	Lime in solution . 3·7 Iron sulphate . 2·5	Lime in solution . 3·7 Iron sulphate . 5·0	Lime in solution . 5·0 Iron sulphate . 2·0	Lime in solution . 5·0 Iron sulphate . 4·0
Metropolitan system .	20	26	29	37	30	27	27	29	33	31	33
" "	6	10	28	64	12	10	10	18	32	27	34
" "	18	21	14	19	22	12	19	25	24	26	21
" "	26	26	26	37	10	24	25	38	33	30	31
" "	10	9	10	12	11	10	12	13	27	26	24
" "	23	29	29	34	27	23	27	35	37	33	33
" "	2	8	15	29	0	0	5	17	20	12	16
" "	12	25	30	33	25	16	22	24	32	26	30
" "	7	19	21	27	10	18	9	20	22	17	14
" "	5	12	13	18	4	5	3	11	16	13	15
" "	3	12	9	18	3	10	13	15	17	14	13
" "	15	16	19	48	44	11	15	17	20	17	21
" "	12	15	21	25	17	10	16	20	22	17	20
" "	9	15	19	23	19	11	17	20	21	18	18
" "	10	14	22	19	9	8	16	14	14	16	17
" "	12	12	17	24	12	7	12	19	22	19	19
" "	15	16	16	15	9	9	11	13	17	13	14
" "	8	8	20	35	8	11	8	14	17	14	20
" "	8	7	19	34	7	10	7	13	16	13	19
" "	3	4	4	4	9	4	4	4	8	7	6
" "	4	5	5	0	7	5	5	7	5	7	7
" "	12	20	26	28	16	15	22	23	24	23	22
" "	6	9	9	14	3	5	5	7	11	9	12
Average . . .	11	15	19	25	13	11	13	18	21	18	19
Cost per annum for chemicals . .	£ 13,505	18,250	36,500	54,750	54,750	15,695	20,805	31,755	50,005	32,850	47,450
Other sources . .	..	52	..	..	..	..	..	..	..	58	61
" " . .	..	..	10	..	..	..	..	..	..	..	..

Lime taken as costing £1 per ton; Iron, £2 per ton; Alumina, £3 10s. per ton.

IN SOLUTION BY VARIOUS METHODS OF CHEMICAL PRECIPITATION.
in grains per gallon.)

Organic matter by treatment of liquid with

12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Lime in solution . 5·0 Iron sulphate . 5·0	Lime in solution . 5·0 Iron sulphate . 8·0	Lime in solution . 5·0 Iron sulphate . 10·0	Lime in solution . 10·0 Iron sulphate . 10·0	Lime in solution . 5·0 Alumina sulph. . 5·0	Lime in solution . 5·0 Iron sulphate . 5·0 Animal charcoal. 5·0	Lime in solution . 5·0 Iron sulphate . 1·0 Alumina sulph. . 5·0	Lime in solution . 7·0 Iron sulphate . 1·5 Alumina sulph. . 5·0	Lime in solution . 10·0 Iron sulphate . 2·0 Alumina sulph. . 10·0	Lime in solution . 14·0 Iron sulphate . 3·0 Alumina sulph. . 10·0	Lime in solution . 15·0 Iron sulphate . 3·0 Alumina sulph. . 15·0	Lime . . 28·0 Iron sulphate . 6·0 Alumina sulph. . 20·0	Lime . . 56·0 Iron sulphate . 12·0 Alumina sulph. . 40·0	Lime . . 700·0 Iron sulphate . 100·0 Alumina sulph. . 500·0	Average.
35	34	36	36	33	40	32	32	34	37	39	44	49	53	34
32	36	38	36	32	32	33	36	67	46	45	40	43	58	33
27	28	30	28	15	27	19	17	25	22	23	21	28	45	23
32	32	36	30	26	32	30	31	30	25	36	30	30	45	30
24	21	25	24	16	24	14	14	16	12	29	14	26	41	19
39	36	36	40	37	38	38	39	33	37	39	44	55	62	36
22	25	28	32	16	21	19	24	22	11	26	20	24	59	19
34	37	41	32	24	26	28	32	29	25	31	28	43	59	30
25	42	25	26	21	26	19	21	16	19	22	29	31	54	22
17	21	22	21	16	29	21	25	25	25	26	25	25	45	18
17	19	21	16	14	15	13	15	16	11	14	8	18	39	15
20	24	25	38	24	24	25	24	26	27	38	40	46	59	27
22	26	25	24	16	22	25	21	21	24	22	25	40	54	22
19	22	32	19	23	18	19	19	18	18	20	19	18	48	20
21	20	20	21	21	19	16	17	22	27	19	17	21	47	19
21	23	23	24	15	19	17	18	22	26	25	28	39	62	21
15	20	11	17	10	19	15	14	15	13	17	16	17	45	16
19	26	27	31	20	23	18	23	28	29	31	30	41	58	23
18	25	26	29	19	22	17	22	26	18	29	29	40	55	20
8	8	10	10	0	7	7	11	12	13	12	13	29	58	10
9	9	7	11	0	12	11	12	13	14	11	13	16	44	10
23	26	22	23	22	20	20	20	22	21	25	22	33	59	23
12	14	13	14	10	10	11	28	18	12	12	14	19	50	17
18	25	25	30	18	22	20	22	24	21	26	24	31	52	..
54,750	76,650	91,250	109,500	82,125	237,250	89,425	100,375	178,850	200,750	268,275	401,500	803,000	9,672,500	..
..	61	69	..	..	..	..	..	..	..	..	..	..	..	..
56	..	..	..	33	..	..	..	..	..	..	..	..	..	..

Volume of sewage taken at 156,800,000 gallons per day.

(*W. J. Dibdin.*)

Land Treatment.

The effluent from the various tank processes described may be suitably oxidised by application to land.

There are two distinct methods of using land. Where a suitable light friable soil can be obtained, filtration is the process adopted, the sewage passing downward through the soil to underdrains. If, on the other hand, the available land be all of a retentive character, which will not allow of the easy passage of water, the method adopted is to pass the tank effluent over the surface of the land by irrigation and to pick it up again in suitable catchwaters and reapply it to a fresh plot, and subsequently to a third or even a fourth plot before final discharge into the stream ; such land should not be underdrained, or only to a very slight extent.

The quantity of liquid which can be dealt with per acre of land will depend upon the character of the land, the strength of the sewage, and the degree of excellence of the preliminary treatment.

The following table gives a scale of quantities for various soils and average sewage, but great care must be exercised in applying the table :—

Soil.	Crude Sewage.		Settled Sewage.		Efficient Preliminary Treatment. Land Secondary.	
	Gallons.	Population.	Gallons.	Population.	Gallons.	Population.
Light sandy loam on gravel and sand	15,000	375	20,000	500	30,000	1,000
Sandy loam on gravel and sand	12,000	300	17,000	400	30,000	1,000
Peaty soil on gravel and sand	10,000	250	13,500	325	30,000	1,000
Sand and gravel	8,000	200	10,000	250	30,000	1,000
Gravelly loam on gravel and sand	6,000	150	8,000	200	20,000	666
Loam getting more clayey	4,500	125	6,000	150	15,000	500
Heavy loam on marl	3,000	75	5,000	130	12,000	400
Clay soil on clay	1,500	50	4,000	120	10,000	333
Stiff clay soil on dense clay	1,000	33	3,000	100	10,000	333

Artificial Bacterial Methods.

The alternative to land treatment for the final or oxidising process in sewage treatment is the use of bacteria beds. These are divided into two main classes :—

(*a*) Contact beds.
(*b*) Percolating or continuous filters.

Contact beds consist of tanks filled with material such as broken clinker, and used by filling them up with tank effluent until the filtering medium is just charged with liquid, allowing it to stand for a given period, draining off, and standing empty. The usual cycle of these operations is as follows :—

Filling	1 hour.
Standing	2 hours.
Draining	1 hour.
Aerating	4 hours.
	8 hours.

With this cycle three fillings per day are possible, and as the liquid capacity of a bed is 33 per cent. of its gross capacity, it follows that a bed is capable of treating each day a quantity of tank effluent equal to its gross capacity—i.e. when containing no filtering medium. The operations of filling and emptying may be done by hand valves or by automatic valves worked by floats. The depth of contact beds should not exceed 4 ft.

The second class of bacteria beds consists of masses of hard rough material, such as broken stone or slag of gauges varying from 3 ins. to ½ in., over which the tank effluent is distributed in the form of spray and through which it percolates. The bed may or may not be enclosed by means of side walls, but it must have a good substantial floor, efficient means of drainage, and a proper system of distribution if good results are to be obtained. The depth of the beds varies from 4 ft. to 10 ft., depending upon the fall available and the size of the filtering medium.

The quantity of tank effluent which can be applied per square yard of surface of the bed depends upon the strength of the sewage and size of the material employed for filtering, and varies from 100 gallons per square yard per day to as much as 400 gallons, but this quantity cannot be maintained for long. A good average quantity is 150 gallons per square yard per day for a filter 6 ft. deep composed of materials averaging 2 ins. diameter; this will allow the bed to take the hourly fluctuations in the rate of flow of sewage, and for short periods it will take storm-water up to three times the figure named.

The sprinkling process can be effected by a variety of arrangements, most of which have revolving arms operating in different ways, but there are also fixed jets and reciprocating travellers for rectangular beds.

The relative merits of contact beds and percolating beds are as follows :—

1. Where there is not much fall available, single contact beds can be constructed with about 3 ft. 6 ins. of fall; double contact beds require 7 ft.

A continuous filter may be constructed with a fall of about 5 ft. 3 ins., but if a coarse filtering material is to be used this must be increased by 2 ft., or possibly more.

2. The tanks used for contact beds must be watertight, and therefore the facilities of the site for making watertight beds must be taken into consideration.

3. The weight of the material used in a continuous filter is greater than that of a contact bed, and therefore the stability of the ground must be taken into consideration.

4. Double contact beds must be provided if an equivalent degree of purification is required to that produced by a continuous filter.

5. Contact beds must be worked by automatic gear if three fillings per day are required, but may be operated by hand if two fillings are sufficient.

6. Generally speaking the gear for operating continuous filters is less liable to get out of order than that for contact beds.

7. Where the facilities for reducing suspended solids are limited, contact beds will sludge up and deteriorate much more quickly than continuous beds.

8. Percolating beds are more adaptable to fluctuating rates of flow than contact beds.

9. The first cost of percolating filters is less than that of contact beds for equal quantities of sewage.

10. Generally speaking, continuous filters give better results than contact beds.

Requirements of the Ministry of Health.

The following are believed to be the requirements of the Ministry with regard to sewage purification plants :—

Quantity of Sewage.

Quantity of sewage per head is usually reckoned at the rate of 30 gallons per day for dry-weather flow, for domestic purposes. In some cases this figure is modified to 20 gallons. If there be trade refuse to be dealt with, this must be added.

The quantity of sewage and rainwater to be fully treated at the works is :—

(*a*) Where the sewers are on the combined system, three times the domestic average plus $1\frac{1}{10}$ trade refuse.

(*b*) Where the sewers are on the separate system, twice the domestic sewage plus $1\frac{1}{10}$ trade refuse.

The quantity of sewage and rainwater to be partially treated is :—

(*a*) Where the sewers are on the combined system, three times the domestic sewage plus $1\frac{1}{10}$ trade refuse.

(*b*) Where the sewers are on the separate system, four times the domestic sewage plus $1\frac{1}{10}$ trade refuse.

Any excess over these quantities may be discharged over the stormwater overflows.

The above degrees of dilution are to be calculated on the average rate of flow throughout the 24 hours. The effect of this is that during the daytime when the average rate of flow is exceeded, the degrees of dilution will be less than those stated above, and on the other hand during the night the degree of dilution will be largely exceeded.

Storm Overflows.

Storm overflows on sewers should as far as is reasonably practicable be avoided, but where they are necessary they should be placed in such positions and with the weirs so fixed that no nuisance is likely to result. In any district where there is an active river authority the Ministry will desire to be informed of the opinion of such authority in respect of any proposed overflows.

In the absence of any special circumstances overflow weirs should be fixed so as not to come into operation until the flow exceeds six times that of the average dry-weather flow.

There should be no overflow for untreated sewage or stormwater at or near the disposal works.

Screens.

All liquid delivered at the disposal works should as a rule be passed through a screening chamber.

Storm-water Treatment.

A weir set at three times the dry-weather flow should be placed *below the screens*, and any volume passing over this weir should be dealt with in storm tanks. The tanks should be two or more in number and their total capacity should not be less than a quarter of the dry-weather flow. They should be so arranged that when they are full they will act as 'continuous flow' tanks, and that they can be readily emptied and kept empty when no liquid is passing into them.

The liquor from the tanks can be discharged without further treatment except in special cases, and the sludge should be dealt with by any of the usual methods which may be most suitable in the particular circumstances.

In cases where a sufficient area of suitable land is available for the purpose, detritus tanks followed by irrigation may be substituted for the storm tanks.

Sewage Treatment.

Detritus Tanks.—There should be two or more detritus tanks below the screening chamber. The capacity of each tank should be about $\frac{1}{100}$th of the dry-weather flow.

Septic Tanks.—Septic tanks should not be less than two in number, and their total capacity should be about equal to the dry-weather flow.

Chemical Preparation Tanks.—For *quiescent* treatment there should not be less than eight tanks, each of which should have a capacity equal to about two hours' dry-weather flow.

For *continuous flow* treatment there should not be less than two tanks, with a total capacity of at least eight hours' dry-weather flow, and in most cases a greater number of tanks will be desirable.

Settling Tanks.—For *quiescent* treatment—same as chemical precipitation tanks.

For *continuous flow* treatment there should not be less than two tanks with a total capacity of from ten to fifteen hours' dry-weather flow.

Filters.—In determining the sizes of percolating filters and contact beds the Ministry have, in order to allow for the strength of the sewage to be treated, adopted the division into 'strong,' 'average,' and 'weak' sewages recommended by the Royal Commission.

The strength of sewage should, when possible, be ascertained by analysing average samples of crude sewage taken in dry weather at frequent and regular intervals throughout seven days, and in proportion to the flow. Possibly, in the case of small works, the period for taking samples for analysis might be somewhat shorter, but the period should not be less than forty-eight hours, and Saturday and Sunday should be avoided. In every case, the daily rainfall during the period when the samples were being taken and during the preceding days should be ascertained.

The analysis should in all cases include the following items :—

In parts per 100,000 *by weight.*

(1) Ammoniacal nitrogen.
(2) Albuminoid nitrogen.
(3) Total nitrogen.
(4) Oxygen absorbed from strong permanganate in three minutes at 80 degrees Fahr.
(5) Oxygen absorbed from strong permanganate in four hours at 80 degrees Fahr.
(6) Suspended solids.
(7) Soluble solids.
(8) Chlorine.

It is also desirable that the amount of dissolved oxygen taken up during the oxidation of the ammoniacal and organic matter of the sewage should be given.

The results of analysis would of course require to be properly interpreted ; but as a rough guide it may be taken that from the figure for 'Oxygen absorbed from strong permanganate in four hours at 80 degrees Fahr.' the strength of the sewage may be very roughly classified as follows :—

'Strong' sewage	17 to 25 parts per 100,000
'Average" "	10 to 12 " "
'Weak' "	7 to 8 " "

In cases where the sewage cannot be analysed its strength should be estimated according to the water consumption, the flow per head, the kind of sewage system, whether water-closets are in general use, the volume and nature of trade waste, the amount of dilution by subsoil or surface water, etc.

Failing satisfactory evidence to the contrary it will be desirable to assume that the sewage is 'strong,' for the purpose of estimating the required capacity for the disposal works.

For the purpose of showing the *minimum* total cubic contents of filters required for treating three times the dry-weather flow in different cases, the tables A and B have been prepared on the data given in the Commission's Report.

The rates of filtration given by the Commission are rates which can generally be *doubled* in wet weather. Where it is proposed to deal with *three* times the dry-weather flow, the Commission say that it would generally only be necessary to provide 1½ times the capacity of filter required for the dry-weather flow. This basis has been adopted in arriving at the figure in the Tables A and B (page 1437).

TABLE A.—CONSTANTS FOR CALCULATING THE MINIMUM CUBICAL CONTENTS OF PERCOLATING FILTERS.

Preliminary Treatment.	Strong Sewage.		Sewage of Average Strength.		Weak Sewage.	
	Coarse or Medium Material.	Fine Material.	Coarse or Medium Material.	Fine Material.	Coarse or Medium Material.	Fine Material.
Detritus tanks . . .	15	*	25	*	40	*
Septic tanks	45 †	*	70	*	100	100
Settlement tanks (continuous flow) . .	45 †	*	70	*	100	100
Settlement tanks (quiescent) + ...	50 †	25	100	70	130	130
Precipitation tanks (continuous flow) . .	65	50	100	80	150	175
Precipitation tanks (quiescent)	100	65	130	130	170	200

Notes as to Filtering Material.

(*a*) A filter may be regarded as *coarse* if the material will not pass through a 1-in. sieve; as *medium* if it will pass through a 1-in. but not through a ½-in. sieve; and as *fine* if it will pass through a ½-inch sieve.

(*b*) *Coarse* material will be desirable in all cases where the liquid to be treated contains much suspended matter.

(*c*) In the cases marked * the use of fine material would not be desirable unless the circumstances were exceptional.

† If *medium* sized material were used in these cases the figures should be reduced by about 10.

TABLE B.—CONSTANTS FOR CALCULATING THE MINIMUM CUBICAL CONTENTS OF CONTACT BEDS.

Preliminary treatment.	Strong Sewage.			Sewage of Average Strength.			Weak Sewage.		
	Single Contact.	Double Contact.	Triple Contact.	Single Contact.	Double Contact.	Triple Contact.	Single Contact.	Double Contact.	Triple Contact.
Detritus tanks . . .	—	—	25 *	—	25	†	—	38	†
Septic tanks	—	—	33	—	38	†	75	66 ‡	†
Settlement tanks (continuous flow)	—	—	33	—	38	†	75 *	66 ‡	†
Settlement tanks (quiescent) .	—	—	44	—	50	†	100	†	†
Precipitation tanks (continuous flow) . . .	—	33	†	—	50	†	133 ‡	†	†
Precipitation tanks (quiescent)	—	43	†	—	66 *	†	133 ‡	†	†

Notes to Table B.

(*a*) The beds should not be less than 2 feet 6 inches nor more than 6 feet in depth.

(*b*) The different series of beds, in double and triple contacts, should have an equal cubic contents, failing any evidence to the contrary.

(*c*) Where a blank is left in the table the particular treatment indicated would only be desirable in exceptional circumstances, as the method would not generally be economical.

(*d*) In the cases marked thus †, the particular treatment indicated would only be necessary in exceptional circumstances (e.g. where an unusually good effluent is required).

(*e*) Where three times the d.w.f. has to be dealt with in wet weather, the individual beds, in the cases marked thus ‡, should be small (to facilitate rapid filling and emptying), or the total cubic contents of the filters should be increased.

(*f*) The average liquid capacity of a cubic yard of contact bed is about 50 gallons.

* There are no data in the Commission's Report with regard to these cases.

In order to ascertain the minimum total cubic contents of the filters required, divide the dry-weather flow by the *appropriate figure* (having regard to the strength of the sewage and the kind of treatment proposed), in the tables above, and the result will be the number of cubic yards which the filters should contain for treating up to three times dry-weather flow.

In cases where a sufficient area of suitable land is used for irrigating the filtrate it will probably suffice if the total cubic contents of the filters is half that provided for by the tables, but where the filter capacity is so reduced it may be necessary in wet weather to restrict the flow to the filters to about 1½ times the dry-weather flow and to pass the remainder of tank liquor direct to the land.

Effluent Tanks or Filters.—Where the effluent from filters is not irrigated on land, tanks (with a capacity equal to about two hours' dry-weather flow and with provision for removing the sludge), or shallow straining filters, will in most cases be necessary for the purpose of preventing the suspended matters in the filtrate from passing into the river.

When the sewage, after previous sedimentation, is applied to land filtration the quantity per acre of the most suitable land shall not exceed 15,000 gallons of dry-weather flow per acre per day or the sewage from 500 persons, and surplus land up to 25 per cent. is usually required to enable the land to be rested. This area will be increased, if the land be not of the first quality.

When the sewage, after previous sedimentation, is applied to land by broad irrigation, the quantity is not allowed to exceed 4,500 gallons of dry-weather flow per acre per day, or the dry-weather sewage from 150 persons. Surplus land must also be provided in such cases from 25 per cent. to 50 per cent. for resting purposes. Where the land is less suitable, the quantity per acre may be reduced to as little as 3,000 gallons per day.

When sewage is treated by precipitation or bacterial processes and the final purification is effected by land, the tank or filter effluent may be applied at the rate of 30,000 gallons per acre per day or the sewage from 1,000 persons as a maximum on the best land.

In all cases where land of sufficient area and of a not unsuitable character can be obtained at a reasonable cost the final purification must be by land.

Activated Sludge Process.

(Communicated by Activated Sludge, Ltd.)

The latest development of the sewage problem is that known as the 'Activated Sludge Process,' by which purification is carried out by oxidation of the organic matter present in the sewage by means of air blown through the liquid in the presence of an accumulation of sludge.

Experiments carried out at Manchester during 1913–14 demonstrated that by continually blowing air through successive quantities of sewage, decanting the liquid, and retaining the sludge, the latter became charged with micro-organisms which had the property of increasing enormously the purification effected by the simple aeration of the sewage. The deposit obtained in this manner has now become known as 'Activated Sludge.'

The addition of activated sludge to sewage, when combined with further blowing of fine bubbles of air through the mixture in such a manner as to create and maintain a circulation of air, sludge and liquid, sufficient to prevent settlement of the sludge and keep the sludge and air bubbles equally diffused throughout the liquid, produces a very marked change in the composition of the sewage; first a clotting or clarifying action takes place, then a rapid carbon oxidation process and finally nitrification.

Upon standing, the sludge rapidly settles and separates from the liquid, which when drawn off is not liable to putrefaction and is practically free from bacteria, whilst the sludge is also rendered innocuous and is found to contain a large proportion of nitrogen in a very available form for fertilising purposes.

It will be seen from the following table, which gives the composition of the sludge, that it has a large nitrogen content, so that its value as a fertiliser is extremely high; it contains, in fact three to four times as much nitrogen as the average septic tank sludge:—

Organic and volatile matter	64·70–70·40 per cent.
Minerals	35·30–29·60 "
Nitrogen	3·75– 7·09 "
Phosphoric acid	2·10– 4·20 "

One of the main difficulties has been to design suitable tanks, and the equipment for same, so that a regular circulation is created with a minimum expenditure of power in such a manner as to produce an equal diffusion of air and the biological sludge throughout the whole body of the

sewage in the tanks, without the creation of subsidiary eddies or deposits of sludge in pockets. This has been successfully overcome in the designs and appliances supplied by *Activated Sludge, Ltd.*, 100 *Victoria Street, Westminster, London, S.W.* 1.

A further difficulty originally was in obtaining a satisfactory settlement with a continuous flow, but, due to the researches of Mr. W. Clifford, A.M.I.C.E., of Wolverhampton, this problem was solved by a form of tank-inlet which destroys the energy of the inlet current and eddies.

The Activated Sludge Process has many advantages; the chief of these are as follows :—

(1) The purification is rapid and perfect, and the effluent fully oxidised.

(2) Putrefaction stops at once, and the system is free from smells and flies.

(3) The plant can be installed close to buildings, so that long outfall sewers are often unnecessary.

(4) An inoffensive sludge which is a valuable manure is obtained.

(5) Only a small area of land is required.

(6) There is practically no loss of head (4 ins. to 10 ins.), and the sludge is raised automatically.

(7) Trade wastes which are alkaline, or of constant but low acidity, give no difficulty.

(8) A very small staff is needed, but it requires at least one skilled attendant.

(9) Capital costs are low owing to the simplicity of the plant, the small tank area needed (less than for sedimentation or septic tanks), and the absence of filter beds. Further, by installing the plant near a town, there may be a saving in the cost of outfall sewers.

Taken all round, the cost of installing and maintaining a plant is generally about two-thirds of the cost of septic tanks and filter beds. It should be mentioned that existing tanks can usually be converted, and in many places this has been done quite successfully at small cost.

The plants work well either with a large or small population, and would appear to be well suited for military stations. There are no real disadvantages in the system except possibly the cost of power required for the intensive aeration, which is essential for the work of the process.

A great deal of attention has been devoted to the evolution of a compressor which will give a higher efficiency for the 'diffused air' system. After much thought and experiment a compressor has now been designed which effects a great saving in h.p., and this can be seen in the latest plants.

In addition to the above a great deal of thought has also been given to the production of clean air, and this problem has been solved recently.

In many places compressed air is required for raising the sewage by means of ejectors, in which case no further compressing plant is needed.

The amount of purification of the liquid sewage depends upon the period of aeration allowed, and hence with tanks of sufficient capacity it is capable of dealing with very foul sewage which would be difficult of treatment by other processes.

The entire patents for the process are held by Messrs. Activated Sludge, Ltd., 100 Victoria Street, Westminster.

Over sixty-one permanent activated sludge plant equipments for treating either sewage or trades waste have been installed by *Activated Sludge, Ltd.*, including a few now near completion. These are situated in the following countries: Great Britain, Canada, South Africa, India, Denmark, Holland, France, and Finland.

With these plants in full operation they will be treating 30,000,000 gallons of dry weather sewage, and will serve an aggregate population of 600,000.

In addition to the foregoing the Manchester Corporation have adopted this method for treating half the flow of sewage, and the scheme has been approved of by the Ministry of Health. When the plant is in full operation it will serve a population of over 300,000.

Though the 'diffused air' method has been adopted in the U.S.A. almost exclusively, these plants, which are over twenty in number, have not been included in the above, yet the four plants at Houston, Texas, Milwaukee, Indianapolis, and Chicago will treat an aggregate D.W.F. of 329,000,000 gallons per day and serve a population of 1,745,000.

As further plants have been installed and more and more data have become available from various installations, it has become possible to make comparative tests between 'ridge and furrow' and 'spiral flow' types of tanks. A definite attempt has been made to ascertain the relative values of these two forms of design in reference to weak and strong sewages with and without trades waste. Much valuable information has resulted from the many trials.

In addition, experiments have been carried out in reference to short-circuiting and the effect of increased interfacial contact on the effective capacity of these plants. These experiments have greatly added to the detailed knowledge of the requirements of the process.

The single-unit type is generally adopted for populations up to 1,000, and the double-unit type for populations up to 6,000.

A multi-unit type of not less than 4 units is used for any populations above 6,000.

The Estuary type can be used for any population, irrespective of size, and is arranged for an aeration period of a few minutes only, a high degree of purification not being required with an outfall into large rivers or estuaries, or it can be used for preliminary treatment before final treatment on filter beds.

A general description of the above types can be found in a paper read by Mr. J. A. Coombs, A.M.Inst.M.E., A.M.I.S.E., before the Institute of Sanitary Engineers in 1923.

Standard of Purity for Sewage Effluents.

The Royal Commission on Sewage Disposal appointed in 1898 put forward the following provisional standard of purity for sewage effluents for the guidance of Local Authorities.

1. That it should not contain more than three parts per 100,000 of suspended matter; and

2. That after being filtered through filter paper it should not absorb more than

(*a*) 0·5 part by weight per 100,000 of dissolved or atmospheric oxygen in 24 hours.
(*b*) 1·0 „ „ „ „ „ 48 hours; or
(*c*) 1·5 „ „ „ „ „ 5 days.

In 1913 the Royal Commission issued their 8th Report, in which they summarised their conclusions as follows:

(*a*) The law should be altered so that a person discharging sewage matter into a stream shall not be deemed to have committed an offence under the Rivers Pollution Prevention Act, 1876, if the sewage matter is discharged in a form which satisfies the requirements of the prescribed standard.

(*b*) The standard should be either the general standard or a special standard which will be higher or lower than the general standard as local circumstances require or permit.

(*c*) An effluent in order to comply with the general standard must not contain as discharged more than 3 parts per 100,000 of suspended matter, and with its suspended matters included must not take up at 65° F. (18·3° C.) more than 2·0 parts per 100,000 of dissolved oxygen in five days. This general standard should be prescribed either by Statute or by Order of the Central Authority, and should be subject to modifications by that Authority after an interval of not less than ten years.

(*d*) In fixing any special standard the dilution afforded by the stream is the chief factor to be considered. If the dilution is very low it may be necessary for the Central Authority, either of their own initiative or on application by the Rivers Board, to prescribe a specially stringent standard, which should also remain in force for a period of not less than ten years.

(*e*) If the dilution is very great the standard may, with the approval of the Central Authority be relaxed or suspended altogether. Our experience leads us to think that as a general rule, if the dilution, while not falling below 150 volumes, does not exceed 300, the dissolved oxygen absorption test may be omitted and the standard for suspended solids fixed at 6 parts per 100,000. To comply with this test no treatment beyond chemical precipitation would ordinarily be needed.

If the dilution while not falling below 300 volumes does not exceed 500 the standard for suspended solids may be further relaxed to 15 parts per 100,000. For this purpose tank treatment without chemicals would generally suffice if the tanks were properly worked and regularly cleansed. These relaxed standards should be subject to revision at periods to be fixed by the Central Authority, and the periods should be shorter than those prescribed for the general or for the more stringent standards.

(*f*) With a dilution of over 500 volumes all tests might be dispensed with, and crude sewage discharged, subject to such conditions as to the provision of screens or detritus tanks as might appear necessary to the Central Authority.

EDITORIAL NOTE.—The standards mentioned in (*e*) and (*f*) are not intended to apply to effluents discharged into streams which are used for drinking water or to streams the water of which, at the point of discharge of the sewage effluent, normally takes up more than 0·2 parts per 100,000 of dissolved oxygen in five days at 60° F. Up to the present time the proposals contained in the Report have not been embodied in any Act of Parliament, and have therefore no official authority, and must be treated as suggestions only.

HOUSE DRAINAGE.

House drains are usually made of salt glazed ware pipes varying from 3 ins. to 6 ins. diameter. Drains taking the discharge of water-closets should not be less than 4 ins. diameter.

Wherever possible all house drains should be laid outside the building; they should be laid as far as practicable in straight lines with easy bends, furnished with inspection chambers, and should be arranged so that they may be easily got at in case of necessity.

When it becomes imperative that drains should pass under the buildings, cast-iron pipes should be used and they should be laid in a straight line between two inspection chambers outside the building

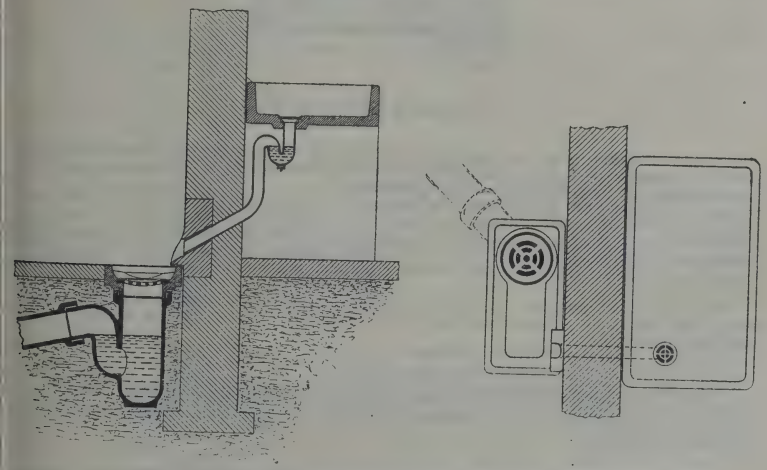


FIG. 3.—Section and Plan of Scullery Sink, with connection to Gully.

The size of drain-pipes should be sufficient to carry off sewage at the rate of forty gallons per head of the maximum population drained in six hours, and in addition rainfall at the rate of ½ in. per hour upon the area of roofs and paved yard surfaces draining to the sewers.

It was formerly considered essential that all private drains should be trapped from the sewer at a point as near as possible to the junction with the sewer, and that an inspection chamber should be built at the trap and should be provided with a fresh-air inlet.

The Local Government Board appointed a Departmental Committee to advise upon the desirability of fixing these intercepting traps near the sewers. In 1912 the Committee made their report, and stated that the case for the necessity of the intercepting trap had broken down, and that it is not only unnecessary but in many cases is harmful. It is probable, therefore, that there will be an early modification of building regulations in most towns, deleting the byelaws requiring intercepting traps between sewer and drain.

The recommendation of the Committee must not be understood to imply the uselessness of traps other than the main intercepting trap: it is just as important as ever that all inlets to drains should be trapped between the drain and the house.

The general scheme of drain trapping should be based upon the following lines:—The main drain to each house or building should be carried from the sewer without a trap or air inlet to the furthest point where a branch connection is to be made, and there a ventilating shaft should be erected and carried up well above the eaves of the house and clear of all windows, dormers, skylights, and chimneys. The end of the pipe should be fitted with a wire guard; most cowls are useless.

Branch drains for sink wastes, bath wastes, and rain-water pipes should terminate with trapped glazed stoneware gullies placed at ground-level and paved round with a containing curb of blue brick on edge on three sides and a short paved channel at least 18 ins. long on the

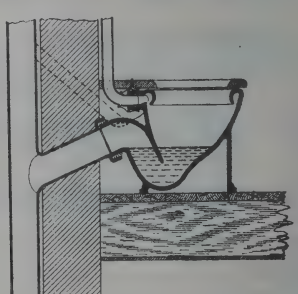


FIG. 4.—Section of Water-closet.

other on to which the waste etc. pipes should discharge. Bath wastes etc. from upper floors should be made to discharge in the open air into the cistern heads of down-pipes which are themselves cut off from the gully as above described.

Branch drains for soil pipes should be untrapped at the foot of soil pipes, and the latter should be carried up outside the external walls of the building in a straight line to above the eaves to form a ventilating column, the same precautions being adopted as in the case of the ventilation column for the end of the drain. Where there is only one soil-pipe connection it can often be arranged at the end of the main drain and so avoid the provision of more than one ventilation shaft.

When it is found inevitable that soil-pipes should be fixed inside buildings they should be of drawn lead throughout their entire length and should be carried up through the roof to give thorough ventilation.

Sinks and water-closets should, whenever practicable, be placed against external walls so that they may discharge at once into a drain outside the main wall, as shown in figs. 3 and 4.

Water-closets are best placed where they can be thoroughly ventilated directly from the external air with windows extending to the ceilings, and they should be arranged to be entered from a well-ventilated ante-room or passage with doors to shut off communication with the other portions of the house.

LONDON COUNTY COUNCIL REGULATIONS FOR WATER-CLOSETS (*Abridged*).

Building (for closet) must have one external wall abutting on a space 100 ft. square super (or if in a basement approached directly from an opening at least 5 ft. wide and 40 ft. square super) and must not be directly approached from a room used for habitation, work, storage, or preparation for food. Walls abutting on such rooms must be of brick from floor to ceiling.

A window opening directly into the external air at least 2 ft. square, and in addition at least one ventilating air brick, air shaft, or other effectual means of ventilation must be provided.

Floor of closets approached from the external air to be of hard impervious material, having a fall to the door of half inch to the foot.

Door with proper fastening to be provided.

Cisterns giving an adequate and effectual flush must be fitted to all closets. Closet cisterns must be entirely separate from cisterns containing drinking water. A proper supply of water to the cistern must be supplied. No service pipe may be allowed to be connected in any way with any part of the closet apparatus except the cistern. Downpipe and union between closet and cistern must have internal diameter of not less than 1¼ in.

Closet Basin and Trap.—The basin must be of non-absorbent material of such shape that a sufficient quantity of water is held in such a manner that the soil falls direct into the water clear of the sides.

No container to be fitted under basin.

An efficient syphon trap must be fitted immediately behind or in connection with the basin. The trap must be constructed to always provide a sufficient water-seal between the basin and the drain. Traps must be ventilated where more than one closet is connected with the same soil pipe. Ventilating pipe must not be less than 2 ins. internally, and connect with the arm of soil pipe not less than 3 ins. nor more than 12 ins. from the highest part of the trap. Ventilation must be on the drain side of the water-seal, and the ventilation pipe must be carried either to the open air at a point as high as the top of the soil pipe or to the soil pipe above the highest closet.

No D trap or similar trap must be fitted.

Soil pipe must be outside buildings wherever practicable. Soil pipes inside buildings must be drawn head with wiped joints, or heavy cast iron with molten lead joints, properly caulked. Pipe to be continued without diminution and as straight as possible to a height to allow of safe outlet by open end for foul air. Height must be above highest part of roof of building, and where practicable 3 ft. above any window that lies within 20 ft. measured in a straight line from open end. Wire guard to be fitted to open end, the area of the opening in which must be equal to not less than size of pipe.

Soil pipe must not directly connect with waste of bath, rain-water pipe, or to a sink, and soil pipe must have no trap in it nor between it and the drain.

Joints.

Lead Pipe to Iron.—A brass thimble to be used—the lead wiped to open end and the other connected with the iron by a joint of molten lead, properly caulked.

Stoneware to Lead.—Brass socket or thimble wiped to lead and connected to stoneware with Portland cement.

Stoneware to Iron.—Stoneware to be inserted into socket in iron and connected with joint made with Portland cement.

Dimensions and Weights of Soil Pipes.

Internal diameter must not be less than 3½ inches.

Diameter.	Lead. Weight per 10 feet Length not less than	Iron. Weight per 6 feet Length not less than
3½ inches.	65 lbs.	48 lbs.
4 ,,	74	54 ,,
5 ,,	92 ,,	69 ,,
6 ,,	110 ,,	84 ,,

General Notes.

Water-closet basins are all made with traps attached, and this is sufficient protection against sewer air coming into the house from the soil pipe. To ensure proper ventilation of the branch pipe from the w.c. trap to the soil pipe and to prevent unsealing by syphonic action where closets are placed over one another and are connected to the same soil pipe, a small auxiliary ventilation pipe should be connected near the trap and be carried upwards at an angle of about 45° into the soil pipe, as shown in fig. 4.

Water-closet basins should be so designed as to present as large a surface of water as possible into which the excreta may fall when the closet is in use; they should have flushing appliances which effectually wash the whole of the internal surface of the basin with the minimum of water and they should have all parts easily accessible for cleansing by hand. Closets with a syphonic action are most effectual and much to be preferred to any type of valve closets. The pedestal type of closet with lift-up lid so that it can be used as a urinal is the one most in favour.

Water-closets should be fitted with waste-preventing water-cisterns of not less than 2-gall. capacity and a 3-gall. cistern if allowed by the local waterworks regulations is preferable.

Flush pipes should be of lead or copper and should be 2 ins. diameter with a head of 6 ft. to give efficient flushing.

Urinals should not be provided at all inside private houses, and whenever they are fixed inside a building they should be made throughout of glazed stoneware with curved surfaces and as few joints as possible so as to avoid any angles in which the urine can lodge. They should be fitted with lead or copper sparge pipes capable of thoroughly washing all the surfaces liable to be soiled with urine.

Slate urinals may with advantage be painted with a mixture of common coal tar and naphtha; they should be thoroughly washed out at least once a day. Slate is not a material to be recommended for the construction of urinals; all stalls and basins should be of glazed stoneware.

The usual allowance of water for each stall in a public urinal is half a gallon per minute. The waste pipes for each stall should be 2 ins. in diameter.

White glazed bricks are preferable for facing the walls of public urinals; ordinary brick walls cemented over and painted are decidedly objectionable. The joints in the brickwork must not be thick under any circumstances, as they would present an absorbent surface.

Baths and housemaids' sinks should be of glazed porcelain fitted with trapped waste pipes which should be carried through the nearest external wall and be made to discharge in the open air over the cistern head of a downpipe: the top of the cistern head should be covered with a copper wire guard to keep out the birds, dead leaves, etc.

Kitchen and pantry sinks should be of glazed stoneware and should be fixed against an external wall, and their trapped lead waste-pipes should be carried through the wall and be made to discharge in the open air upon a paved channel leading to a trapped gully.

SECTION XXVI

PART II

IRRIGATION — AVAILABLE SUPPLY — EVAPORATION — ABSORPTION—EVAPORATION FROM SOILS—LOSSES FROM IRRIGATION CANALS — MEAN VELOCITIES — CRITICAL VELOCITY—DUTY OF WATER.

Contributed by Reginald Ryves, Assoc.M.Inst.C.E., M.Cons.E.

(Author of 'A Note on Mass Dams and Dams of Arches,' etc.)

IRRIGATION.

Available Supply of Water.

Irrigation from Large Rivers.—The discharges of the river during the seasons when the water will be required are calculated from the observed depths over weirs, from differences of water level above and below bridge openings, and by the methods hereafter to be described under 'Capacities of Canals.' Whether these supplies will be fully available or not may depend upon the water levels which can be maintained above the weir, and upon what cultivable areas are commanded by the water at these levels. In this respect the scheme must be considered as a whole, and by making suitable regulations as to the crops which may be grown on certain areas and at certain seasons the availability of the supply may be increased.

Supplies from Defined Catchments.—In the case of a supply from a defined catchment the estimates of run-off may be made by the methods described under 'Rainfall,' the necessary deductions being made when the whole of the water stored cannot be directly utilised. Out of the whole recorded range of annual or seasonal rainfalls, and corresponding runs-off, one will be chosen as that suitable as a basis for the project, and the capacity of the reservoir designed accordingly. A table drawn up for catchment areas in Nagpur, Central Provinces, India (*Strange*), gives estimated yields for monsoon rainfalls ranging from 1 in. to 60 ins., and from this table the following examples are taken.

MONSOON RAINFALLS AND ESTIMATED RUNS-OFF FOR NAGPUR.

Monsoon Rainfall in Inches.		1	5	10	20	30	40	50	60
Runs off in millions of cubic feet per square mile	Good catchment	0·002	0·116	0·999	6·970	18·33	34·85	56·69	83·63
	Aver. catchment	0·001	0·087	0·749	5·227	13·75	26·13	42·51	62·73
	Bad catchment .	0·001	0·058	0·499	3·485	9·17	17·42	28·34	41·87

Evaporation from a Water Surface.

The actual rate of evaporation from the surface of a pool of water depends mainly on four factors: the temperature of the water itself; the velocity of the wind; the degree of humidity of the air; and the temperature of the air. As regards the first, this is more or less proportional to the air temperatures if we are measuring evaporation over considerable periods of time in different places. As regards the second, the velocity of the wind, this factor does not as a rule vary so much as others if we take a period such as a year; but it sometimes varies a great deal within areas of moderate extent, and it should be taken into consideration in making estimates of evaporation. The degree of humidity varies very greatly, not only in different countries or different districts, but also in proportion to the distance from the sea and, in some cases, with

elevation. There may be a marked decrease in the humidity of the air in a distance of a few miles from a long, straight coast line, the decrease being more gradual as we pass farther inland. There are also sharp differences between places just within and those just without the path of a monsoon current. The relation between water temperature and the rate of evaporation was studied at four stations in California (*Fortier*) with the following results, the evaporation being in sixty-fourths of an inch per day. The tanks used were of galvanised iron, 22 ins. in diameter and 28 ins. deep sunk in the ground.

Water Temperature and Evaporation.—53°F., 6; 62°F., 12; 73°F., 23; 80°F., 31; 88°F., 39.

The following were the results of experiments to test the rates of evaporation in air currents of different velocities, that in still air being taken as unity. (*Russell.*)

Wind Velocity and Evaporation.—Velocity 0, evaporation 1·00; velocity 5 miles an hour, evaporation 2·2; velocity 15, evaporation 4·9; velocity 20, evaporation 5·7; velocity 25, evaporation 6·1; velocity 30, evaporation 6·3. Observations taken at the Assuan reservoir show the relative importance of average month's temperatures and average month's wind velocities. The results do not, of course, aid in the establishment of a relation between actual wind velocities, actual temperatures, and rates of evaporation, but they are of practical use for purposes of comparison.

AVERAGE VELOCITIES OF WIND, AVERAGE TEMPERATURES, AND RATES OF EVAPORATION, ASSUAN, EGYPT. LATITUDE, 24°. YEAR 1912.

Month .	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Wind velocity, miles per hour .	3·6	4·2	6·6	5·3	4·2	3·0	3·3	3·5	1·2	1·7	3·4	3·7
Temperature °F. .	60·7°	66·7°	72·3°	80·7°	87·2°	91·4°	91·2°	92·1°	89·3°	83·3°	73·6°	62·2°
Evaporation, ins. per day	0·12	0·17	0·24	0·31	0·35	0·45	0·43	0·44	0·32	0·29	0·21	0·15

Humidity and Evaporation.

By taking a sufficient number of observations of rates of evaporation, it is possible to establish at the same time the relation between evaporation and air temperature and that between evaporation and humidity. Experiments of this kind with water at a constant temperature seem to be lacking, nor have observers, as a rule, noted the actual temperatures of the water. Results are, however, comparable in groups, such as those with small experimental tanks, and those with floating tanks in deep and shallow waters, respectively.

The following table gives the results of observations at Vehar reservoir, near Bombay, latitude 19° (*Conybeare*), and in Nagpur, 21° (*Binnie*). The values seem to be low, but this hardly affects their application in practice, as the engineer would draw the curves and fix his own zero line on the result of monthly or annual evaporations for the locality.

APPROXIMATE MONTHLY EVAPORATIONS IN FEET WITH GIVEN TEMPERATURES AND RELATIVE HUMIDITIES.

Percentage of Saturation.	Mean Temperatures, Fahr.						
	65°	70°	75°	80°	85°	90°	93°
88	0·14	0 17	0·19	0·21	0·24	0·27	0·30
85	0·19	0·22	0·22	0·23	0·27	0·30	0·33
80	0·22	0·27	0·29	0·30	0·32	0·36	0·38
75	0·24	0·29	0·33	0·35	0·37	0·40	0·42
70	0·26	0.30	0·34	0·35	0·38	0·42	0·44
65	0·28	0.31	0·34	0·36	0·40	0·44	0·46
60	0·30	0·35	0·38	0·40	0·42	0·47	0·49
55	0·32	0·37	0·42	0·46	0·50	0·52	0·54
50	0·35	0·40	0·45	0·50	0·55	0·60	0·62
45	0·45	0·50	0·57	0·67	0·71	0·75	0·78
40	0·61	0·66	0·70	0·72	0·77	0·82	0·84

The figures in the following table are taken from results of observations by the Egyptian Public Works Survey Department (*Cay*). It is clear that the rate of evaporation depends considerably upon the mean altitude of the sun, since, for air temperatures which are nearly the same, the rate of evaporation is affected by the latitude and the month. This is shown by the small tables, and the evaporation at latitude 24° in October with air temperature 83° and humidity 41 may be compared with that at latitude 27° in August with nearly the same humidity.

OBSERVATIONS BY EGYPTIAN PUBLIC WORKS DEPARTMENT.

Locality	Abassia, Cairo. Lat., 30° 1′.					
Month	May.	June.	July.	Aug.	Sept.	Oct.
Mean temperature of month, Fahr.	75°	78°	81°	80°	77°	73°
Relative humidity	47	50	55	62	70	71
Evaporation, inches	·32	·25	·20	·22	·17	·18

Locality	Asyut. Lat., 27° 11′.					
Month	May.	June.	July.	Aug.	Sept.	Oct.
Mean temperature of month, Fahr.	81°	84°	—	85°	81°	76°
Relative humidity	26	26	—	40	46	56
Evaporation, inches	·55	·61	—	·51	·37	·27

Locality	Assuan. Lat., 24° 2′.					
Month	May.	June.	July.	Aug.	Sept.	Oct.
Mean temperature of month, Fahr.	90°	90°	90°	90°	89°	83°
Relative humidity	16	20	20	20	32	41
Evaporation, inches	·62	·60	·52	·52	·47	·35

Temperature 80°–81°F.				Temperature 89°–90°F.			
Humidity.	Evap.	Month.	Lat.	Humidity.	Evap.	Month.	Lat.
62	·22	Aug.	30°	32	·47	Sept.	24°
55	·20	July	30°	20	·60	June	24°
46	·37	Sept.	27°	20	·52	July & Aug.	24°
26	·55	May	27°	16	·62	May	24°

The effect of altitude upon evaporation was tested at four stations on the same mountain in California with the following results :—

Evaporation at Different Altitudes.—4,500 ft., 2·69 ins. ; 7,100 ft., 2·04 ins. ; 10,000 ft., 1·63 in. ; 12,000 ft., 1·61 in.

Annual Evaporation.

At stations selected as representing the chief irrigation districts of California the following were evaporations for a year (*Fortier*). At Berkeley, the cooler coast area with relatively high rainfall, 41 ins. ; at Chico, the bottom of the Sacramento Valley, 53 ins. ; at Pomona, representing Southern California, 66 ins. ; at Tulare, the San Joachin Valley, 68 ins. ; at Calexico, the Imperial Valley, 71 ins.

The evaporation at a number of representative stations is given in the following table, but the methods adopted in measuring evaporation varied considerably. At Croydon, the evaporation from a 5-in. vessel in air was more than 50 per cent. greater than that from the 12-in. vessel floating in water.

EVAPORATION AT REPRESENTATIVE STATIONS.

Locality.	Approximate Latitude.	Evaporation in Inches.	Remarks.
Whitehaven, England	54½°	29·91	Elevation 90 ft. near coast.
Bolton-le-Moors, England	53½°	25·65	Average of 10 years. Elevation 320 ft.
Croydon, England	51½°	19·95	13 years, max. 22·85, min. 15·01. A 12-in. vessel floating in a tank 4 ft. in diameter.
Kennich, Devonshire, England	50½°	20·88	Elevation 836 ft. Average of 4 years.
Dijon, France	47½°	26·11	Inland station.
Boston, U.S.A.	42½°	39·11	
Croton River, U.S.A.	41½°	24·15	
New York, U.S.A.	41°	39·21	
Tharsis Mines, Spain	37½°	60	Average of 7 years, max. nearly 65 ins.
Chicco, California	39½°	53	Galvanised iron tanks, 2 to 3 ft. in diameter, and 30 to 36 ins. deep; sunk in the earth.
Berkeley ,,	38°	41	
Tulare, ,,	36°	68	
Pomona, ,,	34°	66	
Calexico, ,,	—	71	
A station in California	—	30	Elevation 6,225 ft.
Perth, Western Australia	32°	65·8	
Rajputana, India	25° to 28°	73·8	General average.
The Rand, South Africa	26°	63	
Tulsi Lake, Bombay Presidency	19°	36·4	Floating boxes. Average of 8 years.
Red Hills, Madras, India	13°	66·9	Near the coast.

Seasonal and Monthly Losses by Evaporation.

It is often necessary to be able to estimate the losses by evaporation during particular seasons, and monthly rates of evaporation, or daily rates in individual months, are frequently recorded. For considerable areas in India the seasonal losses may roughly be reckoned as: In the cold weather 12 ins., in the hot weather 32 ins., during the monsoon 16 ins.; total, 60 ins.

In the following table, some of the rates of evaporation are comparable, but the table has been drawn up chiefly in order to show the relative rates of evaporation in different months at the same station.

MONTHLY EVAPORATIONS FROM WATER SURFACES. (Inches.)

Locality.	Approx. Lat.	Month.					
		Jan.	Feb.	Mar.	April.	May.	June.
Emdrup, Denmark (av. of 11 years)	56°	0·7	0·5	0·9	2·0	3·9	5·3
Bolton-le-Moors, England, 320 ft. (av. of 10 years)	53½°	0·64	0·95	1·59	2·59	4·38	3·84
Whitehaven, England, 90 ft.	54½°	0·95	1·01	1·77	2·71	4·11	4·25
Tulare, California	36°	1·5	2·7	3·3	3·8	7·2	10·5
Perth, Australia	32°	2·06 (July)	1·75 (Aug.)	3·20 (Sept.)	5·51 (Oct.)	7·69 (Nov.)	9·47 (Dec.)
Cairo, Egypt	30°	—	—	—	—	9·88	7·56
Assuan, Egypt	24°	—	—	—	—	19·16	17·96
Pashan, Poona, India	18°	5·27	3·92	5·27	8·10	11·78	*
Red Hills, Madras, India.	13°	4·37	4·93	6·57	7·51	8·67	8·16

* Monsoon month.

MONTHLY EVAPORATIONS FROM WATER SURFACES. (Inches.)—*Cont.*

Locality.	Approx. Lat.	Month.						Year.
		July.	Aug.	Sept.	Oct.	Nov.	Dec.	
Emdrup, Denmark (av. of 11 years)	56°	5·2	4·4	2·6	1·3	0·7	0·5	27·9
Bolton-le-Moors, England, 320 ft. (av. of 10 years)	53½°	4·02	3·06	2·02	1·28	0·81	0·47	25·65
Whitehaven, England, 90 ft.	54½°	4·13	3·29	2·96	1·76	1·25	1·02	29·91
Tulare, California	36°	11·6	9·8	7·4	5·5	3·8	2·0	68·5
Perth, Australia	32°	10·22 (Jan.)	8·35 (Feb.)	8·26 (Mar.)	5·21 (April)	2·27 (May)	1·80 (June)	65·79
Cairo, Egypt	30°	6·35	6·95	5·09	5·49	—	—	—
Assuan, Egypt	24°	16·11	16·11	14·17	10·74	—	—	—
Pashan, Poona, India	18°	Mon	soon m	onths.	7·75	5·7	4·34	—
Red Hills, Madras, India.	13°	5·91	3·92	4·38	4·80	3·29	4·01	66·88

Losses by Evaporation and Absorption taken together.

In a great many cases the available data of losses from reservoirs are those for evaporation and absorption, or percolation, taken together. The more nearly the engineer can estimate what proportion of the total loss is due to evaporation alone, the more easily will he be able to decide as to the necessity or expediency of taking measures to reduce percolation. Fairly high losses may be tolerated from reservoirs where a considerable proportion of the percolating water reaches wells from which it can be lifted and used; and this may in some cases be an advantage when the level of the water in the reservoir is very low, or, at least, a mitigation of the disadvantage. Actual losses by percolation can be estimated when the rate of evaporation is obviously very small. Conversely, the proportion lost by evaporation may be estimated when the losses by percolation are known to be small. The losses may be measured as depths on the maximum waterspread, or as actual depths on the mean of the waterspreads at the beginning and end of each short period of observation. Thus, there are often apparent discrepancies between really similar cases, especially when the reservoirs are very shallow in parts, and when, as often happens, the maximum rate of evaporation occurs when the tank is very low.

Losses by percolation are sometimes very large. The losses from four irrigation reservoirs in the United States were as follows, measured in acre-inches or acre-feet referred to the *maximum* waterspread in acres:—(1) one year, 50·4 ins., all attributed to evaporation; (2) maximum of 2 years, 53·8 ins.; (3) maximum of 4 years, 132 ins.; (4) maximum of 2 years, 17·3 ft., ¾ of which was attributed to percolation.

At Red Hills tank, Madras, a total loss of about 7·5 ft. seems to have been indicated by one set of tests, and 8·39 by another series. An allowance of 9 ft. is now made, and is considered to be ample, a fairly liberal estimate being desirable as the water is used for the supply of the city. Tanks in Rajputana were found to lose 9·77 ft. per annum, of which 3·66 ft. was attributed to absorption.

The reservoirs of the Sheffield waterworks are estimated to have lost only about 15 to 15¼ inches by evaporation and absorption, the loss at Rotherham in a neighbouring area being 22 ins.

The following were the results of observations at Red Hills Tank, Madras, the year being roughly divided into seasons which do not, however, begin and end at even approximately the same dates every year.

SEASONAL LOSSES (INCHES PER DAY) BY EVAPORATION AND ABSORPTION, RED HILLS TANK, MADRAS.

Humid Season under the modified influence of the South-West Monsoon.	North-East Monsoon and Cool Dry Season.	Hot Dry Season.
July 0·33	Nov. 0·27	Mar. 0·26
Aug. 0·32	Dec. 0·13	April 0·30
Sept. 0·38	Jan. 0·24	May 0·37
Oct. 0·27	Feb. 0·24	June 0·36
Average 0·33	Average 0·22	Average 0·31

EVAPORATION AND ABSORPTION (ALMOST ENTIRELY EVAPORATION) RECKONED ON THE TOP AREAS OF RESERVOIRS NEAR DHARWAR, BOMBAY PRESIDENCY (*Strange*).

Month.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Total.
Evaporation, ins. per day	0·16	0·16	0·16	0·33	0·67	0·67	0·51	0·31	0·16	0·16	0·16	0·17	3·65 ft.

Evaporation from the Soil.

A study of rates of evaporation from the soil is of practical importance as bearing upon estimates of the actual amounts of water required by crops under varying conditions, and the probable losses from the ground when the water is applied some time before cultivation. The importance of the subject is the greater in proportion to the extent to which the cultivation has the character of fruit growing or gardening, as distinct from the growth of large areas of grain crops. In orchards especially, it is possible so to apply the water that the loss by evaporation is considerably reduced. It is often an advantage to keep the water in distinct channels as long as possible.

CALIFORNIAN EXPERIMENTS ON EVAPORATION FROM THE SOIL.

Important series of tests have been carried out during recent years in California, and have been reported by Mr. S. Fortier, Chief of Irrigation Investigations, United States Department of Agriculture.

The experiments were carried out with tanks about 47 ins. deep and 23½ ins. diameter, sunk into the soil and filled nearly to the brim. These tanks were weighed in order to measure losses. The following tabular statement gives the results of experiments made in July and August on the evaporation from soils containing different proportions of water, measured as inches depth over the area of the surface. In the case of the initial free moisture this represented about 4½ to 6 per cent. The amounts of irrigation water added represented, respectively, very light, light, and ordinary irrigation.

WATER CONTENTS IN SOIL AND EVAPORATION (IN INCHES).

Initial moisture	2·8	2·7	2·7	4·1
Irrigation water	0	2·6	4·8	6·3
10 days' evaporation . . .	0·4	0·9	1·2	1·5

Evaporation from the soil may be much reduced by beating or crumbling the dry surface to a powder, by spreading a layer of finely divided soil over the surface, or by irrigating by means of furrows, afterwards spreading the dry soil from between the furrows by some means which will tend to crumble or powder it. In small-scale irrigation and where the cost of the water is high these considerations may be of importance. The following results were obtained in California with experimental tanks containing sandy loam, the evaporation from which when it was left uncovered after the water had been applied was compared with the evaporation after coverings of different depths of finely divided sandy loam had been added. The result of the experiment with the thinnest layer is, of course, the most important generally. During the fourteen days of the experiment the shade temperature of the air at noon was often more than 100°, while the soil temperature in the sun, at noon, varied from 120° to 140°. The figures were :—

Evaporation in hundredths of an inch per day : from uncovered soil, 72·5 ; from soil protected by a 4-inch layer, 20·6 ; 8-inch layer, 10·0 ; 10-inch layer, 2·0.

The following were the results of a twenty-one days' test.

SOIL EVAPORATION IN PERCENTAGE OF WATER APPLIED.

Days	2½	6½	10	14	17	21
Bare soil . . .	11	18	21	25	28	32
3-inch cover . .	2	5	7	9½	11½	14

A further series of experiments was carried out with tanks 47 inches deep and 23½ inches diameter.*

* See *Engineering News*, Sept. 5, 1912, but note that in figs. 2 and 3 the diagrams of evaporation in inches have been accidentally transposed.

In one set of tests the tanks were nearly filled with soil, leaving room for the covering of loose soil in each case, spread after the application of the water, while in another set of tests the tanks were nearly filled and the water applied at the bottoms of furrows of corresponding depths, the soil being afterwards spread. The following table gives the results of both experiments:

EVAPORATION AND SOIL COVERINGS.

Period after water was applied: days		7	14	21	28	21	28
		Evaporation in percentage of water applied.				Evaporation in inches.	
Surface irrigated and left		17·5	25	31·5 (29)		1·75	
Surfaces irrigated and covered with loose soil (inches)	3 ins.	4·8	9·5	13·7 (12·5)		0·75	
	6 ins.	1·5	3·2	6·0 (5·7)		0·34	
	9 ins.	1·5	1·3	4·1 (3·3)		0·22	
Surface irrigated and left		13·2	16·4	18·6	20·8		1·25
Water applied at the bottoms of furrows, depths in inches	3 ins.	9·2	12·0	14·9	16·5		0·99
	6 ins.	7·0	9·6	12·3	14·3		0·86
	9 ins.	6·1	7·5	9·9	12·0		0·72

In the column for the 21st day, the figures in brackets are calculated from the evaporation in inches, and possibly correspond to earlier readings. The other figures in the column are taken from the curve.

Relation between Evaporation from Soil and Evaporation from Water.

The experiments, on the results of which the table below is based, showed what were the evaporations from soils containing different proportions of water, and from a water surface.

Percentage of Free Water.	Temperatures, Fahrenheit.				Weekly Evaporation in Inches.	
	Air in Shade.	Soil in Shade.	Soil in Sun.	Surface of Water.	Soil.	Water.
Saturated.	71°	76°	95°	77°	4·75	1·88
17·5%	76°	78°	106°	80°	1·33	1·94
11·9%	76°	78°	106°	80°	1·13	1·94
8·9%	76°	78°	108°	80°	0·88	1·94
4·8%	76°	78°	108°	80°	0·25	1·94

ANNUAL EVAPORATIONS IN INCHES DURING TWELVE YEARS, LEA BRIDGE, ENGLAND.

Water: max., 26·93; min., 17·33; mean, 22·2.
Soil: max., 25·14; min., 12·07; mean, 19·53.
Sand: max., 9·10; min., 1·42; mean, 4·65.

(*Greaves.*)

Evaporation from Ice.

At Boston waterworks, U.S.A., the evaporation from ice was about 0·06 inch per day, of ins. for the cold season.

Water Losses from Irrigation Canals.

No general rules can be given for estimating the rate at which water is lost from irrigation nals. Some are practically watertight, and only lose water by evaporation, while others lose rge proportions of their supply by leakage.

On the Ganges Canal, at one period the water sent down was accounted for as follows:— rigation, 56 per cent.; loss in canal, 15 per cent.; in distributaries, 7 per cent.; in village water- urses, 22 per cent.

In the Punjab, a loss of 8 cusecs per million square feet of wetted surface has been allowed, d larger amounts in some cases. Certain canals with discharges from 400 to 450 cusecs were

found to lose about one cusec per mile. The Bari Doab Canal, when eighteen years old, lost about 12 to 14 per cent. of its discharge in a length of fifty miles.

Recently, instead of allowing 8 cusecs per million square feet of wetted area, it has been usual to allow, within the limits 4 ft. to 12 ft. depths, one cusec per foot depth per million wetted square feet.

Many canals lose a great deal of water for some time after their construction, and afterwards become reasonably watertight. The deposit of silt at a reasonable rate for some time after the canal is in service may be facilitated by suitable designing of the cross-sections and temporary adjustments of levels at the falls; but no general rules can be given as to this difficult problem.

When L is the loss from a canal, measured in the first mile, the loss up to a further distance of D miles is $L\,D^x$, where x varies from $\frac{5}{6}$ to $\frac{9}{8}$.

Losses through a Dam.

An extreme case of seepage through a gravel fill dam. The dam was 70 ft. high; upstream slope, 3 to 1; downstream slope 1½ to 1. With the gates closed the seepage rates were approximately, during three years: with 20 ft. of water (gauge height), 60 cusecs; with 30 ft. of water, 84 cusecs; with 40 ft. of water 100 to 120 cusecs; with 50 ft. of water, 112 to 135 cusecs.

Capacities of Canals: Mean Velocity.

The discharge or capacity of a canal or river is the product of the cross-sectional area and the mean velocity. The mean velocity is usually found from Kütter's formula (see p. 1481), a coefficient of roughness, n, being chosen with regard to the nature of the soil and the probable behaviour of the canal with respect to silting and erosion. Since the formula takes account of the water slope or fall, and of the hydraulic mean radius,

$$\frac{\text{area}}{\text{wetted perimeter}}$$

every measurement or calculation of discharge by other means tends to fix the value of n for the particular conditions of the bed of the canal or stream. Small discharges may sometimes be measured directly in basins or symmetrical pools, and at notches or specially prepared weirs (pp. 1348-1352), but calculations for discharge over large weirs are themselves subject to disturbing factor and their value in the determination of n is limited.

For irrigation canals in favourable soils and working under favourable conditions the value $n = 0{\cdot}0225$ is considered suitable, and this value has been adopted in the design of very important works. For canals in less favourable conditions the value 0·025 is often adopted, and for canals distinctly below average conditions n may be taken as 0·0275. The value 0·030 may be applied to some rivers and to canals in 'defective condition,' whilst for channels which are much obstructed n may be taken as 0·035. The first two values above are those of most importance in irrigation engineering. For aqueducts of rubble masonry n may be taken about 0·017 to 0·020, and for ashlar and brickwork, 0·013.

Bazin's Formula.

Bazin's new formula is often used for channels, especially for those which, in irrigation systems, are relatively small. It is derived from the general formula

$$V = c\sqrt{RS},$$

by making

$$c = \frac{157{\cdot}6}{1 + \frac{m}{\sqrt{R}}},$$

where c is the coefficient, and V, R, and S have the values given on page 1481.

m = 0·109 for smooth cemented surfaces.
= 0·29 for ashlar and brickwork.
= 0·83 for rubble masonry.
= 1·54 for very smooth earthen channels, pitched, or partly pitched.
= 2·36 for ordinary earthen channels.
= 3·17 for canals encumbered with weeds or boulders.

Direct Measurement of Mean Velocities.

The Use of Floats.—Floats of various kinds have been employed for the measurement of the velocities of canals and rivers, being sent down the reach so as to maintain as far as possible their proper positions in the cross-sections, the average velocity being calculated from float speeds and depths in each strip of the reach. Double floats are often used, the lower and larger float which is a little heavier than water, being held at a determined depth below the surface by a smaller

surface float to which it is attached by a cord. Thus the velocities at different depths and at different distances from the centre-line of the stream can be measured. The essential difficulty in using these floats is that if the lower float has a specific gravity considerably greater than that of the water the surface float must be relatively large, and affect the result appreciably, while if the specific gravity of the lower float be but little greater than that of the water it is liable to be lifted towards the surface by small upward currents.

For the lower floats both cylinders and spheres have been employed; for instance, cylinders 6 ins. in diameter and 12 ins. long, or 6 to 8 ins. in diameter and 9 to 12 ins. long; and spheres 2 ins. and 3 ins. in diameter.

Various forms of surface floats have been used, including very thin discs of considerable area, intended to slip easily along the surface without seriously affecting the speed of the lower float. This form seems to be suitable in calm weather, while a deeper float of smaller surface area may be preferable when there is a breeze. Calm days are best for float observations of any kind, but if a river or canal flows with or against prevailing winds of considerable velocity observations on calm days may be to a small extent misleading.

Rod Floats.—For canals, and for reaches of rivers in which the water varies but little in depth, a good form is the rod float, which may be a tube weighted at the bottom so as to float upright, or a wooden pole similarly weighted. In the Ganges canal experiments both one-inch poles and one-inch tubes were used, the latter proving to be the better. The rods should float with their bottom ends just clear of the bed of the canal.

Current Meters.—Current meters are often used for measuring the velocity of streams and canals, and must be preferred to floats when there is no reach of sufficient regularity and length for the successful use of the latter. With a current meter the velocity at a particular cross-section may be found, and the measurement of that cross-section will then suffice, instead of the number which the irregularity of a reach may render necessary. It is not always easy in practice to keep the current meter at the desired depth, but in some cases it is held there by a rod. In a sluggish stream, the meter may be towed behind a boat, the speed of which is measured. Current meters should be calibrated, and from time to time tested, by towing them at a measured speed in still water, or, failing that, up and down the same reach of the canal or river. The mechanism of the meter can be stopped and started by a brake, on the stop-watch principle, this brake being worked by a cord from the boat. But some meters are fitted with an electrical apparatus, the wires of which form part of the tow line, and record the revolutions visibly in the boat.

The Pitot Tube.—If a tube be partly immersed, vertically, in a current of water, the lower end being suitably bent and remaining open, the water in the tube rises above the surface of the flowing water. The Pitot tube, designed on this principle, gives approximately the relation, $V = \mu \sqrt{2gh}$, where V = the velocity of the current, and h is the height of the water in the tube above the surface of the stream. Instruments which have been employed have given the results $V = 1{\cdot}7 \sqrt{h}$. A much more elaborate instrument on the same principle (*Darcy*) has also been employed, and has given good results in small channels with fairly high velocities.

Perrodil's Hydrodynamometer.—This instrument is a device for measuring the velocity of a current, by the torsion which is produced in a wire by the pressure of the water against a disc mounted on an arm at right angles to the wire. The velocity is found by the equation $V = c \sqrt{a}$, where a is the angle of torsion, and c a coefficient found by experiment, or calculated from the coefficient of torsion of the material of the wire. The instrument is very sensitive and can be used for very slow currents.

Mean Velocity in a Vertical.—The mean velocity of the water in a given vertical in the cross-section of a stream is also the actual velocity at some proportion of the total depth in that vertical. What this proportion is will depend upon the nature of the stream, and will not be the same for all the verticals. For streams of considerable width and not very variable depth at the cross-section, measurements, by means of a current meter, of the velocities at the assumed depth of mean velocity may yield a fair approximation to the mean velocity of the stream, and a closer approximation may be obtained by making preliminary tests, with rod floats for instance, to determine the depth of mean velocity in the particular case. Values given usually lie between 0·60 and 0·75, or 0·60 and 0·70 of the depth.

Relation between Mean and Maximum Velocities.—For a rough estimation of the velocity of a stream the maximum surface velocity may be measured and the mean velocity deduced from it. If V be the maximum velocity, the mean velocity is KV, where K is a coefficient usually ranging from 0·60 to 0·80. In the following table values of K are given for earth channels and rubble masonry channels.

VALUES OF 'K' IN THE EQUATION 'V MEAN = KV MAXIMUM.'

Hydraulic mean depth (feet)	1	2	3	4	5	6	7	10	15	20
Rubble masonry channels	·77	·79	·80	·81	·81	·81	·81	·82	·82	·82
Earthen channels	·65	·71	·73	·75	·76	·77	·78	·78	·79	·80

Critical Velocity.

The 'critical velocity' is that mean velocity at which, for a canal of given depth, the current will neither deposit much silt nor unduly erode its bed. A determination of the critical velocity the theory of which was evolved by R. G. Kennedy (see Min. Proc. Civil Engineers, vol. cxix.) is of great importance in the design of irrigation canals. The removal of silt from the canals is costly, and the loss of valuable fertilising material is a serious matter to the cultivators. A large amount of silting of the canals and distributaries is often inevitable, but attempts are made to lessen it by designing the canals in accordance with the principle of critical velocity.

The equation for determining the critical velocity for a given depth of water in the canal is

$$V_o = cd^m.$$

The values of c and m vary somewhat according to the nature of the silt. For fine sand-silt brought down from the hills usual values are, $c = 0{\cdot}84$ and $m = 0{\cdot}64$. The following table gives the critical velocities calculated on this basis, for different depths, and the observed critical velocities on the Shwebo and Mandalay canals, Burma. With the latter velocities there was on the whole, a slight tendency to scour.

Critical Velocities.

Depths in feet	1	2	3	4	5	6	7	8	9	10	12	15	20
$V = 0{\cdot}84\ d^m$, suitable for the Punjab	0·84	1·30	1·70	2·04	2·35	2·64	2·92	3·18	3·43	3·67	4·12	4·75	5·71
Observed in Shwebo and Mandalay Canals	—	—	1·72	1·98	2·24	2·48	2·75	—	3·09	—	—	—	—

A canal which would be non-silting on a slope of 1 in 7,600 if drawn from the Indus in Sind would require to have a slope of 1 in 4,200 to be non-silting if carrying the silt usually found in the Punjab (*Buckley*).

If the theory of critical velocity be accepted as regards silting and erosion up to the old limit of velocity for different soils, but be rejected when those velocities are reached, the maximum depths allowed for large canals will be correspondingly restricted. If, for instance, a maximum velocity of 3·5 ft. per sec. be prescribed, the depth will be limited to about 9 ft. On the old theory, a higher velocity would cause scour, while on the theory of critical velocity, greater depths with a limit of 3 to 5 ft. per sec. would cause silting. There is, however, no sudden change in the physical conditions, and if the theory of critical velocity holds up to 9 ft. depth it doubtless holds for considerably greater depths; and it has been accepted in the design of very important irrigation systems.

Hydraulic Mean Depth: Mean Velocity: Scour.

(*P.A.M. Parker.*)

For:	Fine Silt.			Heavy Silt and Fine Sand.			Coarse Sand.		
There is no scour in a channel of H.M.D.	1·0	2·5	5·0	1·0	2·5	5·0	1·0	2·5	5·0
Until a mean velocity is reached of	0·4	0·7	0·9	0·9	1·5	1·75	1·75	2·25	3·0

	Small Pebbles, Size of Peas, and gravel.			Large Pebbles, Hen's Egg, and Coarse Gravel.				Large Stones	
There is no scour in a channel of H.M.D.	1·0	2·5	5·0	1·0	2·5	5·0	10·0	1·0	10·0
Until a mean velocity is reached of	2·25	3·0	3·5	5·0	6·0	7 0	9·0	15·0	23·0

VALUE OF c IN $V = c\sqrt{RS}$. $n = 0{\cdot}0250$. (By Kütter's formula, page 1481.)

R in Feet.	S					
	1 in 1,000. 1 in 1,000.	0·5 in 1,000. 1 in 2,000.	0·3 in 1,000. 1 in 3,333.	0·15 in 1,000. 1 in 6,667.	0·10 in 1,000. 1 in 10,000.	0·05 in 1,000. 1 in 20,000.
1·0	55·4	54·9	54·3	52·9	51·8	49·4
1·5	61·3	60·9	60·5	59·5	58·7	56·8
2·0	65·5	65·2	64·9	64·3	63·7	62·4
2·5	68·7	68·5	68·3	68·0	67·6	66·9
3·0	71·2	71·2	71·1	71·0	70·9	70·6
4·0	75·1	75·3	75·4	75·7	76·0	76·6
5·0	78·1	78·3	78·6	79·3	79·9	81·3
6·0	80·4	80·8	81·2	82·2	83·1	85·2
7·0	82·3	82·7	83·3	84·6	85·7	88·5
8·0	83·9	84·4	85·1	86·6	88·0	91·3
9·0	85·3	85·9	86·6	88·4	89·9	93·8
10·0	86·5	87·1	88·0	89·9	91·6	96·0
11·0	87·6	88·3	89·2	91·3	93·2	98·0
12·0	88·5	89·3	90·2	92·5	94·6	99·8

VALUES OF c IN $V = c\sqrt{RS}$. $n = 0{\cdot}0225$. (By Kütter's formula, page 1481.)

R in Feet.	S					
	1 in 1,000. 1 in 1,000.	0·5 in 1,000. 1 in 2,000.	0·3 in 1,000. 1 in 3,333.	0·15 in 1000. 1 in 6,667.	0·1 in 1,000. 1 in 10,000.	0·05 in 1,000. 1 in 20,000.
1·0	62·5	61·9	61·2	59·7	58·5	55·7
1·5	68·8	68·4	67·9	66·8	65·9	63·8
2·0	73·2	72·9	72·6	71·9	71·2	69·8
2·5	76·5	76·4	76·2	75·8	75·4	74·6
3·0	79·2	79·2	79·1	79·0	78·8	78·5
4·0	83·3	83·4	83·6	83·9	84·2	84·9
5·0	86·3	86·6	86·9	87·6	88·3	89·9
6·0	88·7	89·1	89·5	90·6	91·6	93·9
7·0	90·7	91·1	91·7	93·1	94·3	97·3
8·0	92·3	92·8	93·5	95·2	96·6	100·3
9·0	93·7	94·3	95·1	97·0	98·6	102·9
10·0	94·9	95·6	96·5	98·5	100·4	105·1
11·0	96·0	96·7	97·7	99·9	102·0	107·2
12·0	96·9	97·7	98·8	101·2	103·4	109·0

(For the same *actual* R (such as 3·28 ft., or 1 metre) the coefficient for metric units is the efficient for British units $\times \frac{100}{181}$, or $\frac{5}{9}$, nearly.)

Duty of Irrigation Water.

The duty of irrigation water, or the area irrigated by a given rate of flow during the season, pends upon the nature of the crop, the initial proportion of moisture in the soil, the rate of aporation, and the rainfall during the irrigation season. It may also depend upon custom and quired rights and is often affected by the degree of care or of carelessness exercised by the ltivators. All figures relating to duty are, therefore, to be accepted with due reserve for pur-ses of estimates. The duty reckoned on the amount passing the headworks is, of course, less an that reckoned on amounts measured out to the cultivators, and the former figures will be fected by the length of the main canal and principal branches, and the rate of loss therefrom. ie duty of irrigation water may be measured in cusecs continuously for the crop; in feet; or acres per million cub. ft. stored.

On the Jamrao Canal system, India, the duty of one cusec per 50 acres has been allowed for ring the inundation season, and 100 acres during the cool season. The duty has been as high 83 acres in the inundation season, for 'dry crops' such as millet and cotton. In the Punjab 0 acres has been allowed for in the rains, and 200 acres in the cool season.

The following duties, in acres per cusec, may be noted:—

Palked canal, Bengal Deccan, 63; Ekrak tank project, Bombay, 123. Pahakarpur canal, mbay, 165; Kabul river canal, Bombay, 114; Lower Swat river canal, Bombay, 175; Letabo ial project, Transvaal, 145; Mooi river, Transvaal 145.

Duties of Certain Important Irrigations.

Lower Chenab: at heads of distributaries, kharif crops, 89 to 111, usually about 95; rabi crops, 217 to 284, usually about 250. At heads of canals: kharif, 73 to 95, usually about 75; rabi, 190 to 237, usually about 220.

Jamrao: kharif, 85; some branches give 90 at their heads, and one gives 100; average at heads of branches, 85.

Sind: proposed under conditions to be brought about by the Sukkur project; kharif crops, 87; rice, 43½; rabi crops about 180.

Kharif Crops: Triple Canal Project, 100; Lower Bari Canal, 109; other cases, 65 to 75, and 85.

Rabi Crops: Lower Bari Canal, 200; Lower Chenab, 208; Upper Bari Doab, 234; Lower Bari Doab, 198.

By amounts: in Kathiawar, jowari, a grain crop, requires 100,000 cub. ft. per acre, and in Jeypore State the same crop requires about 120,000 cub. ft., including losses and contingencies. In the Madras Presidency, where large areas are irrigated from numerous shallow reservoirs, the quantity, including all losses, which is stored per acre is, roughly, about 216,000 cubic ft., or nearly 5 ft. depth, for the 5 months' 'monsoon' rice crop, and 175,000 cubic ft., nearly 4 ft. depth, for a cool weather rice crop. In Central India, the storage is about 200,000 to 250,000 cubic ft. per acre.

Total Depths in Inches.

Punjab: wheat, barley, and poppy, 10·6; senji, 10·5; gram, 3·4; sugar cane, 25·3; Indian corn, 10·6; cotton, 10·6; charki, 6·3.

Punjab: the Colony Canals (H. W. Nicholson); not including preliminary watering of the ground: kharif crops: sugar-cane, 30 to 45; rice, 35 to 40; cotton, 12 to 20; maize, 12 to 18; great millet, 6 to 9; rabi crops: wheat and barley, 9 to 10; sometimes 15 for wheat; toria (*Brassica campestris*), 6 to 10; senji (*Mendicago sativa*) 15 to 20. *Bari Doab:* kharif crops, 32; rabi crops, 20.

Duty of Irrigation Water: Averages or Estimated Averages: Acres per Cusec.

(Duty × 14·3 = hectares per cu. metre per sec., or, $\frac{6{,}040}{\text{duty}}$ = cu. metres per day per hectare.)

Southern California, surface irrigation, 150 to 300; S. California, sub-irrigation, 300 to 500 Southern Arizona, 100 to 150; New Mexico, 60 to 80; Utah, 60 to 120; Colorado, 80 to 120; Northern Italy, 60 to 150; Madras Presidency, rice 66, 'dry crops' 132.

The average duty of five canal irrigation systems in the Bombay Deccan, from 1894–1895 to 1900–1901, excluding two famine years, was, successively:

For *Kharif*, 70, 52, 74, 111, and 138, with a mean of 89; and for *rabi*, 60, 68, 90, 75, 85, with a mean of 76.

Costs of Irrigation Projects.

The costs of irrigation projects in India do not admit of comparison unless the nature and purpose of the project in each case be described in considerable detail. Some projects are highly productive, others are protective, and many are of an intermediate character. The conditions are very different in the United States, and, on the assumption that the works have been carried out on the narrower economic basis, the following costs may be worth noting.

Costs of Irrigation Projects of the United States Reclamation Service.

Area in Thousands of Acres	216	206	164	131	129	118	103	100	72	60
Cost of water rights in dollars per acre	30 to 36	22 to 30	45 to 50	55 to 66	45 to 55	22 to 30	52	30 to 35	30	45

Cost of Irrigation with Pumped Water, S. Africa.

On the total cost of 63 pumping projects, the cost per acre was 6*l.* 17*s.* Near the coast, the cost of putting two feet per acre on to the land may be taken as between 1*l.* and 2*l.* for a 50-ft lift, and between 1*l.* 10*s.* and 2*l.* 10*s.* for a 150-ft. lift. Up country, the costs would be about 2*l.* 10*s.* and 3*l.* respectively. (*Legg.*)

COSTS OF IRRIGATION: NEBRASKA.

In Nebraska, 1920, 1 per cent. of farm lands irrigated; average per farm, 147 acres; capital invested, 5*l.* 4*s.* per acre; annual cost of operation and maintenance, 6*s.* 3*d.* per acre; average depth of irrigation water on the land, 2·4 ft.

Waste Weir Capacities.

For rates of rainfall and calculations for run-off, see 'Rainfall,' pp. 1461, 1462. For discharges of weirs, see pp. 1348–1352. The following formula is used in India for the discharges of the overflow weirs of storage tanks and reservoirs.

Discharge of clear overfall weirs :—

$$D = c\,b\,\sqrt{H^3}.$$

D = discharge in cusecs; b = width of the crest in feet; H = total height above the weir crest in feet, allowing for afflux; c is a coefficient usually about 3·333, or as low as 3·25.

In ordinary practice in the Bombay Presidency, India, it is usual to assume a general rainfall over the whole of a small catchment, and to calculate the run-off accordingly, thus :—

Catchment in Sq. Miles . . .	Up to 5.	5 to 10.	10 to 25.	25 to 75.	75 to 150.	Over 150.
Run-off in ins. of rain per hour .	2·00	1·50	1·25	1·00	0·75	0·50

In using this table special circumstances have to be considered; mountain catchments would be given larger runs-off, and for catchments wholly in the plains smaller runs-off would be assigned. (*Strange.*)

METRIC VALUES OF c IN $V = c\sqrt{RS}$. $n = 0{\cdot}0250$.

(See page 1455.)

R in Metres.	S						
	1/40,000 = 0·000025	1/20,000 = 0·00005	1/10,000 = 0·0001	1/5,000 = 0·0002	1/2,500 = 0·0004	1/1000 = 0·001	1/100 = 0·01
	c						
0·025	9	10	11	12	13	13	14
0·05	12	13	15	16	17	18	18
0·10	17	18	19	20	21	22	22
0·20	22	23	24	25	26	27	27
0·30	26	28	29	30	30	31	31
0·50	31	32	33	34	34	35	35
1·00	40	40	40	40	40	40	40
2·00	50	48	47	46	45	45	45
3·00	56	53	51	49	48	48	47
5·00	64	59	54	53	52	51	50
10·00	75	66	60	57	55	54	53
15·00	81	71	63	59	57	56	55
20·00	85	72	64	60	58	57	56
30·00	90	76	67	62	60	58	57

Note.—A curve drawn for one slope will give intermediate values for that slope and for all values of R.

Areas—Depths and Flow.

For the full table see Buckleys 'Irrigation Pocket Book'; the figures given below suffice for the calculation of any acre-feet-time quantity, from cusecs.

Cusecs	Acre-feet per.				
	Hour.	12 hours.	24 hours.	Week.	30 days.
1	0·08	0·99	1·98	13·88	59·5
2	0·17	1·98	3·96	27·76	119·0
3	0·25	2·97	5·95	41·65	178·5
4	0·33	3·97	7·93	55·53	238·0
5	0·41	4·96	9·92	69·42	297·5
6	0·49	5·95	11·90	83·30	357·0
7	0·58	6·94	13·88	97·18	416·5
8	0·66	7·93	15·87	111·10	476·0
9	0·74	8·92	17·85	124·95	535·5

Basic Economy of Dams.

Volume of Water stored per Unit Volume of Masonry in the Dam.

Poona, India, 62; Beetaloo, Australia, 79; Booton, New Jersey, 200; Cross River, New York, 610; Granite Springs, Wyoming, 716; Wachusett, Massachusetts, 1,369; Sodom, New York, 1,569; Sweetwater, California, 1,679; Assouan, Egypt, 1,980; Periar, Madras, 2,620; Roosevelt, Arizona, 7,426.

Losses of Irrigated Area by Degradation.

The principal causes of losses of irrigated area, or of reduced productivity, are alkalinity of the soil and waterlogging. As regards the latter, the importance of including measures for effective drainage, as far as may be necessary, in the irrigation project, is now generally realised. The measures to be taken in order to deal with alkalinity cannot be briefly described in general terms, but are fully discussed in standard works. The extent of the two evils, taken together, in the United States may be judged from the following quotation: 'It is safe to say that 15 to 20 per cent. of the lands reclaimed by irrigation have been ruined or are endangered by seepage or alkali. Assuming that a total of 20 million acres have been irrigated within the United States, then from 3 million to 4 million acres have been affected, and possibly a million acres rendered useless." (D. W. Murphy, 1923.)

Silting of Reservoirs.

Muchkundi: capacity, 704 million cub. ft.; catchment, 26 sq. miles; accumulated silt, in 22 years, 58 million, and in 26 years, 64 million cub. ft.; respective rates, 101,000 and 95,000 cub. ft. per sq. mile of catchment per annum. Capacity reduced 8·2 per cent in 22 years; 9·9 per cent. in 26 years.

Gokak: capacity, 908 million cub. ft.; catchment, 1080 sq. miles; accumulated silt, in 18 years, 155 million, in 19 years 174 million, and in 20 years, 189 million, or 8,750 cub. ft. per sq. mile of catchment per annum. Capacity reduced 28 per cent. in 20 years.

Lake Fife: not having sluices for silt, in the dam; at 14 ft. above sill, area of water surface: in 1883, 88·76 million sq. ft.; in 1905, 72·34 million sq. ft.; loss of capacity in 22 years, 16·33 million cub. ft., or 18 per cent.

Lake Whiteing: having sluices for silt, in the dam; no appreciable change in capacity in 5 years.

Proportions of Silt Borne by Rivers and Canals.

Reputed maximum proportions of silt to water, by weight: Rivers—Mississippi, 1/572; Nile, in August, 1/666; Indus, at Sukkur, 1/163 to 1/198, velocity 6·4 to 8·3 ft. per second; a tidal river in East Bengal, during six days, ranged from 1/455 to 1/25. The Vaal, rising, and 3 ft. 6 ins. over weir, 1/268; falling, and 1 ft. 7 ins. over weir, 1/660; Rhône, velocity 8 ft. per second 1/45; Vistula, velocity 10 ft. per second, 1/48; Kistna, June, 1/42.

Cubic feet of damp silt per million cub. ft. of water: Sirhind canal (1897, 32,600 million cub. ft. intake), 5,464, (1895, 43,000 million cub. ft. intake) 1,650, (1896, 54,600 cub. ft. intake) 2,343. Sone canals, June, 1,875; July, 3,250; Aug., 2,750; Sept., 625; Oct., 62. Guadalquivir, on successive dates, March 30 to May 2, 2,321, 775, 521, 695, 2,048, 596, 273, 222, 198.

Fluctuations of the Vaal River.

(W. Van. Warmelo.)

A table gives for eight gauging stations on the River Vaal and its tributaries the average flow for each month of the year, in one case based on 2 years' observations, in two cases 8 years', in other cases 9 to 17 years'. A rough averaging of the 8 cases gives the following months' flows, as percentages of the average 12 months' flow: Oct., 4; Nov., 10; Dec., 12; Jan., 17; Feb., 21; March, 20; April, 7; May, 2; June, 1¼; July 1½; Aug., 1½; Sep., 3. For the River Vaal, at Standerton, the figures, based on 16 years' observations, were: Oct., 5·56; Nov., 14·99; Dec., 14·75; Jan., 27·15; Feb., 20·12; March, 11·49; April, 2·39; May, 1·05; June, 0·63; July, 0·53; Aug., 0·72; Sept., 0·62.

A Typical South African Irrigation.

Van Rynveld's Pass: catchment, 1,477 sq. miles; average rainfall, 14½ ins.; area irrigated, max., 22,314 ac.; average, 17,000 ac. Dam, length, 1,170 ft.; crest width, 10 ft.; clear height (max.), 109 ft.; height plus deepest foundation, 152 ft.; capacity of reservoir, 64,000 acre-feet.

The Hartebeestpoort River: irrigation controlled by the Hartebeestpoort Dam; altitude of river bed, 3,827 ft.; catchment, 1,560 sq. miles; average rainfall near the dam, about 23 ins. Dam: height above river bed, nearly 190 ft.; thickness at base, 73 ft.; radii at base, downstream face, 75 ft., upstream face, 148 ft.; increasing radii to vertical top section where the upstream face radius is 240 ft.; one tangential abutment; crest and top section width, 15 ft.; both batters 1 in 5·714; freeboard above full supply level, about 22·75 ft., capacity of reservoir, at waste weir crest level, 136,241 acre-feet; capacity above outlet level, 123,200 acre-feet; waterspread at F.S.L. (waste weir crest level), 6·7 sq. miles; 9·2 sq. miles available.

The Sukkur Barrage Project (Under Construction).

Barrage 4,926 ft. long, with 66 openings of 60 ft.; gates, 63 ft. 3 ins. by 18 ft. 6 ins. in height; The Rice Canal, capacity, 12,346 cusecs; length, 87 miles; North-West Perennial Canal, 4,313 cusecs, 97 miles; South-East Perennial Canal, 2,767 cusecs, 140 miles; Rohri Perennial Canal, 10,256 cusecs, 205 miles; Eastern Nara Supply Channel, 12,200 cusecs, 15 miles; 242 miles of River Nara canalised. Totals of areas to be irrigated, acres: rice, 823,000; cotton, jowari, etc, 1,739,000; rabi crops, 3,338,000. Cultivation acreage, total, 5,900,000 annually in a total commanded area of 8,132,000 acres. Estimated cost, 1,836 lakhs; or, taking the rupee at *1s. 4d.*, 12,240,000*l.*; taking the rupee at *1s. 6d.*, 13,770,000*l.* Estimated annual tonnages of crops after 30 years' development: rice, 515,000: cotton, 190,000; jowari, &c., 575,000; wheat, 935,000.

Dimensions of Sluices.

Lake Menty Dam, Sundays River, South Africa.—Five free roller sluice gates, each 30 ft. wide by 25 ft. high; about 25½ tons weight; counterpoise, 53 tons; designed for water head of 26 ft. Each gate is built up of latticed bowstring girders as the span elements.

Sennar Dam, Blue Nile.—The portion called the 'sluice dam' is 606 m. (1,988 ft.) long, with 80 sluices 2·0 m. wide by 8·40 m. high to the springers (6·56 ft. × 27·55 ft.). The head regulator has 14 sluices, each 3·0 m. wide by 5·0 m. high to the springers (9·84 ft. × 16·4 ft.); seven to be provided with gates and seven (held in reserve) blocked.

Automatic Syphon Spillways: Early and Recent Examples.

Champlain Canal, U.S.A. (G. F. Stickney, 1910).—At lock No. 9 the syphon spillway was 57 ft. long as against 200 ft. if an ordinary weir had been built for the small permissible depth on sill. Each syphon had an area of 7¾ sq. ft.; head, 10½ ft.; discharge, 160 cusecs; flared inlets. At Whitehall, on the same canal, a similar weir, 6 syphons; 16 ft. head. These syphons were formed in the body of the weir. (See *Engineering News*, October 13, 1910.)

Maramsilli Reservoir.—A syphon spillway to pass 40,000 cusecs. (See Paper No. 4602, *Proceedings Inst. C.E.*, by Powys Davies.)

Bridgeport Dam, Nevada, 1926.—Cross-section, 3 ft. by 6 ft.; air vents in syphon hoods at different elevations, so that the syphons will come into action one at a time.

Arch Dam: Measured Strains under Water Load.

Stevenson's Creek Dam, California.—A concrete dam built for the purpose of measuring strains under water load and comparing deduced stresses with calculated stresses. Founded on solid rock, in a gorge. Height 60 ft., crest length 140 ft., upstream radius 100 ft., thickness at base 7½ ft., at crest 2 ft. Tests were made at night to minimise temperature effects. At 30 ft. below crest the maximum deflection under full load, 60 ft. water depth, was 0·378 in. At the crest the deflection was downstream at the crown and upstream between the quarter points and the ends. Computed for a modulus of elasticity of 3,600,000, the stresses were: at the crown, 260 lbs. per sq. in. (theoretical 207); at the abutments, 900 to 1,000 lbs. per sq. in. (theoretical 879). Considered as assigned in part to arch resistance and in part to vertical elements resistance, the share of the latter in sustaining the water load seems to have been less than that assigned by theory. This may have been due to the formation of a horizontal crack at the base of the upstream face between the dam and its foundation, which appeared when the water had risen to 30 ft. depth. The formation of this crack is in accordance with the theory regarding the design of the foundations at and near the upstream toe of a dam, according to which the dam should not there be keyed into its foundation. [See 'Mass Dams and Dams of Arches' (R. Ryves): Madras Government Paper, 1910.]

Measured Shrinkage of an Hydraulic Fill Dam.

(*C. H. Eiffert*, '*Engineering News Record*,' *Jan.* 27, 1927.)

Huffman Dam.—Height of dam above ground level, about 62 ft.; width of crest, 32 ft.; symmetrical to central vertical plane; two berms; both slopes, from toe, 3 to 1; between berms, 2½ to 1; to crest, 1·825 to 1. Shrinkages, including settlement of foundation which is believed to have been very small: at 40 ft. below crest level, 0·40 to 0·68 per cent.; at 30 ft. below crest level, 0·31 to 0·54 per cent.; at 20 ft. below crest level, 0·44 to 0·64; at 10 ft. below crest level, 0·24 on east side and 0·73 on west side; at the crest, 0·60 on the east side and 0·49 on the west side; average, 0·51 per cent.

SECTION XXVI

PART III

RAINFALL — WELLS — WATERWORKS — DAMS — FLOW OF WATER IN PIPES—WATER PIPES—WATER TANKS.

RAINFALL.

(Contributed by Reginald Ryves, A.M.Inst.C.E., M.Cons.E.).

Rainfall in the British Isles.

For valuable data and studies relating to rainfall in the British Isles reference may be made to a paper on 'The Distribution of Mean and Extreme Annual Rainfall over the British Isles,' by H. R. Mill (Min. Proceedings Civil Engineers, vol. clv., 1903–1904); also to 'Variations in the English Climate during the Thirty Years 1881–1910,' by W. Marriott (Quarterly Journal R. Met. Soc., July 1911). The former paper is accompanied by useful maps of rainfall distribution, and the latter by diagrams showing deviations from the mean values, month by month, for temperature, rainfall, number of 'rain-days,' and atmospheric pressure. Temperature and the number of rain-days have a considerable bearing upon water-supply and sewerage schemes. Reference may also be made to a paper on 'The Abnormal Summer of 1911,' by C. Harding (Quart. Journal R. Met. Soc., January 1912).

The rainfall of each of the three divisions of the British Isles decreases from 100, 80, or 60 inches in the mountains and moorlands near the Western coasts to about 25 inches (over a few areas down to 20 inches) near the Eastern coasts of Scotland and England, and in the Midlands, and to about 35 inches on the East coast of Ireland. Over more than a third of England the rainfall ranges from 25 to 30 inches, and over a considerable total of smaller areas the fall is from 30 to 40 inches. There is a similar range, 30 to 40 inches, over about half Scotland, and a large area in the Western Highlands has a rainfall ranging from 60 to 100 inches. Over the Eastern half of Ireland the fall is from 35 to 40 inches, and over most of the Western half from 40 to 50 inches. For the period 1870–1899 the average annual falls were as follows: England, 31·62; Wales, 49·53; Scotland, 46·85; Ireland, 42·28; British Isles, 39·25. For the period 1881–1910 the average for England was 31·90.

Average, Maximum and Minimum Rainfalls.

It is generally agreed that a period of 30 to 35 years (*Binnie*) is long enough to establish for the average annual rainfall a value which will be nearly the true average, if such there be, and anyhow will be the mean of probabilities. For reasons, some of which are theoretical and others practical, many engineers prefer a period of 35 or 30 years to the longer periods for which records are in some cases available.

In the British Isles for the period 1870–1899 the rainfall of the 'wettest' year exceeded the average fall by 43 per cent., and that for the 'driest' year was 29 per cent. below the average (*Mill*). The following, expressed in percentages of the averages, are the figures for the different parts of the British Isles and for the whole area, taking in every case the wettest and driest years for the area referred to, period 1870–1899:—

England, 146 and 70; Wales, 147 and 75; Scotland, 147 and 72; Ireland, 133 and 69; British Isles, 143 and 70.

For the period 1881–1910 (*Marriott*) the percentage figures for England are 131 and 76·7. This period seems, however, to have been somewhat abnormal. The actual rainfalls compare thus:

England.	Maximum.	Average.	Minimum.
Period 1870–1899	46·98	31·62	22·83
Period 1881–1899	41·78	31·90	24·45

This suggests that although the 30 years' period may be satisfactory as regards the average annual rainfall it may not include a fall approximating to the maximum, nor one approximating

to the minimum. Probability would, indeed, seem to be against such a result, but it is interesting to note the differences of nearly 5 inches and 1½ inch above.

At stations in the British Isles the following annual rainfalls in percentages of the average have been recorded : 58·8, 59·8, 61, 60·5, 63·6 and 64·5, showing defects from 35½ to 41 per cent. of the averages.

Sir Alexander Binnie considered the true mean rainfall to lie between the period of 33 and 35 years. From 14 stations scattered over the world he arrived at the following results :—

1. The percentage of years, in which the rainfall is above the mean rainfall, is 45·8.
2. The percentage of years, in which the rainfall is below the mean rainfall, is 54·2.
3. The average fall of wet years is 1·19 of the mean rainfall.
4. The average fall of dry years is 0·83 of the mean rainfall.
5. The average fall of the three consecutive dry years is 0·76 of the mean rainfall.
6. The maximum rainfall is 1·52 of the mean.
7. The minimum rainfall is 0·59 of the mean.
8. The proportional number of periods of three consecutive dry years in 100 years is 20·3.

Rainfall in Foreign Countries.

The following figures are maximum annual rainfalls (for whole countries) expressed as a percentage of the average annual fall in each case (*Binnie*) :

Norway, Denmark, Holland and Belgium, 148 per cent. ; France. 161 ; Italy, 159 ; Switzerland, 147 ; Germany, 139 ; Bavaria and Austria, 144 ; Russia, 166 ; India, 162 ; Australia, 156 ; North America and Canada, 141 ; typical observations for the world, 151.

The following are actual inches of annual rainfall, maximum, average and minimum, for a period of 24 years, in the Madras Presidency, 7 stations :—

70, 47, 31—78, 40, 17—48, 29, 9—60, 50, 17—43, 28, 17—165, 117, 87—182, 131, 95.

The probable figures for a given area, when they cannot be based on records fairly covering the area itself, may be estimated partly from station records and partly from averages for a larger area, the probable range of maximum and minimum values being studied from both points of view, and depending to a considerable extent upon the size of the area under consideration.

The Driest Group of Three Years Running.

Experience has shown that the most serious shortage in water-supplies usually occurs as the result of the defect of rainfall in the driest group of three years running, and this consideration is usually one of the factors in the design of water supplies and irrigation works. It must not be assumed, however, that there are no cases in which the worst single dry year is not the governing factor, and on the other hand, the worst period may in some countries be more than three years. The principle is, however, to be accepted in all cases, inasmuch as there is, for every place, some period which is that towards the end of which the effects of a drought will probably be most severely felt. The rainfall records will go far towards disclosing the critical period, but the nature of the soil, and the extent and nature of natural storage facilities, may also have to be taken into consideration.

The estimated average annual rainfall for the three years' period is sometimes put at 80 per cent. of the general average, though it is doubtful whether so high a percentage could be relied upon in any country. Sometimes it is put at 75 per cent. At Cape Town the average rainfall for the driest three years is 73 per cent. of the general average. In any case it must be remembered that the available run-off in the three years, as will be shown later, may be a much smaller percentage of the average available run-off. If, out of 50 inches of rain, 15 are lost by evaporation and absorption, we have 35 inches available. With a 40 inch, or 80 per cent. fall, we should have 25 inches available, or about 71 per cent., and the loss in the dry year might be greater than the average.

Run-off and Losses.

The available supply and the losses by evaporation and absorption are often expressed as percentages of the rainfall, but the amount of run-off or of loss bears no definite relation to the amount received by the catchment. The yield of a catchment area may better be reckoned as proportionate to the rainfall less some constant quantity which may be called the 'handicap' (*Lapworth*). This method is not, however, applicable to all cases, though in most cases it is suitable for the purposes of preliminary plans and may often give quite accurate results. The following are 'handicaps' for different areas (*Lapworth*) :

Average in Great Britain, 10 to 12 inches ; Thames Valley, 16 inches ; parts of Dartmoor, nearly 18 inches ; North-Eastern and Eastern parts of the United States, about 16 to 20 inches ;

in California, 23 inches or more; in India, up to 30 inches; in South Africa, about 25 inches. The mean annual loss from 29 streams in England ranged from 28 inches (loss) to a *gain* of 2 inches. Average about 14 inches; range of 18 of the 29, 11 inches to 17 inches. Small losses, or, in extreme cases, gains, may be the result of precipitation not recorded by rain gauges. In some catchments the dews are very heavy; in some there is often heavy condensation on trees and herbage, especially heather, during fogs or drifting mists.

It is necessary to find the particular 'handicap' in every case, since its amount necessarily depends upon topographical and geological features, upon the area of the catchment and the manner in which the water is collected. Further, it must be noted that the method is by no means generally applicable, and notably fails when the effect of one year upon the next is strongly marked. In the Ajamenta Valley, Gold Coast Colony, the following, in inches, were year's falls and the corresponding yields (*Hunter*):—

38·8, 1·800—59·9, 8·280—47·7, 2·540—42·4, 0·140—30·8, 0·560—29·6, 0·004—40·2, 0·006.

Again, if we take the figures for the Sweetwater catchment basin, California, we find that the following comparisons may be made (*Folwell*):—

A year's rainfall of 21 inches yielded 12 per cent., but a fall of 23·4 inches yielded only 9 per cent., while another year's fall of over 23 inches yielded less than 0·4 per cent. A fall of 17·2 inches yielded 4 per cent., but falls of 18 to 19 inches yielded less than a quarter per cent. The average fall of nearly 21 inches yielded less than 6 per cent., but an actual year's fall of 20 inches yielded 8 per cent.

The yield from the Coolgardie catchment, in a period of six years (*Palmer*) ranged from 0·20 per cent. to 3·5 per cent., while the rainfall ranged only from 19 to 33¼ inches.

In a period of 10 years the worst discharge of the Guadalquivir (Spain) was 9 per cent. of the rainfall, and in the best year it was 50 per cent. In the Karroo, S. Africa, a yield of 2 or 3 per cent. would be expected from a year's fall of 8 to 10 inches, and from a fall of 20 inches the yield would be about 8 or 10 per cent. (*Legg*).

Generally, in dry countries with a small rainfall the ratio of evaporation to the rainfall, or to a part of the rainfall, increases rapidly with a decrease in the actual amount of the fall. Conversely, in wet countries with a fairly large proportion of rainy or cloudy days the effect of relatively dry conditions or of scanty rainfall is not felt to nearly the same extent. In some cases it is found that the rainfall to be considered is that of only a part of the year, and it is then necessary to study maximum and minimum rainfalls, and the worst three years, as applying only to this season. In Natal about ⅞ of the rainfall occurs in the wet season, September to April. In Southern Rhodesia, about ½½ from November to March. In other cases, especially when the area does not feel the full effects of any of the seasonal rains, it is necessary to examine the rainfall records in detail for the worst three years, and to eliminate all falls of less than some predetermined amount (single falls or day's rain). Next, the yield from each of a series of falls should be estimated as, in each case, a proportion depending partly upon the amount of the fall and partly upon the interval which had elapsed since the previous fall. The maximum percentage yield will be assigned to continuous rain on soaked ground and soaked subsoil. In dry areas it may be necessary to adopt such a method of estimating the yield, when, owing to the nature and distribution of the rains, no general rule can be applied to the whole rainfall of the year, or to that of a season. For a rough estimate it may be sufficient to eliminate small or isolated falls and to calculate the yield of the remainder as a diminishing proportion of the remaining rainfall, less some constant. In some conditions the proportion need not be a diminishing one.

Hartebeestpoort Dam (near): altitude over 3,800 ft.—Monthly rainfalls and evaporations (approximate), inches: January, rainfall 4·99 and evaporation 6·51; and in that order, February, 4·11 and 5·65; March 3·31 and 5·07; April 0·80 and 5·13; May 0·69 and 5·10; June 0·06 and 4·35; July 0·27 and 4·91; August 0·73 and 6·60; September 0·48 and 7·91; October 2·26 and 8·41; November 4·66 and 7·63; December 3·98 and 7·40; the year 26·34 and 74·67.

Absorption and Evaporation.

While it is possible, by the exercise of judgment, to form some idea as to the extent of losses by absorption for a particular area, it is clear that the large number of factors involved makes it impossible to lay down any general rules. Under some circumstances all the rain runs off, under other circumstances it is all absorbed, and there is every conceivable intermediate condition.

A few points are, however, worth noting. Clay soils, after the surface is wet, absorb water only very slowly. Some light soils are absorbent up to a given rate of absorption and rainfall in excess of that rate runs off. If the water absorbed by the soil percolates to places where it is available for use, the loss by evaporation from the soil will largely depend upon the average depth of the subsoil water. A dusty surface to a great extent prevents evaporation from the soil.

In practice, the loss from evaporation and percolation taken together is found by gaugings of the streams from the catchment, or, provisionally, is based upon data obtained from similar

catchments, with such modifications as seem to be desirable owing to differences in the conditions. The estimate of the loss by evaporation and absorption, obtained from one set of data, should agree with the estimate of total yield based upon another set of data, or upon general considerations. References to evaporation from free water surfaces and from soils will be found under 'Irrigation,' pp. 1445, etc.

Dr. Walter Leather gives the following formula for estimating evaporation from water surfaces:—

$$E = 2{\cdot}0\ (\log t - 1{\cdot}74) + 0{\cdot}33\ (\log D - 1{\cdot}00) + 0{\cdot}36\ (\log W - 0{\cdot}125)$$

where,

E = Evaporation in millimetres for 24 hours ; D = Dryness = 100 − (humidity at 8 A.M.); W = Mean wind velocity for the 24 hours in miles per hour; t = Mean temperature in degrees F. for the 24 hours.

Rainfall Quantities and Rates.

One inch of rain is equal to :—

2,323,200 cubic feet per square mile; 14,485,000 gallons per square mile ;
3,630 cubic feet per acre; 22,633 gallons per acre.

One inch of rain per hour is at the rate of :—

645 cubic feet per second on a square mile, nearly 1 (1·01) cubic foot per second on an acre:
241,419 gallons per minute on a square mile;
377 gallons per minute on an acre.

I. Table showing Equivalent Rainfall in Cubic Feet per Minute.

Areas in Acres. (A_1)	Rainfall in Decimals of an Inch in 24 Hours. (r)								
	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
1	0·2521	0·5042	0·7562	1·1083	1·2604	1·5125	1·7646	2·0170	2 2687
2	0·5041	1·0084	1·5125	2·2166	2·5208	2·0250	3·5290	4·1340	4·5370
3	0·7563	1·5126	2·2687	3·3249	3·7812	4·5370	5·2930	6·0510	6·8060
4	1·0084	2·0168	3·0249	4·4332	5·0416	6·0500	7·0580	8·0680	9·0740
5	1·2605	2·5210	3·7812	5·5416	6·3020	7·5620	8·8230	10·0800	11·3430
6	1·5126	3·0252	4·5374	6·6499	7 5610	9·0750	10·5870	12·1000	13·7200
7	1·7646	3·5294	5·2937	7·7583	8·8820	10·5870	12·3500	14·1100	15·8600
8	2·0166	4·0336	6·0499	8·8666	10·0800	12·1000	14·1100	16·1300	18·1500
9	2·2687	4·5378	6·8061	9·9749	11·3400	13·6120	15·8800	18·1500	20·4200
10	2·5208	5·0416	7·5625	11·0833	12·6000	15·1250	17·6400	20·1700	22·6900

Cubic feet per minute = $A_1 r \times 2{\cdot}521$.

II. Table showing Equivalent Rainfall in Cubic Feet per Minute.

Area in Square Miles (A_2)	Rainfall in decimals of an inch in 24 hours. (r)								
	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
1	161·3	322·6	484·0	645·3	806·6	968·0	1129·3	1290·6	1452·0
2	322·6	645·3	968·0	1290·6	1613·3	1836·0	2258·6	2581·3	2904.0
3	484·0	968·0	1452·0	1936·0	2420·0	2904·0	3388·0	3872·0	4356·0
4	645·3	1290·6	1936·0	2581·3	3226·6	3872·0	4517·3	5162·6	5808·0
5	806·6	1613·3	2420·0	3226·6	4033·3	4840·0	5646·6	6453·3	7260·0
6	968·0	1935·9	2904·0	3872·0	4839·9	5808·0	6776·0	7743·9	8712·0
7	1129·3	2258·6	3388·0	4517·3	5646·6	6776·0	7905·3	9034·6	10164·0
8	1290·6	2581·3	3872·0	5162·6	6453·3	7744·0	9034·6	10325·3	11616·0
9	1452·0	2904·0	4356·0	5808·0	7260·0	8712·0	10164·0	11616·0	13068·0
10	1613·3	3226·6	4842·0	6453·3	8066·6	9680·0	11293·0	12906·0	14523·3

Cubic feet per minute = $A_2 r \times 1613{\cdot}7$.

Flood Discharges.

For every area, however small or however large, there is some period of time at the end of which the effect of continuous rain reaches the maximum. What this period is depends upon all the circumstances, the size of the area in question, the nature of the rainfall, the physical character of the catchment, and the nature of the vegetation or of artificial works all affect the result.

The maximum rate of rainfall for the period in question is therefore a leading factor in the calculation of the flood discharge of the area. For some small areas the maximum discharge may be that which occurs when natural storage on the catchment has reached the maximum, and the rate of run-off is then equal to the rate of rainfall, or to some proportion of it, allowing for underground escape of a part of the water. In most cases, however, the maximum capacity of the catchment for surface water is reached only for short periods after the heaviest rushes of rain, and the amount of such storage affecting the result is the average over a relatively long period, and cannot be estimated with any degree of accuracy. A period longer than the critical period will give a lower rate of discharge because the rate of rainfall will be less, and a period shorter than the critical period will give a discharge lower than the maximum because the water from the more distant parts of the catchment will not have time to reach the outlet. If we knew the rate of flow over the ground and along the watercourses we could find the time required for water to arrive at the outlet from the part of the area most distant in time, in many cases the farthest point in distance. But we seldom know these average speeds, except sometimes in the case of a sewerage system. It is usually necessary to have recourse to empirical formulæ, or formulæ partly empirical and partly rational, and the engineer has to exercise judgment in choosing one coefficient affecting the whole quantity or several coefficients affecting different factors. In some large river basins the effects of short storms over several tributary valleys may, by the simultaneous arrival of the resulting floods, yield a larger discharge than that due to the lower rate of rainfall for the critical period corresponding to the whole area. In such cases the purely empirical formula may be better than the rational formula, because the engineer makes a note of every real coefficient established by experience, and all these coefficients are strictly comparable.

Further, in the case of a steep, rocky valley, the river of which drains flat uplands, or glens under dense jungle, the heavier rainfall for the shorter 'period of total contribution' for the main valley may give a larger flood discharge than the smaller rainfall for the longer period of total contribution for the whole catchment. Even in normal river basins, areas projecting beyond the average distance of the watershed of the distant parts of the catchment may be eliminated, the loss in area being more than made up for by the gain in rate of rainfall for the reduced period of total contribution (*Ryves*).

The following formulæ are used in calculating flood discharges of rivers and, in some cases, are also employed for quite small catchments.

Ryves' formula—

$$Q = CM^{\frac{3}{4}}.$$

Q = discharge in cu. ft. per sec.; M = area in square miles, C is a coefficient usually ranging from 450 to 1,000, according to the nature and situation of the catchment; rainfall data are also taken into consideration, by comparisons with established results.

This formula is largely used in Southern India. (Discharge in cu. metres per sec. = the same coefficient $\times \frac{15}{1000} \times$ (area in sq. kilomes.) $^{\frac{2}{3}}$).

Dickens' formula—

$$Q = 825\ M^{\frac{3}{4}}.$$

This is the form in which the equation is usually presented, but it is doubtless advisable to vary the coefficient as in the case of the Ryves' formula.

The Dickens' formula is probably more particularly suited to the conditions of Bengal and other parts of Northern India, but both formulæ may be usefully employed in other countries.

The formula $Q = CM^{\frac{4}{5}}$ has been found to apply, for *ordinary floods* in the New England and Appalachian catchments, with a coefficient C = 130 to 200; in Eastern Middle State river basins, with a coefficient from 60 to 100; and for Western tributaries of the Mississippi, with coefficients from 12 to 50 (*Fanning*).

Chamier's formula—

$$Q = 640 \times R \times C \times \frac{M^{\frac{3}{4}}}{M}.$$

R = average rate of greatest rainfall in inches per hour for such duration as will allow of the flood-water flowing to the outlet from the farthest extremity of the catchment. C = coefficient of surface discharge, giving the proportion of rainfall that may be expected to flow off the surface, M = area of catchment in square miles.

This formula seems to have given good results, and by comparing the calculated discharges for many catchments with those actually observed it should be possible to arrive at some idea of the figures for the rates of flow, from watershed to outlet, upon which the period of total contribution depends and from which, therefore, the rate of rainfall is derived. Since this factor cannot, in comparison of results, be disentangled from the factor C, it will take longer to extend the use of the formula than it does in those cases in which the exercise of judgment and the results of practice focus on to a single coefficient.

In order that the length of the catchment might be taken into consideration the following formula was proposed:

Burge's formula—

$$Q = C \cdot \frac{M}{(L)^{\frac{1}{3}}},$$

where L is the length of the main river or stream in miles; C is usually taken as 1,300.

A modification of this formula has been proposed, as follows (*Jackson*):—

$$Q = C \times \frac{B}{L} 100\ M^{\frac{2}{3}},$$

where L is the extreme length and B the extreme breadth of the catchment area.

It may be suggested that when it is possible to make a fair estimate of the period of tota l contribution, and, therefore, of the maximum rate of rainfall, such an estimate should form the basis of the calculation for maximum flood discharge, and when no such estimate can be made an empirical formula with a single coefficient should be used.

Storm-water Discharge of Sewers.

The same principles that govern the discharges of large river basins hold in the case of the storm-water discharge of sewers, but it is usually much easier to estimate the average rate of flow from the most distant parts of the catchment (measured in time) and, therefore, to estimate the period of total contribution, the rainfall for which can be found from local records.

The following are formulæ employed:

Bürkli-Ziegler's formula—

$$Q = R \times C \times \sqrt[4]{\frac{S}{A}}.$$

Q = discharge in cubic feet per second per acre.
R = average rainfall in cubic feet per second per acre 'during heaviest rainfall.'
C = 0·75 for paved streets; 0·31 for rural districts; average 0·625.
A = area of district drained in acres.
S = general fall of area per thousand.

It is clear that R will depend upon the period of total contribution which will have to be found in each case in order that the formula may be applied. The factor C would, as regards unpaved areas at any rate, also depend upon the period of total contribution.

Kuichling's formula—

$$Q = A \times a \times t \times (b - c \times t).$$

A = area drained, in acres; a, b, c, empirical constants which vary for different localities; t = time required for the concentration of storm water at the outlet.

This formula seems needlessly complicated, since if t be known the rainfall can be found and a single modifying coefficient could be applied to it, as well as one to be applied to the quantity as a whole, if considered necessary.

Lloyd-Davis' formula—

$$Q = \left(60{\cdot}5 \times \frac{60}{Tc} \times R\right) \times Ap.$$

Q = cubic feet per minute; Tc = time of concentration in minutes (time of flow through the longest sewers); R = rainfall in inches during Tc; Ap = percentage of impermeable area in acres.

In some respects this is a good formula, but the permeable area would also affect the total in most cases. It would seem better to treat permeable and impermeable areas separately, and add the resulting discharges together to get the total discharge, but it would be difficult to do this except where the period of total contribution was the same for both parts of the area.

Having found the period of total contribution, the maximum rate of rainfall for that period must be found from local rainfall records. Thus, a curve drawn for records of heavy falls for a district in Southern India gave the following results (*Ryves*):—

Heaviest fall in 30 mins., 2·0 ins.; in 60 mins., 3·0 ins.; in 85 mins., 3·8 ins.; in 104 mins., 4·2 ins.; in 134 mins., 4·8 ins.; in 150 mins., 4·9 ins. Such curves are not necessarily drawn for the heaviest 'spot' falls, which are usually due to cyclones traversing a very narrow path. The maximum spot rainfall may be much greater than the maximum for the storm-water area of

a large town. Even when the maximum rainfall does affect the whole area it is not always worth while to design the works for this fall. For instance, in some places cyclones are rare, and the maximum falls may greatly exceed the largest intervening falls, for periods of many years, being perhaps 4 or 5 times greater. The same principle may hold with respect to large areas, and the cost of works to deal with another fall such as that which occurred in East Anglia in August 1912 or with floods such as those experienced in Paris in 1913, may be so great that it is better to risk the chance of a similar visitation.

Heavy Single Falls of Rain over Considerable Areas in the British Isles.

London, whole area, 2·5 ins. in 24 hours.
Lake District, 714 sq. miles, 5·63 ins.
Eastern Ireland, 1,160 sq. miles, 4·76 ins. } single fall in less than 3 days.

Aug. 1912. East Anglia 18 sq. miles, over 8 ins. in about 24 hours.
" " 238 " 7 " " 24 "
" " 705 " 6 " " 24 "
" " 1,039 " 5 " " 24 "
" " 3,463 " 3 " " 24 "

Before 1912 the maximum fall for 24 hours recorded in Norfolk was 4·48 ins.

Heavy Station Rainfalls in the British Isles.

Inches in 24 hours: Seathwaite, 8·03 and 7·00; Ben Nevis, 7·74 and 7·29; Rosthwaite, 6·94; Angerton Hall, 6·70; Lyme Regis (' in the night,' July), 3·58 ins.; Ballycumber, 3·8 ins. For shorter periods:—Norwich, 0·52 ins. in about 5 min.; Dover, 0·44 ins. in 12 min.; Margate, 0·51 ins. in 20 min.; Hellingley, Sussex, 1·21 ins. in 50 min., and 0·73 ins. in 12 min.; Oxted, 2·14 ins. in 24 hrs.; East Grinstead 1·80 ins. in 1½ hrs.

Banstead, 3·59 ins. in about 90 mins.; Wallington, 2·77 ins. in 65 mins., and 3·50 ins. in 60 mins.; Wimbledon, 1·58 in. in 80 mins.; Croydon, 1·85 in. in 2 hours 48 mins., and 0·8 in. in 15 mins.; Ponders End, 1·05 in. in 19 mins.; Birmingham, 1·04 in. in 27 mins.; Burnham, 1·73 in. in 40 mins.; a fall of 1·2 in. in 15 mins. seems to be the quarter-hour record for the British Isles.

Heavy Station Rainfalls, Canada and United States.

Toronto, 0·5 in. in 10 minutes; and 0·6 in. in 15 mins.; New York, 1·2 in. in 10 mins.; Philadelphia, 1·6 in. in 20 mins.; Chicago, 0·97 in. in 7 mins.

Heavy Station Rainfalls in or near the Tropics.

Central America, 0·6 in. in 10 mins.; 1·1 in. in 30 mins.; 1·7 in. in 60 mins. Panama Isthmus, 6 ins. in 95 mins.; 4·9 ins. in 60 mins.; 5·86 ins. in 60 mins. Philippines, 27 ins. in 24 hours, also (1913) 48 ins. in 48 hours, and 24 ins. in 8 hours (same storm). Manila, 17 ins. in 15 hours. Near Johannesburg, 3·2 ins. in 15 mins. Near Durban, 15·6 ins. in 15 hours; 17·6 ins. in 24 hours; 6 ins. in 3 hours. Mauritius, 18 ins. in 24 hours, and the mean of 15 stations 9·86 ins. in 24 hours; 99 ins. in 6 days; 24 ins. in 24 hours. Ceylon, 21 ins. in 24 hours; 8 ins. in 4 hours.

In 2 days: Santa Cruz, Teneriffe, 12·58 ins.
In 24 hrs.: Newlands, Cape Peninsular, South Africa, 16·5 ins.
In 12 hrs.: Beaumont, Texas, 13·54 ins.
In 8 hrs.: Santa Cruz, Teneriffe, 3·47 ins.
In 4½ hrs.: Beaumont, Texas, 12·76 ins.

Heavy Station Rainfalls in India.

Madras, 4·95 ins. in 3 hours; 2 ins. in 18 minutes; 3 ins. in 60 minutes, 10, 11, 12, 13, 18, and 20 ins. in 24 hours. Madras Presidency (South Arcot), 7, 8, 9, and up to 11·3 ins. in 24 hours. Central Provinces (Talgaon), 7·75 ins. in 6 hours. West Coast, Bombay Presidency, 8 ins. in 2 hours. Bombay Town, 7 to 9 ins. in 24 hours. Sholapur, 10 ins. in 7 hours.

Forests and Rainfall.

In a considerable number of cases it has been shown that the removal of forests has been followed by a diminution in the rainfall, and in other cases the rainfall has increased with the extension and growth of the forests. The extent of the difference probably depends upon whether the coolness of the forest area just turns the scale in favour of rain at critical times, the resulting increased coolness and dampness causing further falls of rain; or whether, on the other hand, the forests merely present the best conditions in areas where the conditions generally are favourable to steady rainfall at frequent intervals. A point which is often overlooked is the effect of trees in increasing the total precipitation considerably beyond that recorded by rain gauges. A large proportion of the rime which collects on the twigs of trees in frosts afterwards reaches the ground as water, and, in climates such as those of the British Isles, the total amount of water deposited on the twigs from fogs and drifting clouds is considerable, and most of it reaches the streams or underground storage, or at least replaces losses from subsequent rainfall.

Of more importance, however, to hydraulic engineers is the effect of woodlands in modifying the run-off. The rush of water from bare hillsides is exchanged for the slower delivery from the matted carpet of the woodland, losses by evaporation may be much diminished and the melting of snow usefully retarded. In catchments from which flood waters are largely lost, woodlands may increase the available run-off by extending the period of surface flow. The maximum floods of rivers are reduced, and the lowest summer flow increased. Woodlands are usually much more effective than minor vegetation, such as gorse and heather, in preventing the soil from being carried from the land into an open reservoir.

To protect a reservoir from silting, it may be unnecessary to plant large areas, the silt being arrested by suitable planting of narrow belts of woodland, or by the protection of natural growth, along the margins of the streams.

Some engineers consider that in the case of small reservoirs the shelter afforded by a belt of trees along the margins is of value in reducing the amount of scour of the banks caused by wave action. Afforestation over considerable areas in large river basins would, in many cases, reduce the amount of silting in navigable rivers and estuaries.

A matter which does not receive sufficient attention in connection with hydraulic engineering is the effect of judicious planting or woodland conservation over small areas. A narrow belt of woodland along the foot of a slope will arrest the soil brought down by rains from the hillside. The encouragement of dense vegetation along the bottom of a narrow valley or glen may check the rate of flood discharge to a useful extent. The planting of suitable trees along ridges, and for a little way down the slope facing the rain bearing and damp winds, will produce the maximum of certain desired effects, in proportion to the area occupied. Suitable tree and bush growths in swampy areas and around their margins will increase their effect in checking flood discharge, and may prevent these areas from contributing large quantities of silt to the streams during very heavy rains. Areas of soft, cultivable soil liable to denudation may similarly be protected. Generally, a country which is, in the ordinary English sense of the words, ‘ well-timbered ’ is, from the point of view of the hydraulic engineer, a favourable country ; and in the development of new lands the future effects of a proposed agricultural policy should be considered from this point of view, and in consultation with hydraulic engineers.

Rain Gauges.

The smallest diameter for a serviceable rain gauge is 5 ins., and is the size generally used. Trials with gauges of various diameter ranging from 1 in. to 2 ft. have shown that if they are set perfectly level, and observed with great care, exactly the same rainfall has been registered by all of them.

The standard height above ground for rain gauges is 1 ft.

The higher a gauge is fixed above the ground the smaller is the quantity of rain caught, owing to the eddies carried by the wind about any prominent upstanding object. The curve diagram (fig. 1), given in Beardmore’s Hydrology, gives the divisor to be used for increasing the

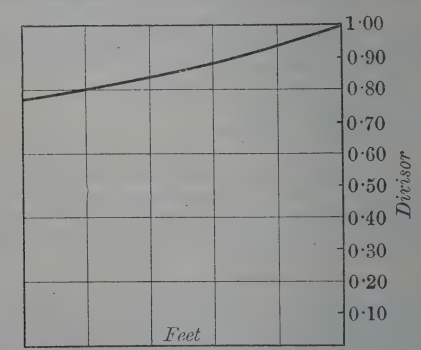


FIG. 1.

quantity of rain observed at any given height above ground level, so as to make the observation equal to that at ground level.

It is more important to have rain gauges placed at a uniform height above the ground than to have them of uniform diameter.

Available Power from Rainfall.

In terms of *average* values of rainfall, catchment area, and head, the available power can be expressed :—

$$\text{H.P.} = 0{\cdot}00828\, f\, m\, h\,;\ \text{E.H.P.} = 0{\cdot}0073\, f\, m\, h\,;\ \text{kW} = 0{\cdot}0062\, f\, m\, h\,;$$

where

f = average rainfall in inches ; m = catchment area in sq. miles ; h = average head in ft.

Example :—The catchment of the Lochaber water-power scheme is 303 sq. miles ; the average annual rainfall is 73 in. ; and the average head of water available near Fort William is 742 ft. What will be the theoretical power ?

$$\text{H.P.} = 0{\cdot}00828 \times 73 \times 742 = 136{,}000\ \text{H.P.},$$

and, as 1·0 H.P.-year = $1 \times 8{,}760 \times 0{\cdot}746 = 6{,}535$ kW-hours, the output (theoretical) would be

$$6{,}535 \times 136{,}000 = 888{\cdot}76\ \textit{million kW-hours.}$$

(*W. T. Taylor*, '*The Electrical Review*,' *October* 12, 1923.)

WELLS.

(Contributed by W. H. Booth, F.G.S., M.Am.Soc.C.E.)

The back of the steining should be puddled to a depth of 12 or 15 feet, so as to make the water pass through a considerable amount of soil before entering the well.

The ground around should be puddled, sloped away from the well, and paved, and the lining carried up about 2 feet above the ground level, to keep all dirty water out of the well. The mouth should be covered over and the water drawn by a pump rather than a bucket.

Form of Wells.—Generally circular, but when there is no steining or a large water-yielding surface is required, as in headings driven from the shaft, a rectangular, elliptical, or other form may be used. Ordinary wells have a clear diameter of from 4 to 5 feet, but when very deep may require to be made large enough at the top to allow of reductions as the depth increases, still leaving room enough below for any pumping machinery.

Temperature in deep wells increases about 1° F. for every 55 feet in depth below 60 feet, at which depth it is pretty uniform at 50°.

Tubing for bore-holes is sometimes of cast iron, the lengths being held together by wrought-iron collars fitting over the ends and flush with the outside of the tubes.

The approximate average cost (pre-war prices) in England may be taken at 1*s.* 3*d.* per foot for the first 30 feet, 2*s.* 6*d.* per foot for the second 30 feet, and so on, advancing 1*s.* 3*d.* per foot for every additional 30 feet in depth. This does not include cost of tubing, conveyance of plant and tools or working in rock of unusual hardness. (See also Artesian Wells, page 1471.)

STEINING.

This is lining the well, chiefly to keep the sides from falling in. Where bricks are not available stone may be used, and even timber, but the latter soon decays. Iron cylinders are also employed.

Brick Steining.—The bricks should be hard, well burnt, and well shaped. Malm paviors are very good ; if stocks are used, they should be very carefully picked. The bricks are either laid dry, called '*dry steining*,' or in cement, or good hydraulic mortar, where strength is required or to keep out water.

In cement work cast-iron curbs are sometimes built in at suitable intervals, to facilitate the execution of the well, and also to strengthen the work.

In dry steining one or two courses set in cement are introduced for strength at intervals varying mostly from 5 to 12 feet.

The bricks are laid flat, breaking joint. The thickness of the steining varies with the depth and diameter of the well and the firmness of the ground ; from 9 inches for diameters up to 9 feet, to 14 inches for diameters up to 14 feet, with an extra half-brick in very bad or loose soils. The best method of laying them is in half-brick rings, with headers at intervals, tying them together. Courses of headers are objectionable, unless the diameter of the well is large.

To exclude land or other springs not under very great pressure, concrete or clay puddle is introduced behind the steining ; clay puddle is the more certain to be watertight. When the bricks are laid dry, the swelling of the earth behind will gradually fill up the spaces between them. It is very essential that the steining should be well backed up by working as close as possible to the sides of the excavation ; and wherever, from any irregularity in the excavation, this is not convenient, the space should be well filled in either with puddle or brickwork ; the latter is preferable, especially where a slip of earth has taken place, in which case the brickwork should be laid in cement. The principal object is to prevent the steining failing by being forced in at one part and out at the other by the pressure of the ground.

The ground round a well should be waterproofed for 30-feet radius of a circle about the well. This ensures that no water can even reach the back of the steining, which has not passed through a considerable bulk of earth.

Well-Sinking.

There are two methods of sinking and steining wells, the first adapted to dry or firm, and the second to wet or loose, ground.

First Method.—The excavation being sunk to a safe depth, a curb or ring of timber is placed at the bottom, formed in two or more thicknesses and lap-jointed to equalise its strength, cut circular on the inside but not on the out, of a breadth sufficient to receive the brick-lining of the well, and not less than 3 inches thick. On this, truly concentric with a central plumb-line, the brick lining is built up to the surface, the earth or a puddling of clay being punned in hard round the outside as the work rises. The excavation is now resumed in the centre, leaving enough earth undisturbed under the curb to support the work done. When a safe depth is again attained, the earth under the curb also is often removed in four equidistant places, the duty of support devolving temporarily on the intermediate portions left as piers; and from a broad central footing of timber 4 raking struts are set up and firmly fixed, to support the curb in the points from under which the earth was taken. This being done, the piers of earth are dug away, and the bottom is then, as before, made level around as a bed for a second curb; and thus the work proceeds in stages down to the required depth, the projecting angles of the curbs outside, by their penetrating the soil, contributing to the support of the brickwork in its progressive extension downwards. Sometimes the curbs, instead of being propped from below, are suspended by cross-timbers from the mouth of the well by iron rods.

Second or Older Method.—The surface of the ground having been levelled, or an excavation made to a safe depth, an iron curb with a sharp lower edge, or a wood curb shod with iron, with an outer diameter equal to that of the brickwork cylinder, is laid on the surface or in the excavation, and as the brick steining is built upon it, it sinks by its own gravity, the bricklayer continuing building up at the surface, while the digger inside descends, the soil being hoisted out as fast as excavated. When from the swelling of the ground the descending work becomes earth-bound, the process has to be recommenced at its base to a smaller diameter.

Iron Cylinders are sunk as just described for brick cylinders. They are mostly inserted in order to continue the well when the brick steining has been interfered with by running sands or the irruption of water. Until the water-yielding stratum has been passed through, the sinking of the cylinders is carried on with the assistance of the ordinary boring tools. The cylinders are generally of cast iron, made up of 5 or 6 feet lengths, bolted together by means of internal flanges, leaving the exterior surface perfectly smooth. The bottom length has, instead of a lower flange, a cutting edge to facilitate the descent. The joints are made watertight, either with gasket soaked in tallow or by being caulked with iron cement. Wrought-iron cylinders used for steining are jointed with angle and T iron by rivets countersunk on the outside, so as to leave a smooth surface. When the cylinders become earth-bound they are loaded, or else pressed down by jacks or rammed down by wooden 'dollies.'

The Number of Bricks and Quantity of Brickwork in Wells and Cylindrical Sewers for each Foot in Depth or Length.

Diameter of Well, in Feet.	Half-Brick Thick.			One Brick Thick.		
	Number of Bricks.		Cubic Feet of Brickwork.	Number of Bricks.		Cubic Feet of Brickwork.
	Laid Dry.	Laid in Mortar.		Laid Dry.	Laid in Mortar.	
1·0	28	23	1·6198	70	58	4·1235
1·3	33	27	1·8145	80	66	4·7124
1·6	38	31	2·2089	90	74	5·3015
1·9	43	35	2·5035	102	82	5·8905
2·0	48	41	2·7979	112	92	6·4795
2·3	53	44	3·0926	122	100	7·0686
2·6	58	48	3·3870	132	108	7·6577
3·0	68	57	3·9760	154	126	8·8357
3·6	79	65	4·5651	174	142	10·0139
4·0	89	73	5·1541	194	159	11·1919
4·6	100	82	5·7432	214	176	12·3701
5·0	110	90	6·3322	234	192	13·5481
5·6	120	98	6·9213	254	209	14·7263
6·0	130	107	7·5103	276	226	15·9043
6·6	140	115	8·0994	296	242	17·0825
7·0	150	123	8·6884	316	260	18·2605
7·6	160	131	9·2775	336	276	19·4387
8·0	170	140	9·8665	358	292	20·6167
8·6	180	148	10·4556	378	308	21·7949
9·0	191	156	11·0446	398	326	22·9729
10·0	212	174	12·2227	438	360	25·3291

Quantity of Water in Wells.

To ascertain the quantity of water in a well, take half the circumference (in the clear) and multiply by half the diameter; multiply the result by the depth, which gives the cubic measures, then reckon 6 gallons and 1 pint to the foot cube.

To Increase the Yield from a Well already Executed.

1. The water-level in the well may be lowered by pumping, etc., by which the hydraulic depth for the inflow is increased.

2. The bore-hole may be deepened, thus probably leading to denser strata, through which there would be less percolation, and thus more yield to the well.

3. Headings may be driven laterally from the well; the best level for them is just above the lowest level to which the water is ordinarily pumped; in plan they should be straight lines through the well.

4. Dynamite or other explosive is lowered down to the bottom of the bore-hole, and then exploded by electricity.

Protective Distance from Drains.

A well should not be closer to a drain than 4 feet for every foot in depth; thus a 20-foot well should be at least 80 ft. from any possible source of corruption. Wells 100 ft. deep, if with water-tight sides, may be relied upon as safe from leakage contamination, as this depth of soil is capable of removing a greater amount of organic matter that may exist in the water.

Prof. Frankland gives 200 yards from a cesspool, cemeteries, etc., as the nearest safe distance; in Italy, 100 yards; in France and Austria, 200 yards. But much will depend on the dip and nature of the strata.

Artesian Wells.

In the best modern practice, artesian wells are lined with stout steel-socketed wrought-iron or steel pipes, to a point at least lower than the lowest water level. In chalk bores the pipes are lightly driven at least 10 feet into the chalk—or further, if necessary—the projection of the sockets being very effectual in securing the shutting off of the upper, and perhaps undesirable, waters from the lower.

No pipe should be less than $\frac{1}{4}$ inch thick, from 3 to 6 inches diameter, up to $\frac{3}{8}$ inch thick for pipes of 10 to 16 inches.

When the water level is considerably below surface, the yield of a well is measured by the capacity of the largest pump that can be put down the bore tube. Deep-bore pumps consist simply of a plain barrel hung in the water by a wrought-iron rising main pipe of slightly greater diameter. The bucket is hung by rods inside the rising main, and these project through a stuffing-box in an outlet casting on the top of the main, and are actuated by a crank or other means to give a stroke of 18 to 24 inches in ordinary cases. A plunger is added in the outlet casting for forcing to considerable heights above surface, and a balance lever should be connected to the cross-head by links.

The best water-bearing strata in England is the Lincolnshire (Oolitic) limestone, which contains many spouting copious wells; notably one at Sleaford, only 6 inches diameter, which overflows at 30,000 gallons per hour 3 feet above surface. The chalk is very free bearing in many parts, but capricious and occasionally nearly dry. The Keuper marl yields good brewing water at Newark, Burton, Leicester, etc., but not very copiously, and apt to be very small in amount and capricious in character. The Keuper sandstone is a free yielding stratum, and gives good soft water. The Permian sandstone is also a fair and at times a copious water-bearing rock, and so also is the magnesian limestone.

The Lower Greensand sometimes yields copiously, and, as a rule, the more copious the supply, the better the quality. It is at times ferruginous. The Lias clay is apt to produce saline water; so also is the London clay. The Upper Tertiary beds of the London basin below the London clay often yield fair but slightly alkaline supplies.

The carboniferous rocks vary greatly, and often give copious supplies, and but few rocks are quite dry. As a rule, the more copious yields are all within 200 feet of the surface. Deeper boxes yield less and less. Water has been obtained from the Lower Greensand in Windsor Forest at 1,243 feet below surface, the quantity being small, the quality good, and the water rising to about 230 feet above sea level, or overflowing the surface nearly 8 feet.

For borings in rock having a surface outcrop near the site of the boring, the water level will usually be little or nothing above the nearest watercourse crossing such outcrop, but where borings penetrate an impermeable surface, and reach a rock having a distant outcrop, the water level will be determined by such outcrop, and, though lower than the receiving surface, will be higher than a distant draining point, if any.

It is by no means unusual for well borers to pass through water and declare it to be absent. They will also continue boring into strata that are hopeless as water-bearing strata under the impression that they have not yet passed through the upper stratum. Thus in places the Gault way rests upon the Kimmeridge clay, and it is difficult to distinguish one clay from the other. Well boring should only be carried out under educated inspection, and regular samples of everything passed through should be kept, and records of the water level every morning and of any change during the day. Small changes in the material and variations of the water level are often very instructive and significant to the hydrogeologist.

Wells in the lower chalk formation are frequently failures, owing to failure of the workmen to recognise the evidences about them.

While there can be no good done by carrying wells to excessive depths, it is a common experience to find wells that have been sunk only to their high-water mark horizon, so that when the water level sinks the well is dry. This is a frequent occurrence in the lower chalk, in which there is a very wide difference between the highest and the lowest water levels. Wells sunk in high-water periods invariably run dry when the lower-water period approaches.

For the varying strata of the British Isles, and the usually small depths required, the ordinary system of boring with chisels and rods appears to be as cheap as any other. For depths beyond 500 feet the rope is often used. No one system can be adhered to, but rods, ropes, and the diamond must be employed, according to the requirements of each case.

More recent practice is to bore by means of the rotary chilled steel shot system. A plain thick steel pipe is notched at its lower end and rotated upon the rock to be pierced. A quantity of chilled steel shot is fed down the pipe. This gets under the lower end of the pipe by way of the notches, and, rolling on the rock under heavy pressure, comminutes by the intensity of the rolling crushing action. Water forced down removes the groundaway rock, and good cores are obtained. Several feet per day may be bored in hard limestone. The method involves no loss of costly diamonds.

To calculate the rate of flow of an artesian well, a simple plan is to lower a bottle of aniline fluid to a depth of, say, 500 feet, and then electrically explode a cap to burst the bottle. The time required for the fluid to appear at the surface gives an accurate gauge as to the velocity of flow. It is claimed that this method gives results as accurate as a weir. The diameter of the pipe being known, the rate of flow readily follows. (*W. H. Booth.*)

WATERWORKS.

(Revised by R. Fairfax Middleton, Assoc.M.Inst.C.E.)

MASONRY DAMS.

Rankine gives for low masonry walls to retain water that the thickness at the base should be about $\frac{4}{10}$ of the height either for rectangular walls or for those of trapezoidal form where the thickness at the top is $\frac{1}{4}$ that at the base.

Another rule for low dam walls is: Thickness at bottom 0·7 height; thickness at middle 0·5 height; thickness at top 0·3 height.

For high masonry dams Molesworth gives H = height of dam in ft.; x = any depth below

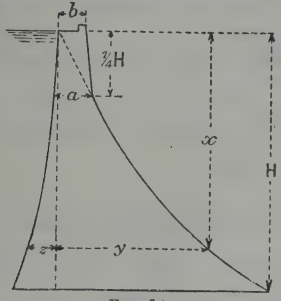


FIG. 1A.

the water surface in ft.; y = offset from vertical line to outer face of dam at any depth x; z = ditto ditto to inner face; b = width of dam at top in ft.; a = width of dam at 1/4H from top in ft.; P = limit of pressure on masonry in tons per sq. ft.

$$b = 0{\cdot}4a; \quad y = \sqrt{\frac{{\cdot}05\,x^3}{\mathrm{P} + {\cdot}03\,x}}; \quad z = \left(\frac{{\cdot}09\,x}{\mathrm{P}}\right)^4;$$

y at any section must not be less than 0·6 x.

In modern practice a common typical section is triangular, the inner face being given a slight batter, and the back a batter which will generally approximate to 1 in 1½ but depends upon the weight of the masonry and the exact form of the wall.

The dam must be so proportioned that the resultant thrust acts within the middle third of the base, both with the reservoir full and empty; this provision should also apply to any horizontal section of the dam. The theoretical apex of the triangle must be high enough to allow, if necessary, for the water overtopping the wall, also for wave action.

EARTH DAMS.

The top width may be anything from 6 ft. to 20 ft., depending on the height of the dam and the freeboard.

The inner slope will generally be about 3 to 1 for gravel or other good material, but with clays it may not stand at this and must then be made flatter.

The outer slopes may be as steep as 2 to 1 depending on the angle at which the material will stand; the outer slope should be well drained. The inner slope must be protected from wave action; this is generally done by laying stone pitching or concrete slabs on the surface of the bank.

Watertightness is generally obtained by means of a core of puddled clay in the centre of the bank, the puddle being carried right down through the solid ground below the bank and well bonded into the impervious material on which the reservoir is built.

The puddle wall should generally be about 4 ft. thick at the top and both sides batter outwards about 1 in 40 to ground level, below which the thickness of the puddle should be quickly reduced to about 6 ft. and carried down at this as far as necessary. This applies to good puddle; the thickness must be increased if the puddle is of poor quality.

The puddle is sometimes replaced by a concrete wall; care must, however, be taken to avoid the possibility of unequal strains upon such a wall, as these might lead to cracking and possible failure.

Another method is to fill the trench in the solid ground with concrete and to build on this a wall of puddle. In this case the puddle must be well tongued into the concrete so as to ensure a watertight joint.

The François Cementation Process (*The François Cementation Co., Ltd.*) has been successfully employed for the injection of dam foundations to render them watertight, thus considerably reducing the amount of required excavation and the necessity of masonry aprons: e.g. the Mazoe Dam, in South Africa. (*A. H. Krynauw, Engineering Society of South Africa, May* 18, 1918.)

The same process is employed with equal ease and efficiency to seal off leakages making through existing dams and reservoirs: e.g. Stobshiel Reservoir, Scotland; Upper Booth Dam, near Halifax.

See also 'Shafts,' Section XXXIX.

Lining Distribution or Service Reservoirs.

In small reservoirs watertightness may be obtained by covering the whole of the bottom and sides of the reservoir with a layer of puddle. The puddle in this case should be covered with concrete to protect it from damage. In reservoirs of any size, however, the cost of the method would be prohibitive.

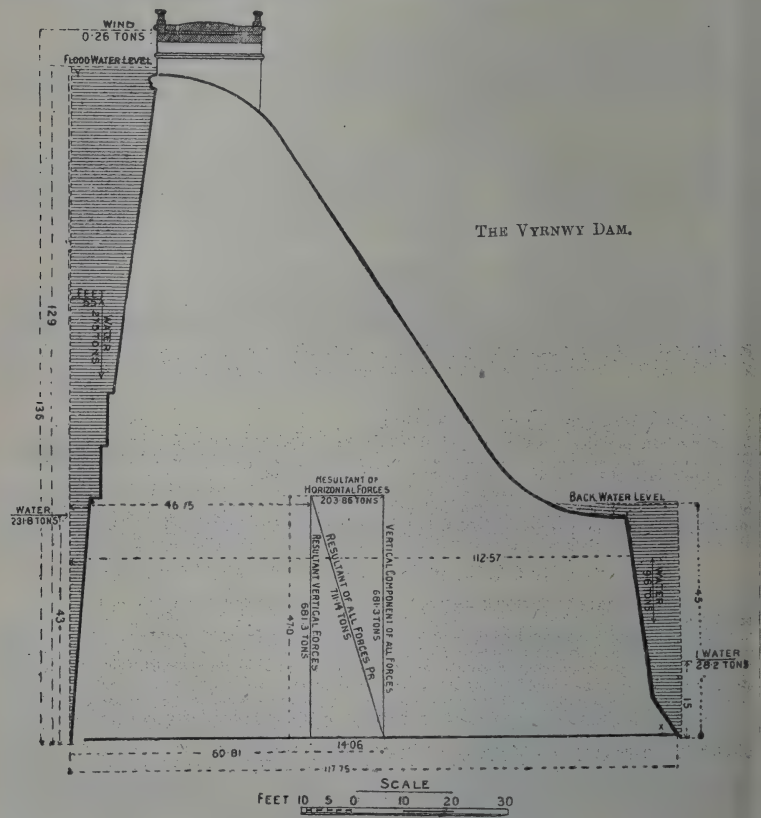


FIG. 2.—Cross-section of Vyrnwy Dam.

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THE CROTON DAM.

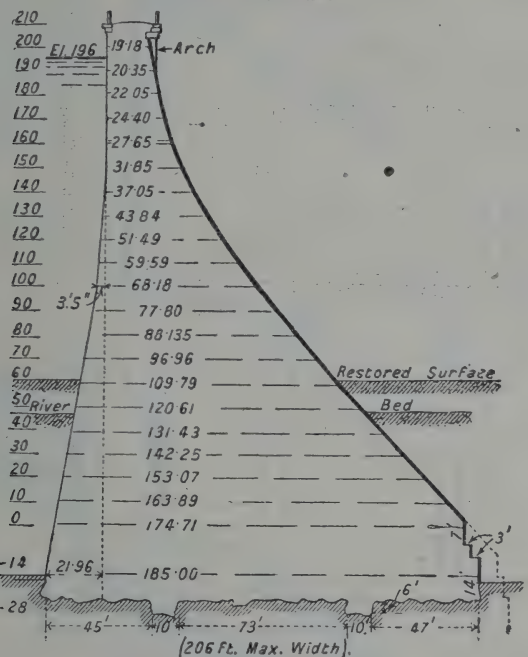


FIG. 3.—Cross-section of Croton Dam.

THE VYRNWY DAM.

The Vyrnwy Dam (fig. 2) is 1,350 feet long on the top, the plan being straight. The maximum height above the foundation is 136 feet. The profile adopted is designed to resist the water pressure and also to form a waste-weir; the front face of the wall is, therefore, made to conform to the curve described by water in overflowing, and to deflect it into the basin in front of the dam. The foundation is laid on a clay slate rock. The dam is built of 'Cyclopean rubble,' the stones varying in weight from 2 to 8 tons. For the lower part of the dam the stones are set in mortar composed of 2 parts washed sand, 1 part Portland cement; in the main portion of the work, instead of plain sand, a mixture of 1 part of the latter with 2 parts pulverised quarry rock was used for making the mortar, 2½ parts of the mixture being mixed with 1 part Portland cement. The area of the section, shown by fig. 2, is 8,972 square feet. With the reservoir full and the wind blowing with a force of 60 lbs. per square foot, the maximum stress on the masonry is 6·36 tons per square foot. Where the bed rock has the lowest elevation there are 26 drains in a length of 198 feet of the wall; these drains are 9 to 12 inches square, and lie on the rock near such places where leakage is apt to occur; they are 25 feet from the front face and 30 feet from the back face, and connect with a central tunnel 4 feet high by 2½ feet wide, which traverses the foundation longitudinally at an elevation of 46·3 feet above the base of the cross-section. By means of a cross-tunnel leading down-stream any water that may filter into the foundation above the elevation of the drains is discharged at the front face of the dam.

THE ASSUAN RESERVOIR.

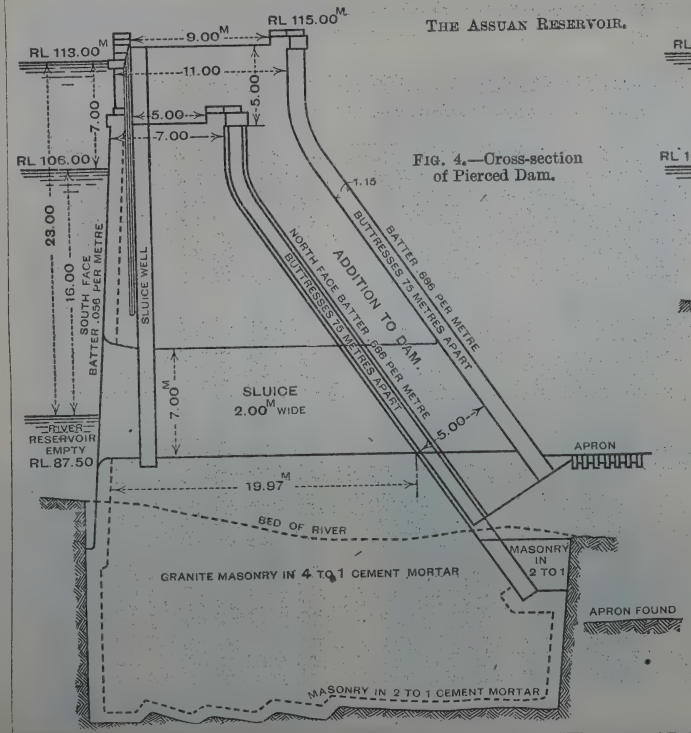


FIG. 4.—Cross-section of Pierced Dam.

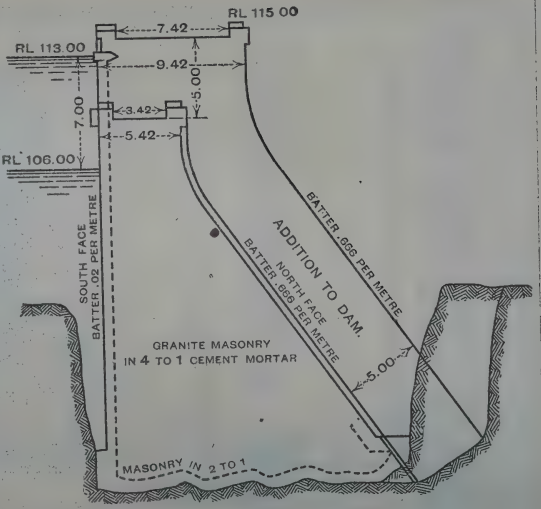


FIG. 5.—Cross-section of Solid Dam.

Mean High Flood Level at Aswan 92.80.
Mean Low Water Level.....85.10.

Contents of Reservoir-Original Dam 980,000,000M3
" " " Heightened Dam 2,300,000,000M3

The Assuan Dam.

The Assuan Dam, fig. 5, p. 1476 is a granite rubble masonry structure founded on a similar rock which is traversed by dykes of softer igneous material. It is situated at the head of the first cataract of the Nile.

As originally constructed it was just under two kilometres in length, the top level of the structure was RL. 110·00, the water being held up to a level of 106·00.

It is pierced for the greater part of its length by sluices which are closed by steel gates, most of them working on the Stoney principle. There are 180 sluices in all, of which 22 are at a level of 100·00 and 18 at 96·00; these sluices are 3½ metres high by 2 metres wide. Of the others, which are 7 metres high by 2 metres wide, 75 are at RL. 92·00 and 65 at RL. 87·50; 30 of the lowest sluices are lined with cast iron, the rest smooth-faced granite ashlar.

The original dam was finished in the summer of 1902.

It was found that the rush of water through the sluices was such as to erode what had appeared to be solid rock, and it was therefore necessary to build masonry aprons along practically the whole length of the pierced dam.

Between 1907 and 1912 the dam was raised so as to impound water to a level of 113·00 metres, and it was at the same time thickened by a blanket wall five metres thick on the downstream side.

The original reservoir impounded 980,000,000 cubic metres of water, or 216,000,000,000 gallons.

The heightened reservoir contains 2,420,000,000 cubic metres, or 533,370,000,000 gallons.

The reservoir is used for irrigation purposes.

GENERAL ARRANGEMENT OF RESERVOIRS.

In reservoirs filled by gravity a waste weir must be provided to carry off flood water, and should be so designed that the maximum flood will not cause the water to rise more than 18 inches over the lip of the weir.

The waste weir channel should be built in solid ground: it is generally constructed in a flight

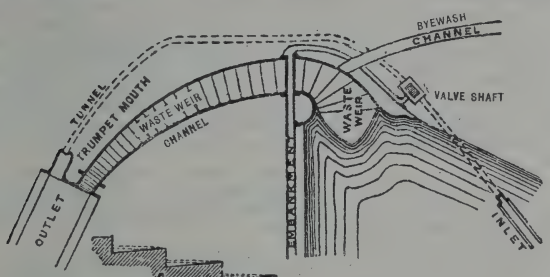


Fig. 6.

of steps, so as to check the velocity of descent; the risers vary from 1 ft., which is best, to about 5 ft., and the tread should, if possible, be at least double the riser. The best form is a series of weirs and pools, or tumbling bays, or flights of steps with long landings or pools at intervals, the drop into pool being as small as possible. The pools may be formed as shown at A (fig. 6): depth of pool = drop, length of pool = drop × 10.

Fig. 6 shows a tunnel round the flank, also the valve shaft, byewash, and other accessories.

The tunnel and byewash are used for passing storm waters during construction, the former being used afterwards for supply purposes and the latter for passing turbid water in times of storm.

Storage Reservoirs.

The capacity of storage reservoirs is arrived at from the formula

$$C = \frac{500}{\sqrt[3]{R}},$$

where,

C = number of days' storage, = R available rain in inches, as explained under heading 'Gathering Grounds.'

Messrs. W. J. E. Binnie and H. Lapworth have lately suggested the following formula for calculating storage:—

$$s = 15\frac{(n-d)^2}{r^{1\cdot85}},$$

where,

s = inches of storage required to supply (constantly from a stream) n inches per annum; d = the extreme minimum dry-weather flow reduced to inches per annum; r = mean run-off, also in inches per annum.

The storage required in gallons is equal to $s \times$ area of gathering-ground in acres $\times$ 22,610.

The formula is empirical, and was arrived at by a study of the data of seven areas of supply.

GATHERING GROUNDS.

In arriving at the water available from an area the average rainfall on the area must be found from rainfall records; ¾ of this is then generally taken as the average for the three driest consecutive years and then a deduction must be made for evaporation, generally 14 to 16 inches; the remainder, subject to special conditions, will be the available rain; ⅓ of this often has to be given in compensation.

The above applies to ordinary cases in the United Kingdom. For a study of run-off under various climatic conditions, see 'Rainfall' (p. 1461).

On the moorland gathering-grounds supplying Sheffield, rainfall averages 40 ins. a year, two-thirds of which is reckoned on as available; one-third goes as compensation to millowners, etc., and one-third to inhabitants. Every 1,000 acres is said to give an average of 1,250,000 gallons per diem. On the Leeds moorland gathering-grounds ¼ cubic feet per second, or 134,600 gallons per diem per 1,000 acres, is the usual minimum dry-weather discharge; the formation is millstone grit, rainfall 26 ins. to 45 ins., of which 14 ins. is allowed for evaporation and 6 ins. as compensation to millowners.

FILTRATION.

(Contributed by H. F. Rutter, M.Inst.C.E.)

Filtration should be preceded by sedimentation. The researches of Dr. A. C. Houston prove that prolonged storage not merely reduces enormously the ordinary and harmless bacterial contents of river waters, but that such storage is a complete protection against danger from pathogenic microbes in the case of water initially infected with such germs.

The area of sand surface needed per million gallons per diem varies considerably, according to the character of the water and the fineness of the filtering medium. Yields of from one million to two million gallons per acre are common values. Modern filters have four feet of water over the sand, two feet nine inches of sand supported by eight inches of graduated shingle. Care should be taken that the uppermost layer of shingle should consist of stones less than half the size of a pea, so as to avoid the danger of the sand being drawn through the shingle. The means of collecting the water should cover the whole floor of the filter and should not consist of transverse pipes placed at intervals. A satisfactory and inexpensive method is to cover the floor with transverse rows of bricks laid dry end to end with a space of 4½ inches between each two rows. These are then completely covered with bricks laid dry at right angles to the rows. A series of 4½ in. by 3 in. channels are thus formed, which lead the filtrate to the central channel made below the floor.

A Deacon meter on the outlet pipe forms a useful means of checking and recording the rate of flow of the filter. Float gauges should be provided to show the relative levels of the water over the sand and in the outlet pipe. The difference between these levels indicates the head under which the filter is working. This head may vary from one inch when the filter is started slowly after cleaning, up to 2 or 3 feet.

Means should be provided for drawing the raw water from above the sand to waste, in case it be required to clean a filter immediately which has become clogged. A quarter to half an inch of sand with the matter arrested thereon is removed by flat shovels. This sand can be washed and spread again either at once, or after the depth of the sand has been reduced by five or six successive cleanings. The cleanings may be at intervals of from one week to four months, according to the character of the water, and the amount of algal growth in the water, which latter condition may materially affect the life of the filter. The removal and cleaning of the main body of the sand is needed at very rare intervals. Filters are in use yielding water of perfectly satisfactory bacteriological character in which the main body of sand has not been changed for forty years.

When a filter is to be cleaned the water should not be drawn down in the sand to a level more than 12 inches below the surface of the sand. This leaves the surface quite hard enough to support the weight of the cleaners, and prevents the sand becoming unduly compacted.

All sensible suspended matter is arrested on the surface of the sand of a filter, and the largest elimination of bacterial life takes place at or near the surface. The bacterial contents are, however, still further reduced progressively in the passage of the water through from five to ten inches of the depth of the sand.

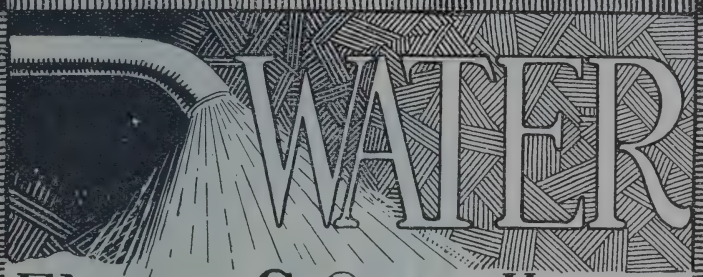
THE 'TORRENT' FILTER.

(The Pulsometer Engineering Co., Ltd., Reading.)

With this plant (fig. 7) the filtration is effected by passing the water under pressure through a certain thickness of suitable filtering medium, arrangements being made so that the entire filtering medium can be thoroughly cleaned.

The construction is very substantial, all parts are accessible, and the various valves for operating and cleaning the filter are brought together at one point for convenient handling. There are no mechanically operated components either inside or outside the filter, so that there are no parts to wear or keep in adjustment.

The filter is made either cylindrical or square (the latter when it is necessary to economise space or when the filter has to be brought in parts into an existing building through ordinary doors). A strainer plate is fixed near the bottom of the filter casing, and this plate carries



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layers of graded filtering medium. The unfiltered water admitted to the upper part of the filter percolates through the filtering medium, where the matter in suspension is retained, and reaches the space below the strainer plate in a clear and bright condition. The bottom of the filter casing is connected to the filtered water main.

The cleaning of the filter is effected by means of air agitation and a reverse flow of filtered water. If there is sufficient pressure in the filtered water main, say equal to 10 to 15 ft. head,

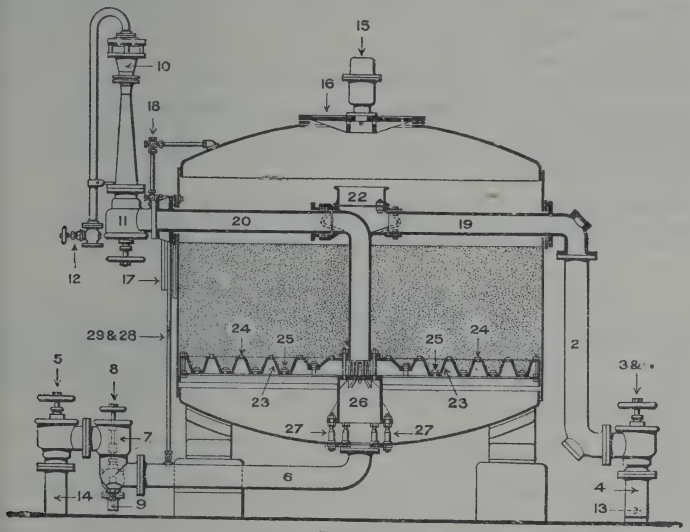

FIG. 7.

a reverse flow from the filtered water main can be used; but if there is not sufficient head in this main, or if the filtered water reservoir is below the level of the filter, it is necessary to employ a centrifugal pump to force the washing water through the filter.

The agitation (by compressed air) is effected by means of a separate system of air nozzles in the strainer plate, through which the air is equally distributed over the whole area of the filter bed. The air nozzles being entirely separate from the strainers make it possible to use the air simultaneously with the reverse flow of water during the process of cleaning, if found

LIST OF COMPONENT PARTS.

1. Unfiltered water inlet valve.
2. Unfiltered water inlet and wash-out bend.
3. Wash-out valve.
4. Wash-out pipe.
5. Filtered water outlet and wash water inlet valve.
6. Filtered water and wash water bend.
7. Patent wash water regulating valve.
8. Drain valve.
9. Drain pipe.
10. Air blower.
11. Blower valve.
12. Steam stop valve to air blower.
13. Unfiltered water pipe.
14. Filtered water pipe.
15. Automatic air escape valve.
16. Manhole cover.
17. Differential mercury gauge.
18. Water gauge glass.
19. Internal inlet and wash-out pipe.
20. Internal air pipe to strainer plate.
22. Internal wash-out and inlet bell mouth.
23. Strainer plate.
24. Air nozzles.
25. Strainers.
26. Stool for strainer plate.
27. Studs for strainer plate stool.
28. Pressure pipe from underside of filter medium.
29. Pressure pipe from above filter medium.

desirable. The air main is carried above the filter, so that there is no risk of its becoming water-logged, which might cause obstruction to the passage of the air.

A steam blower may be used for supplying the compressed air, but if steam is not available, a small air compressor, with or without an air receiver, can be employed.

The air causes a violent ebullition in the filter and has the effect of raising the filtering medium, so that the various particles are free to move, and in knocking against one another dislodge all the matter which adheres to their surfaces. Whilst the air agitation is going on an upward flow of water carries away, through the wash-out pipe, the impurities which have been dislodged by the action of the air.

This system of cleaning effects a considerable saving in the amount of wash-water used as compared with that necessary when water only, or water and mechanical agitators, are used.

The time taken to clean the filter may be from 10 to 20 mins.—depending on the nature of the water and the time the filter has been at work since the last cleaning. Reference to the diagram on p. 1479 will show that as the nozzles are distributed equally all over the strainer plate and the air has free access to all of them, the cleaning process is as thorough at the sides of the filter as it is in the middle.

A differential gauge is fitted to show the head lost in the filter. This gauge gives an indication of when the filter requires cleaning, because the difference in pressure between the top and bottom of the filter increases as the impurities accumulate on the filtering medium.

MAINTENANCE AND RENEWAL OF WATERWORKS.

In the Metropolitan area, 'pumping' constitutes, on an average, 43 per cent. of the entire maintenance expenditure. During the last thirty years 4,408,846*l.* has been expended out of revenue on pumping operations and on the maintenance and renewals of the pumping-engines and machinery, which during that period have supplied the Metropolis with 1,745,718 million gallons of water for all purposes; thus the cost of pumping alone has been, on the average, 2*l.* 10*s.* 7¼*d.* per million gallons, or ·000606*d.* per gallon.

The cost of repairs and renewals of water-mains and pipes amounted to 2,964,127*l.*, or an average of 1*l.* 14*s.* per million gallons.

The average maintenance cost per mile of water-main or pipe-way (adopting the analogy of a railway as a means of conveyance) has been 24*l.* 5*s.* 5*d.*

The cost per million gallons for filtration is 0·37*l.* (*Price-Williams.*)

Standard of Purity of Water.

Total hardness in practice varies from 0 to 30 degrees; 5 degrees is generally considered best.

Water containing more than the following quantities of impurities should be looked upon with suspicion: Chlorine, 1 part per 100,000; Nitrites, 0·2 part per 100,000; Nitrates, 0·3 part per 100,000; Ammonia, 0·1 part per 100,000; Organic Carbon, 2 parts per 100,000; Organic Nitrogen, 3 parts per 100,000; Albumenoid Ammonia, 0·01 part per 100,000.

WATER TESTING.

Simple and ready tests for rough analysis.

For *Sewage.*—Four drops of a solution of potash (Condy's Fluid) to a small glass of water. The colour turns pale or yellow if decomposed organic matter is present.

Lead.—Six drops of sulphuric acid in small glass of water. White precipitate will be found if lead is present.

Zinc.—Six drops of ferro-cyanide of potassium to small glass of water. Green colour if zinc is present.

Copper.—Eight drops of ammonia in small glass of water. Water turns blue if copper is present.

CHEMICAL PURIFICATION OF WATER.

Water is sometimes purified by chemical means: there are several methods, of which the most important are (1) by the addition of chloride of lime and (2) by submitting the water to the action of ozone.

By these methods the impurities are not removed, but the water is sterilised and all the bacteria which it contains are destroyed.

Reservoirs in which vegetable growth or algæ has become profuse have been cured by dragging a bag of sulphate of copper behind a boat to and fro over the area of the reservoir. A very minute fraction of this poisonous salt will effectually destroy all growth, and it is said that the salt cannot be detected in the water after the process is complete. Apparently the organic matter has absorbed it; but as the salt is extremely poisonous great care must be taken that too much is not used.

Action of Water on Lead.

Peaty water from moorlands has a solvent action on lead pipes, due to acidity. It varies, in terms of a sulphuric acid equivalent, from 1 to 44 parts in 100,000. Peaty grounds of small incline are particularly acid, and such water is dangerous on account of its action on lead pipes. According to Mr. Ackroyd the solvent action would not occur if the acidity did not exceed ·5.

Diameter of Pipes.

The diameters of pipes are usually calculated by either Eytelwein's or Kütter's formula.

Eytelwein's formula is

$$V = \sqrt{(11704\,RS) + \cdot 01698} - \cdot 1303$$

where,

V = velocity in feet per sec.; R = Hydraulic mean radius in feet = Area ÷ wet perimeter = D ÷ l for circular section of pipe, where D = diameter of pipe in feet; S = sine of inclination = h ÷ 4, where h = head in feet; l = length in feet.

An adaptation of this formula which gives good average results is

$$Q = 4 \cdot 7\, D^2 \sqrt{\frac{Dh}{l}}$$

where,

Q = discharge in cub. ft. per min., and D is in inches.

This formula gives rather high results in the case of small pipes with flat gradients, and somewhat low results for large pipes with steep gradients.

Kütter's formula is

$$V = \left[41 \cdot 6 + \frac{1 \cdot 811}{n} + \frac{\cdot 00281}{S} \right] \div \left[1 + \left(41 \cdot 6 + \frac{\cdot 00281}{S} \right) \frac{n}{\sqrt{R}} \right] \sqrt{RS}.$$

where V, R, and S have the meanings stated above, and n is Kütter's coefficient for roughness, which varies from ·009 to ·017, ·013 being a value which is frequently taken.

For new asphalted cast-iron pipes, Barnes (*Inst. C.E. Proc.*, ccxi., Jan. 1922) gives the following formula:—

$$Q = 47 \cdot 087\, d^{2 \cdot 769}\, i^{0 \cdot 529}$$

where,

Q = discharge in cub. ft. per sec.; d = diameter in ft.; i = hydraulic gradient = $\left(\frac{\text{height}}{\text{length}}\right)$.

Incrustation and Corrosion of Iron and Steel Pipes.

High-water velocity is favourable to corrosion and incrustation. Cast-iron being taken to rust at the rate of 100, wrought-iron may be taken as 129, and steel at 133. Some waters, as chalk-well waters, treated by Clark's process, will simply cause a clean layer of carbonate of lime inside a pipe. Upland waters, especially if containing peat acid, cause rust. Old red-sandstone water neither rusts nor causes deposit. Greensand water causes rust. Filtered water is better than unfiltered. Angus Smith composition (see Index) is not a permanent protector. Founders do not as a rule exercise proper care in dipping pipes; the pipes ought to be well brushed out, by passing through them a revolving steel brush *from both ends*, so as to get the brushing effect each way, and they should be then at once heated and dipped. Dipping should be vertical, and the pipes ought to again be brushed by the revolving steel brush when immersed in the dip, without which treatment perfect contact may be difficult to secure between the iron and the composition. It is undoubtedly at the pinholes, caused by minute air bubbles, that the first encroachments of corrosion are made upon the pipe.

According to H. F. Rutter, pipes of cold-blast iron are far superior to those of hot-blast, as regards resistance to corrosion.

Tracing Leakages.

To identify and trace the source of underground water, such as leakages from canals, reservoirs, pipes, etc. :—

Fluorescin.—Mix fluorescin with the supposed source of the leakage. One grain is sufficient to colour 100 tons of water.

Indigo.—One grain of indigo dissolved in sulphuric acid will colour a ton of water.

The coloration is more easily detected by placing the water in a very long test-tube and looking through the latter endways.

Waste Water Detection.

(*The Palatine Engineering Co., Ltd.*)

The detection of invisible leakages between the reservoir and the consumer is usually done by meters of the 'Deacon' type, similar to fig. 8. A large recording meter is fixed on the main

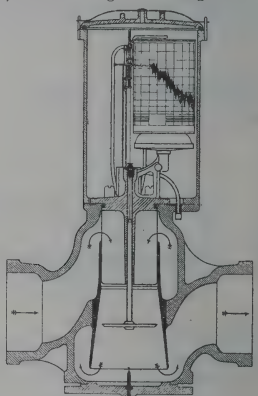

FIG. 8.

at the reservoir. The supplied area is divided into districts of about 2,000 inhabitants and arranged so that the whole supply comes from one direction, and passes through a Deacon meter. Fig. 8A is a plan of the area showing valves.

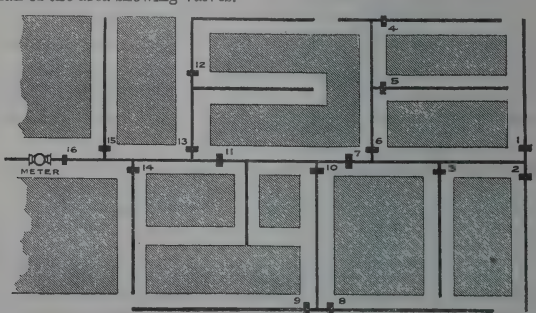

FIG. 8A.

A typical chart for twenty-four hours in an uncontrolled district is shown in fig. 9. The minimum flow during the night is 2,000 gallons per hour (represented by the shaded portion), or 48,000 gallons per day. In the absence of night supplies for trade purposes, this water is leaking through defects. The water used or misused (represented by the cross-hatched portion) is 29,775 gallons, making a total supply of 77,775 gallons per day.

To locate this waste a chart is fitted in which the time scale is multiplied by four. During the night the inspector proceeds to the end of the district and closes No. 1 valve, and the other valves in succession, at about 15-minute intervals, noting the time and the location of the valve.

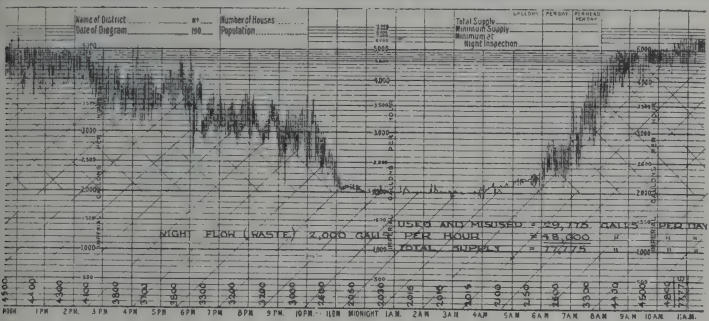

FIG. 9.

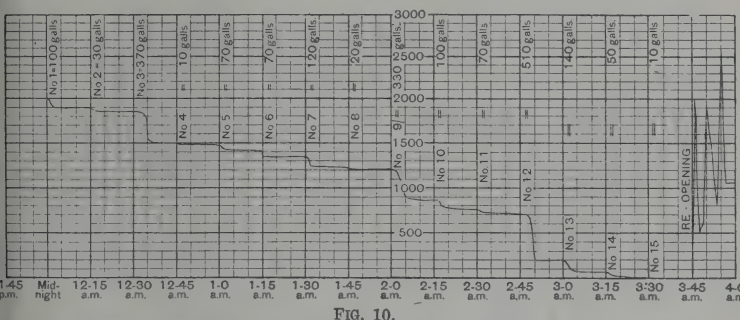

FIG. 10.

The result is shown in fig. 10, the rate of flow in each portion before isolating being clearly recorded. There is an indication of large defects in portions supplied through valves Nos. 3, 9, and 12. These are afterwards traced by a form of stethoscope and examination of fittings.

Consumption of Water.

This varies very largely in different parts of the country: in Edinburgh as much as 40 gallons per head per day are consumed, and in Glasgow much more. Where trade requirements are small 25 gallons per head per day should, however, usually be sufficient for domestic consumption, garden, and street watering, and for flushing.

Hardness of Water.

Hardness is termed *Permanent* or *Temporary* according as the hardness is due to the bi-carbonate of lime and magnesia, which cease to be soluble at 212°, or to sulphate of lime, which remains in solution to much higher temperatures. There exist at the present date two methods of removing either or both of these forms of hardness, the first being by treatment with caustic lime and caustic soda, and the second by filtration over zeolites.

(1.)

Treatment by Caustic Lime or Caustic Soda.

Lime sulphate is dealt with by carbonate of soda, and is converted into the mono-carbonate of lime, while sulphate of soda remains in solution as a very soluble salt. Practically these two lime salts, or the magnesia, are the only salts calling for practical treatment. The following are the reactions which take place, from which it is obvious that where caustic soda can be procured cheaply it may be used where both impurities are present, and will perform a double duty and take the place of some or all of the caustic lime.

(*a*) A water containing only bi-carbonate of lime :

Bi-carbonate of Lime	+	Caustic Lime	=	Carbonate of Lime
$CaO+2(CO_2)$	+	CaO	=	$2(CaCO_3)$
$56+88$	+	56	=	$2(100)=200$ of deposit

(*b*) A water containing carbonate of magnesia :

$$MgO+2(CO_2) + CaO = (MgCO_3)+CaCO_3$$
$$40 + 88 + 56 = 84 + 100$$

(*c*) A water containing sulphate of lime :

Sulphate of Lime		Carbonate of Soda	
$CaSO_4$	+	Na_2CO_3	$=CaCO_3+Na_2SO_4$
136	+	106	= 100 + 142

or water (*a*) treated by caustic soda :

Bi-carbonate of Lime		Caustic Soda		Carbonate Lime		Soluble Carbonate Soda Water
$CaO+2(CO_2)$	+	$2(NaHO)$	=	$CaCO_3$	+	$Na_2CO_3+H_2O$
144	+	80	=	100	+	106 + 18

(*d*) A water with both salts in solution :

$$\{[CaO+2(CO_2)] + CaSO_4\} + 2\{HNaO\}$$
$$144 \qquad 136$$
$$= \text{first reaction } [CaO+2(CO_3)]+CaO+[Na_2SO_4+H_2O]$$
$$= \text{second reaction } \begin{bmatrix} CaCO_3+CaCO_3 \\ \text{insoluble} \end{bmatrix} + \begin{bmatrix} Na_2SO_4+H_2O \\ \text{soluble} \end{bmatrix}$$

Both actions go on simultaneously.

When the bi-carbonate exists in greater proportion than 144 to 136 of the sulphate, the difference in excess must be dealt with by caustic lime as per (*a*). When the sulphate of lime is in excess beyond 136 to 144 of bi-carbonate, the excess is to be dealt with by carbonate of soda as in (*c*). There is no such salt as bi-carbonate of lime except in solution in water containing carbonic acid gas. It is taken as evidence of the existence of the bi-carbonate that the carbonic acid gas is found in the equivalent necessary proportion which would form a bi-carbonate.

(2.)

REMOVAL OF PERMANENT OR TEMPORARY HARDNESS BY FILTRATION OVER ZEOLITES.

The exchange which takes place may be represented by the following formulæ which show the reaction, P representing the zeolite or 'Permutit.'

For the softening of temporary hardness :—

$$P - Na_2 + CaH_2(CO_3)_2 = P - Ca + 2NaHCO_3$$
$$P - Na_2 + MgH_2(CO_3)_2 = P - Mg + 2NaHCO_3$$

For the softening of permanent hardness :—

$$P - Na_2 + CaSO_4 = P - Ca + Na_2SO_4$$
$$P - Na_2 + MgSO_4 = P - Mg + Na_2SO_4$$

The reaction continues for so long as any of the base originally existing in the active Permutit remains, after which all action ceases, and the active base has to be restored to its original state by a treatment with a sodium salt.

Thus by a process of exchange to and fro, which is effected without any wastage in the zeolite itself, a softening action is secured, which is continuous and capable of thoroughly and completely removing all hardness in any water supply. The method of softening water by this treatment of filtering through zeolite affords the only means for complete elimination of both temporary and permanent hardness at one and the same time, a water of zero degrees of hardness resulting for so long as the designed capacity of the plant is not exceeded.

By adoption of zeolytic filtration, it has become possible to entirely remove from a water supply all traces of iron in the water, thereby eliminating to a great degree the high corrosive property possessed by certain supplies.

Softening Water.

Dr. Clark's process softens water rendered hard by calcium bi-carbonate. It consists in mixing with it about one-tenth (for spring water from chalk) of water saturated with lime in solution, the lime in which, combining with the free carbonic acid of the bi-carbonate, forms a solid precipitate of chalk. It will soften Thames and New River water down to $3\frac{1}{2}°$, or lower than if boiled for an hour; but it can rarely bring any water below $2\frac{1}{2}°$ of hardness, what is left being termed permanent hardness. Prolonged boiling will drive off the free carbonic acid from the bi-carbonate, precipitating the carbonate. According to Clark's scale, $\frac{1}{4}$ oz. of soap will remove 1° of hardness from 10 gallons of water.

TABLE SHOWING VELOCITY IN FEET PER SECOND, AND SUPPLY IN GALLONS PER MINUTE, FOR LONG PIPES FLOWING FULL.

(See note, page 1487.)

Diameter of Pipe in Inches.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Diameter of Pipe in Inches.
	Head of Water divided by Length of Pipe.										
	$\frac{1}{1000}$		$\frac{2}{1000}$		$\frac{3}{1000}$		$\frac{4}{1000}$		$\frac{5}{1000}$		
[illegible]	·173	·05	·278	·08	·363	·10	·436	·13	·502	·14	[illegible]
[illegible]	·212	·11	·336	·17	·436	·22	·522	·27	·600	·31	[illegible]
[illegible]	·278	·32	·436	·50	·562	·64	·670	·77	·770	·88	[illegible]
1	·336	·69	·522	1·07	·670	1·37	·798	1·63	·911	1·86	1
1¼	·388	1·24	·600	1·91	·770	2·45	·911	2·90	1·04	3·31	1¼
1½	·436	2·00	·670	3·08	·856	3·93	1·02	4·67	1·16	5·44	1½
1¾	·481	3·00	·736	4·60	·938	5·86	1·11	6·94	1·27	7·91	1¾
2	·522	4·26	·798	6·51	1·02	8·29	1·20	9·81	1·37	11·17	2
2½	·600	7·64	·911	11·62	1·16	14·76	1·37	17·45	1·56	19·85	2½
3	·670	12·30	1·02	18·66	1·29	23·64	1·52	27·92	1·73	31·73	3
4	·798	26·03	1·20	39·23	1·52	49·63	1·79	58·53	2·04	66·46	4
5	·911	46·48	1·37	69·79	1·73	88·14	2·04	103·84	2·31	117·80	5
6	1·02	74·64	1·52	111·66	1·92	140·83	2·26	165·77	2·56	187·95	6
7	1·11	111·09	1·66	166·07	2·09	209·22	2·46	246·10	2·79	278·90	7
8	1·20	156·92	1·79	234·11	2·26	294·70	2·65	346·45	3·01	392·46	8
9	1·29	212·71	1·92	316·87	2·41	398·58	2·83	468·35	3·21	530·36	9
10	1·37	279·16	2·04	415·34	2·56	522·08	3·01	613·22	3·40	694·24	10
11	1·45	356·95	2·15	530·42	2·70	666·39	3·17	782·42	3·59	885·56	11
12	1·52	446·66	2·26	663·07	2·83	832·63	3·33	977·29	3·76	1105·8	12
15	1·73	793·27	2·56	1174·7	3·21	1473·2	3·76	1727·8	4·26	1956·7	15
18	1·92	1267·5	2·83	1873·4	3·55	2347·2	4·16	2751·4	4·71	3110·0	18
24	2·26	2652·2	3·33	3909·2	4·16	4891·4	4·88	5727·8	5·51	6470·3	24
30	2·56	4698·8	3·76	6911·3	4·71	8638·9	5·51	10109·7	6·22	11415·0	30

	Head of Water divided by Length of Pipe.										
	$\frac{6}{1000}$		$\frac{7}{1000}$		$\frac{8}{1000}$		$\frac{9}{1000}$		$\frac{1}{100}$		
[illegible]	·562	·16	·618	·18	·670	·19	·720	·21	·770	·22	[illegible]
[illegible]	·670	·34	·736	·38	·798	·41	·856	·44	·911	·46	[illegible]
[illegible]	·856	·98	·938	1·08	1·02	1·17	1·09	1·24	1·16	1·33	[illegible]
1	1·02	2·08	1·11	2·27	1·20	2·45	1·29	2·63	1·37	2·79	1
1¼	1·16	3·69	1·27	4·04	1·37	4·36	1·47	4·67	1·56	4·96	1¼
1½	1·29	5·91	1·41	6·46	1·52	6·98	1·63	7·47	1·73	7·93	1½
1¾	1·41	8·79	1·55	9·68	1·66	10·38	1·78	11·10	1·89	11·79	1¾
2	1·52	12·41	1·66	13·56	1·79	14·63	1·92	15·65	2·04	16·61	2
2½	1·73	22·04	1·82	23·30	2·04	25·96	2·18	27·75	2·31	29·45	2½
3	1·92	35·21	2·09	38·43	2·26	41·44	2·41	44·29	2·56	46·99	3
4	2·26	73·68	2·46	80·36	2·65	86·61	2·83	92·51	3·01	98·60	4
5	2·56	130·52	2·79	142·30	3·01	153·31	3·21	163·69	3·40	173·70	5
6	2·83	208·16	3·09	226·84	3·33	244·32	3·55	260·81	3·76	277·10	6
7	3·09	308·76	3·37	335·60	3·62	362·21	3·87	386·57	4·09	408·45	7
8	3·33	434·35	3·62	473·09	3·90	509·38	4·16	543·49	4·41	575·83	8
9	3·55	586·82	3·87	639·02	4·16	687·85	4·44	733·83	4·71	777·50	9
10	3·76	767·92	4·09	833·58	4·41	899·75	4·71	959·88	4·99	1016·9	10
11	3·97	970·39	4·32	1066·1	4·65	1147·2	4·96	1223·7	5·26	1298·4	11
12	4·16	1222·9	4·53	1331·3	4·88	1432·0	5·18	1522·7	5·51	1617·6	12
15	4·71	2159·7	5·12	2349·8	5·51	2527·4	5·87	2694·9	6·22	2853·8	15
18	5·18	3426·1	5·65	3737·0	6·08	4019·3	6·48	4284·7	6·86	4536·5	18
24	6·08	7145·4	6·61	7769·1	7·11	8351·6	7·58	8900·4	8·02	9421·1	24
30	6·86	12601·3	7·50	13772·4	8·02	14720·4	8·54	15684·5	9·04	16599·0	30

TABLE SHOWING VELOCITY IN FEET PER SECOND, AND SUPPLY IN GALLONS PER MINUTE, FOR LONG PIPES FLOWING FULL (*continued*).

Diameter of Pipe in Inches.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Diameter of Pipe in Inches.
	Head of Water divided by Length of Pipe.										
	$\frac{2}{100}$		$\frac{3}{100}$		$\frac{4}{100}$		$\frac{5}{100}$		$\frac{6}{100}$		
½	1·16	·33	1·47	·42	1·73	·50	1·96	·56	2·18	·62	½
¾	1·37	·70	1·73	·88	2·04	1·04	2·31	1·18	2·56	1·31	¾
1	1·73	1·98	2·18	2·50	2·56	2·94	2·90	3·33	3·21	3·68	1
1¼	2·04	4·15	2·56	5·22	3·01	6·13	3·40	6·94	3·76	7·68	1¼
1½	2·31	7·36	2·90	9·24	3·40	10·85	3·85	12·27	4·26	13·59	1½
1¾	2·56	11·75	3·21	14·73	3·76	17·28	4·26	19·57	4·71	21·60	1¾
2	2·79	17·43	3·50	21·84	4·09	25·53	4·63	28·95	5·12	31·98	2
2½	3·01	24·53	3·76	30·72	4·41	35·99	4·99	40·67	5·51	44·93	2½
3	3·40	43·39	4·26	54·35	4·99	63·55	5·63	71·79	6·22	79·27	3
4	3·76	69·11	4·71	86·39	5·51	101·10	6·22	114·15	6·86	126·01	4
5	4·41	144·20	5·51	179·73	6·44	210·17	7·27	237·17	8·02	261·70	5
6	4·99	254·50	6·22	317·08	7·27	370·57	8·20	418·02	9·04	461·08	6
7	5·51	404·30	6·86	504·05	8·02	588·82	9·04	663·96	9·97	732·18	7
8	5·99	598·62	7·50	749·83	8·71	870·78	9·82	981·68	10·83	1082·4	8
9	6·44	840·68	8·02	1046·8	9·36	1222·0	10·55	1377·3	11·63	1518·3	9
10	6·86	1134·1	8·54	1411·6	9·97	1647·4	11·24	1856·4	12·38	2046·2	10
11	7·27	1482·3	9·04	1844·3	10·55	2152·0	11·89	2424·5	13·10	2665·9	11
12	7·65	1888·3	9·52	2348·8	11·10	2740·1	12·49	3082·9	13·78	3401·4	12
15	8·02	2355·3	9·97	2928·7	11·63	3416·1	13·10	3838·9	14·43	4239·6	15
18	9·04	4149·7	11·24	5157·0	13·10	5998·2	14·75	6769·5	16·25	7457·0	18
24	10·07	6653·8	12·38	8184·8	14·43	9539·1	16·25	10738·1	17·89	11826·3	24
30	11·63	13664·4	14·43	16958·3	16·81	19754·1	18·92	22228·8	20·83	24474·3	30
	Head of Water divided by Length of Pipe.										
	$\frac{7}{100}$		$\frac{8}{100}$		$\frac{9}{100}$		$\frac{1}{10}$		$\frac{2}{10}$		
½	2·37	·68	2·56	·73	2·74	·79	2·90	·83	4·26	1·22	½
¾	2·79	1·42	3·01	1·53	3·21	1·64	3·40	1·36	4·99	2·54	¾
1	3·50	4·01	3·76	4·32	4·01	4·60	4·26	4·89	6 22	7·13	1
1¼	4·09	8·34	4·41	9·00	4·71	9·60	4·99	10·17	7·27	14·82	1¼
1½	4·63	14·77	4·99	15·89	5·32	16·94	5·63	17·95	8·20	26·13	1½
1¾	5·12	23·50	5·51	25 27	5·87	26·95	6·22	28·54	9·04	41·50	1¾
2	5·57	34·79	5·99	37·41	6·38	39·89	6·76	42·23	9·82	61·35	2
2½	5·99	48·87	6·44	52·54	6·86	56·01	7·27	59·29	10·55	86·08	2½
3	6·76	86·18	7·27	92·64	7·74	98·73	8·20	104·50	11·89	151·53	3
4	7·50	137·72	8·02	147·20	8·54	156·85	9·04	165·99	13·10	239·93	4
5	8·71	284·34	9·36	305·50	9·97	325·41	10·55	344·32	15·26	498·17	5
6	9·82	500·86	10·55	537·99	11·24	572·99	11·89	606·13	17·18	876·11	6
7	10·83	795·20	11·63	854·02	12·38	909·42	13 10	959·72	18·92	1389·3	7
8	11·76	1175·3	12·63	1262·1	13·41	1343·7	14·22	1421·2	20·52	2051·3	8
9	12·63	1648·4	13·56	1765·8	14·43	1884·3	15·26	1992·7	22·02	2874·7	9
10	13·44	2221·3	14·43	2384·8	15·36	2538·6	16·25	2684·5	23·43	3871·0	10
11	14·22	2900·4	15·26	3113·5	16·25	3314·2	17·18	3514·5	24·76	5051·3	11
12	14·96	3691·7	16·06	3962·7	17·09	4217·9	18·07	4459·7	26·04	6425·9	12
15	15·66	4601·1	16·81	4938·6	17·89	5256·2	18·92	5557·2	27·25	8004·7	15
18	17·63	8091·3	18·92	8683·1	20·13	9240·3	21·28	9768·3	30·63	14059·7	18
24	19·41	12830·1	20·83	13766·8	22·16	14648·5	23·42	15484·0	33·70	22273·1	24
30	22·59	26545·4	24·24	28477·6	25·79	30296·3	27·25	32018·8	39·17	46016·9	30
36	25·41	46642·4	27·25	50029·4	28·99	53218·5	30·63	56238·9	44·0	80770·7	36

TABLE SHOWING VELOCITY IN FEET PER SECOND, AND SUPPLY IN GALLONS PER MINUTE, FOR LONG PIPES FLOWING FULL (*continued*).

Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Velocity in Feet per Second.	Supply in Gallons per Minute.	Diameter of Pipe in Inches.
Head of Water divided by Length of Pipe.										
$\frac{5}{10}$		$\frac{6}{10}$		$\frac{7}{10}$		$\frac{8}{10}$		$\frac{9}{10}$		
5·32	1·52	6·22	1·78	7·02	2·01	7·74	2·22	8·42	2·41	$\frac{3}{4}$
6·22	3·17	7·27	3·71	8·20	4·18	9·04	4·61	9·82	5·01	1
7·74	8·89	9·04	10·37	10·19	11·69	11·24	12·89	12·20	14·00	$1\frac{1}{4}$
9·04	18·44	10·55	21·52	11·89	24·25	13·10	26·66	14·22	29·00	$1\frac{1}{2}$
10·19	32·48	11·89	37·88	13·39	42·67	14·75	47·01	16·01	51·02	2
11·24	51·57	13·10	59·98	14·75	67·70	16·25	74·57	17·63	80·91	$2\frac{1}{2}$
12·20	76·21	14·22	88·82	16·01	99·99	17·63	110·14	19·13	119·48	3
13·10	106·64	15·26	124·54	17·18	140·18	18·92	154·37	20·52	167·45	4
14·75	188·42	17·18	219·03	19·33	246·46	21·28	271·34	23·08	294·29	5
16·25	298·28	18·92	347·32	21·28	390·73	23·43	430·11	25·41	466·42	6
18·92	617·47	22·02	718·66	24·76	808·21	25·25	824·14	29·55	964·31	8
21·28	1085·4	24·76	1262·8	27·84	1419·8	30·63	1561·7	33·21	1692·6	10
23·43	1720·4	27·25	2001·2	30·63	2248·9	33·70	2474·8	36·53	2682·4	12
25·41	2539·4	29·55	2953·2	33·21	3319·2	36·53	3651·1	39·59	3957·0	14
27·25	3557·6	31·67	4134·9	35·60	4647·9	39·17	5113·0	42·44	5540·9	15
28·99	4789·7	33·70	5568·3	37·87	6256·8	41·65	6881·1	45·13	7456·4	16
30·63	6246·9	35·60	7262·3	40·01	8161·0	44·00	8974·3	47·67	9724·4	18
32·20	7947·9	37·41	9234·4	42·00	10365·4	46·24	11411·6	50·10	12364·4	20
33·70	9892·2	39·17	11504·2	44·00	12923·0	48·38	14209·8	52·40	15391·1	22
37·87	17380·0	44·00	20192·7	49·42	22679·2	54·33	24932·9	58·85	27009·8	27
41·65	27524·2	48·38	31972·0	54·33	35903·4	59·72	39465·9	64·52	42641·5	30
48·38	56839·1	56·18	66005·2	63·07	74102·4	69·32	81442·6	75·07	88204·4	36
54·33	99731·6	63·07	115785·0	70·80	129971·0	77·80	142825·0	84·25	154688·	42
Head of Water divided by Length of Pipe.										
$\frac{5}{10}$		$\frac{9}{10}$		$\frac{1}{1}$						
9·04	2·59	9·63	2·76	10·19	2·92					$\frac{3}{4}$
10·55	5·38	11·24	5·73	11·89	6·06					1
13·10	15·00	13·93	15·98	14·75	16·92					$1\frac{1}{4}$
15·26	31·14	16·25	33·14	17·18	35·04					$1\frac{1}{2}$
17·18	54·76	18·28	58·28	19·33	61·61					2
18·92	86·83	20·13	92·40	21·28	97·68					$2\frac{1}{2}$
20·52	128·21	21·84	136·42	23·08	144·20					3
22·02	179·67	23·43	191·16	24·76	202·05					4
24·76	315·71	26·34	335·86	27·84	354·95					5
27·25	500·29	28·99	532·18	30·63	562·22					6
31·67	1033·7	33·70	1099·9	35·60	1162·0					7
35·60	1815·6	37·87	1931·1	40·01	2040·2					8
39·17	2876·1	41·65	3058·2	44·00	3230·8					9
42·44	4242·3	45·13	4510·7	47·67	4764·9					10
45·50	5940·0	48·38	6315·4	51·10	6671·1					11
48·38	7993·0	51·44	8499·2	54·33	8975·8					12
51·10	10423·5	54·33	11081·3	57·38	11704·2					14
53·70	13252·8	57·08	14088·5	60·29	14880·0					15
56·18	16501·3	59·72	17540·4	63·07	18525·6					16
63·07	28946·2	67·04	30767·7	70·80	32492·7					18
69·32	45811·5	73·67	48690·4	77·80	51416·9					20
80·44	94508·9	85·49	100438·1	90·26	106052·8					24
90·26	165708·0	95·92	176090·0	101·26	185902·0					30

Note.

The values in the foregoing table are calculated from the formula

$$V = 140\sqrt{rs} - 11\sqrt[3]{rs};$$

where V = velocity in feet per second, r = *hydraulic mean depth* (= area of wet cross section divided by wet perimeter = for full pipes, $\frac{1}{4}$ diameter) in feet, s = sine of inclination, or total fall divided by total length.

For pipes of greater diameter than above divide the proposed diameter by 4, then twice the velocity opposite to the quotient in the table will be the velocity required, or the corresponding supply multiplied by 32 will be the approximate supply in gallons per minute.

Velocity in Feet per Sec. = $8{\cdot}025\sqrt{H}$ ($8{\cdot}025 = \sqrt{2g}$)	Head in Feet (H)	Lbs. Press. per sq. in.	Diameter of Bore in Inches and Area of Bore in Feet.													
			½ in. ·00136	¾ ·00306	1 ·00545	1¼ ·0085	1½ ·01227	2 ·02182	2½ ·03408	3 ·04909	3½ ·0668	4 ·0872	5 ·1363	6 ·1963	7 ·2672	8 ·349
			THEORETICAL DISCHARGE (Area in feet × Velocity = Cubic feet per Sec.-× 6·227													
8·025	1	·4335	·0681	·1529	·2719	·4247	·6131	1·090	1·703	2·453	3·338	4·357	6·811	9·809	13·35	17·44
11·35	2	·8670	·0963	·2162	·3851	·6007	·8669	1·542	2·408	3·469	4·721	6·163	9·632	13·87	18·88	24·67
13·90	3	1·300	·1180	·2648	·4717	·7356	1·062	1·888	2·950	4·248	5·782	7·537	11·80	16·99	23·13	30·22
16·05	4	1·734	·1362	·3058	·5438	·8494	1·226	2·180	3·405	4·906	6·675	8·714	13·62	19·62	26·70	34·89
17·95	5	2·170	·1523	·3419	·6090	·9498	1·371	2·438	3·808	5·485	7·464	9·744	15·23	21·94	29·86	39·01
19·66	6	2·601	·1668	·3745	·6671	1·040	1·502	2·670	4·171	6·008	8·176	10·67	16·68	24·03	32·71	42·73
21·23	7	3·034	·1802	·4046	·7205	1·124	1·622	2·884	4·506	6·490	8·832	11·53	18·02	25·95	35·33	46·16
22·70	8	3·468	·1926	·4324	·7703	1·201	1·733	3·084	4·817	6·938	9·442	12·33	19·27	27·75	37·77	49·34
24·08	9	3·901	·2043	·4587	·8157	1·274	1·839	3·270	5·107	7·359	10·01	13·07	20·43	29·43	40·06	52·33
25·38	10	4·335	·2154	·4835	·8612	1·343	1·939	3·447	5·385	7·759	10·55	13·78	21·54	31·02	42·22	55·17
26·62	11	4·768	·2258	·5080	·9030	1·411	2·035	3·619	5·651	8·134	11·09	14·48	22·58	32·57	44·32	57·90
27·80	12	5·200	·2359	·5297	·9484	1·471	2·124	3·773	5·900	8·498	11·56	15·10	23·59	33·98	46·25	60·43
28·93	13	5·635	·2458	·5523	·9819	1·534	2·213	3·935	6·148	8·845	12·06	15·74	24·58	35·41	48·19	62·96
30·03	14	6·069	·2548	·5723	1·017	1·591	2·294	4·077	6·366	9·171	12·49	16·32	25·48	36·70	49·93	65·24
31·08	15	6·502	·2638	·5922	1·055	1·645	2·375	4·219	6·580	9·484	12·93	16·88	26·38	37·93	51·68	67·55
32·10	16	6·936	·2724	·6116	1·088	1·699	2·452	4·360	6·810	9·812	13·35	17·43	27·24	39·24	53·41	69·78
33·09	17	7·369	·2804	·6306	1·122	1·752	2·528	4·491	7·014	10·12	13·78	17·96	28·08	40·45	55·01	71·87
34·05	18	7·813	·2884	·6488	1·153	1·803	2·600	4·622	7·209	10·40	14·16	18·49	28·89	41·56	56·60	73·96
34·98	19	8·236	·2969	·6670	1·186	1·853	2·673	4·796	7·412	10·68	14·56	19·01	29·69	42·77	58·21	76·04
35·89	20	8·670	·3046	·6838	1·218	1·900	2·742	4·876	7·616	10·97	14·93	19·49	30·46	43·87	59·72	78·02
36·75	21	9·102	·3115	·7008	1·246	1·947	2·808	4·992	7·787	11·24	15·30	19·98	31·20	44·95	61·14	79·88
37·64	22	9·537	·3189	·7176	1·276	1·993	2·875	5·112	7·982	11·50	15·66	20·45	31·94	46·01	62·61	81·79
38·52	23	9·970	·3264	·7344	1·306	2·040	2·942	5·232	8·169	11·77	16·03	20·93	32·69	47·09	63·86	83·71
39·31	24	10·40	·3336	·7490	1·334	2·080	3·003	5·340	8·343	12·02	16·35	21·35	33·37	48·06	65·41	85·46
40·13	25	10·84	·3405	·7645	1·360	2·124	3·065	5·451	8·512	12·26	16·69	21·79	34·06	49·05	66·76	87·22
43·95	30	13·01	·3732	·8384	1·491	2·329	3·359	5·973	9·327	13·44	18·30	23·89	37·32	53·76	73·15	95·57
46·76	34	14·74	·3964	·8919	1·586	2·478	3·574	6·355	9·911	14·30	19·47	25·42	39·71	57·19	77·88	101·7
47·48	35	15·17	·4026	·9058	1·610	2·516	3·629	6·453	10·06	14·52	19·77	25·81	40·32	58·08	79·03	103·2
50·76	40	17·34	·4307	·9671	1·722	2·686	3·878	6·895	10·77	15·52	21·11	27·56	43·07	62·04	84·45	110·3
53·83	45	19·51	·4556	1·025	1·822	2·847	4·107	7·303	11·40	16·43	22·38	29·21	45·63	65·73	89·80	116·9
56·75	50	21·68	·4828	1·086	1·931	3·018	4·353	7·739	12·09	17·42	23·71	30·96	48·35	69·65	94·79	123·9
59·52	55	23·84	·5046	1·135	2·018	3·153	4·548	8·088	12·64	18·20	24·78	32·35	50·53	72·79	99·06	129·4
62·16	60	26·01	·5276	1·184	2·110	3·290	4·750	8·443	13·16	19·01	25·86	33·75	52·76	75·87	108·4	135·1
67·14	70	30·35	·5692	1·281	2·277	3·557	5·131	9·123	14·25	20·53	27·96	36·83	57·00	82·11	111·8	146·0
71·78	80	34·68	·6090	1·367	2·436	3·799	5·484	9·751	15·23	21·94	29·86	38·98	60·92	87·74	119·4	156·0
76·13	90	39·02	·6461	1·451	2·584	4·029	5·817	10·34	16·16	23·28	31·66	41·34	64·61	93·06	126·7	165·5
80·25	100	43·35	·6810	1·529	2·719	4·247	6·131	10·90	17·03	24·53	33·38	43·57	68·11	98·09	133·5	174·4
113·5	200	86·70	·9632	2·162	3·852	6·007	8·671	15·42	24·08	34·69	47·21	61·63	96·32	138·7	188·8	246·7
139·0	300	130·1	1·180	2·648	4·717	7·357	10·620	18·88	29·50	42·49	57·82	75·47	118·0	169·9	231·3	302·2
160·5	400	173·4	1·362	3·058	5·438	8·494	12·260	21·80	34·05	49·06	66·76	87·14	136·2	196·2	267·0	348·9
179·5	500	216·8	1·523	3·419	6·090	9·498	13·710	24·38	38·08	54·85	74·64	97·44	152·3	219·4	298·6	390·1
196·6	600	260·1	1·668	3·745	6·671	10·40	15·020	26·70	41·71	60·08	81·76	106·7	166·8	240·3	327·1	427·3
212·3	700	303·5	2·802	4·046	7·205	11·24	16·220	28·84	45·06	64·90	88·32	115·3	180·2	259·5	353·3	461·6
227·0	800	346·8	1·926	4·324	7·703	12·01	17·340	30·84	48·17	69·33	94·42	123·3	192·7	277·5	377·7	493·4
240·8	900	390·2	2·043	4·587	8·157	12·74	18·390	32·70	51·07	73·59	100·1	130·7	204·3	294·3	400·6	523·3
253·8	1000	433·5	2·154	4·835	8·612	13·43	19·390	34·47	53·85	77·59	105·6	137·8	215·4	310·2	422·2	551·7

For intermediate heads, multiply $\sqrt{H}$ by gals. per sec. for 1 ft. head corresponding to pipe of 95 ft. Gals. per sec. = $\sqrt{95} \times 2{\cdot}453$ (gals. per sec. for 3 in. pipe

Diameter of Bore in Inches and Area of Bore in Feet.

9 ·4418	10 ·5454	11 ·6599	12 ·7854	13 ·922	14 1·069	15 1·227	16 1·396	18 1·767	20 2·18	22 2·64	24 3·142	30 4·909	36 7·068	42 9·621	48 12·57	Head in Feet (H).
IN GALLONS PER SECOND.																
galls. in a cu. ft.) = Galls. per second as below.																
22·08	27·25	32·98	39·25	46·07	53·42	61·3	69·8	88·3	109·0	131·9	157·0	245·3	353·2	480·8	627·9	1
31·22	38·54	46·64	55·51	65·16	75·55	86·7	98·7	124·9	154·2	186·6	222·0	346·9	499·5	679·9	888·1	2
38·24	47·21	57·12	67·98	79·80	92·59	106·2	120·8	153·0	188·8	228·5	271·9	424·9	611·8	832·7	1087·6	3
44·15	54·51	65·95	78·49	92·14	106·9	122·6	139·5	176·6	218·0	263·8	314·0	490·6	716·4	961·5	1255·8	4
49·37	60·95	73·74	87·76	103·0	119·5	137·1	156·0	197·5	243·8	295·0	351·1	548·5	789·8	1075·1	1404·2	5
54·08	66·76	80·77	96·14	113·9	131·9	150·2	170·9	216·3	267·0	323·2	384·5	600·8	865·2	1177·6	1538·1	6
58·41	72·11	87·25	103·8	121·9	141·8	162·2	184·6	233·7	288·5	349·0	415·4	649·0	934·5	1272·0	1661·4	7
62·44	77·09	93·27	111·11	130·3	151·1	173·3	197·3	249·8	308·4	373·1	444·0	693·8	999·0	1359·8	1776·1	8
66·23	81·76	98·92	117·7	138·2	160·3	183·9	209·3	264·9	327·0	395·8	470·9	735·9	1059·6	1442·3	1883·8	9
69·81	86·19	104·3	124·1	145·7	168·9	193·9	220·6	279·2	344·7	417·2	496·4	775·9	1116·9	1520·3	1986·0	10
73·37	90·47	109·6	130·3	153·1	177·4	203·6	231·7	293·2	361·9	438·0	521·2	814·4	1172·6	1596·3	2085·0	11
76·48	94·41	114·2	136·0	159·6	185·1	212·4	241·7	305·9	377·6	457·0	543·8	849·7	1223·5	1665·4	2175·2	12
79·78	62·27	119·1	141·7	166·4	192·9	221·3	252·0	318·8	393·5	476·2	566·8	885·5	1275·1	1735·7	2267·0	18
82·65	101·9	123·4	146·8	172·5	199·9	229·4	261·2	330·4	407·7	493·4	587·2	917·5	1321·1	1799·3	2349·4	14
85·51	105·5	127·7	151·9	178·4	206·9	237·5	270·2	342·0	422·1	511·0	607·9	950·0	1368·0	1862·1	2432·0	15
88·31	109·0	131·9	157·0	184·3	213·7	245·3	279·0	353·2	436·1	527·7	627·9	981·2	1412·8	1923·0	2511·7	16
91·16	112·4	136·0	161·8	190·1	220·3	252·8	87·6	364·0	449·1	543·5	647·0	1011·7	1456·4	1982·1	2589·1	17
93·70	115·6	139·9	166·4	195·6	226·6	260·1	295·9	374·5	462·2	559·3	665·8	1040·2	1497·6	2039·7	2663·3	18
96·36	118·8	143·8	171·1	201·0	232·9	267·3	304·2	385·0	475·2	575·5	684·5	1068·2	1539·9	2096·3	2737·6	19
98·74	121·9	147·5	175·5	206·1	238·9	274·2	312·0	394·9	487·6	590·0	702·1	1097·0	1579·6	2150·1	2808·3	20
101·2	124·8	151·1	179·8	211·2	244·7	280·9	319·6	404·5	499·2	604·1	719·2	1123·5	1617·7	2203·1	2876·8	21
103·7	127·8	154·7	184·1	216·2	250·5	287·5	327·2	414·1	511·2	618·7	736·3	1150·4	1656·5	2254·9	2944·8	22
106·1	131·0	158·4	188·2	221·3	256·4	294·3	334·9	423·8	523·2	633·2	753·6	1177·3	1695·3	2307·6	3014·0	23
108·2	133·5	161·6	192·3	227·7	263·7	300·4	341·8	432·6	534·1	646·3	769·1	1201·6	1730·3	2355·3	3076·2	24
110·4	136·3	169·9	196·2	230·4	267·1	306·6	348·8	441·5	545·1	659·6	784·9	1226·4	1766·0	2403·8	3140·0	25
121·1	149·3	180·1	215·0	252·6	292·7	336·0	382·5	483·9	597·8	723·3	860·3	1344·0	1935·5	2634·8	3441·0	30
128·8	158·9	192·4	228·8	268·8	311·4	357·4	406·9	514·8	635·5	769·6	915·8	1430·1	2059·2	2803·1	3660·8	34
130·8	161·3	195·4	232·4	272·9	316·2	363·0	413·2	522·7	645·3	781·4	929·4	1452·2	2090·9	2847·5	3717·2	35
139·6	172·4	208·6	248·2	291·4	337·8	387·8	441·2	558·4	689·3	834·4	992·7	1551·8	2233·8	3040·7	3971·4	40
148·1	182·9	221·1	263·0	308·9	357·9	410·8	467·7	591·6	730·3	884·4	1052·0	1643·0	2366·4	3221·4	4407·6	45
156·9	193·5	234·3	278·7	327·3	379·3	435·3	495·6	626·9	773·9	937·2	1114·7	1742·0	2507·7	3413·7	4458·2	50
164·0	202·6	244·9	291·2	342·1	396·4	454·9	517·9	655·2	808·8	979·4	1165·0	1820·0	2620·7	3567·5	4660·0	55
171·0	210·9	255·5	303·9	356·9	413·8	474·9	540·4	684·0	844·2	1021·9	1215·8	1901·1	2735·9	3724·1	4864·1	60
185·0	228·1	276·1	328·5	385·9	447·1	513·2	584·2	739·1	912·3	1104·8	1314·1	2053·0	2956·3	4024·3	5255·7	70
197·5	243·8	296·0	351·1	412·1	477·8	548·4	624·0	789·8	975·1	1180·0	1404·2	2194·0	3159·2	4300·3	5616·6	80
209·4	258·6	312·9	372·3	437·1	506·8	581·7	661·8	837·7	1033·9	1251·5	1489·0	2327·7	3350·7	4561·0	5957·1	90
220·8	272·5	329·8	392·5	460·7	534·2	613·1	697·6	883·0	1090·1	1319·2	1569·8	2452·9	3531·9	4807·6	6279·2	100
312·2	385·4	466·4	555·1	651·6	755·5	867·1	986·6	1248·8	1542·0	1865·7	2220·2	3469·0	4995·0	6799·2	8880·5	200
382·4	472·1	571·2	679·8	798·0	925·2	1062·0	1208·3	1529·4	1888·2	2085·0	2719·1	4248·6	6117·5	8327·2	10876·0	300
441·5	545·1	659·5	784·9	921·4	1068·4	1226·3	1395·2	1765·9	2180·3	2638·4	3139·6	4905·8	7063·7	9616·2	12558·0	400
493·7	609·5	737·4	877·6	1030·3	1194·5	1371·1	1559·9	1974·5	2437·8	2950·0	3510·5	5485·0	7898·0	10751·0	14042·0	500
540·8	667·6	807·7	961·4	1138·6	1318·5	1501·9	1708·8	2162·9	2670·4	3231·5	3845·4	6008·8	8651·5	11777·0	15381·0	600
584·1	721·1	872·5	1038·4	1219·0	1413·3	1622·2	1845·7	2336·2	2884·8	3490·4	4154·1	6490·0	9344·7	12720·0	16614·0	700
624·4	770·9	932·7	1111·1	1303·2	1510·9	1734·2	1973·1	2497·5	3084·0	3731·4	4440·4	6938·0	9990·0	13598·0	17761·0	800
662·3	817·6	989·2	1177·4	1382·2	1602·5	1839·4	2092·7	2648·9	3270·4	3957·6	4709·4	7358·7	10596·0	14423·0	18838·0	900
698·1	861·9	1042·9	1241·1	1457·0	1689·2	1938·9	2206·0	2792·2	3446·5	4171·8	4963·5	7758·9	11169·0	15203·0	19857·0	1000

required diameter. Example:—Required gals. per sec. passing through a 3-in. pipe, under head and 1 ft. head = 9·746 × 2·453 = 23·906 gals. per sec. (*J. H. Horobin.*)

TABLE GIVING HEAD NECESSARY TO DELIVER A GIVEN NUMBER OF GALLONS OF WATER PER MINUTE THROUGH VARIOUS-SIZED PIPES.

Gallons per Minute.	Diameter of Pipes in Inches.																		
	1	2	3	4	5	6	7	8	9	10	12	14	15	16	18	20	22	24	30
	Factors.																		
15	1·02																		
20	1·64	·051																	
55		·392	·051																
80		·823	·108																
120			·243	·057															
180			·549	·131															
200				·160	·052														
300				·361	·118														
350					·161	·064													
500					·329	·132	·061												
700						·259	·120												
750						·297	·137	·0706											
900							·198	·101											
1,000							·244	·125	·069										
1,150								·180	·100										
1,300								·212	·117	·069									
1,600									·178	·105									
2,000										·164	·066								
2,200										·199	·080								
2,800											·129	·050							
3,000											·141	·0688	·0487						
3,500												·0954	·0677	·0495					
4,000												·122	·0867	·0627					
4,500													·1108	·0804	·0446				
5,000													·135	·0981	·0544				
5,300															0630				
6,500															·0927	·0546			
7,000															·107	·063	·040		
8,500																·094	·060	·0374	
10,000																	·081	0516	
10,600																		·0550	·0194
12,000																		·0744	·0243
14,500																			·0356

To find required head multiply length of pipe in yards by factor in table for given pipe and quantity of water required; the result is the head in feet.

EXAMPLE.—Head in feet required to pass 1,000 gallons of water per minute through 30 yards of pipe. In table under 8, and in line with 1,000, will be found ·125; then ·125 × 30 = 3·75. which is feet head required.

The figures in the table are true for plain, smooth, straight pipes. Additional head must be allowed if pipes are at all of a rough nature or broken in contour internally. For each right-angle bend having a radius of about twice the diameter of pipe, and passing the average quantities given in table, about 1½ ins. of additional head must be allowed. (*T. Box.*)

TABLE SHOWING GALLONS OF WATER PER MINUTE CORRESPONDING TO SPEED OF WATER THROUGH PIPES, IN FEET PER SECOND.

Diameter of Pipe.	Speed of Water through Pipes. Feet per Second.									
	1	5	6	7	8	9	10	11	12	13
Ins.	Gallons per Minute.									
1	2·04	10·2	12·2	14·2	16·3	18·3	20·4	22·4	24·4	26·5
2	8·16	40·8	48·9	57	65·2	73·4	81 6	89·7	97·8	106
3	18·19	94·9	109	127	153	163	181 9	200	218	236
4	32	162	195	227	260	293	324	357	390	421
5	50	250	300	350	400	450	500	550	600	650
6	73	365	440	514	558	661	735	808	882	955
7	100	500	600	700	800	900	1,000	1,100	1,200	1,300
8	130	650	780	910	1,040	1,170	1,300	1,430	1,560	1,690
9	165	825	970	1,155	1,320	1,485	1,650	1,815	1,980	2,145
10	204	1,020	1,224	1,428	1,632	1,836	2,040	2,244	2,448	2,652
12	294	1,472	1,736	2,030	2,325	2,620	2,945	3,210	3,515	3,806
14	400	2,000	2,400	2,800	3,200	3,600	4,000	4,400	4,800	5,200
15	461	2,305	2,766	3,227	3,688	4,149	4,610	5,051	5,532	5,993
16	520	2,600	3,120	3,640	4,160	4,680	5,200	5,720	6,240	6,760
18	662	3,313	3,975	4,638	5,300	5,963	6,626	7,288	7,950	8,613
20	820	4,100	4,920	5,740	6,560	7,380	8,200	9,020	9,840	10,660
22	990	4,950	5,940	6,930	7,920	8,910	9,900	10,890	11.780	11,270
24	1,175	5,875	7,020	8,242	9,420	10,957	11,775	12,952	14,130	15,307
27	1,491	7,455	8,946	10,437	11,928	13,419	14,910	16,401	17,882	19,373
30	1,837	9,187	11,025	12,862	14,700	16,538	18,375	20,212	22,050	23,887
33	2,227	11,137	13,365	15,592	17,820	20,047	22,275	24,502	26,730	28,957
36	2,625	13,125	15,750	18,375	21,000	23,625	26,250	28,875	31,500	34,125
39	3,110	15,550	18,660	21,770	24,880	27,990	31,110	34,210	37,320	40,430
42	3,600	18,000	21,600	25,200	28,800	32,400	36,000	39,600	42,200	46,800
45	4,125	20,625	24,750	28,875	33,000	37,125	41,250	45,375	49,400	53,625
48	4,720	23,600	28,320	33,040	37,760	42,480	47,200	51,920	56,640	61,360
51	5,308	26,540	31,848	37,156	42,464	47,772	53,080	58,388	63,696	69,904
54	5,490	29,700	35,640	41,580	47,520	53,460	59,400	65,340	71,280	77,220
60	7,365	36,825	44,190	51,555	58,920	66,295	73,650	81,015	88,380	95,745

(Gwynnes Pumps, Ltd.)

METROPOLITAN WATER BOARD STANDARD SOCKETS (Table, page 1492).

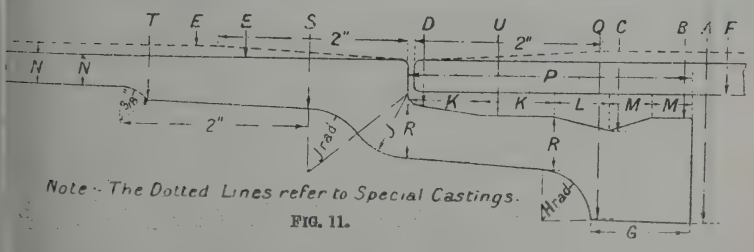

FIG. 11.

The joints of the above standard pipes are made by caulking a ring of lead wire ¼ in. in diameter to the bottom of the socket, then running in molten lead for the remainder of the depth, and afterwards caulking or 'setting up.' Alternatively, lead wool may be caulked in for the whole depth.

METROPOLITAN WATER BOARD.

STANDARD SOCKETS FOR STRAIGHT AND SPECIAL CAST IRON PIPES.

Size of Pipe	A	B	C	D	E*	E†	F	G	H	J	K	L	M	N*	N†	P	Q	R	S	T	U	Length of Pipes over all.		Weight of Pipe and Socket.		Weight of Pipe and Socket, 3 ft. shorter in Length.		Lbs. weight of Lead in each Joint.
	(See page 1491 for reference.)																					Ft. In.	Ft. In.	Cwt. Qrs. Lbs.		Cwt. Qrs. Lbs.		
2	5⅝	3⅛	3 7/16	2⅞	2	2	2⅝	1 3/16	9/16	11/16	¾	⅝	7/16	5/16	5/16	3	5¼	9/16	3	2⅞	3	6 3	—	0 2 0		—		3
3	6⅜	4¼	4 9/16	4	3	2⅞	3⅜	1⅛	⅝	¾	¾	⅝	7/16	⅜	½	3	6⅝	⅝	4⅛	4	4¼	9 3	—	1 0 14		—		4½
4	8⅛	5⅜	5 11/16	5⅛	4	3⅞	4⅞	1 3/16	11/16	13/16	¾	⅝	7/16	9/16	9/16	3	8	11/16	5¼	5⅛	5⅜	9 3	—	1 3 0		—		5½
5	9⅛	6⅜	6 11/16	6⅛	5	4⅞	5⅞	1 3/16	11/16	13/16	¾	⅝	7/16	7/16	9/16	3	9	11/16	6¼	6⅛	6⅜	9 3	—	2 0 14		—		6½
6	10½	7½	7 13/16	7¼	6	5⅞	7	1 1/4	¾	⅞	⅞	⅝	7/16	½	⅝	3¼	10⅜	¾	7⅜	7¼	7½	9 3¼	—	2 3 14		—		8
7	11¼	8½	8 1/2	8½	7	6⅞	8	1½	⅞	⅞	⅞	⅝	7/16	½	⅝	3¼	11⅜	¾	8⅜	8¼	8½	12 3¼	9 3¼	4 1 7		3 1 7		9
8	12⅞	9⅝	9 1/16	9⅜	8	7⅞	9⅛	1 5/16	13/16	15/16	⅞	⅝	7/16	9/16	11/16	3¼	12¾	13/16	9¼	9⅜	9⅝	12 3¼	9 3¼	5 1 21		4 0 21		10
9	13⅞	10⅝	10 1/16	10⅜	9	8⅞	10⅛	1 5/16	13/16	15/16	⅞	⅝	7/16	9/16	11/16	3¼	13¾	13/16	10⅓	10⅜	10⅝	12 3¼	9 3¼	6 0 7		4 2 21		11
10	15¼	11⅜	12 1/16	11⅛	10	9⅞	11¼	1⅜	⅞	1	1	⅝	7/16	⅝	¾	3½	15⅛	⅞	11⅝	11¼	11⅜	12 3½	9 3½	7 2 0		5 3 0		14
12	17⅝	13⅜	14 3/16	13⅜	12	11⅞	13⅜	1 7/16	15/16	1 1/16	1	⅝	7/16	11/16	13/16	3½	17½	15/16	13⅜	13⅜	13⅞	12 3½	9 3½	9 3 7		7 2 0		17
14	20	16	16 5/16	15⅜	14	13⅞	15½	1½	1	1⅛	1	⅝	7/16	¾	⅞	3½	19⅞	1	15⅝	15⅜	16	12 3½	—	12 2 0		—		19½
15	21	17	17 5/16	16⅜	15	14⅞	16½	1⅝	1	1⅛	1	⅝	7/16	¾	⅞	3½	20⅞	1	16⅝	16⅜	17	12 3½	—	13 1 7		—		20½
16	22½	18¼	18 9/16	18	16	15⅞	17⅝	1 9/16	1 1/16	1¼	1⅛	⅝	7/16	13/16	15/16	3¾	22⅜	1 1/16	18	17⅞	18¼	12 3¾	—	15 1 21		—		28
18	24½	20¼	20 9/16	20	18	17⅞	19⅝	1 9/16	1 1/16	1¼	1⅜	⅝	7/16	13/16	15/16	3¾	24⅜	1 1/16	20	19⅞	20¼	12 3¾	—	17 1 0		—		31
20	26⅞	22⅜	22 1/16	22⅛	20	19⅞	21⅞	1⅝	1⅛	1 5/16	1⅛	⅝	7/16	⅞	1	3¾	26¾	1⅛	22⅛	22	22⅜	12 3¾	—	20 2 21		—		34
21	28¼	23½	23 13/16	23¼	21	20⅞	22⅞	1 11/16	1 3/16	1⅜	1¼	⅝	7/16	15/16	1 1/16	4	28⅛	1 3/16	23¼	23⅛	23½	12 4	—	23 1 0		—		39
22	29¼	24½	24 13/16	24¼	22	21⅞	23⅞	1 11/16	1 3/16	1⅜	1¼	⅝	7/16	15/16	1 1/16	4	29⅛	1 3/16	24¼	24⅛	24½	12 4	—	24 1 7		—		40½
24	31⅝	26⅜	26 1/16	26⅜	24	23⅞	26	1⅞	1¼	1 7/16	1¼	⅝	7/16	1	1⅛	4	31½	1¼	26⅜	26⅛	26⅝	12 4	—	28 1 7		—		44
30	38⅜	32⅞	33 3/16	32⅝	30	29⅞	32¼	1⅞	1⅜	1 9/16	1¼	⅝	7/16	1 1/16	1¼	4	38¼	1⅜	32⅝	32½	32⅞	12 4	—	39 2 14		—		54½
33	41¾	36	36 5/16	35⅞	33	32⅞	35⅜	1 1/16	1 7/16	1⅝	1¼	⅝	7/16	1 3/16	1 5/16	4	41⅝	1 7/16	35⅞	35⅝	36	12 4	—	45 3 7		—		60
36	44⅜	39	39 5/16	38⅞	36	35⅞	38⅜	1 1/16	1 7/16	1⅝	1¼	⅝	7/16	1 3/16	1 5/16	4	44⅝	1 7/16	38⅜	38⅝	39	12 4	—	49 3 7		—		65
42	51⅛	45⅛	45 7/16	44⅜	42	41⅞	44⅛	2	1½	1 11/16	1½	⅝	7/16	1½	1⅝	4	51	1	44⅞	44⅜	45⅛	12 4	—	61 0 21		—		75
48	57⅛	51⅛	51 7/16	50⅞	48	47⅞	50½	2	1½	1 11/16	1½	⅝	7/16	1½	1⅝	4	57	1½	50⅝	50¾	51⅛	12 4	—	69 2 7		—		85

WEIGHTS OF LEAD PIPE REQUIRED BY WATER COMPANIES.

Company.	Weights, per Yard, of Lead Pipe.						Minimum Depth of Underground Pipes.	Weight, per Yard, of Warning Pipe.		
	⅜ In.	½ In.	⅝ In.	¾ In.	1 In.	1¼ In.		½ In.	¾ In.	1 In.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.		Lbs.	Lbs.	Lbs.
Metropolitan Water Board	5	6	7½	9	12	16	2 ft. 6 ins.	3	5	7
Colne Valley.	5	7	9	11	16	—	3 ft.	—	—	—
Croydon .	4	5	7	9	12	16	2 ft.	—	—	—
East Surrey .	5	6	8	10	14	—	—	—	—	—
,, when pressure exceeds 300 ft.	6	7	9	11	16	—	—	—	—	—
South Essex.	—	6	7½	9	12	16	1 ft. 6 ins.	—	—	—
Sutton . .	—	6	7½	9	12	16	2 ft. 6 ins.	3	5	7
West Surrey.	4	5½	—	9	14	20	3 ft.	—	—	—

Sizes of Lead Pipe are Internal. 1¼ is the usual Minimum Size for Closet Pipe, and 9 lbs. per Yard Minimum Weight.

Comparative Value of Cast-Iron, Wrought-Iron, and Steel Drain Pipes.

Extra heavy cast-iron soil pipes in a number of buildings in nearly all cases had the cast-iron vents evenly pitted on the inside, but in the house drains and branch wastes the lead-caulked joints had opened up more or less. Black steel vents showed scaling to a considerable depth after only 10 years' use. Galvanising was observed to be less of a protection against corrosion on steel pipes than on wrought-iron pipes. The galvanised coating does not adhere so firmly to the smooth surface of steel pipes as to the comparatively rougher surface of wrought-iron pipes. The galvanising on steel pipes showed signs of disappearing within 10 to 20 years. The investigation furnished ample evidence in favour of genuine wrought-iron pipe as a far more durable material for house drainage purposes than steel pipe.

(*W. P. Gerhard, Proc. of the American Soc. of Mech. Engineers.*)

Stoneware Drain Pipes (p. 1422) have the advantage over all the foregoing, in not corroding at all.

Unbalanced Pressures on Bends, etc.

Where any considerable pressure has to be sustained by pipes of large size the unbalanced pressures on bends, etc., must be resisted, horizontally by strutting or tying, vertically by strutting or anchoring. The unbalanced pressure on any bend may be found thus :—

Unbalanced pressure on back of bend = the sum of the areas of the ellipses shown in the elevation × the pressure per unit of area, or $A \times B \times \cdot7854 \times 2P$ = unbalanced pressure.

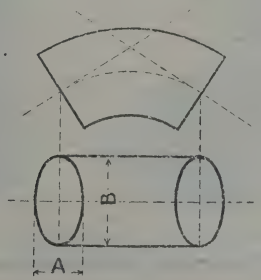

FIG. 12.

WATER TANKS.

Water tanks for house supplies should be covered from the light in order to prevent vegetable growth, but they should be ventilated. A good form of ventilator is an ordinary house sewer air inlet with the mica flaps removed. These should be placed, one or more, according to the size of the tank, at each end of the tank, standing a foot or two above the cover. At one end their openings, which are lateral, should face to, say, the south-west, and at the other end in the opposite direction, so as to set up a flow of air.

The cheapest tanks, to be durable, are excavated partly in the ground, the removed earth being banked against the walls built above ground and rammed at an inward slope so as to afford support against the water pressure. The walls may be of brick or of concrete, rendered internally in good cement mortar. The banks of spoil should be neatly trimmed and sodded or grass sown, and in this way a tank may be almost hidden. Where economy of material is an object, a tank is best circular, since the bank outside can be harder rammed without danger of turning the walls inwards.

These 'tanks' should not be confounded with 'cisterns.'

GUEST & CHRIMES LTD

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Manufacturers of

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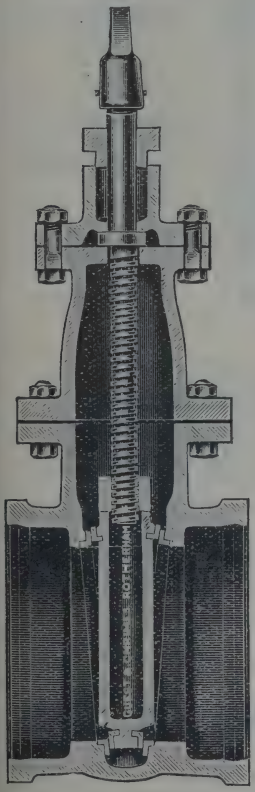
For Water, Steam
Sewage, Gas & Oil.



CHRIMES' HIGH PRESSURE SCREW-DOWN TAPS.

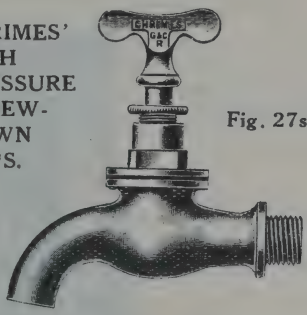
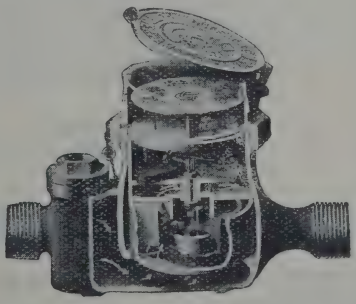


Fig. 27s.

WATER METERS:—

"VENTURI"
"SPIRAL"
"TURBINE"
"CAPSTAN" FAN
and
"PLANET" POSITIVE METERS.
½ in. & upwards.



London Office: **Cecil Chambers, 76 Strand, W.C.2.**

F. 1494

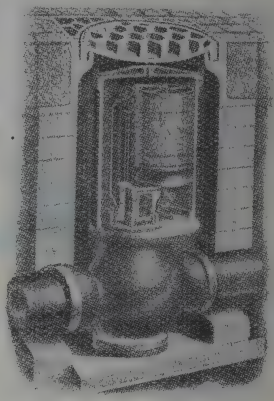
WASTE WATER
DETECTING METERS

(*See Editorial Notice pages 1482, 1483.*)

Venturi Type Meters

Electrical and Mechanical Level Recorders

Recording Meters for Large Mains

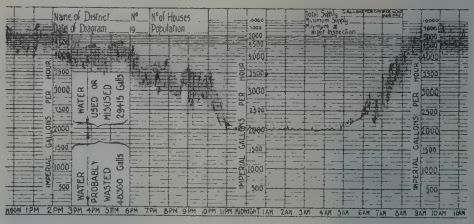


Trade Meters Rotary and Full Bore

Recorders for all types of Weirs

Kelvin Integrating Bulk Meters

Deacon's waste water detecting meters



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SECTION XXVII

METERING AND MECHANICAL TESTING APPLIANCES.

PART I

METERING OF WATER, AIR, GAS, STEAM, AND COAL.

(Contributed by J. L. Hodgson, B.Sc., A.M.Inst.C.E., M.I.Mech.E., A.F. Royal Ae. Soc.)

REVOLUTION INDICATORS.
(pp. 1497–1514)

PART II

MECHANICAL TESTING OF MATERIALS.

(Contributed by W. & T. Avery, Ltd.)

(pp. 1515–1516)

Steam Meters

The increasing use of Steam Meters in industrial boiler plants is the surest indication of their service.

Economies have been effected through the installation of such meters that have surprised the engineers concerned ; but the wonder is that still there are concerns which do not make use of these money-saving instruments.

Specify Kent's Steam Meters and Economise

Literature on Request

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F. 1497

SECTION XXVII

METERING AND MECHANICAL TESTING APPLIANCES.

PART I

METERING OF WATER, AIR, GAS, STEAM, AND COAL.

(Contributed by J. L. Hodgson, B.Sc., A.M.Inst.C.E., M.I.Mech.E.)

The metering of fluids is undertaken to enable running costs to be apportioned, sales to be effected on an equitable basis, to control the mixing of reagents in various chemical processes, or to detect wasteful or inefficient use so that working costs may be reduced and unnecessary additions to plant obviated, etc.

Various efficient and accurate types of water and gas meters have been in use for many years; it is only recently, however, that accurate and reliable air and steam meters have been developed. The first large installation of air meters was made on the Rand in 1911, where now more than 300 million h.p. hours per annum are metered, at an ascertained annual aggregate money saving of 130,000*l.**

The following is a brief summary of the principal classes of fluid and gaseous meters, with notes as to their application, and the names of the leading makers:—

1. Meters Based on Volume or Weight Measurement.

(*a*) Tanks or weighing. [For liquids, condensed steam.]

(*b*) Receivers of known capacity discharging between known pressures and temperatures. [For air and gas.]

(*c*) Piston displacement meters. [For water (Messrs. George Kent, Ltd., Luton; Messrs. Beck & Co. Ltd., Southwark, London; Messrs. Frost, Manchester).]

(*d*) Water-sealed drum meters. [For gas (The Gas Meter Co., London).]

(*e*) Bellows meters. [For gas (The Gas Meter Co. Ltd.).]

2. Meters which Measure the Velocity at a Point or Points in the Cross Section of the Stream.

(*a*) Pitot tube meters. [For water, air and gas (Messrs. George Kent, Ltd.). For air and gas (The Rotary Meter Co. (1905), Ltd.) For steam (The General Electric Co. of Schenectady and the British Thomson Houston Co. of Rugby).]

(*b*) Professor Morris's hot wire velocity indicator. [For air and gas (The Cambridge Instrument Co. Ltd., Cambridge).]

(*c*) Impact meters. [For measuring air velocity in mine tunnels (Messrs. Davis).]

(*d*) Anemometer meters. [For water in open channels (Messrs. George Kent, Ltd.). For air in conduits and passages (Messrs. Davis).]

(*e*) Floats. [For measuring the velocity of water in open channels.]

3. Meters which Depend on the Drop of Pressure due to an Obstruction Placed in the Stream.

(*a*) Weirs. [For liquids in open channels (The Lea Recorder Co. Ltd., 28 Deansgate, Manchester, and Messrs. George Kent, Ltd.).]

(*b*) Venturi tubes. [For water, air, steam and gas (Messrs. George Kent, Ltd.).]

(*c*) Nozzles. [For gas (Messrs. George Kent, Ltd.). For steam (The General Electric Co. of Schenectady, and Messrs. George Kent, Ltd.).]

(*d*) Circular, cord, or tongue orifices. [For water, air, gas and steam (Messrs. George Kent, Ltd.).]

(*e*) Variable orifices. [For water, air, gas and steam (Messrs. George Kent, Ltd.).]

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* See Hodgson, *Proc. Inst. C.E.*, Vol. CCIV, Part 2, and Mavor, *Trans. Inst. Mining Engineers*, Vol. L, Part 4.

ROTARY OR TURBINE METERS.

(*a*) Which measure the whole of the flow passing. [For water (Messrs. Guest & Chrimes Ltd., Rotherham; Messrs. Hayward Tyler, Luton; Messrs. George Kent, Ltd.; the Self Engineering Co., London). For air and gas (The Rotary Meter Co. (1905) Ltd., Victoria Works, Whitefield, Manchester, and Messrs. George Kent, Ltd.).]

(*b*) Which are placed in a shunt circuit. [For air, steam, and gas (Messrs. George Kent, Ltd.).]

5. METERS BASED ON THE MOVEMENT OF A SPRING OR WEIGHT CONTROLLED OBSTRUCTION PLACED IN THE PIPE LINE.

(*a*) In which a disc moves axially in a circular chamber with conical or perforated walls. [For water (The Palatine Engineering Co. Ltd., Bootle, Liverpool). For gas or air (The Rotary Meter Co. (1905) Ltd., Victoria Works, Whitefield, Manchester). For steam (The Drayton Meter Co.).]

(*b*) In which a shaped plug opens up an orifice. [For steam (The St. John Steam Meter Co., New York).]

(*c*) In which a weighted hinged gate is opened by the flow. [For water and air (Messrs. George Kent, Ltd.).]

6. METERS BASED ON THE DROP OF PRESSURE CAUSED BY FRICTIONAL LOSSES IN A LENGTH OF CHANNEL OR PIPE LINE.

[For measuring irrigation water (Messrs. George Kent, Ltd.).]

7. METERS BASED ON THE INTRODUCTION OF A MEASURED AMOUNT OF (*a*) HEAT, OR (*b*) CHEMICAL REAGENT, AND THE CONSEQUENT RISE OF TEMPERATURE OF THE FLUID, OR DILUTION OF THE REAGENT AT SOME POINT FURTHER DOWNSTREAM.

(*a*) The Thomas meter. [For air and gas (Messrs. Humphreys & Glasgow, London).]

(*b*) [A method used for measuring the discharge of rivers and canals, recently further developed for the measurement of air and steam flows. Salt solution is usually introduced when measuring water-discharges, and ammonia or carbon dioxide gas when measuring steam or air flows.]

8. METERS BASED ON INCREASE OF WEIGHT DUE TO CHEMICAL ABSORPTION.

Notes.

Meters of classes 1 (*c*), (*d*) and (*e*) can be made accurate to within plus or minus 1 per cent. from zero flow up to the maximum flow which they are designed to measure. The chief source of error of meters of class 1 (*d*) is variation in the water level, and in meters of classes 1 (*b*) and 1 (*e*) wear of the valves.

Meters of classes 2 (*a*), (*b*) and (*c*) are usually only accurate down to one-third or one-sixth of the maximum flow for which they are designed, as their indication depends upon the square of the velocity of the fluid. Few anemometers are accurate when working at less than one-tenth of their maximum rated capacity.

Meters of classes 3 (*a*), (*b*), (*c*) and (*d*) are usually accurate down to one-fifth or one-tenth of the maximum flow. If specially sensitive differential pressure-measuring devices are provided, such meters may be made accurate down to one-twentieth or one-thirtieth of the maximum flow. By using a variable orifice, the range over which accurate measurement is possible with any given indicator or recorder is greatly extended. These meters have the very real advantage of having in the pipe line no moving parts which can be deranged by dirt or erosion. The Venturi tube, with its smooth contours which eliminate eddying, is a valuable device when measuring dirty gas. Meters of this class show many ingenious arrangements for obtaining an accurate measurement of the differential pressure over a wide range and for compensating for variations in the specific gravities of the fluids or gases to be measured.

Meters of class 4 are not usually accurate in practice below one-tenth of the maximum flow, though many makers claim much higher ranges of accuracy. Endeavours have been made to increase the range of accurate measurement by opening up additional jets at low flows, or by introducing additional resistance at the high flows. While these devices frequently give excellent results under test conditions, they rapidly get out of adjustment under working conditions. Water meters of this class can often carry considerable overloads, thus greatly increasing the range over which accurate measurements may be obtained.

Meters of classes 5 (*a*), (*b*) and (*c*) are capable of high accuracy over a large range of flow when measuring clean fluids. They rapidly lose their accuracy, however, when measuring dirty fluids, owing to the small clearances becoming choked.

The accuracy of meters of class 6 is dependent upon an accurate knowledge of the area of the channel and its resistance coefficient. These are apt to change owing to silting up and the growth of weeds.

In the following pages the main features of some of the best known, or the most noteworthy, meters are described and illustrated.

Water Meters

The Kent Mark III Positive Water Meter.

This meter is shown diagrammatically in fig. 1. Its sequence of operations is as follows:—

1. The piston A descends, and the disc P throws over the valve C.
2. The piston B descends, and the disc R throws over the valve D.
3. The piston A descends, and the disc Q throws over the valve C.
4. The piston B descends, and the disc S throws over the valve E; and so on.

Stops M limit the motion so that an exact quantity of water is measured off each stroke.

Projections K enter the outlet passage at the end of the stroke and prevent jar by slightly throttling the flow.

The cylinders are lined with brass, and the valves and valve faces are made of gun-metal. The valves are caused to oscillate slightly each time they are thrown over in order to keep the rubbing surfaces polished. For the same reason the pistons are caused to rotate a slight amount at each stroke.

The valves are held up against the port block by rollers L carried by springs which press inwards towards the valve faces.

The meter body is jointed along the line XY, which enables all parts to be readily accessible (actually the inlet and outlet flanges are at right angles to the positions shown in the diagram).

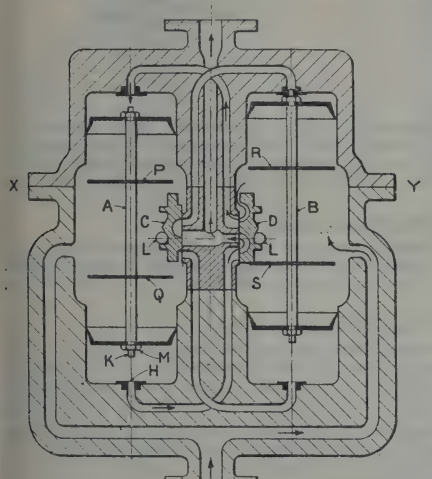

Fig. 1.

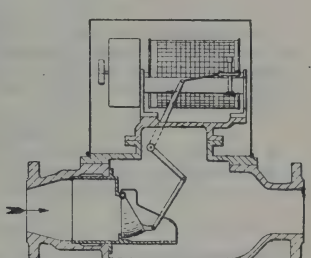

Fig. 2.

The Kent Waste Water Meter.

This meter (fig. 2) consists of a weighted gate pivoted on a horizontal axis and surrounded by a machined shield. The gate opens with increase in the flow, and takes up a definite position at each flow. Its motion is transmitted to the diagram through a stuffing box by means of link mechanism.

It is possible with this meter to measure with accuracy down to very small fractions of the full flow.

Owing to the absence of all sliding parts in this meter, the friction of the mechanism is extremely small.

The bulk of the meter, and the loss of pressure across it, are also reduced to a minimum by its arrangement, which allows of a direct flow between inlet and outlet.

The Beck 'Imperial' Water Meter.

In this meter (figs. 3 and 4) the rotation of the arm A attached to the spindle D, which drives the counter, causes the spherical valve cap V to rock on its seating S, thus opening the lower parts of each of the three cylinders C successively to the inlet and discharge sides of the meter.

The valve cap V is prevented from turning round on its own axis by the projections Q, which engage in recesses left in the valve seat S. The length of the stroke of the pistons is limited by the flange P on the valve cap V, which comes into rolling contact with a machined surface on the valve seat S.

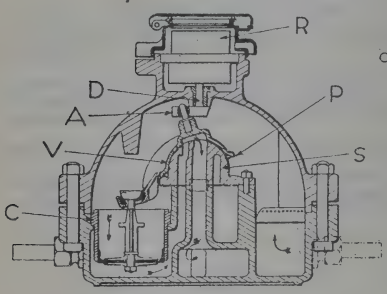

Fig. 3.

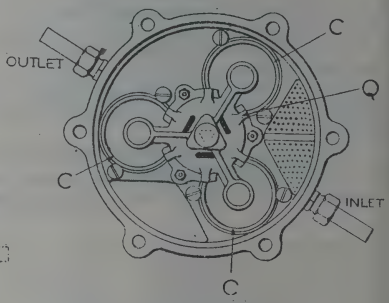

Fig. 4.

It will be seen that the valve cap V moves with a lens-grinding action. This ensures that it and the seating will remain polished and unscratched even when gritty water is being measured.

The valve cap and the pistons are made of hard gun-metal, the valve seat and bushes of vulcanite, and the cylinders of either vulcanite or gun-metal; vulcanite being used for water of exceptional hardness.

The Deacon Water Meter.

In the Deacon Water Meter (fig. 5) a weighted disc moves vertically in a conical shield. Its motion is transmitted to the diagram by means of thin wire passing through a gland. Guide plates are provided to steady the flow at the entrance to the conical shield. See also p. 1482.

The Kent Venturi Water Meter.

This meter (fig. 6) consists of (*a*) a Venturi tube VT through which the water passes; (*b*) a large mercury **U**-tube provided with floats FU and FT (which are displaced by the differential pressure which exists when water is passing between the upstream and throat pressure holes of the Venturi tube); and (*c*) diagram counter and recording mechanisms, which are actuated by the movements of the floats.

The motion of the floats is transmitted to the outside of the **U**-tube by means of gland spindles GU and GT, which actuate toothed wheels that engage with the racks RU and RT.

The law of flow through a Venturi tube is given by the equation :—

where,
$$Q = \frac{\Omega\, a_1}{7{\cdot}88}\left[\frac{h\,W}{n^2-1}\right]^{1/2},$$

Q = flow in lbs. per sec.; Ω = coefficient of discharge for the tube (usually about 0·99); a_1 = area of tube at upstream pressure holes in sq. ins.; na_1 = area of tube at throat pressure holes in sq. ins.; h = difference of pressure between upstream and throat pressure holes in ins. of water; W = weight in lbs. of 1 cub. ft. of the fluid passing.

The counter recording mechanism operates as follows :—A cylindrical cam LC, which has a slightly raised portion, is rotated once every ten minutes by clockwork. A pivoted arm A, which carries the roller L, which is kept in contact with the surface of the cam by a spring (not shown), is lowered by the rack to which it is attached when the flow increases. The greater the distance the arm is lowered, the larger is the fraction of each revolution of the cam during which the roller is on the unraised portion of the cam. By means of mechanism (not shown) it is arranged that a toothed wheel which drives the counter is put into gear with the clock train during the period that the roller L is on the unraised portion of the cam. The boundary line between the raised and the unraised portions of the cam is so shaped that when the pivoted arm A carrying

the roller L moves down a distance H from its zero position an amount proportional to $\sqrt{H}$ is added on to the counter reading. In this way, with suitable gear wheels in the counter train, a counter record of the amount of fluid that has passed is obtained.

Valves U and T are provided so that the upstream and throat pressures may be shut off, and the meter checked by opening the equalising valve E.

Any air that accumulates in the pressure pipes may be blown off through the air vents provided.

To reduce the chance of air getting into the pressure pipes, these should be taken off horizontally, and not at the top, as shown for clearness in the diagram.

These meters will measure accurately down to one-fourteenth of the maximum flow (and special meters of this type down to one-thirtieth of the maximum flow).

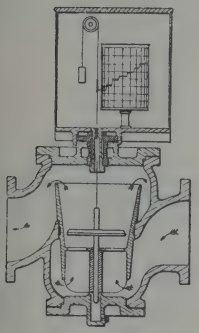

FIG. 5.

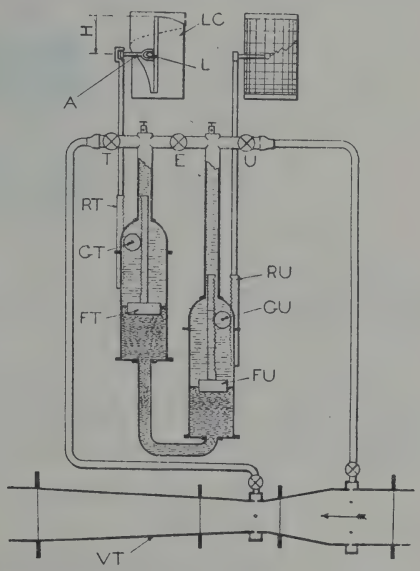

FIG. 6.

The functions of the downstream cone of the Venturi tube is to recover the kinetic energy which exists at the throat, thus enabling the major portion of the pressure difference which has been created between the upstream and throat pressure holes to be recovered.

The friction loss due to the insertion of the water Venturi tube is about 2 lbs. per sq. in. at the maximum flow.

Venturi meters have been used to measure water in all sizes of pipes from about ½ in. to 20 ft. in diameter. They provide the most convenient and accurate method known of measuring the flow of water in large mains. There is a minimum of obstruction to the flow, and there are no moving parts in contact with the flowing water.

Water Weighers.

THE 'AVERY' AUTOMATIC WATER WEIGHER.

The principle of the 'Avery' Automatic Water Weigher (fig. 6A) is that of an equal-armed beam A, with the weights contained in the weight box B, suspended at one end and the weigh hopper C at the other.

A quantity of water, determined by the weights in the weight box B, is allowed to enter the weigh hopper C through the feed valve D.

When the correct amount of water is obtained, the supply from the feed valve or valves D is, by means of a combination of levers, automatically cut off.

Immediately after the supply is cut off, the weigh hooper C automatically tips and discharges its load.

THE 'AVERY' AUTOMATIC WATER WEIGHER—*cont.*

As soon as the contents of the weigh hopper C have been discharged, the weigh hopper automatically returns and assumes the weighing position, at the same time opening the feed valve or valves D, and the cycle of operations is repeated.

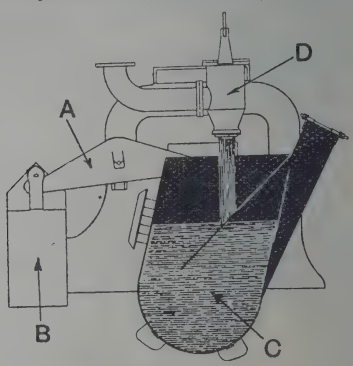

FIG. 6A.

On the large-capacity machines there are two valves at D, the larger one feeding the main flow into the weigh hopper C, then closing, with the result that the final dribble of liquid to complete the weighing and ensure accuracy is fed through the supplementary small valve D.

A mechanical counter keeps an exact record of the number of times the machine operates.

Truck and Hopper Weighers.

THE 'AVERY' PATENT AUTOMATIC WEIGHBRIDGE AND TOTALISER.

This machine, fig. 6B, automatically weighs trucks while at rest on the weighbridge. It also records on special counters the total weights during any period, and the number of weighings made by the machine.

If all the trucks have the same tare weight the machine can be arranged to record the total net weight of material passed over the scale.

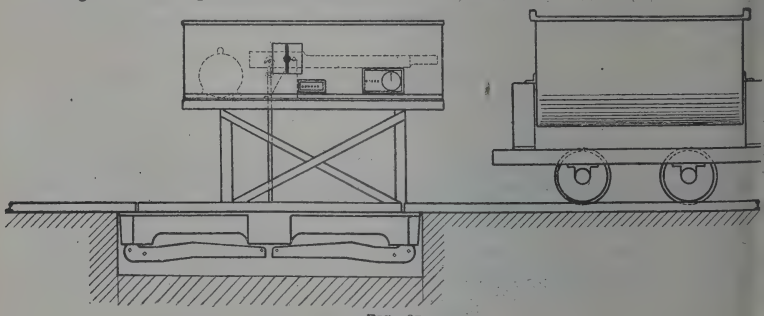

FIG. 6B.

With suitable weighing levers, etc., the machine can be arranged for use with overhead ropeways, grabbing hoists for transporters, overhead runways carrying coke skips for gasworks, etc.

A special type of the mechanism is also used with the Avery 'Automatic Hopper Weighe and Totaliser,' which automatically records the weight of material discharged from grabs o skips. The material dealt with includes coal, coke, ore, pitch, etc., and pieces of any size fron nuts to the largest lumps can be weighed, as there are no feed valves.

When grabs are used to unload barges or steamships this type of machine is most suitable as the total intake of coal is then automatically recorded; also the load of each barge or shi can be ascertained. All the machines described are approved by the Board of Trade as lega weighing instruments, and the recorded weights are therefore beyond dispute.

Weir Recorders.

The Lea 'V' Notch Weir Recorder.

The discharge for a 90° V notch with sharp edges bevelled at 45° on the downstream side is given by the equation.

$$Q = 2{\cdot}48H^{2{\cdot}48}$$

where,

Q = discharge in cub. ft. per sec.; H = head, in ft. above the bottom of the notch.

In the Lea Recorder (fig. 7) the movement of the float F in the weir chamber, which is proportional to H, is transmitted to a cylindrical cam C. By means of this cam, a movement of the pen arm P, which is proportional to Q, is obtained.

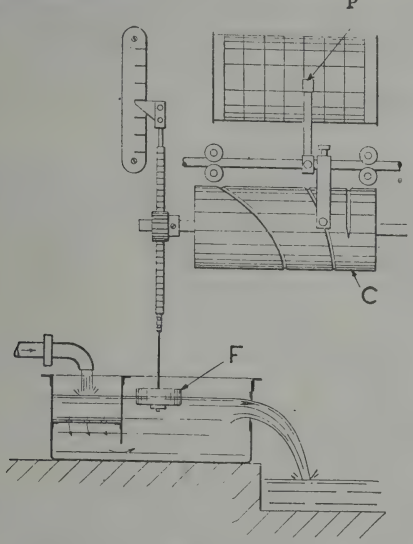

Fig. 7.

These recorders are specially suitable for the measurement of boiler feed-water and condensates, also rivers, streams, reservoir supplies, sewage effluents, etc., or in such cases where it is necessary to measure the water in some form of open channel.

In the Kent Weir Recorder a flat cam is used, and the straight line movements are replaced by movements about fixed pivots.

In the Wright Weir Recorder the weir notch is made of such a shape that the motion of the float is proportional to the quantity passing. In this recorder there is, therefore, no cam between the float and the recorder pen. The approximate shape of the weir notch is shown in fig. 8.

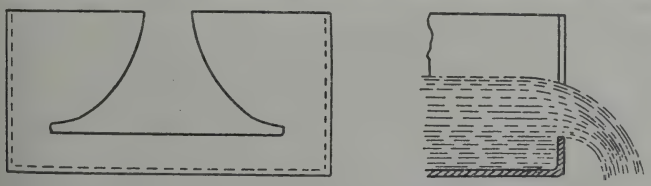

Fig. 8.

Notes on the Use of Orifices, Nozzles, and Venturi Tubes for Test Purposes.

Q = discharge in lbs./secs.;
E = coeff. of discharge;
a_1 = area of main in ins.;
a_2 = area of orifice on throat of nozzle in sq. ins.;
n = a_1/a_2;
N = $a_1\sqrt{n^2-1}$;
d_1 = dia. of main in ins.;
d_2 = dia. of orifice on throat of nozzle in sq. ins.;
h = differential pressure across orifice or nozzle in ins. of water;
p_1 = abs. pressure in lbs./sq. ins. at upstream pressure hole;
p_2 = abs. press. in lbs./sq. ins. at downstream or throat pressure hole;
T_1 = abs. temp. in F.° at upstream pressure hole;
W_1 = specific weight of fluid at upstream pressure hole in lbs./cu. ft. = $2{\cdot}7P_1/T_1$ for air (values for water, steam, and other fluids can be obtained from various published tables);
μ = viscosity of the fluid in foot, pound, sec. units;
γ = ratio of the specific heats if the fluid is gaseous.

The discharge through an orifice, shaped nozzle, or Venturi tube for gaseous or liquid flows can be calculated from the formula:

$$Q = 0{\cdot}127\ EN\sqrt{hW_1}\ \text{lbs./secs.}$$

The value of the coefficient of discharge, E, is the same for the same values of the viscous flow criterion $Q/d_2\mu$, whatever be the density and viscosity of the fluid used, provided that when the fluid which is being metered is a gas, it does not appreciably change in density as it passes through the orifice or nozzle (*i.e.*, p_2/p_1 should be between 1·0 and 0·98).

For shaped nozzles and Venturi tubes, if the numerical value of the viscous flow criterion $Q/d_2\mu$ is greater than 3,000,

$$E = 0{\cdot}94\text{–}1{\cdot}00;$$

for orifices:

$$E = 0{\cdot}605\text{–}0{\cdot}615,$$

provided that:

(*a*) The numerical value of viscous flow criterion $Q/d_2\mu$ is greater than 1,200;
(*b*) d_2/d_1 is not more than 0·6, and that orifices are used which have:
(*c*) square edges if the orifice plate is thin (less than $\frac{3}{10}$th the diameter of the orifice);
(*d*) square edges bevelled off on the downstream side if the orifice plate is thick;
(*e*) pressure holes not more than one pipe diameter upstream, and not more than half a pipe diameter downstream of the orifice.

For the above values to hold, the orifice or nozzle should be installed with at least 6 diameters upstream and 3 diameters downstream of straight parallel pipe free from bends, tees, branch pipes and control cocks.

When using orifices or nozzles for measuring flows of viscous liquids, curves connecting the differential pressure 'h' with the numerical factor multiplying $\sqrt{h/W_1}$ in the volume discharge equation, can be plotted for various values of the kinematic viscosity μ/W.

If the relation between the temperature and the kinematic viscosity for the liquid has been previously determined, a knowledge of the temperature enables the correct numerical factor for any observed head to be read from the plotted curves.

If the flow is gaseous and pulsating, sufficient capacity or throttling must be introduced between the source of pulsation and the metering point to smooth out the pulsation of flow at the metering point, otherwise the meter will read fast. In the case of liquid flows, an air vessel or an open tank may be used.

If gaseous discharge takes place above the critical pressure ratio (*i.e.* if p_2/p_1 is less than $\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ when $n=\infty$), the following formulæ hold for shaped nozzles:

$$Q = 0{\cdot}325\ EN\sqrt{p_1W_1}\ \text{for air;}$$

$$= 0{\cdot}316\ EN\sqrt{p_1W_1}\ \text{for steam.}$$

For fuller treatment see Hodgson on 'The Orifice as a Basis of Flow Measurement,' *Proc. I.C.E.*, 1925; 'The Metering of Industrial Fluids,' *Proc. Inst. Mining Eng.*, Nov. 1927.

Gas Meters.

The 'Drum' Type Station Gas Meter.

In this meter (fig. 9) gas enters through the hollow axis in the four compartments of the drum in a pipe which is put just above the water level, and fills each compartment successively, and by its pressure causes the drum to revolve in the direction of the arrow and to register the volume passed on a set of dials.

Meters of this type are used to measure gas in mains of all sizes, from ¼ in. upwards.

Owing to their costliness, the larger meters of this description are now being superseded by new patterns of meter, such as the Thomas and the Kent-Hodgson Meters.

The main sources of error of this meter are deformation or corrosion of the drum, deposition of naphthalene in the drum, and variations in the water level There are various ingenious devices for preventing the meters from being over-filled, and for maintaining the correct water level. If the meter is overloaded, the water level is depressed, and the meter reads slow.

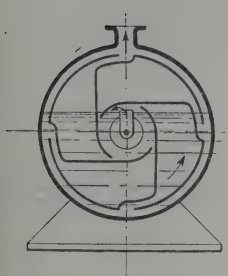

Fig. 9.

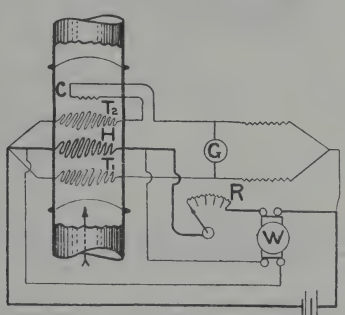

Fig. 10.

The Thomas Gas Meter

In this meter (fig. 10) the gas is passed through a short length of pipe which contains two electrical resistance thermometers T_1 and T_2, which form part of a Wheatstone Bridge. An electrical heater H is placed between the two thermometers. Any increase in the flow of gas causes a lowering of the temperature of the downstream thermometer and a deflection of the needle of the galvanometer G. This is made automatically, by means of a suitable mechanism, to reduce the resistance in the heater circuit, so that the temperature of the gas is always raised the same amount (about 2° F.) by the heater.

The readings on a Wattmeter W, placed in the heater circuit, give the number of cubic feet of gas reduced to standard temperature and pressure.

The Kent-Hodgson Venturi Gas Meter.

In this meter (fig. 11) the 'Venturi Head' $(p_1 - p_2)$ is measured by means of the bell B and an amount proportional to $(p_1 - p_2)$ is added on to the counter reading by means of the cam, feeler, ratchet, and pawl device C.F.R. every time the cam G, which is driven by the wet gas meter W, makes one revolution.

The speed of rotation of this meter is determined by the amount of gas that escapes to atmosphere through a small orifice at O, across which the pressure difference is maintained constant by means of the regulating valve RV.

In this way the counter is made to register the volume of gas passing through the Venturi tube, irrespective of variations in the specific gravity of the gas; the registration of the meter being identical with that of the ordinary Drum type Station Gas Meter.

A diagram, D, is provided which shows the rate of flow of gas at any instant. The readings of this diagram are, however, not corrected for variations in the specific gravity of the gas.

If tar, naphthaline, or other depositable matter settles in the Venturi throat, the meter tends

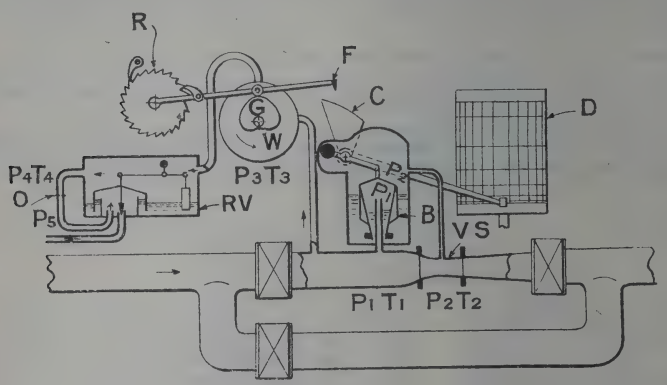

FIG. 11.

to read fast. It is found that when measuring coal gas, such deposits can be entirely prevented by keeping the walls of the throat at a few degrees higher temperature than that of the gas passing through.

The Venturi tube is installed on a bye-pass, and the throat section VS is made so that it can easily be swung out of the pipe line for inspection and cleaning.

The loss of pressure at the maximum flow due to the insertion of the gas Venturi tube is arranged not to exceed 1 in. of water gauge.

The range of accurate registration is down to one-tenth or one-fifteenth of the maximum flow.

If it is desired to reduce the meter readings to standard cubic feet of dry gas, corrections must be made for variations in the barometric pressure, atmospheric temperature, and the tension of aqueous vapour by means of tabular numbers, as is the case with the Drum type Station Meter.

The Venturi Gas Meter is also made in a cheaper form in which the integrating mechanism is driven by clockwork, and any variation in the specific gravity, temperature, and moisture content of the gas is corrected for by means of tabular numbers, *i.e.* the meter readings are multiplied by

$$\frac{(p_1 - p'_1)}{p_1} \sqrt{\frac{W_D}{W_S} \cdot \frac{p_1}{T_1} \cdot \frac{T_S}{P_S}},$$

where,

W_D = weight of a cub. ft. of dry gas at p_1 and T_1; W_S = weight of a cub. ft. of gas containing water vapour at p_1 and T_1; p'_1 = pressure of water vapour at temperature T_1, P_S and T_S the standard temperature and pressure.

See Hodgson, *Proc. Inst. C.E.*, vol. cciv., pp. 164–165.

THE THORP ROTARY GAS METERS.

In the Thorp Rotary Gas Meter (fig. 12), the counter C is actuated by an anemometer fan F, which rotates about a vertical axis.

The gas, after being carefully guided by a series of nozzles N into a vertical direction, impinges on the underside of the blades, thus helping to take the weight of the fan off the bottom pivot. The rate of revolution of the fan is proportional to the actual volume of gas passing

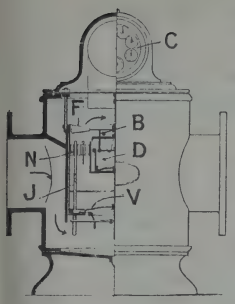

FIG. 12.

except at low flows, when the friction of the mechanism is appreciable. At these flows a weighted valve V (which lifts at the higher flows) causes the whole of the gas to pass through a few jets J, and so to impinge on the fan at an increased velocity. In this way the friction of the mechanism is compensated for, and accurate readings obtained down to one-tenth of the maximum flow.

The dashpot D is provided to steady the motion of the weighted valve. A brake B is attached to this valve, which stops the fan immediately the flow is turned off, as the valve then falls.

This meter registers the actual volume of gas passed, and is subject to the same corrections for variations in the temperature, pressure, and moisture content of the gas as is the ordinary Drum type Station Meter, or the Kent-Hodgson Venturi Gas Meter.

Clogging of the nozzles through which the gas discharges on to the fan causes the meter to read fast. A special form of meter in which the nozzles can be cleaned from the outside, and in which any deposit thrown off from the fan does not accumulate round it, has been devised for measuring dirty gas.

THE 'KENT-HODGSON' ROTARY GAS METER.

This meter (fig. 12A) consists of a body casting inserted in the main, or by preference in a by-pass in the main, a turbine T placed in such a position that gas passing through the two nozzles J on the upstream side of the orifice K impinges on its blades, and a counter mechanism actuated by the turbine. The turbine, orifices, and nozzles can be inspected and cleaned through the hand-holes provided.

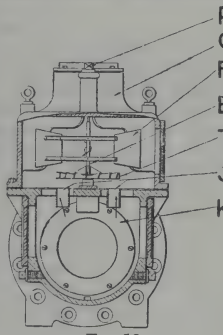

FIG. 12A.

The meter carries the measurement of gas on the rotary principle to the utmost refinement. The speed of rotation of the turbine is kept low by means of the damping fan F, so that wear on the bearings is reduced to a minimum. The weight of the turbine is carried on a mercury float, so that the all-important pivot bearing never wears appreciably, and is also protected by being covered with mercury. The upper thrust bearing and the high-speed wheels of the counter train run in an oil bath. The motion of the turbine is transmitted to the counter dial by means of a magnetic drive similar to that shown in fig. 15, thus eliminating all gland friction and the possibility of moisture depositing on the counter glass.

The turbine chambers and the mechanisms they contain are identical, whatever be the size of the main. The only parts of the meter which vary in size are the body casting which contains the orifice, the orifice itself, and the change wheels which are fitted into the counter train. The length of the body casting in practically all sizes is 24 ins., so that the meter is very light to handle and requires only a short length of pipe line for its installation. It is accurate down to $\frac{1}{10}$th of full flow, and will stand considerable temporary overloads without damage.

HOT WIRE ANEMOMETER.

In this instrument a bare wire with a large temperature coefficient is heated electrically and exposed to the gas flow whose velocity it is required to measure. The velocity V of the gas can then be obtained from the relation

$$I^2 = A\theta + B\theta \left[V.W\,K_p \right]^{\frac{1}{2}}$$

where,

θ = temperature elevation of the wire;
I = current in amps.;
V = velocity of the gas;
W = specific weight of the gas;
K_p = specific heat of the gas at standard pressure;
A & B = constants.

Referring to the diagram (fig. 13), R_1, R_2, and R_3 are resistances with no temperature coefficient, R_4 is the anemometer wire which is maintained at constant temperature when the gas velocity varies by adjusting the resistance R_5 so that the needle of the galvanometer G remains at zero. The current through R_4 is thus proportional to the reading of the high resistance voltmeter V.

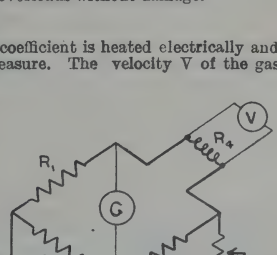

FIG. 13.

The formula given above holds for ordinary gas speeds (9·5 to 30 ft. per second). At speeds below these, free convection currents carry away a considerable proportion of the heat, and the formula requires modification.

The accuracy of the instrument is affected by changes in the temperature of the gas itself, and for this reason it is desirable, when high accuracy is required, to work at a temperature elevation of about 1,000° C. In this case the anemometer wire should be of platinum. For ordinary work a temperature elevation of 200° C. or 300° C. is sufficient, and the anemometer wire may be made of electrolytic nickel.

It will be noticed that the velocity of the gas is approximately proportional to the fourth power of the current. This makes the accurate range of the instrument small, and it also makes it unsuitable for obtaining the mean velocity of fluctuating flows.

In Professor MacGregor Morris's Hot-Wire Anemometer, as made by The Cambridge & Paul Instrument Co., the four arms of the Wheatstone bridge are made of electrolytic nickel.

The wires which compose the two opposite arms of the bridge are shielded from the air current, and the two remaining wires are exposed to it. The instrument is thus automatically compensated for changes in the air temperature, so that it is not necessary for the temperature of the wires to be more than 100° F. above that of the air current to be measured. A constant potential difference is maintained across the bridge, and the air velocity is measured in terms of the out-of-balance current of the galvanometer.

The instrument is calibrated against known velocities in a wind tunnel.

Steam Meters.

The Kent-Hodgson Steam Flow Meter.

This meter (fig. 14) consists of an orifice O placed in the steam main, two cooling chambers CU and CD (whose function it is to condense any steam that passes into them and to serve as reservoirs of water), and pressure pipes PU and PD which transmit the difference of pressure between the upstream and downstream sides of the orifice, due to the steam flow, to the two sides of the differential pressure diaphragms D and to the inside of the pressure diaphragms P.

Any increase of the flow causes an increase of the difference of pressure between the upstream and downstream sides of the orifice, and consequently causes the diaphragms D to contract and

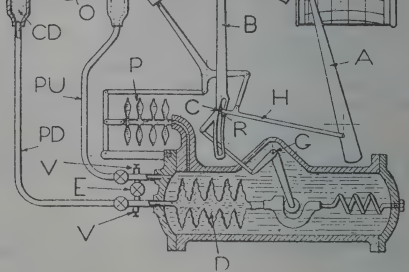

FIG. 14.

the pointer B to move about its pivot C (the motion of the diaphragms D is transmitted to th outside of the diaphragm case through a stuffing box G); while any increase in the pressure o the steam causes the diaphragms P to expand and the arm H to descend.

Air vents V and an equalising valve E are fitted.

The product of the angular movement of the arm B (which is proportional to the differentia pressure $(p_1 - p_2)$ and the travel of the roller R in its slot (which is proportional to the absolut pressure of the steam p_1) is transmitted to the pen arm A, which is thus given a motion pro portional to $(p_1 - p_2)\, p_1$.

Since the rate of discharge of steam through an orifice is represented approximately by the equation,

$$Q = K\sqrt{(p_1 - p_2)p_1},$$

where,

p_1 = absolute pressure of the steam on the upstream side of the orifice; p_2 = absolute pressure of the steam on the downstream side of the orifice; Q = lbs. of steam per hour; K is a constant depending upon the size and proportions of the orifice used.

The diagram can be divided to show the rate of steam flow at any instant, automatically corrected for variations in the pressure. (The corrections for variations in the superheat or wetness of the steam* are made by means of tabular numbers.)

The meters can be arranged to record by counter also if desired.

With any given orifice plate the meter is accurate down to one-fifth of the maximum flow for which the plate is designed to deal. If it is desired to measure over a greater range of flow than this, a new orifice plate must be inserted. Each meter is designed to work in connection with any orifice plate. Each orifice plate is calibrated with actual fluid before leaving the works, and the accuracy obtained in practice with this meter is within plus or minus 1 per cent.

With slight modifications, the meters can be used for the measurement of compressed air.

The Hodgson Rotary Steam Flow Meter.

This meter, which is being manufactured by *Messrs. George Kent, Ltd.*, of London and Luton, as shown in section by fig. 15. A portion of the steam passing through the instrument is diverted by means of an orifice plate through nozzles A, by means of which it is caused to impinge on a turbine. The speed of this turbine is kept low by means of a damping fan C, which rotates in water, resulting in a minimum of wear on the turbine bearings. The retarding torque at any given speed due to this fan is made so great that any variation in the corresponding torque due to the turbine, caused by variations in the density of the steam in which it rotates, can be neglected. The turbine rotates at normal flows with a speed proportional to $Q\sqrt{W}$, where Q is the weight of steam passing per second, and W is the density of the steam in pounds per cubic foot. From this it will be seen that a variation of 2 per cent. in the density of the steam will involve a correction of only 1 per cent. in the flow reading. Besides reducing wear on the pivots, the use of the damping fan increases the range of the meter, since it increases the relative velocity between the impinging steam and the turbine. The counter E is mounted in a compartment below the main, a magnetic drive D from the turbine being employed so that leakage of steam or water into this compartment is impossible. Radiating fins assist in keeping the counter cool. The maximum flow which the meter will measure can be altered by changing the orifice plate B; and by fitting a blank plate in place of this orifice plate, and putting the meter in a bye-pass in a large main into which a suitable orifice plate is inserted directly, the largest mains can be metered at a small cost.

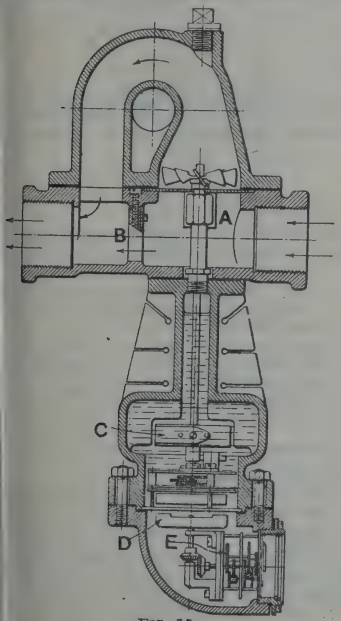

FIG. 15.

The ratio of the revolutions per minute to the rate of flow is constant.

The meters as supplied are accurate down to $\frac{1}{10}$ of the maximum flow, and will stand temporary overloads of 100 per cent. without damage. The meters are also suitable for measuring compressed air.

* About 1 per cent. for every 2 lbs. change in the pressure, or 20° F. change in the superheat, or 2 per cent. change in the wetness.

The Kent-Hodgson Spring-Controlled Flexible Diaphragm Instruments.

The diaphragms in these instruments being required to be sensitive to small differences of pressure, have, with the springs which control them, to be protected from any damage due to overload, or to the application of any considerable unbalanced static pressure, to which they may by mischance be subjected; this, in the Hodgson instrument, is effected by means of a cradle on both sides of the diaphragm. Further, in order that the accuracy of the instrument shall be maintained in use, the diaphragm is reinforced with flexible material which will not stretch radially or circumferentially. The cradle is in the form of a portion of a cone, on which a suitably shaped diaphragm can roll and unroll without stretching. From fig. 16 it will be seen that whatever position along its axis the stiff central plate BC may take up, the length AB is always equal to the length AB_1.

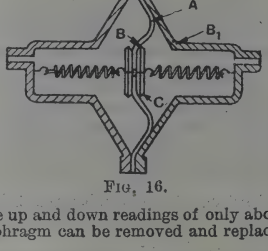

Fig. 16.

In order to obtain a good zero, the controlling springs are under stress when there is no load on the instrument, so that there is no backlash to be taken up when the diaphragm begins to move.

The motion of the centre of the diaphragm is transmitted to the indicating pointer or the recording pen by suitable means (not shown in the figure).

The instruments as constructed show a lag between the up and down readings of only about 1/500th part of the maximum applied pressure. The diaphragm can be removed and replaced without altering the adjustment of the instrument.

The arrangement is more especially suitable for use in connection with the measurement of flow through orifices and Venturi tubes, where small pressure differences at high static pressures have to be measured.

The instruments as supplied are fitted with an 18-in. rate of flow scale, and can be arranged to record by diagram or by diagram and counter.

Coal Meters.

These meters are designed to measure either (*a*) *the total quantity* of coal going to any particular furnace, or (*b*) *the rate* at which the coal is fed. The Avery meter (type *a*) actually *weighs* the coal supplied. The Lea and Kent meters (type *b*) *measure the volume*, i.e. not the weight, of the coal supplied.

The 'Avery' Automatic Coal Weigher.

The principle of the 'Avery' Automatic Coal Weigher (fig. 17) is that of an equal-armed beam A with the weights contained in the weight box B suspended at one end and the weigh hopper C at the other.

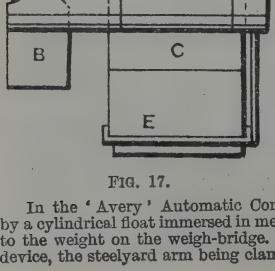

Fig. 17.

A quantity of coal, determined by the weights in the weight box B, is allowed to enter the weigh hopper C through the feed shoot controlled by the valve D.

When the correct amount of coal is obtained, the supply from the feed shoot is, through a combination of levers, automatically cut off by the valve D.

Immediately after the supply is cut off, the door E of the weigh hopper C automatically opens and the load is discharged.

When the load is clear of the weigh hopper door E it closes again and automatically opens the feed valve D, and the cycle of operations is repeated.

A mechanical counter F keeps an exact record of the number of times the machine operates.

Coal or other granular material which is carried by belt conveyors can be weighed to an accuracy of *plus* or *minus* 1 per cent. by supporting a short length of the conveyor on a weigh-bridge and introducing a device which automatically integrates the product of the speed of the conveyor, and the *net* reading of the weigh-bridge.

In the 'Avery' Automatic Conveyor Weigher, the pull on the steelyard arm is balanced by a cylindrical float immersed in mercury, the movement of the arm being thus made proportional to the weight on the weigh-bridge. Integration is effected by means of a feeler and free-wheel device, the steelyard arm being clamped while the feeler is in contact with it.

Lea Coal Meter—Chain Grate Type.

The object of this meter is to measure the amount of coal consumed by a chain grate mechanical stoker.

The coal, as it passes from a hopper underneath a movable fire door, assumes the form of a continuous stream of rectangular cross-section. The volume of coal, therefore, having passed during any given time is the product of the width of the chain grate, the height of coal as it passes under the fire door, and the linear distance travelled by the grate.

Of these three factors two are variable: firstly, the depth of coal passing over the grate (due to the variation in lift of the fire door): secondly, the speed of the grate (or the distance travelled by the grate over a given time). The meter is so constructed as to take both these variables into account in the following manner:—

A specially cut toothed drum, having at one end teeth cut round the whole of its periphery, and a uniformly decreasing number of teeth cut along the whole of its length, is driven by a small driving chain from the grate itself; thus the speed of the drum is proportional to that of the grate, and accordingly proportional to the linear distance travelled by the grate over any given time.

Meshing with this toothed drum is a sliding pinion, which is directly connected to the fire door by means of a steel cable; its position on the toothed drum, and consequently the number of teeth with which it engages, is, therefore, dependent on the amount to which the fire door is raised or lowered. Thus, the rotation of this pinion is dependent on both the grate speed and the fire door lift, and, consequently, this rotation is in a direct proportion to the volume of coal having passed.

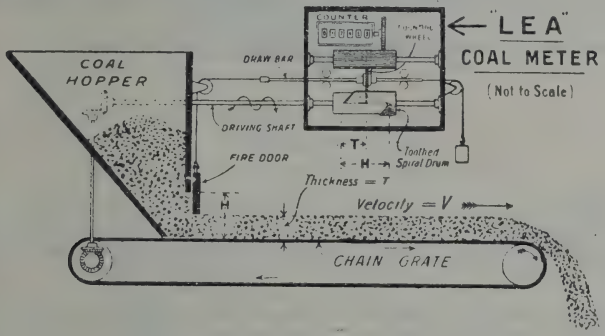

FIG. 18.

The principle of operation of the Lea Coal Meter is as follows:

If W = width of grate in ft.; T = thickness of fire in ft.; V = velocity if grate in ft. per hour; then, cubic ft. per hour = W × T × V = cross-sectional area × V.

The rotation of the pinion is transmitted directly to a row of seven counting dials, the movement of which gives a visible indication of the volume of coal having been fed on to the grate.

It should be pointed out that the meter cannot weigh anything directly; it is solely a measurer of volume, but it eventually determines the nett weight of coal consumed. The Lea Recorder Co., Ltd., guarantees the accuracy of its Coal Meters to be within 2·5 per cent. by volume.

It is quite a simple matter to arrive at the actual weight of coal consumed, by means of tests carried out to determine the average weight of a cubic foot of the particular fuel being used. No variation is caused by the size of the particles of coal, as it is a fact that equal volumes of dry graded coal weigh the same, irrespective of the size of the particles, or whether they are in the form of nuts, peas, or slack.

These Coal Meters can be fitted with patent 'Rate of Flow' Indicator, which, when worked in conjunction with the various speeds of the Stoker drive, gives, on specially graduated scales, the actual amount of coal being consumed at any moment in lbs. per hour.

Lea Coal Meter—Lancashire Type.

In this type of meter the volumetric principle of measurement is adhered to, and the meter is operated directly by the rams, or pusher plates, of stokers of the Proctor, Bennis, and other similar types. The meter is so arranged as to take into account variations of both the speed at which the rams are operated and the differences of travel of the rams, so that a true indication of the amount of fuel fed into the furnaces is given.

The Lea Recorder Company guarantee the meter to be correct within 2·5 per cent by volume.

Lea Cubi-Meter.

The object of this machine, which is a development of the Lea Coal Meter (chain grate type), is to measure bulk supplies of coal, ores, grain, or any other similar granular material, in a continuous manner, in conjunction with elevators or conveyors, on which the material is being handled.

The principle of measurement is volumetric, and is as follows :—

The material to be measured is passed on to an endless belt, in a similar manner to the coal passing on to the grate of a chain grate stoker. The meter itself is similarly driven by a small chain from this belt.

As the material travels over the belt it passes underneath a swinging door, the lift of which varies with the thickness passing under it. Directly connected to this swinging door is a link motion which operates the sliding pinion in the meter. Thus the rotation of the meter dials is proportional to the speed of the belt, and also to the height of the material passing along it, the two factors being combined in the meter giving a true indication of the volume of material having passed through the machine.

These machines are guaranteed to be accurate within 2 per cent. by volume.

Revolution Indicators.

The Jaquet Indicator.

(John Dickinson, 76, Gray's Inn Road, London, W.C. 1.)

This indicator, fig. 19, is an accurate standard instrument which in the shortest time gives positive readings of revolution rate per minute or, using the disc wheel fitted in the case, of linear speed per minute. The standard time unit adopted is 6 seconds, and this unit is controlled by the precision watch movement fitted in the indicator. 1½ seconds are allowed for starting and stopping the watch movement, which also automatically switches the counting mechanism in and out at the start and finish of the 6 second reading unit.

The lever with button which projects from the case winds the watch mechanism ; for each reading one pressure on the button suffices, and the lever is designed not only to wind the watch but also to zero the counting mechanism from the previous reading. This does away with any necessity for resetting the counter after taking a test ; the last reading remains on the dial *until the indicator has been placed in position on the machine* under test and a new reading is required ; then the finger is pressed on the knob and allowed to slide over it so that it can fly back to its full extent, thus resetting the counter and winding the watch.

Either a black or red disc is shown on the face of the counter dial, the colour altering with the direction of rotation and corresponding to that of the set of graduations to be used, black for right-hand, red for left-hand rotation.

One revolution of the large pointer = 1,000 revs. (or 100 m. if the measuring disc is attached) of the small pointer = 10,000 revs. (1,000 m.).

The indicator is designed to stand up to 30,000 revs. per min., and all pivots and bearings are suitable for such high-speed rates.

The indicator is claimed to combine the accuracy of a summating counter with the rapid reading rate usually associated only with tachometers of the centrifugal or magnetic types.

Three fittings are supplied with the instrument: B = rubber point, C = hollow or cup centre, G = measuring disc. The triangular steel point of the spindle can also be used.

The measuring disc G is used for *periphery or rate of cut tests* ; this is fitted with a rubber rim 10 cm. circumference, or if readings are required in feet, the diameter is altered to suit. In cases where shaft centres are inaccessible the revolution rate of same can be determined by using

the measuring disc G and converting the peripheral speed reading to the corresponding revolution rate.

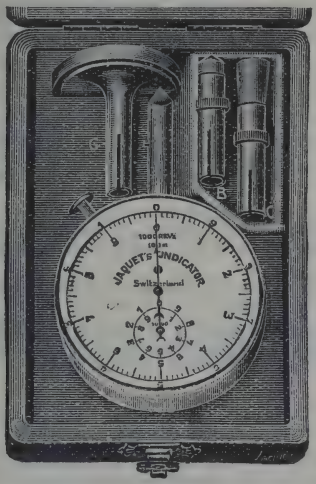

FIG. 19.

An additional model of the foregoing is now made in which 1 rev. of the long pointer = 100 r.p.m.

THE JAQUET HAND TACHOGRAPH.

(*John Dickinson, 76 Gray's Inn Road, W.C. 1.*)

The Jaquet hand tachograph, fig. 20, is used for recording revolution rate, drawing the curve in rectangular co-ordinates on a moving paper strip, marking the time units horizontally and the revolution rate vertically.

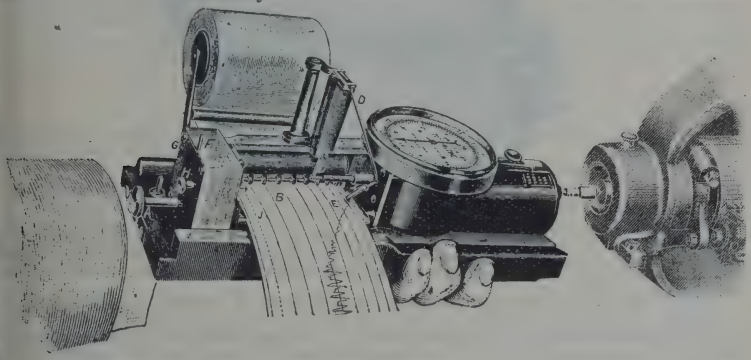

FIG. 20.

It can be used for any desired revolution rate per minute between 30 and 4,000, and allows records of wide speed fluctuations, such as the running-down rate of rotating bodies, and also of such speed rate changes of only 1 to 2 per cent. as occur under governor control.

The mass effect of the recording system is reduced to a minimum, so that records of cycle speed fluctuations are possible.

The record strip is fed forward between two clockwork-driven feed rolls, the clockwork is wound up by the thumb nut A, whilst a trigger at the back (not visible in the fig.) and triggers H and F act respectively to stop or vary the strip feed rate.

Narrow discs are mounted on the top feed roll at positions corresponding to the calibrated revolution rates indicated on the tachometer dial; these discs are in contact with an inking roll C and mark on the record strip parallel lines spaced to agree with the calibration of the instrument.

After a test the r.p.m. value of the inked-in parallel lines can be written in on the record.

The revolution rate during test is taken from the tachometer dial. The thumb nut H winds the watchwork actuating the time recorder J, which marks the record at definite intervals of 1 or $\frac{1}{5}$ second as selected. Usually the apparatus are provided with 1 second registering time markers.

Record of the revolution rate is effected by the pen E, connected through a system of levers D to a spindle projecting from the tachometer and working at right angles to the line of strip advance. Suitable recording ink, which is supplied with the instrument, is put into the pen by a small brush.

An additional fitting may be had, by the use of which the chart spacing may be increased or multiplied, at a small extra charge.

Optical accessories are also available in the way of a flexible drive attachment, whereby readings may be taken from inconvenient positions to allow for easy reading; a neat reducing and multiplying gear-box is also available, at a nominal cost.

The Veeder Magnetic Counters.

(*F. E. Dickinson, St. Andrew's House, Holborn Circus, London, E.C.* 1.)

The 'Veeder Magnetic Counters' differ from the general run of Veeder counting mechanisms in that they operate by the making and breaking of an electric circuit. Their uses are many and varied. They can be placed at a distance from the machine or apparatus the operations of which it is desired to keep account, and they are useful where the articles to be counted are small, or thin, or light in weight, making it difficult to count by mechanical means. No extra contact device need be provided where the counter is to be used in conjunction with other devices already

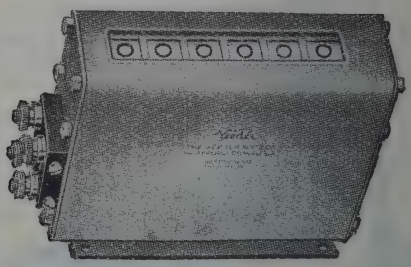

Fig. 21.

electrically operated, and where it is desired to know the number of times these devices are started or stopped. In other cases it is necessary to provide some mechanical device which will close and break the electrical circuit which operates the counter. The counters are made for either direct or alternating current.

Mechanically operated Veeder Counters are used for counting, measuring, and particularly in recording output of many varied products often at different stages of manufacture.

The counter shown by fig. 21 is the larger of the two magnetic devices and is furnished with or without a reset attachment (for the purpose of resetting the counter to zero at any particular point).

SECTION XXVII.

PART II.

MECHANICAL TESTING OF MATERIALS.

(*W. & T. Avery, Ltd., Soho Foundry, Birmingham.*)

As the practice of mechanical testing is essentially a weighing operation, care should be taken by users to see that the machine employed for any testing operation, in which accuracy of results is of vital importance, is one in which the load indications are derived through the medium of weighing levers of the type adopted in good weighing machine practice.

Chains and Anchors.

High-capacity machines of the horizontal type are used for testing such materials. The chain specimen is usually laid in a trough in the flooor, and during the test is covered by steel plates to prevent injury to the operator. A bay in the trough is provided for accommodating anchors when these are required to be tested.

Wire and Hemp Ropes.

Similar horizontal machines to that described above are also used for testing ropes, and the type of grip holder has to be of special design for securing the specimen. Conical extensions are formed on the ends of the wire rope, and in the case of hemp ropes these are secured in holders of the drum type, or sometimes between wood-lined wedges.

Bar Specimens of Steel and Non-Ferrous Metals.

For such specimens a vertical type of testing machine is usually employed, and this may be of the multiple-lever pattern or of the single-lever type.

The straining medium can be either hydraulic power or the load may be applied by means of an electric motor driving suitable gearing. For small machines a hand drive is sometimes used.

Cement and Concrete.*

Cement is tested both in tension and compression, although concrete is usually tested for its compressive strength only.

The machine for the tensile test is generally of the type in which the load is applied gradually through the medium of a flow of shot.

The compression-testing machine used is generally of the hydraulic type, in which the applied load is indicated by a pressure gauge.

Textile Materials and Leather Belting.

Such materials are tested in machines in which the stress is applied at a constant rate of loading.

Usually the machine is of the vertical type, but for very long specimens horizontal machines are sometimes adopted.

The form of grip holder has to be of a special design to obviate the danger of the specimen breaking in the grips.

* See also p. 504.

TIMBER.

The testing of the strength of constructional and aircraft timber has received great prominence during the last year or two. Various tests are adopted, and special speed rates of load application are specified for each.

TESTING APPLIANCES.

Figs. 1, 2, 3, and 4 show various testing appliances.

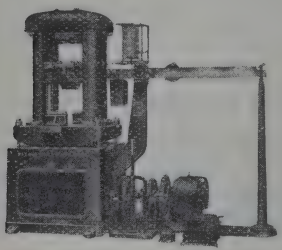

FIG. 1.—Universal Testing Machine.

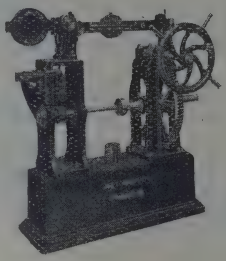

FIG. 2.—Torsion Testing Machine.

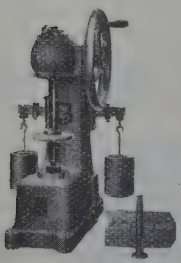

FIG. 3.—Hardness Testing Machine.

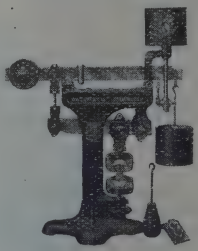

FIG. 4.—Cement Testing Machine.

SECTION XXVIII

HARBOURS AND BREAKWATERS — DOCKS — QUAY-SIDE APPLIANCES—GRAVING AND FLOATING DOCKS — DREDGING—SUBAQUEOUS ROCK REMOVAL—CHANNEL DEMARCATION — BUOYS — LIGHTSHIPS — LIGHTHOUSES — SUBMARINE SIGNALS—DIVING

(Contributed and revised by Brysson Cunningham, D.Sc., B.E., F.R.S.E., M.Inst.C.E.)

SECTION XXVIII

HARBOURS AND BREAKWATERS — DOCKS — QUAY-SIDE APPLIANCES — GRAVING AND FLOATING DOCKS — DREDGING — SUBAQUEOUS ROCK REMOVAL — CHANNEL DEMARCATION — BUOYS — LIGHTHOUSES — SUBMARINE SIGNALS — DIVING.

Contributed by Brysson Cunningham, D.Sc., B.E., F.R.S.E., M.Inst.C.E.

(Author of 'Dock Engineering,' 'Harbour Engineering,' etc.)

HARBOURS AND BREAKWATERS

Harbours are sheltered areas of water affording safe anchorage for ships generally also provided with quays and facilities for landing passengers and cargo. There are many harbours where the requisite shelter is forthcoming naturally from the physical configuration of the coast line (Queenstown, Rio de Janeiro, etc.). Where protection cannot be obtained in this way it has to be provided by means of breakwaters, as at Portland, Dover, and elsewhere.

Breakwaters are of two types: (*a*) the mound of rubble stone, and (*b*) the upright wall of masonry or concrete. Frequently the types are combined. Sometimes the mound predominates

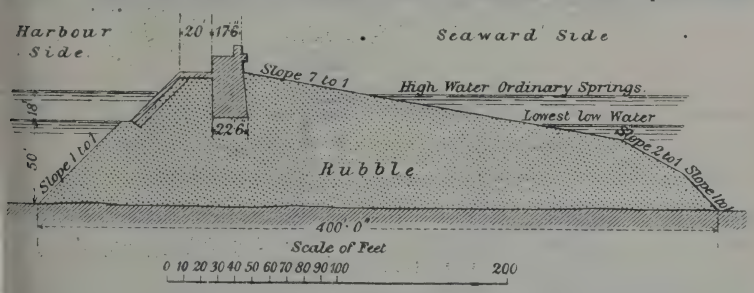

FIG. 1.—Holyhead Breakwater.

and is simply capped by a slight superstructure of regular masonry, as at Algiers and Oran; in other cases it is reduced to a minimum, becoming a mere foundation layer for a wall of massive proportions, as at Ymuiden and Zeebrugge.

The relative advantages of the mound and the wall are as follows:—

1. As regards *efficiency*, the mound is not so serviceable as the wall. The undulations of the sea are transmitted through the interstices of a mass of rubble, and the harbourage area is kept more or less in a state of agitation.

2. As regards *initial cost*, the mound can be formed by unskilled labour, and where that is plentiful and stone abundant, this type of breakwater will commend itself on account of the facility with which it can be constructed. In the absence of these essential conditions, and provided the depth of water be moderate and the foundation sufficiently firm, the wall, involving much less quantity of material, will be found preferable. Especially will this be the case where skilled labour is readily procurable at reasonable rates. Even the difficulty of a defective foundation may be overcome by one or other of several expedients without perceptibly altering the relative positions. But where the sea bottom lies at a considerable depth (40 feet or more) the superior economy of the pure wall cannot be maintained.

CONSTRUCTIONAL COST OF BREAKWATERS.*

Harbour.	Type.	Mean Depth of Water.	Cost per lin. ft.	Remarks.
		Ft.	£	
Alderney .	Composite	90	259	Mound terminates 12 ft. to 15 ft. below L.W.
Algiers. .	Mound	50	122	Large random concrete blocks surrounding rubble.
Dover . .	Wall	40	415	Concrete blocks weighing 26 to 40 tons.
Holyhead .	Composite	54	162	Mound very predominant.
Marseilles .	Mound	35	87	
Bizerta .	Composite	58	60	Wall built on caisson system.
Portland .	Mound	44	127	
Naples . .	Composite	93	186	
Valparaiso .	Composite	60 to 150	560	Concrete monoliths on rubble mound.

An interesting comparison of the estimated (pre-war) cost of four different types of breakwater, based on the conditions at Zeebrugge, Belgium, is made by MM. Bonnet and Braeckman in a paper to the Fourteenth International Congress of Navigation. The depth of the sea bed at Zeebrugge is 26 ft. 3 ins. below zero datum, and the tide rises 15 ft. above zero, giving a total depth of 41 ft. 3 ins. of water. The unit costs per lineal metre (3·28 ft.) are given as follows :—

	Francs.
(*a*) Solid wall of the Zeebrugge type. Total height 66 ft., mean thickness 23 ft.	6,760
(*b*) Composite breakwater with mound of unassorted rubble, the slopes being lightly covered by large natural blocks of 10 cwts. to 6 tons; wall superstructure 33 ft. high	7,600
(*c*) Composite breakwater, mound having core of unassorted rubble, larger material on slopes protected on outer side by artificial blocks of 33 tons deposited haphazard	8,700
(*d*) Composite breakwater with base as before, but with slopes protected by artificial blocks of 31 tons laid symmetrically to inclination	9,000

3. As regards the cost of *maintenance*, this is generally greater in the case of mounds than in the case of walls. A wall, provided it be properly constructed in the first instance, calls for no further attention, save for such rare and occasional damage as results from some storm of

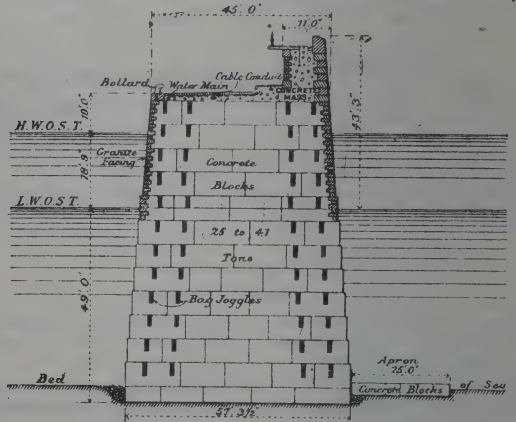

FIG. 2.—Admiralty Pier Extension, Dover.

exceptional severity. The rubble mound, on the other hand, is peculiarly susceptible to wave action, and needs constant replenishment. The cost of this varies very considerably according to situation and exposure. At Holyhead it was for many years as low as 1*s.* 3*d.* per lin. ft. per annum, but latterly there has been some extensive replenishment at considerable outlay; at Genoa, the

* The impossibility of accurately adjusting costs and prices, where they are quoted, to the altered and variable conditions arising out of the war has rendered it advisable to retain them on their old pre-war basis, leaving the necessary adjustments to be made as occasion may require.

cost is stated to be 7*s.*; at Naples, 13*s.*; while at Alderney, during a certain period, it rose as high as 45*s.* This last, however, is quite an abnormal figure, and under ordinary conditions the pre-war annual expenditure on mounds of suitable design hardly exceeded a pound a foot.

Wave Action.

Wave Action.— Wave action on breakwaters is most keenly marked between the levels of high and low water, but it extends to a depth of 30 ft., and there are instances on record of serious disturbances at even greater depths. Thus, at Peterhead, blocks weighing upwards of 41 tons have been displaced at 36½ ft. below L.W.O.S.T. But cases of this kind are exceptional. Generally speaking, at a depth of 5 fathoms the sea is fairly quiescent and a rubble mound may be counted upon to stand therein with side slopes of from 45° to 50°.

Above this level much flatter slopes become necessary : 2, 3, 4, 5, and even 7 to 1. Unfortunately, while the equilibrium of the mound demands such gradual inclinations, they serve also to foster the disruptive action of waves, which, passing up a long seaward incline, have their oscillatory character changed into one of translation. At the summit the impact delivered is so powerful as to produce a pressure which Stevenson records as being six times as great as that against a steep wall. This inimical effect can only be counteracted by the use of huge blocks and monoliths, covering the exposed surface of the mound. The blocks, which in practice rarely weigh less than 25 or 30 tons apiece, and often considerably more, may be deposited either in courses or at random. In the former case they are generally stepped so as to conform to the general inclination. In either arrangement they should be laid as headers, pointing seaward, so as to expose the least extent of surface to wave-action and at the same time gain the utmost

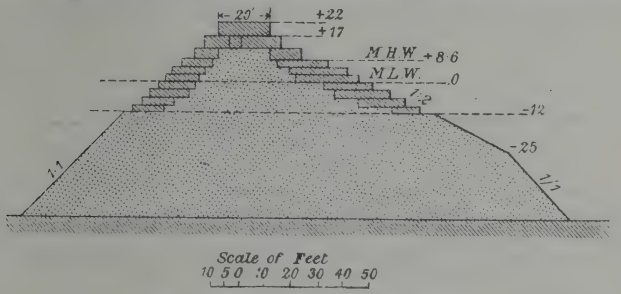

FIG. 3.—Sandy Bay (U.S.A.) Breakwater.

advantage from the moment of resistance to overturning. Hence prisms or parallelopipeds are decidedly preferable to cubes.

The *maximum pressure* exerted by waves does not appear to exceed 3½ tons per sq. ft. At Skerryvore, on the Atlantic, a pressure of from 2½ to 2⅝ tons per sq. ft. has been observed; at Bell Rock, in the North Sea, 1½ ton; at Dunbar (East Lothian) 3½ tons, and at Buckie (Banffshire) 3 tons.

Composite breakwaters, in which the wall plays any important part at all, should be so designed that the *back draught* or *after-tow* of the waves cannot undermine the superstructure. To be really effective, this means that the wall should be carried down to a depth of at least 30 ft. below low water, and though in the past many such walls have been founded at low water level, or very slightly below it, yet the experience gained has proved that this depth is quite inadequate (the low water zone is particularly dangerous), so that of late years there has been a continual tendency towards increasing the depth of the foundation level. At Bilbao the wall commences at 16½ ft. below low water; at Madras 27½ ft.; at Naples 33 ft.; and at Peterhead 43 ft.

Methods of Construction.

Methods of Construction.—Breakwaters are constructed in several ways, according to situation and type.

For **Mound Breakwaters**, rubble may be deposited—(*a*) from barges or scows; (*b*) by means of cranes running on temporary staging; and (*c*) from wagons passing over roads laid at or about the level of the top of the mound and extended as the work proceeds.

The first method is best adapted to sheltered situations, and affords an opportunity of depositing rubble uniformly and simultaneously over the whole site, but it is not practicable to carry on operations in this way at or about surface water level nor above it. Moreover, the progress of the work is very dependent on weather conditions, and there may be long periods of enforced inaction. It is to be noted in passing that irregular deposits of rubble lead to current action and scour. The second method (staging) admits of operations being carried on uniformly over the site, though not with quite the same degree of freedom as in the case of barges. But the advantages of a stable working base with infrequent interruptions and higher degree of safety and

protection for workers, are very pronounced. The damage sustained by timber staging in storms and from the attacks of marine borers are drawbacks which detract from the merits of the system, though, generally speaking, the former is proportionately not a serious matter, and any

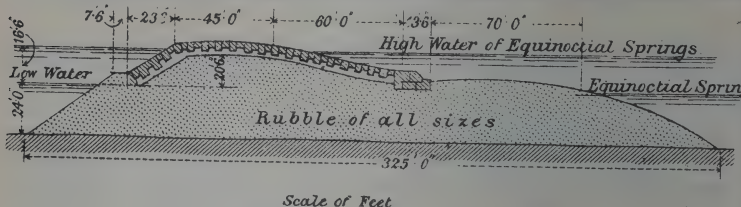

FIG. 4.—Plymouth Breakwater.

evil results of the latter can be to some extent guarded against by careful inspection. The third, or low-level system of construction, by means of tipping from wagons running on tracks laid on the breakwater itself, assists in the consolidation of the work as it proceeds, and saves the cost

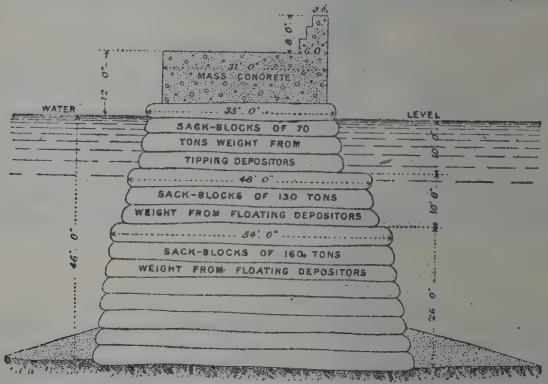

FIG. 5.—La Guayra Breakwater.

of staging, but the area of operation is limited and there is liability to interruption during the prevalence of heavy seas. It is a method more adapted to small embankments, where time also is perhaps not a matter of prime importance.

Wall-Breakwaters.

Walls are constructed either by means of staging, or on the low-level, end-on system: the former being generally more suitable when concrete is deposited in mass, and the latter for blockwork. The blocks, or monoliths, are deposited in place by huge revolving cranes, known as Titans, and overhead travellers known as Goliaths (p. 907). A modern Titan is a powerful cantilever crane capable of dealing with blocks of from 30 to 60 tons weight, at a working radius of as much as 100 ft. A 41-ton steam Titan used on the breakwater at South Shields had a radius of 75 ft., and was carried on 16 central-flanged wheels running on rails set to a 22 ft. gauge. The speeds of the various motions were as follows: Lifting full load, 6 ft. per min.; lifting loads up to 10 tons, 25 ft. per min.; racking full load, 20 ft. per min.; racking loads up to 10 tons, 50 ft. per min.; slewing, one revolution in 4 min. Goliaths are constructed to the same lifting capacity as Titans, and some command a lateral range of travel of 100 ft. or more, but the span is generally limited to about 50 or 60 ft. At Dover, a 42-ton steam Goliath had a range of 130 ft., a clear headway of 25 ft., and a total lift of 120 ft. The speeds of movements were: Lifting, 10 ft. per min.: crab travel, 50 ft. per min.; and main travel, 60 ft. per min.

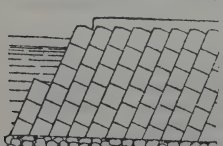

FIG. 6.—Sloping Bond.

Special Methods of Construction.

Special methods of breakwater construction include the use of bags, or sacks, of concrete, weighing from 50 to 200 tons, for deposition under water by divers, as at La Guayra; large caissons, or tanks, of reinforced concrete, with volumes of 60,000 to 70,000 cu. ft., floated out into position, sunk and filled in solid, as at Bizerta; and blocks set on end, slightly tilted (15° to 20°) out of the vertical, so as to form what is called *sloping bond*, the object being to allow for unequal settlement in the foundation. Small breakwaters in shallow waters are sometimes constructed of cribwork—box-shaped frames of timber in openwork with cross partitioning and ties, weighted when in position with rubble—but the system is not very durable and only suitable for comparatively sheltered situations.

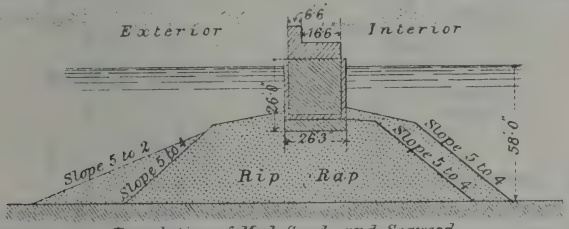

FIG. 7.—Bizerta Breakwater.

DOCKS.

Docks are enclosed repositories for shipping. Where the enclosure is not complete and there is free communication with the sea, the term *Basin*, though not universally employed, is more appropriate. Docks proper are fitted with gates or caissons, either in order to impound the water at a fairly constant level, in which case they are distinguished as *wet docks*, or to exclude the water, in which case they are known as *dry* or *graving docks*. *Floating Docks* are movable structures capable of lifting vessels out of the water and supporting them by their own displacement.

CONSTRUCTIONAL COST OF WET DOCKS.*

(Note: The variety and range of design and equipment render any very effective comparison out of the question.)

	Per acre of Water Surface.		Per acre of Water Surface.
Alexandra Dock, Hull	£28,900	Barry Docks	£12,950
Alexandra Dock, Liverpool	23,300	Prince of Wales Dock, Swansea	18,600
Avonmouth Dock, Bristol	22,600	Queen's Dock, Glasgow	24,450

KING GEORGE V. DOCK, LONDON.

One of the most notable docks constructed in recent years is the King George V. Dock at London, which adds 64 acres to the enclosed water area of the port. The dock has a depth of 38 ft., and the quayage aggregates approximately 10,000 ft. A section of the north, west, and east quay walls is given in fig. 11. An unusual feature on the south side of the dock, shown in fig. 12, is the provision of seven reinforced concrete jetties, each 520 ft. long and 22 ft. wide, which have been constructed at a distance of 32 ft. from the face of the main quay wall, the only shore connection being a timber foot-bridge. The arrangement is due to the fact that a preponderating portion of the goods arriving at the port is transferred to barges for conveyance to their ultimate destination up river. Ships are berthed on the outside of the jetties, and the jetty cranes can discharge goods therefrom either on to the quay for delivery to carts or railway trucks, or for sorting or temporary storage at the sheds behind, or, alternatively, into barges lying in the space between the jetties and the wall.

The entrance lock from the river Thames is 800 ft. long by 100 ft. wide, with a depth of water on the sill of 45 ft. below Trinity high water. The chamber is divided into two compartments, of 550 ft. and 250 ft. respectively, by three pairs of steel lock gates, each leaf of which weighs 309 tons. By the use of a floating caisson, for which provision has been made at the inner end of the lock, the available length can be increased to 910 ft. The cost of the dock with its equipment was about £4,130,000.

* See footnote, page 1520.

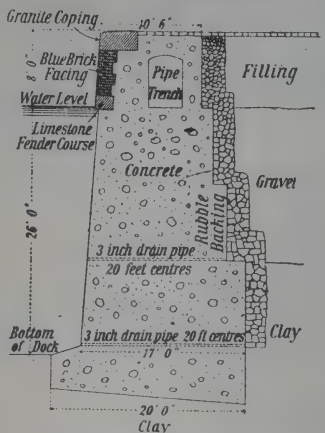

FIG. 8. – Manchester Dock Wall.

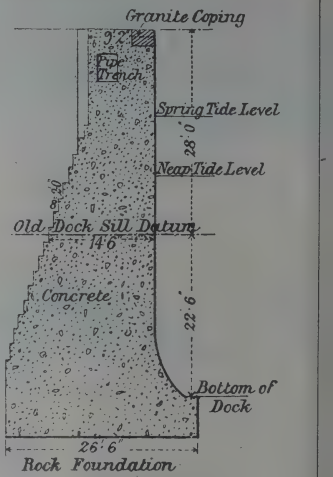

FIG. 10.—Liverpool Dock Wall.

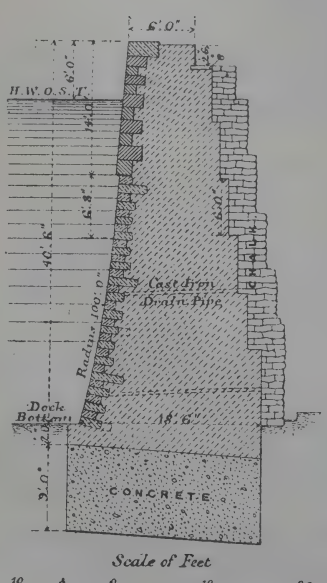

FIG. 9.—Hull Dock Wall.

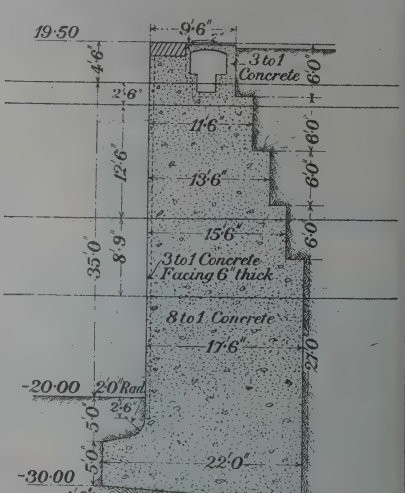

FIG. 11. – King George V. Dock, London: Section of N., E., and W. Quay Walls.

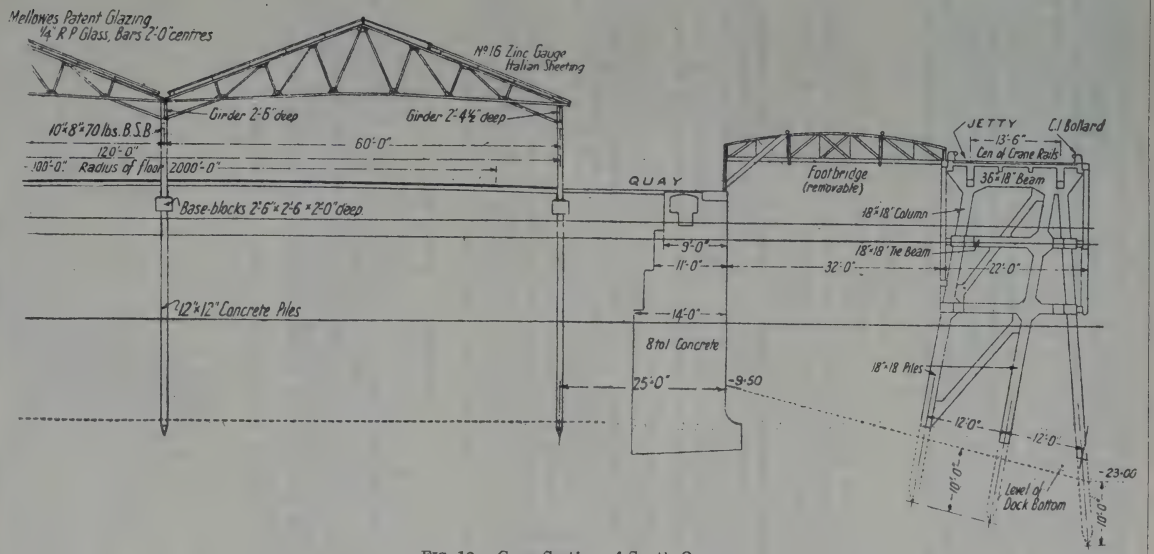

FIG. 12.—Cross-Section of South Quay.

The Gladstone Docks, Liverpool.

Another notable example of recent dock construction is the Gladstone Dock System of the Mersey Docks and Harbour Board, opened to traffic in 1927. It consists of a vestibule, or turning, basin with two branch docks, the whole comprising a water area of 58¼ acres. The vestibule dock is entered from the River Mersey by a lock of outstanding dimensions. It is 1,070 ft. in length and 130 ft. in width, divided into two compartments, with sills 20 ft. below Bay Datum, giving 48 ft. 4 ins. depth of water at H.W.O.S.T., 35 ft. at half tide level, and 22 ft. at L.W.O.S.T. Both the branch docks are 400 ft. wide; one is 1,420 ft., and the other 1,285 ft. long. They are equipped with treble storey sheds of reinforced concrete construction, providing floor areas (including the flat roofs which are designed for light loading) of 32 acres and 23 acres respectively. The system includes a graving dock which is the largest in Europe. The length of the dock from the head to the inner caisson sill is 1,050 ft. 4 ins. The width of entrance is 120 ft. and there is a depth of water over sill of 43 ft. 6 ins. at H.W.O.S.T. This dock has the peculiarity that it can be used as a wet dock, and for that purpose it is equipped with a single storey shed on its north side.

Dock Walls.

Dock Walls.—Under present-day conditions it is necessary for quay walls to possess a perpendicular, or almost perpendicular, face. Ships are now built to a square, box-like section amidships, with vertical sides inclining inwards towards the top. Unless, therefore, there is an absence of batter in the walls, vessels will be unable to lie as closely in contact with the quay coping as is desirable, and quay cranes for loading and discharging them will have to be provided with a greater outreach than is absolutely necessary, at an enhanced cost.

Dock walls are constructed of masonry, brickwork and concrete—nowadays generally the latter, deposited in mass with sometimes a brick or stone facing. There is nearly always a coping course of granite. A toe in front of the wall adds to its stability and prevents any undermining of the foundation. The material forming the backing should be carefully selected so as to admit of proper drainage, and weep or vent holes should be provided in the wall at intervals of 50 feet or so, to admit of water escaping through to the front when the level of the dock is lowered in any way.

The composition of *Concrete* for the hearting of dock walls may safely be put at 8 parts of aggregate by volume to 1 part of sound Portland cement. Of the aggregate the sand while not exceeding 3 times the cement will at least suffice to fill the interstices in the gravel. Stone rubble plums can be used to advantage, provided they are completely bedded in concrete and do not come within 6 inches of each other or the face. The facing of the wall, if of concrete, will be composed of equal parts of gravel, sand and cement.

The *essential features of a quay wall* are weight and resistance to slip. The first is secured by using heavy material and providing ample sectional area; the second by giving a suitable bevel to the surface of the foundation so that it slopes downward from the front of the wall to the back, at the same time taking care that the maximum intensity of pressure does not exceed a certain limit, which, in the case of stiff clay, is 3 tons per sq. ft.; in the case of unconfined sand and gravel, is 2 tons; and in the case of soft, uncertain ground, is 10 cwts. per sq. ft.

Stresses in Dock Walls.

Stresses in Dock Walls.—The calculation of the stresses in a dock wall is a very complex problem, involving a considerable number of elements, the exact determination of which is impracticable, so that they have largely to be based on conjecture. Briefly stated, the conditions are as follows: The wall is subjected to the overturning influence of a wedge-shaped mass of earth which represents the excess of material behind the wall lying above the plane of natural slope of the material. The pressure, of course, is intensified by any surcharge upon the surface area of the wedge. The restraining force is the weight of the wall itself, acting vertically downward, assisted to some extent by the earth backing which may rest upon offsets, if any, at the back of the wall.

In fig. 13, let A B D K G be the outline section of a dock wall.

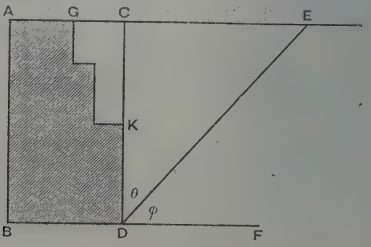

FIG. 13.

Let E D be the plane of natural slope of the ground behind the wall, i.e., the slope which the material would assume if left unsupported. The angle E D F will be designated ϕ and is known as the Angle of Repose.

Let the height of the wall A B be h, and w be the weight per unit volume: and let v be the weight per unit volume of the earth behind the wall.

Then the weight of the wedge of earth behind the wall, tending to overturn it, is

$$\frac{vh^2}{2} \cdot \tan \rho.$$

In order to cover cases where the back of the wall is not vertical and where the surface of the ground is not horizontal, this expression may be written in general terms:

$$\frac{vh^2}{2} \times \text{constant},$$

and the value of the constant, as determined by Professor Rankine in accordance with a theory which neglects any cohesion between the earth particles, is

$$\frac{1 - \sin \phi}{1 + \sin \phi}.$$

The line of action of the overturning force,

$$\frac{vh^2}{2} \cdot \frac{1 - \sin \phi}{1 + \sin \phi},$$

is taken as parallel to the surface of the ground and the point of application at one-third the height of the wall measured from the base.

For simple practical calculations for dock walls where the quay surface is almost invariably

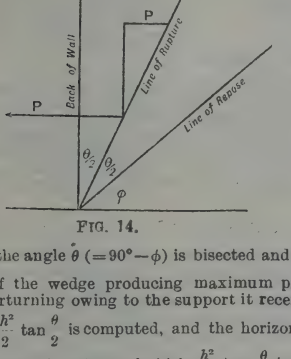

FIG. 14.

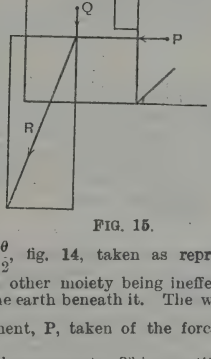

FIG. 15.

horizontal, the angle θ $(=90° - \phi)$ is bisected and the value $\frac{\theta}{2}$, fig. 14, taken as representing the angle of the wedge producing maximum pressure, the other moiety being ineffective as regards overturning owing to the support it receives from the earth beneath it. The weight of the triangle $\frac{h^2}{2} \tan \frac{\theta}{2}$ is computed, and the horizontal component, P, taken of the force acting down the plane of rupture; of which $v\frac{h^2}{2} \tan \frac{\theta}{2}$ is the vertical component. This constitutes the overturning force, which may accordingly be written:

$$P = \frac{vh^2}{2} \tan^2 \frac{\theta}{2}$$

The point of application of P is again at one-third of the height of the wall.

The restraining force Q is measured by the sectional area of the wall A B D G, fig. 13, multiplied by w, together with the sectional area of the earth G K C resting on the wall, multiplied by v, the two acting vertically downwards through their common centre of gravity.

Calling the overturning force P, and the restraining force Q, fig. 15, and completing the parallelogram of forces, the resultant R will be obtained, representing in magnitude and direction the force acting at the base of the wall.

So long as the line of action of R falls within the base of the wall, there is theoretical stability, but, for practical constructional purposes, it is essential:

(1) That the line of action of R should not fall outside the middle third of the base line, and

(2) That the magnitude of R should not be sufficient to crush the base; in which connection it is to be noted that the intensity of pressure increases with the eccentricity of the resultant

(i.e. its distance from the centre) and that when R passes through the limiting point of the middle third of the base, the intensity of pressure on the outer edge is just twice the mean intensity. As a rough practical rule in designing dock walls, the mean width or thickness may be made about one-third of the height. It should never be less than one-fourth. The base width may be about one-half the height, but need never be more than two-thirds.

EXAMPLES OF PROPORTIONS ADOPTED FOR DOCK WALLS.

Port.	Total Height. h	Base Width. b	Sectional Area. A	Mean Width $= \frac{A}{h}$.	Ratios.	
					Base. / Height.	Mean Width / Height.
	Ft.	Ft.	Sq. Ft.	Ft.		
Manchester	38	20	476	12·5	·53	·33
Middlesbrough	48	21	648	13·5	·44	·28
Immingham	51	31	910	17·8	·60	·34
Hull	52	20	736	14·1	·38	·27
Liverpool	55	22	760	13·9	·40	·25
Southampton	71½	39	1,692	23·6	·54	·33

CONSTRUCTIONAL COST OF QUAY WALLS.*

	Height of Wall. Ft.	Cost per lin. yard. £
Albert Dock, Hull	49	58
Albert Dock, London	37½	70
Alexandra Dock, Hull	52	84
Antwerp River Quays	56½	250
Dublin River Quay	42	120
Princes Dock, Glasgow	57½	120
White Star Dock, Southampton	71½	195

Entrance Locks.

Entrance Locks.—During periods when the water in a dock is impounded at a higher level than that of the external water (in some cases continuously), the dock can only be entered through the medium of a lock. The size of lock chambers is governed by the dimensions of the ships making use of them, and these vary at different ports. The largest vessels in existence at the present time are 900 ft. to 950 ft. long by 95 ft. to 100 ft. broad, and they draw from 35 ft. to 40 ft. of water when loaded to their full capacity. No port can claim to be of the first rank which does not receive vessels from 500 to 600 ft. long, with 60 to 70 ft. beam and drawing 30 ft. of water.

Dock Gates.

Dock Gates.—Where the rise and fall of the tide does not exceed about 12 ft. the inducement to provide completely enclosed areas for shipping is not great, but above that limit the necessity for impounding the dock water becomes evident on account of the inconvenience arising from rapid changes of level, frequent alteration in moorings, and chafing against the quayside.

Dock gates are either of steel or wood—in the latter case of greenheart, jarrah, or other hard, heavy, durable timber. Greenheart gates cost more than steel gates—in some cases nearly 50 per cent. more—but their natural durability is very great and the cost of maintenance practically nil. Unfortunately, they are subject to the attacks of sea vermin, and in certain ports considerable trouble has been experienced from this cause. Salt water, especially if contaminated in any way with sewage, is extremely deleterious to ironwork, and the life of a steel gate, under these circumstances, can scarcely be expected to exceed 30 years. Greenheart gates have been found in excellent condition at the end of 50 years.

Stresses in Dock Gates.

Stresses in Dock Gates.—Dock (double-leaf) gates are maintained in equilibrium under the action of four external forces:—(1) the resultant pressure of the water against the back of the gate $= \frac{wh^2}{2}$ per lineal foot of gate, where w (62½ lbs. for fresh, 64 lbs. for salt water) is the weight of a cubic foot of water, and h its height behind the gate. This force acts horizontally at one-third of the height. When there is water on both faces $p = \frac{w}{2}(h^2 - h_1^2)$, and the line of action is

* See footnote, page 1520.

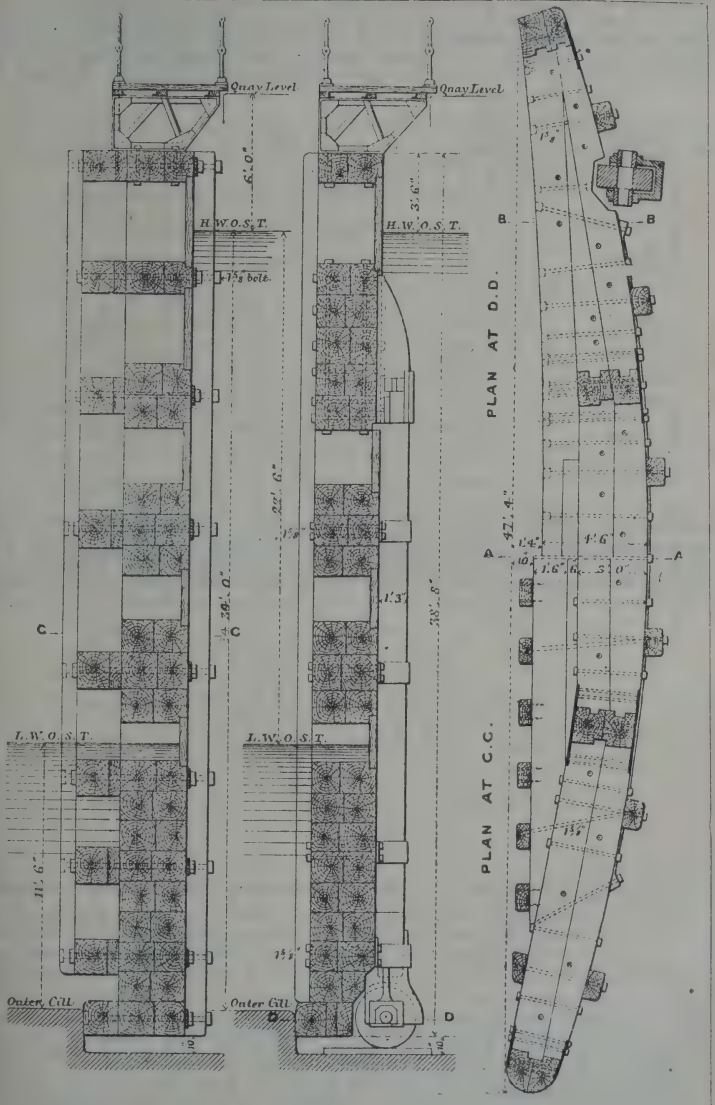

FIG. 16.—Dock Gates. (Timber.)

determined by the centre of gravity of a quadrilateral representing the difference in pressure (2) The reaction of the mitre or meeting posts of the gates acting perpendicularly to the meeting faces, and therefore also perpendicular to the centre line of the waterway. (3) The reaction of the hollow quoins passing through the heel-post of the gate and also through the point of intersection of the other two forces. (4) The reaction of the sill, which is generally neglected.

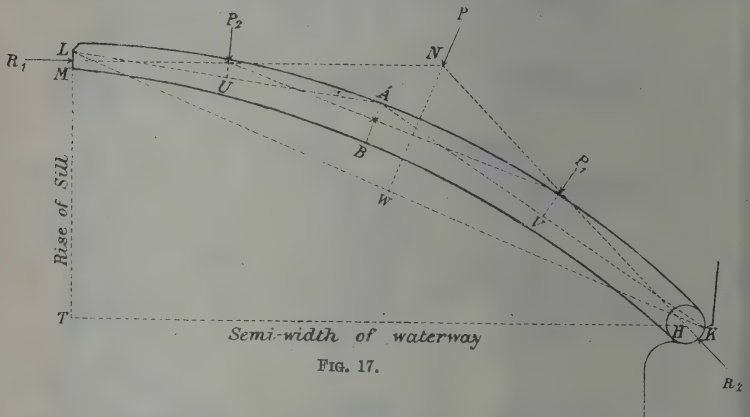

FIG. 17.

Fig. 17 represents the plan of one leaf of a pair of gates. P is the total water pressure upon the back of the leaf, assumed concentrated at its centre. R_1 is the mitre-post reaction of the adjoining leaf, taken as passing through the centre line of the abutting surfaces. R_2 is the reaction of the hollow quoin, assumed to act through the axis of the heelpost. These three forces being in equilibrium, the triangle of forces *ors* (fig. 18) can be drawn, having its sides parallel to

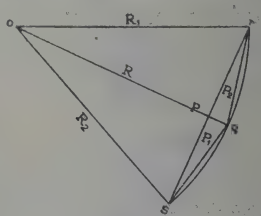

FIG. 18.

the forces P, R_1, and R_2 respectively, and since the magnitude of P is known, the magnitudes of the other two are determined.

If now it be required to find the position and amount of the resultant stress across any section AB (fig. 17) of the gate, the procedure is as follows :—Join the point A to each of the extremities K, L of the water-bearing surface of the leaf; bisect these lines at U and V respectively, and draw perpendiculars to represent the total water pressure on each section. Each section is in equilibrium under the action of these forces : in one case, the water pressure, the heelpost reaction, and the stress across AB; in the second case, the water pressure, the mitre-post reaction, and also the stress acting across AB in the opposite direction. Join the points of intersection of the known forces to obtain the line of action of the resultant pressure at the section AB. Its magnitude may be determined by drawing a parallel line, *qo*, in the force diagram from the point *o* (fig. 18). By taking a series of sections in this way, it will be found that the locus of *q* is sensibly the arc of a circle, and therefore that, except in the case of very flat gates, the resultant pressure is so nearly constant as to be justifiably considered so without serious error.

Rise of Sill.—The 'rise of sill,' MT (fig. 17), varies in different cases from $\frac{1}{4}$ to $\frac{1}{6}$ of the 'span of the gates' or width of waterway. The vicinity of the latter limit is the more common, especially for large cylindrical gates, where a large rise would entail a correspondingly long and deep recess in the side walls.

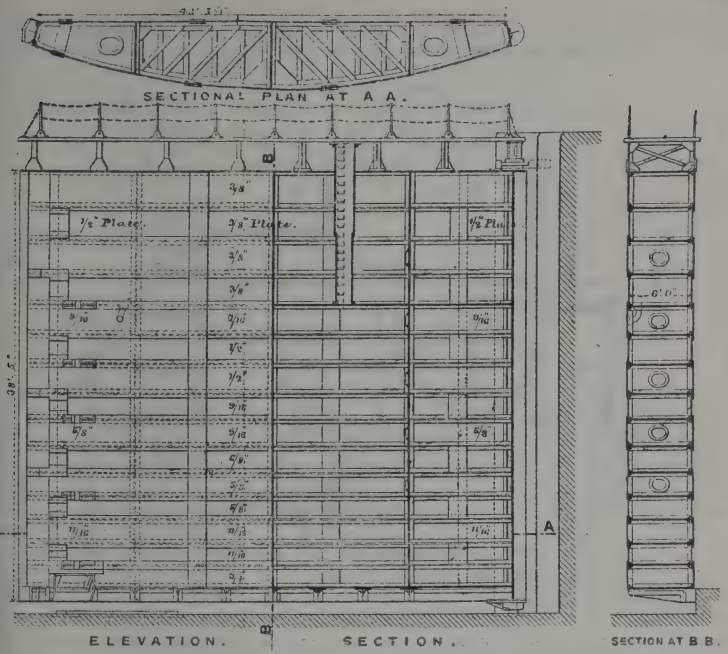

FIG. 19.—Dock Gates. (Steel.)

PARTICULARS OF DOCK GATES.

Port.	Material.	Width of Waterway.	Depth of Water at H.W.O.S.T.	Height of Gates.	Weight of one Leaf.	Cost per sq. ft. of Gate.*	Remarks.
		Ft.	Ft.	Ft.	Tons.	*s. d.*	
Liverpool .	Greenheart	90	39½	44½	165	45 3	
London .	Steel	80	36½	38½	185	—	
Do.	Steel	100	45	38	309	—	
Hull . .	Greenheart	85	34	38½	176	48 0	
Manchester	Steel	65	40	—	—	33 9	Similar Greenheart gates cost 49*s.* 9*d.* per square foot.
Limerick .	Steel	70	23½	26	45	25 3	
Avonmouth	Greenheart, pitch pine and memel	70	38½	48	102	26 0	

CAISSONS.

Caissons are sometimes preferred to gates on the ground that they do not absorb the length of side walls which is required to house gates when a passage is open. Furthermore, although the first cost of a caisson is undoubtedly in most cases greater than that of a pair of gates, yet if the cost of a swing bridge for vehicular traffic, which is a necessary adjunct in the case of gates, be also taken into consideration, the advantage will be found to lie with the caisson.

Caissons are mainly of two types: traversing and floating. Traversing caissons are rectangular boxes with a rectilinear motion either sliding or rolling. When withdrawn from the passage way, they are housed in a special chamber constructed in the side wall. Floating

* See footnote, page 1520.

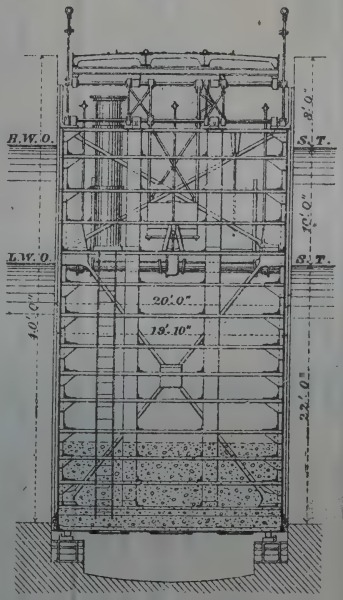

FIG. 20.—Section of Traversing Caisson.

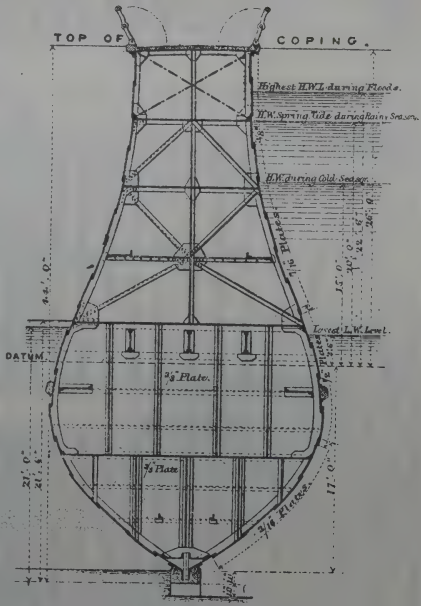

FIG. 21.—Section of Ship Caisson.

caissons are usually ship-shaped, having more or less the form of a navigable vessel, though the curvature of the sides varies very much with the depth of water in which they have to float. Floating caissons are not easy to manage in boisterous weather and strong currents.

PARTICULARS OF CAISSONS.

Port.	Type.	Width of Waterway.	Depth of Water on sill at H.W.O.S.T.	Height of Caisson.	Cost per sq. ft. of Waterway.*
		Ft.	Ft.	Ft.	£.
Quebec	Rolling	62	25½	32	72
Malta	Sliding	94	36½	40½	85·7
Belfast	Ship	80	31	33	35
Barry	Floating	60½	26¾	34½	47·2

QUAYSIDE APPLIANCES.

Quay Cranes.

For general work, quay cranes range in lifting capacity from 1 to 3 tons. The usual capacity is 30 to 40 cwts. It very often happens that the parcels from a ship's hold do not exceed 12 to 15 cwts., and, under these circumstances, a hydraulic crane of single and much higher power than this cannot be worked to advantage, as the consumption of pressure water is the same whether the load be infinitesimal or the maximum. Electric cranes are better adapted to variable loads, since the current consumed is directly proportional to the work done. On the other hand, the initial cost of electric cranes is some 30 to 40 per cent. more than that of hydraulic cranes, and the capital charges (interest and depreciation) are factors of considerable importance in estimating the relative economy.

Crane Types.—Quay cranes are generally movable and include several types.

(*a*) The ordinary crane, with a wheel gauge of 10 to 15 ft. running at quay level.

(*b*) The portal crane, with an arched base spanning one or more lines of railway sidings and admitting of the passage of rolling stock beneath the crane.

(*c*) The semi-portal crane, like an inverted L, with one leg or support running on a rail at quay level, and the back support carried by a rail at a higher level on an adjacent shed structure, the object being the same as in the case of the portal crane.

(*d*) The roof crane, carried entirely on the roof of the shed or warehouse.

Types (*a*) and (*d*) are adapted to cases where there are no sidings and type (*d*) where the shed is situated close to the edge of the quay.

The *cycle of operations* of a quay crane consists of lifting from a hold, slewing, depositing, and returning unloaded, and should, in ordinary cases, where the range of lift does not exceed 50 or 60 ft., be performed in about one minute. A good average under favourable conditions would be 50 cycles per hour; but spread over any lengthy period, this rate could hardly be maintained, for reasons entirely unconnected with the crane.

Speeds of Quay Cranes.—The ordinary speeds of 30 to 35 cwts. quay crane machinery are as follows:—

Lifting, full load	250 ft. to 300 ft. per min.
Lifting, light	350 ft. to 400 ft. per min.
Lowering, full load	400 ft. per min.
Lowering, light	150 ft. per min.
Slewing	one revolution in 25 or 30 seconds.

Luffing Cranes.—It is an important consideration in modern quayside work that cranes should have considerable outreach. Not only is it necessary for them to plumb the hatchways of vessels moored alongside, but in many cases it is desirable to command a barge or lighter beyond. This involves an outreach of 50 to 60 ft. from the face of the quay for even vessels of moderate beam, and entails a luffing or derricking movement of the jib. In view of the obstruction to radial movement caused by ships' yards and stays, the luffing of the crane jib has of recent years become an important feature of crane design. Formerly, the load was unavoidably raised during the inward travel of the jib with a correspondingly unnecessary expenditure of energy and time. This has now been obviated by the introduction of compensating luffing gear by means of which the load is carried at a uniform level throughout its range of travel.

* See footnote, page 1520.

Fixed Quay Cranes.—Fixed quay cranes are provided for dealing with special loads of considerable calibre. The powers provided are generally 5, 7, 10, 12, 15, and 25 tons, with appliances first-class ports ranging up to 150 or 200 tons. The rates of lifting are correspondingly slower about 150 ft. per min. for 5-ton cranes, 30 ft. per min. for 25-ton cranes, and 20 ft. per min. f 50-ton cranes.

(See also ' Wharf Cranes,' p. 909.)

Burtoning.

General cargo is mainly, and in fact almost universally, handled at North American por by a system known as Burtoning, which is the same in principle as the Union Purchase used English ports in conjunction with ships' gear. At American ports, the sheds are equipped wit cargo masts, generally prolongations of the shed front columns, rising to a height of 80 ft. or s above the quay level and supporting a longitudinal girder, or rail, running the full length of th shed. To this rail, at any selected point, a pulley may be attached, worked with a line, o extremity of which is joined, with a similar line from a pulley at the extremity of a ship's boom to the hook carrying the load. Two winches are required for operating: one for each line. Th ship's winch and line serve to lift the load from the ship's hold to deck level; the shed winc then takes charge, and by means of the shed line draws the load overside to the quay, where it lowered to the ground.

Floating Cranes.

Floating Cranes.—For the heavier lifts, floating cranes are often preferred. It is a convenienc to bring the crane to the ship rather than *vice versâ*. Against this must be set the greater initi and working cost of a floating crane. Floating cranes are provided at most first-class ports lifting power ranging from 25 to 100 or 150 tons. A floating crane recently built for a Japanes port has a working load of 200 tons at 105 ft. radius, 100 tons at 150 ft. radius, and 30 tons a 160 ft. radius. The heaviest lifts are performed at the rate of 5 ft. per minute. A revolutio takes 6 to 8 minutes.

A floating crane of 200 tons capacity is among the plant of the Mersey Docks and Harbou Board. It is an electrically-driven, derricking, and revolving crane, 154 ft. in length, 88 ft. i breadth, and 16 ft. in depth. The hoisting speeds vary from 6 ft. per min. for loads of 200 tons to 20 ft. per min. for loads of 60 tons. The highest point of the jib at its highest position is 246 f above the water-line, with a maximum radius for loads of 60 tons amounting to 183 ft., and fo loads of 200 tons, to 110 ft. The vessel is named the *Mammoth*; in conjunction with its outreach it is claimed to possess the largest lifting capacity of any existing floating crane. There are however, two floating cranes of 250 tons capacity at the Panama Canal.

Even for relatively small power lifts (5 tons or less) floating cranes are employed with advan tage at some French ports where the conditions are favourable for their use. The length of th crane pontoons are about 60 ft., a convenient dimension from the point of view of manœuvring the width increases (to prevent transverse oscillation) from 17 to 31 ft. in proportion as th power of the cranes increases from 1½ to 5 tons and the outreach from 25 to 50 ft. The height o the jib pulley varies from 53 to 65 ft. above water level.

(See also CRANE Section, p. 901.)

Transporters.

Transporters.—Where loads are uniform, can be readily handled, and have to be transmitte some distance, a transporter offers considerable facilities for dealing with them at high speeds ranging up to 1,200 or 1,500 ft. per minute. Quayside transporters have generally to be furnishe with hinged cantilever ends capable of being raised when out of action. The travelling motio is not necessarily rectilinear, curved tracks being employed where necessary.

Coaling Appliances.

Shipment of Coal.—Coal is shipped in a variety of ways, principally in this country b means of the hoist and tip or the coaling crane, but also by means of the belt conveyor, perhap more especially abroad. The belt conveyor requires a layout on the quay, which is not alway practicable or convenient in congested areas such as prevail at English docks. The hois raises the wagon to the requisite height and tips it at an angle of 45° or 50°, so that the content pass into a shoot. The crane lifts the wagon bodily, slings it over the ship's hatchway an there empties it. At Cardiff there is an installation on the Lewis-Hunter system by which th wagon, instead of being lifted, discharges its contents into a hopper placed in a pit on the quay and the hopper is lifted by the crane and lowered into the hold, where, being fitted with cone valves it can be emptied within a few inches of the floor. This system is adopted on account of the grea liability of the South Wales coal to breakage and comminution. The protection of coal fro breakage is of such importance that in nearly all cases where coal is tipped from a considerabl height, an anti-breakage crane is provided to lower the first few loads to the bottom of the hold.

Coal wagons in this country are commonly built to contain 10, 12, 15 or 20 tons of coal, an the gross weight ranges from 15 to 30 tons. To this must be added from 6 to 9 tons for th

cradle or platform. Consequently the lifting capacity of a coaling appliance will range between 20 and 40 tons according to the class of wagon dealt with. In certain special cases, as at Goole Docks, provision is made to lift a gross load of 50 or 60 tons, of which up to 40 tons is coal. The coal is brought along the Aire and Calder Canal in tanks, which are floated under the hoists.

In America the size of coaling wagons is very much greater and varies from 40 tons upwards to 100 or 120 tons. At South Wales ports attempts are being made to secure the general adoption of larger-sized wagons (20 ton capacity) than has hitherto been the practice.

The rate of coaling by an ordinary crane or hoist is from 300 to 450 tons and may even reach 600 tons per hour, but it is largely governed by the rate of trimming operations in the hold. The lifting and lowering of the wagons is done at speeds of between 100 and 180 ft. per minute and slewing at about one revolution per minute.

The belt conveyor consists either of a continuous rubber belt or of articulated steel plates. Of the two, the rubber belt has shown itself to be more convenient and more durable than the steel plating, the wear on which is considerable. Rubber belts are run at rates up to 600 or 700 ft. per minute, and they discharge the coal in a continuous stream. The belt is fed by means of a hopper recessed in the quay, into which the coal wagons are emptied. Installations in this country are of moderate proportions, the width of the belt running up to about 48 inches, but in the United States very much larger installations have been effected with belts of 60 ins. diameter. These belts travel up inclined ways to the summit of movable towers, whence the coal is passed on to a transverse belt discharging into the ship. Considerable expedition has been gained by the use of the mechanical trimmer, which is a short, rapidly rotating belt at the foot of the vertical shoot leading into the hold. The speed of the trimmer belt ranges up to 2,000 ft. per minute, and the acquired velocity projects the coal forward into all parts of the hold to distances up to 40 or 50 ft.

Ship's Bunkering.—The foregoing appliances are in vogue in connection with shipping coal cargoes. For the more moderate requirements of ships' bunkers, the loading appliance has generally to be brought to the ship's side, so as to proceed simultaneously with cargo discharging or loading operations. A good deal of bunkering is done by hand, with such primitive assistance as is afforded by baskets, ropes, pulley blocks, and winches, but the rate of coaling under such conditions is very slow and relatively costly—perhaps 2 tons per man per hour. There are a number of special floating machines provided at important ports for doing the work more expeditiously. A typical example, and one of the most modern designs, is the *Suisted Elevator*, built for the company of that name by *Spensers* (*Melksham*) *Limited*, and at work in the port of London. It is capable of handling 300 tons of coal per hour, but such a rate is manifestly only practicable under favourable circumstances; it could not be maintained with trimming operations going on.

Coal Discharge.—For the importation of coal, as also of ore, the grab is perhaps the appliance most commonly in use in this country, as also on a much more gigantic scale at the Lake Ports of North America. As used at English ports, the capacity of the grab runs up to 6 tons, with a total combined load, including the grab itself, of about 12 tons. At the Lake Ports of North America the standard type is a grab capable of taking a load of 12 tons, and the largest can take 17 tons. There is a 'bucket' for clearing up the holds at the close of operations, which when outspread has a span of 24 ft. between the bucket lips.

Grain Elevators.

Grain Elevators.—Grain is handled either by the bucket elevator and conveyor, or by the pneumatic elevator or suction apparatus. The latter has the advantage that the pipes, being flexible, can easily be taken to the furthermost parts of a ship's interior, and that no restrictions are imposed by variations in freeboard and depth of hold. The bucket elevator, though cheaper to construct and requiring less power, is hampered in working by the necessity of ploughing and trimming a preponderant portion of the grain—often as much as 80 per cent.—to the elevator leg. A special gang of competent men is required for the purpose, and this, of course, increases the cost of handling.

It is impracticable to do trimming with a ship's winch at a higher average rate than about 80 tons per hour. Beyond this limit the pneumatic machine becomes more effective, and pneumatic elevators can be constructed so as to give outputs of between two and three hundred tons per hour. On the other hand, conditions at ports are often such that so high a rate of discharge cannot be maintained, operations being governed by the rate of delivery. In practice something like 100 tons per hour is found to be the maximum consistent with effective working.

It has recently been realised that quite small pneumatic plants can be installed in warehouses, mills, etc., with extremely satisfactory and economical results in working. They vary in capacity from 15 to 50 tons per hour, and are generally driven either by the mill shafting or by electric current where available. Convenience in handling, absence of dust and avoidance of trimming are strong points in their favour.

An objection urged against the suction apparatus is that the surface friction of the pipes tends to injure some of the more delicate classes of grain, such as malting barley, but this drawback, for all practical purposes, has been eliminated of late years by the easing of bends and the removal of all internal projections in the pipes. In any case it should not be overlooked that the cutting and driving action of the buckets of a bucket elevator cannot be without some similar attritional effect.

Bucket elevators are either housed at the quayside or are mounted on barges, in both cases being fitted with derrick supports and suspension gear to enable them to be projected forward and set into the ship's hatchway. Elevator speeds generally range between 200 and 400 ft. per minute, but may be as high as 600 ft. per minute. Band or belt conveyors (p. 942) run at 300 to 600 ft. per minute, but for light grain, such as oats, the speed should not exceed 500 ft. per minute.

The development of the pneumatic operation of handling grain has been very marked in recent years. The slow-speed horizontal reciprocating steam-driven suction pumps have been largely superseded by quick-acting vertical pumps driven by internal combustion engines which are coupled direct to the pumps. A further development is the introduction of a multi-stage air exhauster, also driven in many cases by an internal combustion engine through speeding-up gear. This type is perhaps coming mostly into favour, especially where electric power is available.

Timber Appliances.

Timber, as received at ports, is generally divided into the categories of hard wood and soft wood, the former comprising logs of greenheart, teak, oak, etc., and the latter consisting chiefly of deals, battens, and boards of pine and spruce. Logs are handled overside by crane and either floated to timber ponds or conveyed on trollies to storage sites. In Liverpool a special arrangement of tandem axles is employed to which the logs are underslung.

Cargoes of deals may consist of from 150,000 to 300,000 pieces of various sizes and marks. This renders the use of apparatus of the conveyor type difficult and unsuitable, although such appliances have been successfully installed in certain cases. Generally speaking, cargoes of this class are best dealt with by steam cranes of moderate capacity (30 cwts. to 2 tons) which, arranged to run at right angles to the quay front, convey their loads to an adjacent storage ground at speeds up to 600 ft. per minute. The lifting speed is about 160 ft. per minute, and the slewing speed about 1½ to 2 revolutions per minute.

GRAVING AND FLOATING DOCKS.

A modern graving dock is an excavated chamber, two sides, one end and the floor of which are lined, either naturally or artificially, with watertight material, generally concrete with brick or granite facings and dressings. The remaining end is the entrance and is provided with a pair of gates or a caisson. After the entry of a ship, the entrance is closed and the water is pumped from within the dock, though, in certain cases, where graving docks are entered direct from a river or open waterway where tidal conditions prevail, the operation may be assisted, and sometimes be altogether effected, by the fall of the tide.

The floating dock is an open-ended, hollow structure of steel or iron, which, in order to receive a vessel, is sunk to the requisite depth, by allowing its air chambers to fill with water. When the vessel has been berthed, this water is pumped out, the dock rises bodily and so lifts the vessel above the water-line.

It is not altogether easy to make an effective comparison of the respective merits of graving and floating docks, on account of the wide divergence in the conditions to which each structure is specially applicable, and, although there are strong and convinced advocates for the general superiority of one or other of the two systems, a brief summary of the most salient considerations will show that it is scarcely justifiable to decide conclusively in favour of either. Floating docks are almost exclusively adopted at Hamburg, Rotterdam and other Continental ports; in Great Britain there are considerably more graving docks than floating docks.

A graving dock requires a good foundation at a reasonable depth, and a disposition of site which frequently involves the appropriation of a considerable area of valuable land.

A floating dock requires a sheltered position with an adequate depth of water, which, if not obtainable naturally, will have to be gained by dredging. The depth of water to be provided for a floating dock must be sufficient to cover the draught of the ship, the depth of the pontoons and the requisite clearances of a foot or two between keel and blocks and between pontoon and bed. Where there is tidal variation, the amount of this must also be added, if the dock is to be continuously accessible. In this country the tidal range may be anything up to 35 ft., and between 15 and 20 ft. is very general. For a modern ship of average size drawing 28 to 30 ft. of water, the pontoons would have to be at least 20 ft. deep. This means that the total depth of the floating dock berth below high water level would be about 70 feet, and there are circumstances under which dredging to so great a depth would be not merely difficult, but almost impracticable.

In sites where the foundation is defective, the depth of excavation required for the floor of a graving dock may easily equal the depth of the floating dock pontoons, and the difficulties and expense in these cases are just as pronounced.

The utility of a graving dock is measured by the linear dimensions of the largest vessel which it can accommodate. The weight of the vessel is relatively a matter of little or no importance.

On the other hand, the utility of a floating dock is gauged by its maximum lifting capacity and is independent of the exact size of the vessel. Floating docks can, and often do, take vessels

many feet in excess of their own length and, in the case of one-sided docks, in excess of their own width.

The size of the entrance of a graving dock is influenced by the cost of the gates, or caisson, to be used for closing it, and by the greatest width that can safely withstand the pressure of water. In floating docks these considerations do not enter into account.

Relative Costs of Graving and Floating Docks.*

Initial Cost.—The initial cost of graving docks, including pumping and general equipment, measured in terms of their serviceable dimensions (i.e. internal length by breadth of entrance by depth of water over blocks or sill), has varied from 1*s.* 3*d.* to 3*s.* 6*d.* per cubic foot, and, in a rough-and-ready way may fairly be taken for a modern concrete and granite dock of ordinary size, constructed in this country under normal conditions, on a pre-war basis, at 2*s.* per cubic foot.

The cost of floating docks is usually measured in terms of their lifting power, and varies inversely as the size of the dock, ranging from about 14*l.* per ton for a dock which would take small coasting ships to about 6*l.* per ton for one to take large Atlantic liners.

As regards time of construction, a graving dock of any importance could hardly be completed within less than eighteen months or even a couple of years, whereas a floating dock could be ready in half the time. The floating dock could, moreover, be constructed in any convenient locality and transported to its destination at some additional expense for towage and insurance. Many floating docks for the colonies are constructed in home shipyards.

Durability and Upkeep.—A stone or concrete graving dock is practically indestructible, and the only charge brought against it, in this respect, is that of outlasting its utility and becoming obsolete. This is, no doubt, true in regard to the class of vessel for which it is constructed; but, on the other hand, when the growth of shipping has left the graving dock too small for the larger vessels, it is still utilisable for those of smaller size. With the exception of the expenditure on the gates or caisson, which close the entrance, there is practically no maintenance outlay. It is all probably covered by an allowance of ½ per cent. per annum.

The life of a floating dock, considered as an iron or steel structure constantly afloat, will vary with its situation, some waters being more destructive than others. It may be fairly reckoned at from 40 to 50 years, and there is no reason why, with reasonable care and attention, the longer period should not be exceeded. The annual cost of maintenance estimated from several existing examples lies between 1 and 1½ per cent. of the capital outlay. Any cost of dredging required to keep the berth clear of mud deposits must be added to this allowance.

Working Cost.—The amount of pumping to be done in the case of a graving dock generally greatly exceeds that in the case of a floating dock—it may be as much as 3 or 4 times. In a floating dock only so much work is required to be done as is necessary to raise the vessel and the deck of the pontoon above water level. The graving dock chamber, on the other hand, has always to be completely dewatered, no matter what may be the size of the vessel occupying it and the smaller the vessel the greater the quantity of water to be pumped.

Small graving docks on the banks of a tidal river, in cases where time is unimportant, may be emptied of water by natural means. These cases are exceptional.

But even in the larger docks the cost of pumping is small in comparison with the capital charges. For one hundred dockings a year they probably do not amount to more than 10 or 12 per cent. of the whole annual expenditure.

Again, the pumps being only intermittently employed, one pumping station may be made to serve two graving docks, whereas each floating dock requires its own installation. Possibly an extra hand or two is also needed to attend to the valves of the floating dock in order to maintain an even keel during pumping operations, but generally all the valves are worked from a central position.

As regards general adaptability, floating docks have the advantage, already pointed out, of mobility, and they may be transferred from one port to another, whenever the circumstances require. This has already been done on several occasions to fall in with altered trade conditions, or for purposes of war.

A floating dock can be trimmed to take a vessel having a list which conceivably might interfere with its passage through a graving dock entrance with vertical sides. This operation was frequently performed during the war.

The mobility of a floating dock is not free from certain drawbacks. The dock may founder or be wrecked.

All these varying considerations point to the conclusion that there is scope for both graving and floating docks, and that each may be employed to better advantage than the other under some particular set of local conditions.

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* See footnote, page 1520.

SOME OF THE LARGEST FLOATING DOCKS IN THE WORLD.

Location.	Lifting Capacity.	Length.	Inside Width.	Depth of Water over Keel Blocks.	Owners.
	Tons.	Ft.	Ft.	Ft.	
Southampton	60,000	960	130½	38	Southern Railway Co.
Singapore	50,000	855	132	40	British Admiralty.
Rotterdam	46,000	695	142	35	Wilton's Eng. & Slipway Co.
Hamburg	46,000	550	120	30	Blohm & Voss.
Malta	65,000	962	140	38	British Admiralty.
Devonport	33,000	680	113	36	Ditto.
Hamburg	33,000	471	120	30	Blohm & Voss.
Portsmouth	32,000	680	113	36	British Admiralty.
Nikolaieff	30,000	558	136	30	Soviet Government.
Brooklyn, U.S.A.	30,000	685	100	31	Morse Dry Dock Company

THE SOUTHAMPTON FLOATING DOCK.

The following particulars are extracted from a paper read before the Institution of Civil Engineers in January 1925, by Dr. E. H. Salmon (*Min. Proc. Inst. C.E.*, vol. 219) :—

Weights and Lifting Power.—The total net estimated weight of the dock in its final form was 18,990 tons, made up as follows :

	Tons.
Steelwork in hull, including mooring-booms	16,482
4½ per cent. for rivets	741
Joint bolts	17
Machinery	404
Fittings	736
Timber	407
Cranes, crane-rails, and collecting gear	183
Stores and spare gear	50
Proportion of weight of brow and moorings carried by dock	33
	19,053
Less half-weight of mooring-booms	63
Total	18,990

The above weight does not include any allowance for overweight and extras. From measured displacements of the finished dock its actual weight was found to be 19,330 tons. The displacement of the pontoon at Southampton (density of water = 35·09 cubic feet per ton) is 81,840 tons. At the conclusion of the test made to determine the lifting power of the dock, 1,530 tons of water remained in the pontoon. The true lifting power of the dock, therefore, is 81,840 — 19,330 — 1,530 = 60,980 tons.

Cost.—The original contract price for the dock delivered at Southampton was £375,000. The corresponding price of the steelwork in the hull comes to £17 per ton; the machinery, about £120 per ton; the fittings, about £32 per ton; and the timber, £22 per ton. A number of extra fittings over and above the original contract have been added, somewhat increasing the total cost of the finished structure. The above figures include the dock proper and mooring booms, but not the shore work, nor the preparation of the site.

Notes on Floating Docks.

(Contributed by Swan, Hunter, & Wigham Richardson, Ltd.)

The development of different types of floating docks in this country is largely due to Messrs. Clark and Standfield, Westminster, who have designed docks of almost every kind, and for service in many parts of the world.

Floating docks may be conveniently divided into two classes : (*a*) those which are not self-docking, or 'box docks,' and (*b*) those which can be self-docked.

(*a*) The *box dock* is double sided and of ⌊ ⌋ section. It has two side walls, and is the only form of modern floating dock which cannot be divided into more than one part for the purpose of self-docking. The two side walls and the bottom pontoon are one permanent structure. Box docks of great size have been built; for instance, the British Admiralty floating dock of 33,000 tons lifting capacity built at the Wallsend Shipyard and stationed at the River Medway.

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(*b*) By a 'self-docking' type is meant a dock divided into sections any one of which can be lifted on the remainder of the dock for painting or repairs. The following are some of the various types of self-docking docks: the *Bolted-Sectional*, the *Sectional Pontoon* or *Rennie*, the *Off-Shore*, the *Havana*, the *Sectional Box*, the *Multi-Sectional*, and the *Depositing*.

The *Bolted Sectional Dock* combines the advantages of the great longitudinal strength of the '*Box*' type with facility for self-docking. This type is usually built in three sections of approximately equal lengths, the two end sections being stepped to form landings when carrying out a self-docking operation.

Fig. 22 shows, firstly, the whole dock assembled; secondly, the centre section lifted by the two end ones; and thirdly, one of the end sections lifted by the centre and other end section. Examples of the former type of dock may be seen at Port of Spain (Island of Trinidad), Rotterdam, at Callao in Peru, and at Sténia in the Bosphorus. (See fig. 27, page 1541.)

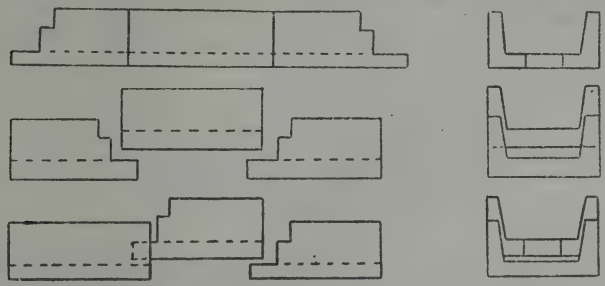


FIG. 22.—Bolted Sectional Floating Dock.

The Sectional Pontoon Dock (also called 'the Rennie Dock,' after its inventor), consists of a number of separate pontoons lying transversely to the length of the dock. Upon these pontoons and bolted to them rest two continuous side walls. The length of each pontoon, i.e. on the keel line, is such that when detached from the rest of the dock it can be passed end-wise between the walls of the latter and so lifted in the same manner as a ship. Each pontoon can be successively dealt with in the same manner. Fig. 23 shows first the whole dock assembled and then

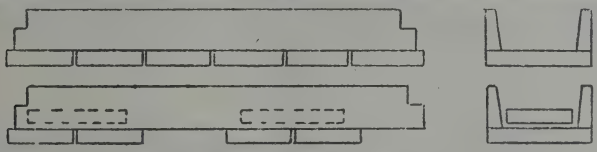


FIG. 23.—Sectional Pontoon Floating Dock.

two of the pontoons lifted by the remainder of the dock. This *Sectional Pontoon* type is very suitable for vessels of moderate dimensions, and owing to its form can easily be constructed in places where docks of other types could not be completed. The separate pontoons not being very large in size can be easily erected and launched, after which the walls can be built upon them. Examples of this type of dock were built at Wallsend-on-Tyne for the Government of Southern Nigeria, and for service at Saratov on the River Volga.

The Off-Shore Dock is an ingenious design patented by Messrs. Clark & Standfield in 1884; a well-known example of it was built at Wallsend-on-Tyne for a ship-repairing establishment at

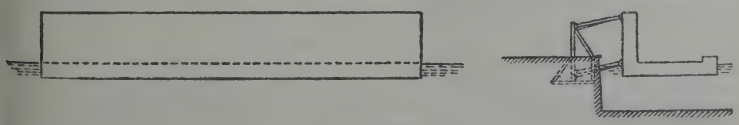


FIG. 24.—Off-shore Floating Dock.

Sunderland, and there is another good example of it also constructed by Messrs. Swan, Hunter, & Wigham Richardson, Ltd., at Penarth, near Cardiff. The off-shore dock (fig. 24), of which the end elevation is 'L' shaped, is very easily handled. The side wall is connected to the

shore by booms or girders hinged at each end. When the dock is sunk to receive a vessel the latter can enter the dock from either end or may be warped in sideways. It is then rapidly centred by telescopic side shores and supported underneath by mechanical bilge-shores. This type of dock is divided into two sections, and as it has only one wall one-half of the dock can be lifted, so to speak, in the lap of the other. Fig. 26 on this page illustrates the self-docking operation.

The *Sectional Box Dock* (fig. 25) combines the advantage of ease and simplicity in self-docking possessed by the Sectional Pontoon dock, with the strength of the solid or *Box* dock. The dock is divided, like the ordinary sectional dock, into sections of such a length that any one section can be

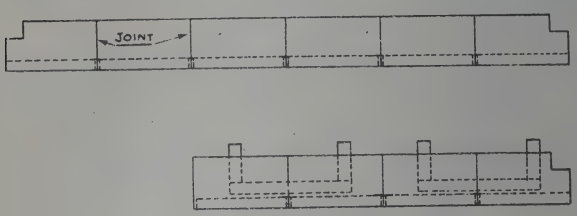


FIG. 25.—Sectional Box Dock.

turned round 90 degrees and docked on the rest of the dock. In the Sectional Box dock, however, the sections are all joined together by a strong, rigid joint of a similar type to that used in the bolted sectional docks running round the whole profile of the dock.

The *Multi-Sectional Dock* is a modification of the Sectional Dock type. In small docks it is not necessary to connect the bottom plating right across the width of the pontoon. The joints at the sections only occur, therefore, round the profile of the side wall, the spaces between the pontoons being decked over to form a continuous platform.

The *Depositing Dock* was designed as early as 1877, by Messrs. Clark & Standfield. In section it is 'L' shaped. The single side wall is continuous, but the bottom pontoon is made up of a series of 'fingers' with spaces between them (fig. 26). The necessary stability is given to the dock

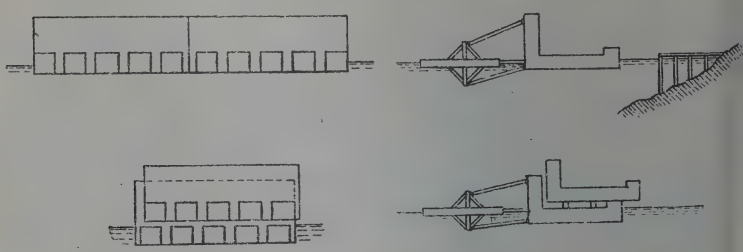
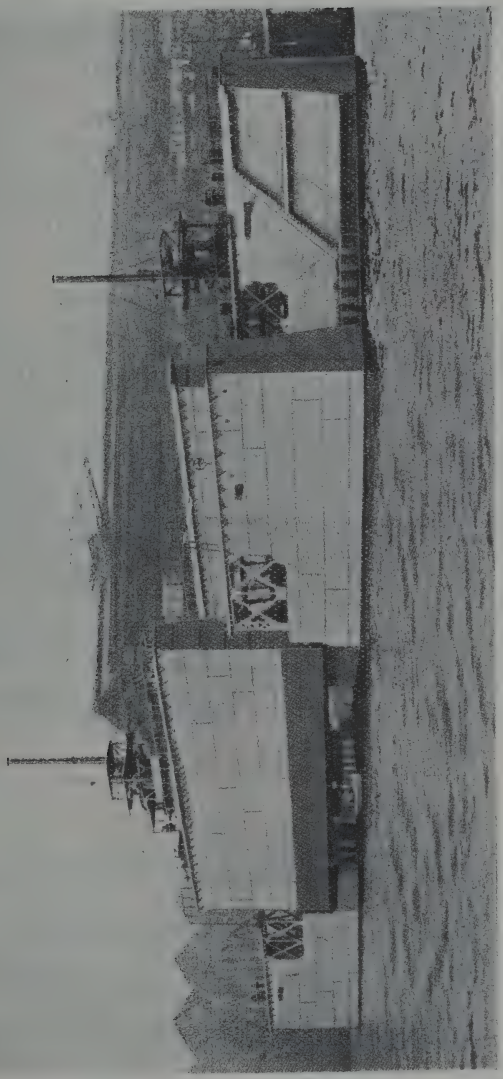


FIG. 26.—Depositing Floating Dock.

by means of parallel booms hinged at each end and connected to a floating outrigger. This type of dock can not only dock vessels, but owing to the peculiar construction of the bottom pontoon is enabled to deposit them on a gridiron formed by groups of piles. There are spaces between each set of piles of such a width as to admit the 'fingers' of the dock. The dock carrying a ship is pushed forward so that the 'fingers' are engaged between the piles and then on sinking the dock the ship is left upon the gridiron. The wall of the dock is divided into two equal lengths either of which can be docked by the other as in the case of the off-shore type.



FLOATING DOCK.

FIG. 27.—Bolted-Sectional Dock.

(Built by *Swan, Hunter, & Wigham Richardson, Ltd.*, Wallsend-on-Tyne, England.)

Self-docking operation; centre section lifted by the two end-sections.

Depositing docks at Kobe and Barcelona have been used for the purpose of lifting large, hollow ferro-concrete blocks for harbour construction. These were built upon the depositing grids, lifted off by the dock, and finally floated off so that they could be towed to their final position and sunk there. In the case of the Kobe dock, some of these monoliths were 120 ft. long by 41 ft. high, and weighed as much as 2,200 tons. In this way the difficulty of launching such large masses was avoided and much expense saved.

DREDGING.

Modern dredging appliances may be summarised under two classes, each with several subdivisions.

Class I.—Digging dredgers, comprising (*a*) the ladder, or elevator, dredger, with a continuous band of buckets; (*b*) the dipper dredger, with a single bucket at the extremity of a long arm, or lever; and (*c*) the grab or grapple dredger, with a drop bucket suspended at the end of a chain.

Class II.—Suction or hydraulic dredgers, comprising (*a*) the sand pump; and (*b*) the suction cutter dredger.

Rock cutters are not dredgers, but constitute an auxiliary class which will be treated separately.

Ladder Dredgers.

Ladder Dredgers, or Elevator Dredgers (sometimes in Europe called bucket dredgers), are characterised by high power and great serviceability under nearly any conditions. They are adaptable to the removal of every variety of material except the harder kinds of rock. The principle upon which they are constructed is that of an endless chain of buckets travelling in an elliptical path about two pivots, or tumblers, set one at each extremity of an inclined plane. The buckets excavate material at the lower tumbler and discharge it into a shoot while passing over the upper tumbler.

Single Ladder v. *Double Ladder Dredgers.*—Dredgers of the ladder type have either one or two ladders. In single ladder dredgers, the ladder is situated along the centre line of the vessel; in the other case, the ladders are placed at each side.

Single ladder dredgers are most in favour for ordinary operations. In machines of the same power, they have the advantage of few working parts and of less working friction. As seagoing craft, they possess a more convenient outline, and their lesser width enables them to pass through narrower waterways and lock chambers. But they cannot work so closely to a quay wall as side ladder dredgers, and, if any breakdown occurs in the chain of buckets, the whole dredger is thrown out of action, whereas, with the double ladder dredger, this is not necessarily the case.

Capacity of Ladder Dredgers.—The capacity of the buckets of ladder dredgers ranges from 5 to 54 cubic ft., but, generally speaking, about 35 cubic ft. is looked upon as the maximum size consistent with convenient utility. A moderately sized dredger, with buckets of 20 to 25 cubic ft. capacity, travelling at speeds from 15 to 20 ft. per minute, and working in water of depths up to 50 ft., may be expected to raise from 400 to 500 tons of stiff clay per hour; in suitable material, such as ballast and gravel, the rate obtained may be as high as 1,000 tons per hour. The most powerful dredgers can double this performance.

Examples of Ladder Dredgers.—The following particulars relate to the 'Corozal,' built in 1911 for the U.S. Government, for work on the Panama Canal:—

Dimensions.	Ft.
Length on load water line	239
,, between perpendiculars	259
,, over all	268¾
Breadth moulded	45
Depth moulded	19½
Draught fully loaded	15½

Propelling speed: 10 knots.

Dredging capacity: 1,200 cubic yds. of mud and sand per hour.

Buckets: Two sets; one of 54 cubic ft. capacity for soft material and one of 35 cubic ft. for stiff clay.

Maximum dredging depth: 50 ft.

The vessel is a hopper dredger, i.e. she discharges into herself instead of into an independent hopper ranged alongside.

The 'Silurus,' built by Messrs. W. Simons & Co., Ltd., Renfrew, is a twin-screw bucket hopper dredger of the following dimensions:

	Ft.
Length between perpendiculars	260
Breadth moulded	46
Depth moulded	20

Propelling speed	8½ knots.
Dredging capacity	2,200 tons per hour.
Buckets, two sets	one of 42 cu. ft. and one of 22 cu. ft.
Maximum dredging depth	50 ft.
Hopper capacity	1,500 tons.

Utility of Ladder Dredgers.—Although the serviceability of ladder dredgers does not extend to the removal of hard rock, yet they are capable of scraping away the surface of the softer varieties of sandstone and chalk, and, for this purpose, the bucket edges are sometimes fitted with spikes or tines. A ladder dredger works admirably in marl and stiff clay, and no difficulty even is found in dealing with heavy boulders which are frequently encountered in clays of glacial formation. The buckets of a first class dredger will readily lift stones weighing from 30 cwts. to 2 or even 3 tons apiece, bringing them up to the surface and within the range of a deck crane. As illustrative of the character of the material dealt with in many cases, the following particulars may be cited, relating to twelve months' work on the river Tees. A quantity of 417,963 cubic yds. was dredged at a cost of 22,432*l.*, equivalent to about 1*s.* 6¾*d.* per cubic yd. About two-thirds of this was hard, boulder clay and there were removed therefrom 1,651 stones, varying in weight from 5 cwts. to 4 tons apiece, of which 1,523 were raised by the dredgers unaided by divers; and, in addition, there were 19 tree trunks, ranging in length from 10 ft. to 20 ft., 16 tree roots and stumps, and 107 miscellaneous obstructions.

Dipper Dredgers.

Dipper Dredgers.—The dipper dredger is almost purely an American type, and has not yet been found in Europe. It is mainly employed on the great lakes of the Northern Continent of America, and on river beds and channels when the working depth does not generally exceed 20 ft. or so, and where space for manœuvring is somewhat restricted. This is accountable for by the fact that the dredger is not manipulated by chain moorings, as in the case of the ladder dredger, but is maintained in position by vertical spuds, or posts, which pass down through the vessel to the bottom of the channel, and are raised and lowered as occasion may require. The dipper arm itself assists in manœuvring, being allowed to remain on the bottom while the position of the spuds is changed.

Capacity of Dipper Dredgers.—The single bucket, or scoop, at the end of the lever arm has a capacity ranging from 1 to 12 or 15 cubic yds. The bucket is operated in a curved upward sweep by suitable gearing, on the same principle as a steam navvy or land excavator. The speed of a good dipper dredger in sheltered inland waters is from 30 to 40 seconds per dipper load, and on the sea coast from 40 to 50 seconds. For hard material, the bucket, as in the case of the ladder dredger, is fitted with teeth.

Examples of Dipper Dredgers.—The following particulars relate to a very large dredger, the 'Onondaga,' which worked in New York Harbour:—

Length of hull	140 ft.
Breadth ,,	50 ft.
Depth ,,	15 ft.
Capacity of dipper bucket	12 cubic yds.
Dredging depth	50 ft.

Size of dipper arm: 80 ft. long by 36 ins. square.
Spuds: Four timbers, 80 ft. long by 5 ft. square.
The dipper arm and spuds are both of Oregon fir.
Engines: Double cylinder, condensing.
Cylinders: 20·5 ins. diameter by 24 ins. stroke.

Another instance of a dipper dredger at Montreal Harbour:—

Length of hull	90 ft.
Width ,,	36 ft.
Depth ,,	10 ft.
Capacity of dipper bucket	7 cubic yds.
Dredging depth	40 ft.
Diameter of hoisting rope	2¼ ins.
Maximum pull on dipper	120,000 lbs.

Forward spuds: Single timbers (Douglas fir) 60 ft. by 42 ins. square.
Engines: Double cylinder (16 ins. by 18 ins. stroke) non-condensing.

Two dipper dredgers, the 'Gamboa' and the 'Paraiso,' each with buckets of 15 cub. yds. capacity, were built by the Bucyrus Co. in 1914 for work on the Panama Canal.

These dredgers have a displacement of about 1,500 tons, and the hulls, which are of steel, have an over-all length of 136 ft., a width of 44 ft., and a depth at bow of 15½ ft. and at stern of 13½ ft. Each dredger has two dipper buckets, the larger, of 15 cub. yds. capacity, for soft material, and the smaller, of 10 cub. yds. capacity, for harder material. The buckets, of ¾ in. plate, have lips of manganese steel, 2 ins. thick, which are 50 ins. deep at the centre, reduced to 9½ ins. at the back edges. They have no teeth. The handles are of Oregon fir, 72 ft. long.

The rate of working is said to average 6,000 cub. yds. per day each, in two 8-hour shifts.

A dipper dredger at work in Bombay Harbour has a bucket capacity of 6 cub. yds., dredges to a depth of 40 ft., and is capable of lifting boulders of over 12 tons weight.

Comparison of Dipper Dredger with Ladder Dredger.—Compared with the ladder dredger the dipper dredger is not quite so serviceable a machine for all-round purposes, and, for the more intractable kinds of material, it has been demonstrated that the former is more efficient than the latter. Thus, in excavating a channel in indurated clay in the St. Lawrence River, dipper dredgers of the most powerful design failed and were replaced by a ladder dredger which completed the work in a satisfactory manner.

The Grab or Grapple Dredger.

The Grab or Grapple Dredger has a bucket which consists of two or more curved plates, or jaws capable of opening and closing under the action of suitable gear. The grab is suspended from the jib head of a crane which does the requisite raising and lowering. The working is actually done very largely under the influence of gravity, the bucket being allowed to fall with open jaws under its own weight and to bury itself in the ground, where the jaws are closed and the bucket with its contents is then withdrawn. The principle of the grab is simple, but there are many complex adaptations in practice. Thus, the appliance may be worked by one or by two chains, each of which arrangements admits of several variations, so that there are quite a number of different machines on the market, each possessing special characteristics and advantages.

Comparison of Single and Double Chain Grabs.—The drawback of a double-chain grab is that it cannot be fitted to an ordinary crane; but, on the other hand, it has less intricate and less delicate mechanism, and, consequently, does not run the same risk of getting out of order. With two chains, moreover, there is less likelihood of the bucket being lost through fracture of the hauling gear. There is the further consideration that in many, if not most, single-chain grabs, the full height of lift has to be made before the grab can be opened in order to discharge its contents. Double-chain grabs can discharge at any stage of the lift. This advantage is shared by a few of the single-chain systems. Its importance lies in the fact that the grab might close upon some immovable object below water, and therefore necessitate the sending down of a diver, unless the jaws can be opened mechanically in that position.

Utility of Grab Dredgers.—The grab is not a suitable appliance for extensive operations. It is best adapted to dealing with material in confined and awkward situations inaccessible to other types of dredger. It is thus excellently suited for the removal of mud and silt in the vicinity of dock entrances and passages. Silt is generally of so impalpable a character that any disturbance of the water in which it lies causes it to rise in suspension, and renders it difficult of removal. The grab proves a most effective appliance for dealing with this soft material, entrapping it with the least admixture of water and the least alteration in consistency. Moreover, the grab is an extremely convenient implement for picking up miscellaneous articles which find their way to the bottom of docks; logs of hard wood, rails, coal, bales of hay and wool, barrels of nails and cement, hoop iron, etc.

Capacity of Grab Dredgers.—Grabs are constructed of a capacity up to 10 cubic yards, but for general purposes the most useful size lies between 70 and 120 cubic ft. They work very successfully in water up to 50 or 60 ft. in depth, at a speed of about one dip per minute, raising in this way from 150 to 250 cubic yds. per hour.

Examples of Grab Dredgers.—Several excellent examples of this class of dredger are constantly at work in the Liverpool docks. The grabs are mounted on barges of 1,100 to 1,400 tons hopper capacity. There are four 5-ton or 7-ton cranes of 16 ft. and 19 ft. radius respectively on each barge, each actuating a grab of 70 or 115 cubic ft. capacity. The principal dimensions of the vessels are:—

1,100 ton barges	200 ft. long by 35 ft. beam by 15½ ft. deep.
1,400 ton barges	225 ft. long by 38½ ft. beam by 16 ft. deep.

The speed of the barges is about 11 knots.

Bag and Spoon Dredging.—This notice of dredging appliances would be incomplete without some reference to a very rudimentary form of apparatus still practised in restricted areas and where operations are on a small scale. This apparatus consists of a strong leather bag of a capacity of from one-half to one cubic yard attached to a steel rim at the end of a stout spar, or pole, from 20 ft. to 35 ft. long. The bag is kept at the bottom by means of the pole, while it is drawn along the surface by a line attached to the rim. The operation is performed by manual labour, and about half a dozen men are required to man a barge for the purpose. The quantity raised and loaded into the barge will range from 60 to 100 cubic yds. per day. The appliance is really only suitable for dealing with mud in timber ponds and in canals.

Suction or Hydraulic Dredgers.

Suction or Hydraulic Dredgers.—Turning now to the second class of dredging plant, the suction or hydraulic type may be described as consisting essentially of a continuous pipe, or tube, through which material is drawn up by suction from the bottom and discharged either into a hopper or through a long pipe line to a depositing site some distance away. The first application of the principle was to the removal of sand—hence the name Sand Pump—but it has since had a much wider application. As regards sand, the method proved extremely effective from the first, the light granular nature of the substance lending itself admirably to easy incorporation with the body of water flowing into the pump intake. Such difficulty as has been experienced has been merely in regard to securing the deposition of the sand within the hopper, the tendency being for a large proportion to flow out over the sides with the escaping water. Considerable reduction in this unremunerative pumping has been made by giving the effluent stream as long a distance to travel as possible and providing the channel with adjustable coamings.

Sand Pump Dredgers.

Sand Pump Dredgers.—For the purposes of suction dredgers, centrifugal pumps are universally employed, and of these, those with a single inlet have an advantage over pumps with a double inlet, in that there is less concussion and interference with the flow. A double inlet pump, on the other hand, disposes of any question of balancing, which has to be met in a single inlet pump by thrust bearings. The most efficient peripheral speed is stated by the Mississippi River Commission to be about 50 ft. per second. The form of the nozzle of the intake pipe materially influences the percentage of sand raised which may be anything up to 50.

Examples of Sand Pump Dredgers.—The largest sand pump dredger in existence at the present day is the 'Leviathan' of the Mersey Docks and Harbour Board. Her dimensions are 465 ft. 9 ins. long between perpendiculars, by 69 ft. wide by 30 ft. 7 ins. deep moulded. She is fitted with four suction pumps, each of 42 ins. diameter, and is capable of filling herself with 10,000 tons of clean sand in 50 minutes from a maximum depth of 70 ft. The speed of the vessel is 10 knots. On arrival at the depositing ground, she discharges herself in 10 minutes through large cylinders extending from valve openings, 5 ft. 6 ins. diameter, in the bottom of each hopper to deck level. These valves have a lift of 4 ft. and are operated by hydraulic rams. At work on the bar and entrance channel of the Mersey, the Leviathan pumps up over 12 million tons of sand per annum.

The following particulars relate to the 'Coronation,' a vessel in the same service :—

Length between perpendiculars	332 ft.
Breadth moulded	52·7 ft.
Mean draught, loaded	17·2 ft.
Maximum dredging depth	65 ft.
Speed	10 knots.
Loaded capacity	3,500 tons.
Pumping capacity	4,500 tons per hour.
Suction pipes (two)	36 ins. diameter, 81 ft. long.
Propelling engines	2,000 i.h.p.
Pumping engines	800 i.h.p.
Cylinders of propelling engines	19 ins., 30 ins., and 49 ins. diameter by 30 ins. stroke.
Cylinders of pumping engines	12 ins., 20 ins., and 32 ins. diameter by 18 ins. stroke.

Suction Cutter Dredgers.

Suction Cutter Dredgers.—The success attending the introduction of the sand pump led to an investigation of the possibility of dealing with less tractable material by the same means. Water jets for loosening and disintegrating hard and compact strata were added, and some satisfactory results being obtained, the further step of introducing rotary cutters was taken. There was found to be little difficulty in treating in this way earth of a marly or brittle nature, easily resolvable into disconnected particles. Trouble, however, was experienced in dealing with clay and tenacious material, which clogged the cutters and choked the intake. Eventually this was overcome by the evolution of cutter blades of a suitable form and pitch.

Capacity of Suction Cutter Dredgers.—Suction cutter dredgers are now constructed capable of removing over 1,000 cub. yds. of stiff clay per hour. In material usually dealt with by bucket dredgers, the cutter suction and discharging dredger 'Lord Willingdon' at Cochin dredged and discharged, through 4,500 ft. of pipe line, 1,500 cub. yds. per hour over an extended period, and on occasion this output has been considerably exceeded.

Use of the Pipe Line.—The use of the pipe line for discharging purposes is becoming very general, especially in cases where it is practicable to use the dredged material for filling and embankment purposes. These lines are often of great length. A dredger working at Oakland, California, U.S.A., has successfully delivered material through 6,170 lineal ft. of 20-in. diameter pipe. Diameters reach as high as 42 ins. when altogether afloat, and 30 ins. to 36 ins. when partly ashore. In calm water thin sheet tubing will suffice, but in exposed situations long lengths of solidly built sections must be provided. The carrying capacity of a 36-in. pipe with 80 per cent. of solid matter conveyed at a rate of 10 ft. per second would be 7,400 cubic yds. per hour. Sand causes considerable wear and abrasion of the piping and requires a high percentage of water with greater velocity to keep it in suspension. Clay, from its unctuous nature, exercises far less frictional resistance and is sometimes rendered sufficiently fluid by 10 per cent. of water. A velocity of 7 ft. per second for clay and mud, and 10 ft. per second for sand, has been found to give good results.

Compound Dredgers.

Compound Dredgers.—A compound type of dredger has recently been introduced fitted with both the suction, or suction cutter, apparatus and a bucket ladder. This enables the dredger to be applied to a wide variety of material in the most effective manner. The bucket ladder is generally placed in the centre well and the suction apparatus at the sides of the vessel, but in some cases the suction pipe is also centrally situated.

Example of Compound Dredgers.—The dredger 'La Loire,' built for service on the river of that name, is a twin screw combined bucket and suction dredger with cutter gear and pipe line shore delivery. Her dimensions are 173 ft. 10 ins. in length by 32 ft. beam by 14 ft. deep. She is fitted with two centrifugal suction and force pumps, capable of raising material from a depth of 25 ft., and of driving it ashore through floating delivery pipes about 30 ft. long and 24 ins. diameter. The suction pipe is 26 ins. diameter and works, together with the bucket ladder, in a centre well.

The cutter has a diameter of 6 ft. 10 ins. and is driven at 12 revolutions per minute, the engine running at 140 revolutions.

The bucket ladder enables the dredger to work to a depth of 52 ft. 6 ins. The buckets have a capacity of 27½ cubic ft. They are driven at a speed of 16 buckets per minute with the engine running at 170 revolutions.

Both suction and bucket apparatus enable the dredger to excavate her own flotation in advance.

The machinery consists of two complete sets of direct acting, triple expansion surface condensing, reversible propelling engines, each arranged to drive a centrifugal pump as well as the bucket dredging gear. Each set of engines indicates about 450 h.p. when running at 170 revolutions per minute. The cylinders are 13 ins., 21 ins., and 33½ ins. by 18 ins. stroke.

The cutter gear is driven by means of belting from a separate engine of 200 h.p., which also serves for a centrifugal pump delivering spoil from the buckets into the upper part of the shoot.

For the purpose of working the bucket dredging apparatus the suction pipes and cutter gear are dismounted, but in deepening the bed of the river Loire the latter proved so effective that over 13 million cubic yds. of alluvial material have been removed without recourse to the bucket apparatus.

Hopper Service.

When dredged material has to be removed some distance to a depositing ground it is excavated by the dredger into its own hopper, or into hopper barges ranged alongside.

A combined hopper dredger costs less in initial expenditure and subsequent upkeep than a separate dredger and hopper of corresponding capacity, and it occupies less valuable space in a crowded waterway.

On the other hand, it involves the discontinuity of dredging operations and the frequent getting out and taking in of moorings. This latter consideration is of importance more to dredgers of the bucket ladder type.

On the whole, it is found expedient on undertakings of considerable magnitude, and in cases where the depositing ground is several miles distant from the dredging site, to maintain a fleet of hopper barges in attendance on bucket ladder dredgers. Suction dredgers, when they do not discharge through a pipeline, more commonly are compound vessels with self-contained hoppers.

Capacity of Hopper Barges.—Barges are constructed capable of receiving from 500 to 1,000 cubic yds. of dredged material (say 650 to 1,350 tons) and of making journeys to sea and back at speeds of 10 to 11 knots.

Example of Hopper Barge.—A typical barge of 800 tons capacity has a length of about 190 ft., breadth 30 ft. and depth 14 ft. The engines are triple expansion, surface condensing, with cylinders 16½ ins., 26 ins. and 43 ins. diameter by 27 ins. stroke, which at 110 revolutions per minute develop 820 i.h.p. and give a speed of 10 knots, steam being supplied at 180 lbs. per sq. in. from marine multitubular boilers.

Cost of Dredging Plant.*

The following figures may be useful as approximate indications of the cost of dredging plant which must, of course, vary from time to time with fluctuations in the price of material and the engagements of the shipbuilding yards.

Ladder Dredgers.—A 5 cubic ft. bucket, single ladder dredger, capable of raising 150 tons of soft material per hour from a depth of 40 ft., has cost in round figures 7,000*l.*

A 15 cubic ft. bucket, single ladder dredger, capable of raising 400 cubic yds. of sand, gravel and clay per hour from a depth of 45 ft., has cost about 27,000*l.* and was constructed in six months.

A one cubic yd. bucket, single ladder dredger, capable of raising 750 cubic yds. of ballast per hour from a depth of 55 ft., has cost about 43,000*l.*, and was built in nine months.

Dipper Dredgers.—A one to two yard dipper dredger costs from $8,000 to $12,000; say 1,600*l.* to 2,400*l.* The hull is of timber, about 60 ft. long by 25 ft. wide, with a draught of 3 ft.

A 3½ to 4 cubic yd. machine dredging to a depth of 30 to 35 ft., would cost about $80,000 to $90,000, say 16,000*l.* to 18,000*l.*

A 10 cubic yd. machine dredging to a depth of 35 ft. would cost about $130,000 to $140,000, say 26,000*l.* to 28,000*l.*

* See footnote, page 1520.

Grab Dredgers.—A twin-screw hopper dredger, with a hopper capacity of 1,200 tons, and fitted with 5 hydraulic grab cranes each of 5 tons bucket capacity, working to a depth of 47 ft., has cost about 35,000*l.*

Suction Dredgers.—A suction hopper dredger with a hopper capacity of 70,000 cubic ft., capable of raising 3,500 to 4,000 tons of sand per hour from a depth of 70 ft., has cost about 75,000*l.* A 2,000 ton suction hopper dredger would cost about 50,000*l.*

Compound Dredgers.—A sea-going hopper dredger, fitted with both ladder buckets (18 cubic ft.) and suction pumps, and capable of dredging by the former means 400 cubic yds. per hour, and by the latter means 650 cubic yds. per hour, from a depth of 50 ft., has cost about 52,000*l.*

Hopper Barges.—A steam hopper barge of 800 cubic yds. capacity, with a speed of 11 knots, costs from 18,000*l.* to 20,000*l.*

Cost of Dredging Operations.*

Conditions and circumstances vary with each locality, so that it is difficult to give reliable figures for general guidance. Sand pump dredging can be done for as little as 1*d.* per cubic yd. or even less, and grab dredging from 2*d.* to 6*d.*, but a very great deal depends on the distance the spoil has to be carried. In bucket dredging, either by ladder or dipper, the range of cost is considerable, depending in addition, as it does, on the kind of material dealt with. The following are a few collected records from various sources :—

BOMBAY HARBOUR AND DOCKS.

Total Maintenance Dredging during Five Years, 1920–1925.†

Costs exclusive of Interest and Depreciation on Dredging Plant.

Location.	Total Quantity Lifted : Cubic Yards.					Cost per Cubic Yard : Annas.				
	1920–1921	1921–1922	1922–1923	1923–1924	1924–1925	1920–1921	1921–1922	1922–1923	1923–1924	1924–1925
Alexandra Dock	24,210	297,500	20,380	144,800	388,000	9·23	7·78	8·01	5·78	6·62
Prince's Dock	50,500	263,500	68,500	17,700	474,000	7·60	6·81	7·30	4·75	5·50
Victoria Dock	159,500	114,000	48,900	344,000	49,000	6·22	6·18	6·87	5·88	10·60
Basins	206,800	131,400	3,335	—	9,330	7·78	12·26	11·60	—	9·10
Alexandra Dock Channels	650,000	149,600	615,000	591,000	1,170,000	4·40	8·56	5·76	4·97	3·60
P. & V. Docks Channels,	689,800	1,098,000	931,500	857,200	1,098,800	5·37	5·01	5·38	4·54	3·83
P. & V. Channels, S.E. Flank	40,700	27,500	—	182,800	82,600	6·83	3·61	—	4·17	3·66
P. & V. Docks Channels, N. Flank	276,500	72,500	184,800	316,000	400,000	4·98	6·18	4·67	4·61	3·44

Port Natal.—The following particulars (extracted from a paper by Mr. William Brown on 'Recent Progress in Dredging Machinery'; *vide* Min. Proc. Inst. C.E., vol. cciii.) relate to the performances of the four principal dredgers at Port Natal, Durban, within a period of several years ended December 31, 1914. The costs include all charges for working, maintenance, insurance, depreciation and interest on capital. The price of coal consumed by the dredgers was low, and seldom exceeded 8*s.* per ton. The three large vessels (Labrus, Cetus, and Nautilus) each employed fourteen Europeans, eighteen Kaffirs, and eleven Indians, or a total complement of

* See footnote, page 1520.

† Extract from paper on 'Maintenance Dredging in Bombay Harbour and Docks,' by E. L. Everatt, *Min. Proc. Inst. C.E.*

forty-three hands, at an annual cost of about 3,850*l.* per vessel. 'With the possible exception of Liverpool, no port hampered by sandbars has made such progress in comparatively recent years as Durban.'

PARTICULARS AND WORKING COST OF SEA-GOING PUMP DREDGING PLANT AT PORT NATAL.

Name of Dredger.	Year Built.	Tonnage.		Hoppr. Capacity (Tons of Sand).	Pumping Speed (Tons of Sand per hour).		Average Spoil handled per ann. (Tons).	Average number of days worked per ann.	Cost per ton handled. (*d.*)	Remarks.
		Net.	Gross.		Contract.	Record.				
Labrus .	1911	1,215	2,097	2,000	2,000	2,000	719,500	244	6·806	Worked exclusively in stiff clay, being fitted with patent clay cutter. All spoil dredged repumped ashore from ship's hoppers for land reclamation.
Cetus .	1905	1,327	2,414	3,000	3,000	7,430	2,151,000	232	2·227	Largely employed for bar work. Spoil mostly coarse loose sand and fine stone, all dumped at sea, two miles from harbour entrance.
Nautilus	1903	1,050	2,034	2,500	3,000	7,894	1,466,000	247	3·109	Employed chiefly on maintenance and deepening of harbour bed and channels. Material mostly fine sand, with occasional admixture of loose clay and mud, all deposited at sea two miles from harbour entrance.
Snipe .	1903	180	265	200	300	340	358,000	256	3·201	Used for clearing up wharf and quay berthage, cutting and maintaining boat channels, occasional reclamation, etc. Spoil deposited within harbour.

Panama Canal.—During 1910 the sea-going suction dredgers 'Culebra' and 'Caribbean' removed 6,083,902 cubic yds. at a cost of 3·7*d.* per cubic yd. The ladder dredger 'Marmot' removed 1,372,665 cubic yds. at 7·82*d.*, and dredger No. 5 removed 560,622 cubic yds. at 13·65*d.* per cubic yd. The small 5 cubic yd. dipper dredgers 'Cardenas' and 'Mindi' removed 1,013,485 cubic yds. at 27·89*d.* per cubic yd. and the 20-in. pipe-line suction dredgers, Nos. 82 and 85, dealt with 2,472,822 cubic yds. at a cost of 14*d.* per cubic yd. During a period of twelve months ended May, 1916, the dipper dredgers 'Gamboa' and 'Paraiso' each removed over 2,900,000 cubic yds., at costs varying from 2·25*d.* to 5·45*d.* per cubic yd., including operation and maintenance.

Mississippi River.—In 1907 three pipe-line suction-cutter dredgers dredged 1,279,000 cubic yds. at 4·12*d.* per cubic yd. including the cost of idle time. In 1908 the same dredgers accounted for 989,000 cubic yds. at 5½*d.* per cubic yd.

New York Harbour.—In 1909, the sea-going suction dredgers 'Manhattan,' 'Atlantic,' 'Raritan,' and 'Navesink,' removed 10,786.638 cubic yds. at a total cost of $424,734 (say 85,000*l.*) or at the rate of 1·97*d.* per cubic yd. made up as follows: Dredging, 1·785*d.*; surveys and examinations, ·125*d.*; contingencies and supervision, ·06*d.* The 'Delaware' removed 1,675,562 cubic yds. at a total cost of 2·39*d.* per cubic yd.

River Thames.—The contract cost of removing hard material (ballast and clay) by ladder dredger from the Thames below London Bridge has ranged at various times before the war from 1*s.* 4*d.* to 2*s.* 6*d.* per cubic yd. largely dependent on the distance the material had to be conveyed. Some work has been carried out departmentally, including all establishment and capital charges, at a figure as low as 7½*d.* per cubic yd. This was for a quantity of about one million cubic yards, and the distance conveyed was about 30 miles.

River Mersey.—At the bar and in the entrance channels of the Mersey nearly 15 million cubic yds. of sand were removed annually at a pre-war cost of ·6*d.* per cubic yd. exclusive of interest and depreciation on the plant.

Siam Irrigation Canals.—The following particulars of the working expenses of a 2½-cu. yd. dipper dredger, employed on the Siamese Irrigation Service, are given by Messrs. Lobnitz & Co.:—

'During the year 1920, working nine hours per day, the total quantity dredged was 312,130 cu. yds., measured in place, or an average of 26,010 cu. yds. per month. The best month in that year was October, with 43,700 cu. yds. at a total cost of 1·95 pence per cu. yd., and the average cost per cu. yd. for the year was 2·87 pence, including labour, fuel, supplies, repairs, and every expense except interest and depreciation. The fuel used was oil, and represented about half the total operating cost. The quantity used was about one ton per day.

'While larger outputs have been made for short periods and under more favourable conditions, this record is notable chiefly for steady running for a long period without appreciable delays or expense on account of the machinery, and this in a tropical country remote from base of supplies. The cost of repairs was 4·3 per cent. of the total cost, and consisted mainly in the replacement of some wire ropes.'

SUBAQUEOUS ROCK REMOVAL.

The removal of hard rock under water is generally effected by one or other of two means: (*a*) by drilling and blasting; and (*b*) by the use of the chisel or rock breaker. In both cases a dredger is subsequently required for the purpose of clearing the débris from the site.

Drilling and Blasting.

Drilling and Blasting.—The first is the older method and remains still a most effective means of dealing with rock of adamantine hardness in huge solid masses, such, for instance, as reefs of granite and other igneous rock, and for the harder varieties of limestone.

The holes are drilled by suitable plant at distances apart dependent upon the nature of the rock and the quantity to be removed. In very extensive operations chambers may be formed for the reception of powerful charges.

Two classes of drill are generally available for boring purposes: (*a*) diamond drills and (*b*) jumper drills. The former are hollow rods, fitted with a head or crown of diamonds, costing from 50*l.* to 60*l.*, and driven at from 200 to 300 revolutions per minute. The latter are bars or shafts of steel, furnished with bits, preferably of circular form, which are worked by percussion at the rate of from 20 to 30 blows per minute.

The blasting material is usually dynamite, or any of the numerous compounds of nitro-glycerine to be found on the market.

The following are brief notes on the methods employed in several instances.

Blyth Harbour.—The rock at Blyth harbour is sandstone of the hardness of basalt in places, and the work was done by six drills lifted by steam power and guided by hand. The distance between the shot-holes was 5 ft. in one direction and 6 ft. 2 ins. in the other. The blasting material, bellite, was lowered in canisters through the drilling tubes and fired by fuses and detonators, the holes being tamped with small gravel. The cost of drilling and blasting came to 3*s.* per cubic yd. of rock *in situ*, adding to which 2*s.* 6*d.*, the cost of dredging, and 8·2*d.* for interest and depreciation on the dredger, the total amounts to 6*s.* 2·2*d.* per cubic yd. The average quantity of rock drilled and blasted per week by one barge was 488 cubic yards. The system was afterwards abandoned in favour of the rock-cutter.

Black Rock Harbour, Buffalo, U.S.A.—Here the rock formation is a very hard limestone containing veins of flint. The blasting material was dynamite and, for a quantity of 14,450 cubic yds., the holes were drilled to an average depth of 9 ft. 9 ins. The cost of drilling and blasting only, including an allowance for interest and depreciation of 2 per cent. per month on 8,000*l.* (the value of the plant), came to 2*s.* per cubic yd. On the other hand, a smaller quantity of 333 cubic yds. with holes drilled only to 3 ft. 6 ins. deep cost 23*s.* 2*d.* per cubic yd.

The drill boat employed on this work was a steel hull, 137 ft. by 33 ft., divided into 20 water-tight compartments. It was equipped with five drill frames located along one of the gunwales each with a travel of 25 ft. on longitudinal tracks. Each frame was fitted with an Ingersoll-Rand drill 2½ ins. in diameter, with 4-in. bits, having a vertical range of 21 ft. without changing the drill bars. Each frame was also provided with an engine for hoisting the drills, two davits for handling drill steels and charging pipes and a pipe which was driven, whenever required, through loose material to the rock to prevent the drill holes from clogging. A 250 h.p. boiler supplied steam to the drills, spud engines and capstans.

Detroit River.—On three sections of the Detroit River, where the blasting material was dynamite and the holes ranged from 5 ft. to 8 ft. in average depth, the total cost is stated to have been 3*s.* 4*d.*, 4*s.* 4*d.*, and 4*s.* 1*d.* per cubic yd., respectively, of useful material, or about half the rates for the whole quantity removed. The holes were spaced 5 ft. apart, and the total number drilled was 94,691 at a cost of about 52,000*l.* It is not apparent that this figure includes any allowance for interest and depreciation.

Fremantle Harbour, Western Australia.—On account of the shallowness of the water, the work of drilling at Fremantle Harbour could be carried on from light wooden stages resting on four-footed trestles. In a couple of days it was possible to erect 20,000 square ft. of this staging, which carried 120 to 160 men drilling with regularity in 20 ft. or more of water. The holes were from 8 ft. to 12 ft. apart, and the charges consisted of 12 to 15 lbs. of dynamite or gelignite. One ton of explosive accounted for 5,600 cubic yds. of rock blasted. The cost of drilling and blasting 1,503,099 cubic yds. was 238,345*l.*, equivalent to 3*s.* 2*d.* per cubic yd.

Rock Breakers or Chisels.

Rock breakers, or chisels, are steel rams weighing from 15 to 20 tons, with pointed ends of hard chrome steel which are detachable for renewal. The appliance is suspended from a frame, or tripod, mounted on a barge, and is worked by a winch. A drop of from 6 ft. to 10 ft. is generally sufficient to produce disintegration. Blows can be repeated with advantage until a depth of 3 ft. is reached, with holes spaced about 3 ft. to 4 ft. apart (about eight blows will give the required penetration), when it becomes desirable to dredge the broken material before proceeding further. A net depth of 2½ ft. over the site will probably thereby be obtained. It is found that the average result in hard rock is 2 cubic ft. per blow and that about 150 blows can be given per hour. This is equivalent in uninterrupted working to about 10 cubic yds. per hour for a single cutter machine; about 50 per cent. more will be achieved by a double cutter. In moderately hard rock the output will be greater, as about 250 to 300 blows can be given per minute. About 200 cubic yds. may be reckoned a good day's work.

There are several types of cutter, but perhaps the Lobnitz rockbreaker is that which is best known. The following are some instances of its employment. It may be added that some of the latest examples of this type of cutter have been fitted with an under-water sleeve, to afford more accurate guidance for the ram or chisel.

Suez Canal.—On the Suez Canal, where the rock consisted of limestone, calcareous agglomerate and tufa, gypsum and alabaster, 132 blows were delivered per hour of effective working, or 8 blows per hour of whole time, allowing for interruptions from passing ships and stoppages for repairs. The average thickness of rock shattered was 2 ft. 7½ ins., and each cubic yd. of rock required a mean of 5·4 blows. The cost, exclusive of dredging but covering everything else except general charges, varied from 2¼*d.* to 7*s.* 6½*d.* per cubic yd.

Blyth Harbour.—At Blyth in hard sandstone of the coal measures, a ram of 15 tons weight, falling through a distance of 8 ft., penetrated the rock to a depth of 3 ft. on an average of 8 or 9 blows. The holes were spaced 4½ ft. apart. The plant comprised two Lobnitz rock-breakers, each consisting of a steel barge carrying sheer legs, from which the rams, 40 ft. to 50 ft. long and 17 ins. to 19 ins. diameter, were suspended. The cost of one rockbreaker was about 6,800*l.* The quantity broken per week by a single machine working night and day was 908 cubic yds., at a cost (including wages, coal, stores, repairs and insurance) of 46*l.* 11*s.* 3*d.*, equivalent to 12·3*d.* per cubic yd. Adding 6¼ per cent. for interest and depreciation on plant, the total cost was 14·5*d.* per cubic yd. The cost of subsequently dredging the loose material (including capital charges) was 2*s.* 9·1*d.* per cubic yd., making 3*s.* 11·6*d.* per cubic yd. in all.

Black Rock Harbour, Buffalo, U.S.A.—The cost of working two Lobnitz machines at Black Rock Harbour in hard limestone rock was 2*s.* 9½*d.* per cubic yd. for a quantity of 52,500 cubic yds. This does not cover the cost of dredging.

Panama Canal.—On the Panama Canal, a Lobnitz cutter worked mounted on a barge 100 ft. long by 28 ft. beam by 8 ft. deep. The extreme variation in the tides necessitated the use of 3 rams, weighing 15, 16 and 19½ tons respectively. The holes were spaced 4 ft. apart, and 3 ft. of penetration was made in each case. From records during 1910–11 the work done was an average of 16·2 cubic yds. per hour of actual working time, or 11 cubic yds. per hour of total time, at an average cost of 3*s.* 4*d.* per cubic yd.

Value of the method of Drilling and Blasting as Compared with the use of Rock Breaker.—While drilling and blasting is most commonly adopted for hard rock in large masses, it does not necessarily follow that the cutter always gives better results in soft rock. In some cases it is found that the cutter has a tendency to stick in the hole which it makes, and for that reason the extent of penetration should be carefully limited. On the other hand, the cutter offers less interruption to the passage of ships close to the area of operations, and it can be used in positions where blasting is inadmissible. Moreover, the rock is broken to a more uniform and more convenient size, which facilitates the action of dredging. The cost of the work done by the cutter is generally, though not invariably, less than the cost by the alternative method.

CHANNEL DEMARCATION.

Entrance channels to ports are outlined by buoys and important changes of direction are also indicated by beacons and lightships.

Uniform System of Buoyage.

The general Lighthouse Authorities of the United Kingdom have adopted the following uniform system of buoyage.

Conical Buoys (those with pointed tops) denote the starboard hand, or that side which would be on the right hand of a mariner, either going with the main stream of flood tide, or entering a harbour, river or estuary from seaward.

Can Buoys (those with flat tops) denote the port hand, being the left-hand side of the mariner under the circumstances described.

Spherical Buoys, with domed tops, mark the ends of middle grounds.

Pillar Buoys, having a tall central structure on a broad base, mark special positions.

Colour.—Starboard-hand buoys are always to be painted in one colour only; port-hand buoys are to be painted another characteristic colour, either single or particolour. Spherical buoys are to be distinguished by white horizontal stripes. Wreck buoys are to be coloured green with the word 'wreck' in white letters across.

Types of Buoys.

Buoy Construction.—Buoys are generally hollow structures of steel or iron plating, at least ¼ in thick. They should be constructed in two watertight sections to prevent sinking in case of penetration of one part.

The size and weight of buoys is as follows:—

		Diam. ft.	Weight. tons.
Day Mark Buoys	First class	12	4
	Second class	10	2½
	Third class	8	1¼
	Fourth class	6	¾
	Fifth class	5	⅜
Gas Buoys		10	4

Gas buoys should be made of welded iron or mild steel, not riveted. Under high pressures the riveted joints tend to leak and are not satisfactory.

Buoy Moorings.—Mooring chains for first-class buoys are about 1¼ ins. diameter, and they are attached to sinkers weighing about 50 cwts. For second-class buoys the chains are usually 1¼ ins. diameter, and the sinkers weigh 40 cwts.

Bell Buoys are provided with a bell from 3 to 7 cwts. in weight struck under the action of the sea either by pendant clappers or by a set of balls rolling freely in horizontal grooves, or by a hammer actuated by carbonic acid gas.

Whistling Buoys emit a sound by means of air imprisoned in a long central tube during the period of rising in a swell and expelled through a whistle during the period of falling. The tube descends into the water to a considerable depth—about 20 ft.

Luminous Buoys.

Luminous Buoys are lighted by means of oil or gas: the former, petroleum; the latter, either oil gas, Blau gas, or acetylene. On account of the high pressure required for compact storage, coal gas is unsuitable for use as a naked flame, the luminosity of the gas being rapidly reduced by pressure. The heating power, however, remains almost intact, and with a mantle satisfactory incandescence is produced, though the brilliancy and luminous intensity are lower than those of the other agencies. The ratio of calorific value is approximately as follows:—Coal gas, 5; oil gas, 10; Blau gas and acetylene, 14.

The difficulty connected with the use of oil burners is the necessary attention to the wicks. In France carbonised wicks are employed, but they call for extreme nicety of adjustment. In this country the *Wigham* burner has an automatic contrivance which ensures a constant change of surface. The consumption of oil amounts to from 2 to 4 pints per day of 24 hours, according to the size of the lamp. Including oil and attendance, but not repairs, the approximate pre-war running cost of a 31-day buoy lamp works out at about ·13*d.* per hour, of which ·065*d.* is for oil. The prime cost of buoys equipped with the *Wigham* lamp is from about 200*l.* upwards.

Oil gas, as manufactured on the *Pintsch* system, is produced at a cost of about 60*s.* per 1,000 cubic feet, about 75 cubic feet of gas being obtained from one gallon of oil. The average burner of a fixed light consumes about ·75 cubic feet per hour. The gas is stored under pressure, generally of about 90 to 105 lbs. per sq in., but reaching up to 150 lbs. A reservoir of 380 cubic feet in a buoy of 10 ft. diameter, charged to 90 lbs. pressure, would hold a sufficient supply of gas for about four months.

Lenses are usually of 200 to 300 millimetres (8 to 12 ins.) diameter. The candle power of lanterns fitted with incandescent burners and lenses of 200 mm. diameter is about 220, and with 300 mm. lenses about 330.

Blau gas is derived from the decomposition at a lower temperature of the raw or residuary products from which ordinary oil gas is extracted, and is richer than the latter in heavy carbides of hydrogen. It is liquefied for storage in bottles. Before use, the gas requires to be expanded

in an intermediate receiver. The cost of production of Blau gas is considerably higher than that of oil gas, but the cost of transport is much less, and the increased heat of the flame gives an increase of 30 per cent. over oil gas to the intrinsic brilliancy of the mantle and the intensity of the lens.

Acetylene, a gaseous compound of hydrogen and carbon, is produced by the access of water to calcium carbide. In the case of buoys, the water is generally admitted to the chamber containing the carbide through a hole in the bottom, the generation of gas being regulated by the pressure arising from its formation. The system is wasteful of carbide, and only suitable for positions where the buoys can be periodically cleaned and recharged. The better principle, wherever feasible, is the inverse arrangement of the application of carbide to water.

From 1 lb. of commercial calcium carbide can be produced about 4½ cubic feet of acetylene, at a pre-war cost of about 1½*d.* for material only.

Acetylene gas produced as above is not chemically pure, and gives rise to deposit on the burners, but this difficulty can be overcome by the addition of a suitable purifier between the gas-generating chamber and the burner. Unattended lights working on this system will run for six months, or even a year, without recharging.

Dissolved Acetylene.—The compression of acetylene for storage purposes is generally illegal, on account of the liability of the gas, so stored, to explode. On the other hand, compressed acetylene in what is known as the dissolved form is perfectly safe, and cylinders of dissolved acetylene, prepared in accordance with official regulations, are classed by the Home Office as non-explosive.

The solvent commonly employed is acetone, which is a liquid hydro-carbon, possessing the property of absorbing about 25 times its own volume of acetylene at atmospheric pressure, and multiples of this to correspond with the number of atmospheres to which compression is carried.

The steel cylinders for the reception of the dissolved acetylene are first completely filled with a substance having a porosity of 80 per cent., which is then caused to absorb as much acetone as would occupy 40 per cent. of the volume of the cylinder. The actual gas capacity of the cylinder is thus 40 per cent. of 25, or 10 volumes per atmosphere of pressure.

Dissolved acetylene cylinders should not be discharged below the atmosphere gauge pressure, because the rate at which the acetone is carried off by the gas greatly increases as the pressure approaches zero. Acetone vapour has no detrimental effect upon the consumption of the gas in the burner. It is generally found necessary to make up the quantity of acetone, after five to ten refillings of the cylinder with acetylene.

Economies in the consumption of dissolved acetylene have been effected by the introduction of mechanism for emitting flashing or occulting lights invented by Mr. Gustav Dalen and others whereby a wide range of intermittent light signals can be produced automatically.

To the same scientist is attributable the *Sun-valve*, or, more correctly, the *Light-valve*, which is a mechanical device sensitive to light and actuated entirely by the alternation of daylight and darkness. It opens the gas supply at nightfall and closes it at daybreak with perfect regularity, resulting in a saving of some 25 to 40 per cent. of the gas, according to climate, as compared with a constantly burning light. The use of the instrument is generally restricted to shore lights, or lights of considerable magnitude.

Mr. Dalen has further produced complete automatic apparatus for mixing in correct and constant proportions the dissolved acetylene and air and for burning the compound in conjunction with incandescent mantles, either as a constant or intermittent light. This apparatus also by its nature, is most applicable to lights of considerable power, superior to those generally fitted to buoys.

As an instance of the cost of buoy illumination by dissolved acetylene may be mentioned nine light buoys in the entrance channel to the Port of Lido, Venice, which command a light range of 6 miles under conditions of average atmospheric clearness, and contain a supply of gas for a period of 110 days. The lenses are 300 mm. diameter, and the burner consumes 15 litres per hour. According to a statement of Sig. Carlo Duse in the 'Giornale del Genio Civile,' the annual pre-war cost per buoy, covering attendance and repairs and four charges of gas, each of 3 cylinders of 5 cubic metres, at 4*s.* per cubic metre, was 15*l.* 12*s.*

Further reference to the cost of acetylene lighting will be found on page 1559.

Lightships.

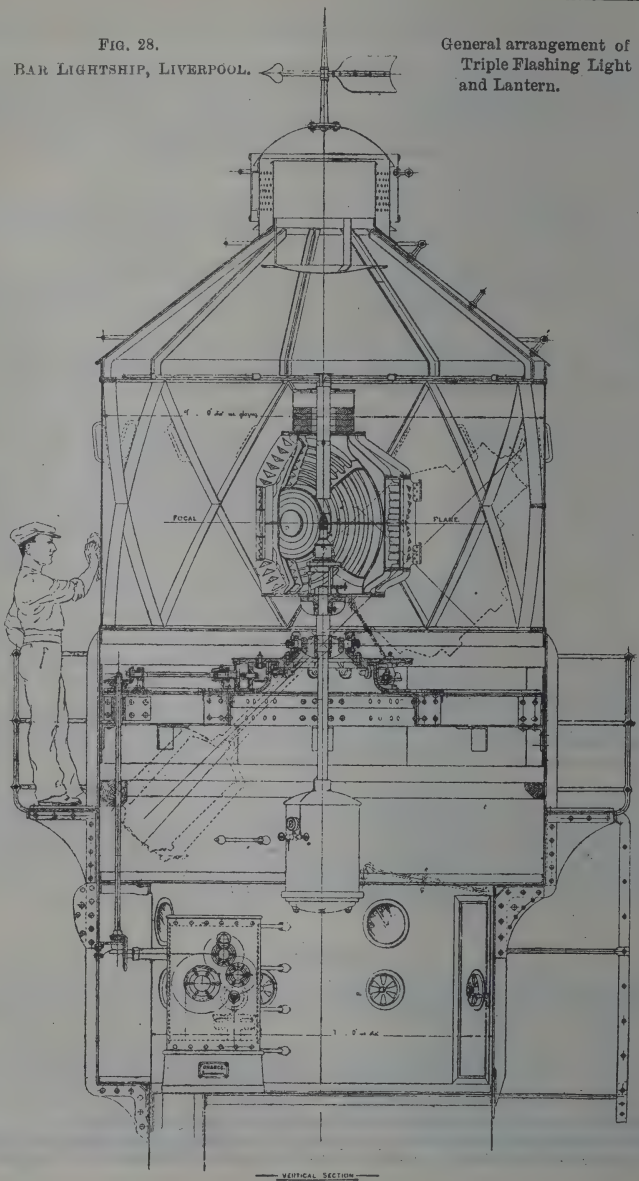
Lightships afford a more powerful light than luminous buoys, and the focal plane is at a much higher level—generally about 35 ft. above the water surface. They are, of course, more costly both in first outlay and maintenance, and are usually manned by a crew, though this is not essential in all cases.

A notable example of an attended lightship is the Bar at the entrance to the River Mersey. The illuminant in this vessel is petroleum with an incandescent mantle, and the lens is of small third order (750 mm. diameter). The whole optical apparatus is swung on gymbals, so that the beam emitted is kept practically horizontal. It is revolved by clockwork, and gives three powerful flashes, so that the whole installation resembles a floating lighthouse.

Small lightships, without constant attendance, are stationed at several places on the coast of this country and of France. A vessel of this type is about 40 ft. long, 12 ft. beam, and 8 ft.

FIG. 28.
BAR LIGHTSHIP, LIVERPOOL.

General arrangement of Triple Flashing Light and Lantern.



deep, fitted with a storeholder containing 2,500 cubic ft. of gas, which is sufficient to maintain a light for 3 months.

Larger vessels, with crews, range from 60 to 150 ft. in length, from 20 to 30 ft. in breadth and from 10 to 20 ft. in depth, the draught being from 7 to 10 ft.

Lenses vary from 500 mm. to 750 mm. in diameter and the candle-power from 2,000 to 250,000. Catoptric reflectors with a candle-power of 4,000 are used in the older types of light vessels.

LIGHTHOUSES.

The Eddystone Lighthouse.

The most recent type of foundations and general construction of lighthouses is well exemplified by the new Eddystone Lighthouse. In this structure the tendency of the curvilinear outline of Smeaton's and of other similar sea-towers that have succeeded it, to elevate the centre of force of each wave-stroke on the structure, induced Sir James Douglas to adopt a cylindrical base, from which base, at a level of 2½ feet above high-water spring-tides, the curved shaft of the tower commences. The difference in the rise of heavy seas on the two structures during stormy weather is remarkable. The cylindrical base has the further advantage of affording a convenient landing platform, thus adding considerably to the opportunities of relieving the lighthouse.

The base is 44 feet in diameter by 22 feet in height. The tower is a concave elliptic frustum, the generating curve having a semi-transverse axis of 173 feet, and a semi-conjugate axis of 37 feet. With the exception of the space occupied by the fresh-water tanks, the tower is solid for 25 ft. 6 ins. above high-water spring-tide level. At the top of the solid portion the wall is 8 ft. 6 ins. in thickness, diminishing to 2 ft. 3 ins. in the thinnest part of the service-room. All the stones are dovetailed both horizontally and vertically. The system consists in having a raised dovetailed band 3 inches in height on the top bed and on end joint of each stone. A corresponding dovetailed recess is cut in the bottom bed and end joint of the adjoining stones, with just sufficient clearance for the raised band to enter it freely in setting. From experiments made with blocks put together in this manner with Portland cement, it is found that the work is so homogeneous as to be as nearly as possible as strong as the solid granite.

Each stone of the foundation-courses (figs. 29, 30) is sunk to a depth of not less, at any part, than 1 foot below the surface of the surrounding rock, and is further secured by two Muntz metal bolts, 1½ inch in diameter, passing through the stone, and 9 inches into the rock below, the top and bottom of each bolt being fox-wedged.

The masonry consists of 2,171 stones, containing 62,133 cubic feet of granite, or 4,688 tons.

Cost of Construction of Various Lighthouses.

Name of Structure.	Total Cost.	Cubic Feet.	Cost per Cubic Foot.
	£ s. d.		£ s. d.
Eddystone (Smeaton)	40,000 0 0	13,343	2 19 11½
Bell Rock	55,619 12 1	28,530	1 19 0
Skerryvore	72,200 11 6	58,580	1 4 7¾
Bishop Rock	34,559 18 9	35,209	0 19 7½
Smals	50,124 11 8	46,386	1 1 7¼
Hanois	25,296 0 0	24,542	1 0 7¼
Wolf Rock	62,726 0 0	59,070	1 1 3
Dhu Heartach	72,584 9 7	42,050	1 14 6
Longships	43,869 8 11	47,610	0 18 5
Eddystone (New)	59,255 0 0	65,198	0 18 2

Classification of Lighthouse Apparatus.

Order.	Focal distance, mm.	Order.	Focal distance, mm.
Hyper-radial	1,330	Small third order	375
Meso-radial	1,125	Fourth order	250
First order	920	Fifth ,,	187·5
Second ,,	700	Sixth ,,	150
Third ,,	500		

Different Descriptions of Lights.

(1) Fixed. (2) Revolving light, gradually increasing at definite equal periods to full power, and then gradually decreasing to eclipse. (3) Fixed light varied by flashes; shows a fixed light, which at certain periods is varied by white or coloured flashes. (4) Flashing; shows a single

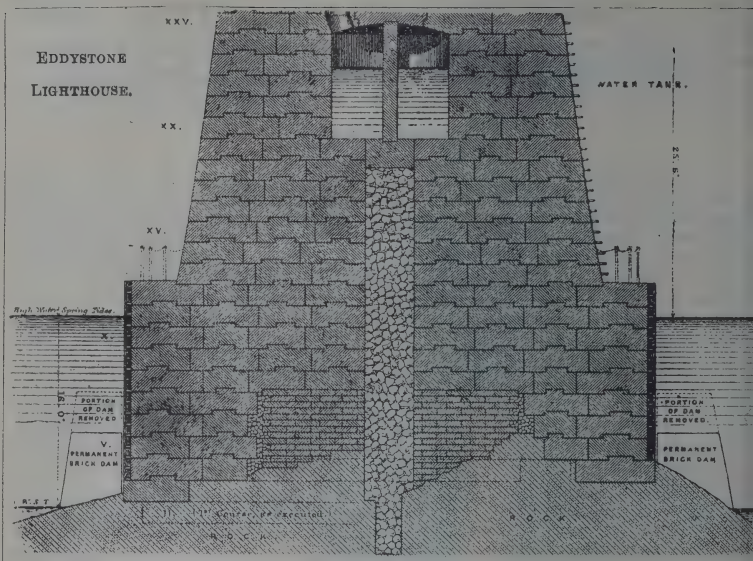

EDDYSTONE
LIGHTHOUSE.
XXV.
XX.
XV.
WATER TANK.
PORTION OF DAM REMOVED
PERMANENT BRICK DAM
PORTION OF DAM REMOVED
PERMANENT BRICK DAM
ROCK

FIG. 29.

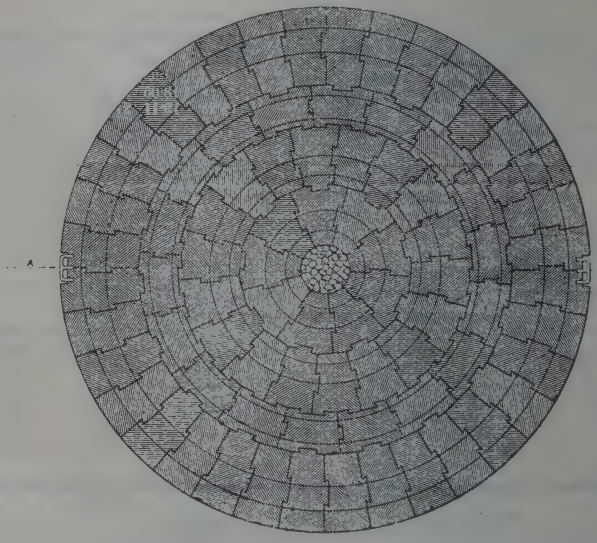

A
A
8TH COURSE

FIG. 30.

flash at short intervals of a few seconds. (5) Group-flashing; shows groups of two or more flashes in quick succession, separated by a period of eclipse between the groups. (6) Occulting, which bursts instantaneously into full power, and after remaining for a period as a fixed light is suddenly eclipsed. (7) Alternating lights of different colours, generally white and red alternately.

Distance visible from Lighthouses.

The following Table shows the distance of the horizon visible from towers of the heights given. In it the necessary correction has been made for refraction :—

H. Heights in Feet.	λ. Lengths in English Miles.	H. Heights in Feet.	λ. Lengths in English Miles.	H. Heights in Feet.	λ. Lengths in English Miles.
5	2·958	80	11·832	250	20·916
20	5·916	90	12·549	300	22 912
30	7·245	100	13·228	350	24·748
40	8·366	120	14·490	400	26·457
50	9·354	140	15·652	600	32·403
60	10·246	150	17·201	800	37·416
70	11·067	200	18·708	1,000	41·833

Optical Apparatus.

The essential part of a lighthouse is the optical apparatus, which is formed of glass lenses and reflecting prisms in order to concentrate the light from the burner in the required direction. The optical apparatus of a fixed light concentrates the rays in the vertical plane only, and sends out a disc of light which illuminates the horizon over the whole 360° or any less angle which may be required. That of a flashing light concentrates the rays in both the vertical and horizontal planes, and thus throws out a series of beams, the number varying with the character which the light is required to give. The whole apparatus is revolved, and by this means the beams sweep round the horizon and appear as flashes at definite intervals to the mariner.

Large lights are supported on a mercury float whereby friction of movement is reduced to a minimum; ball bearings are satisfactory for lights of the fourth order and upwards. The adoption of the mercury float and of the group flashing system, has revolutionised lighthouse practice. The former enables the largest type of optical apparatus the weight of which runs up to 10 tons, such as that illustrated in fig. 31 (p. 1558), to be rotated by the little finger only, and the latter has so greatly increased the distinctive characters which can be given to lights that there is now no danger of confusion between them.

It is usual to arrange the optical system so that the flashes have a minimum duration of ·2 seconds; it has been found that a shorter duration is not sufficient for the mariner to detect the flash. Fig. 31 also illustrates the lantern which protects the optical apparatus.

Sources of Lighthouse Illumination.

For the ordinary necessities of lighthouse illumination mineral oil is the most suitable and economical illuminant. The use of paraffin in the place of colza oil increases the luminous intensity of a four-wick burner by 10 per cent., and of a one-wick burner by 100 per cent.

Oil and gas lights, when shown through similar lenses, are equally affected by atmospheric variations. The electric light is absorbed more largely by haze and fog, but in all weathers and at all distances its penetration has proved superior.

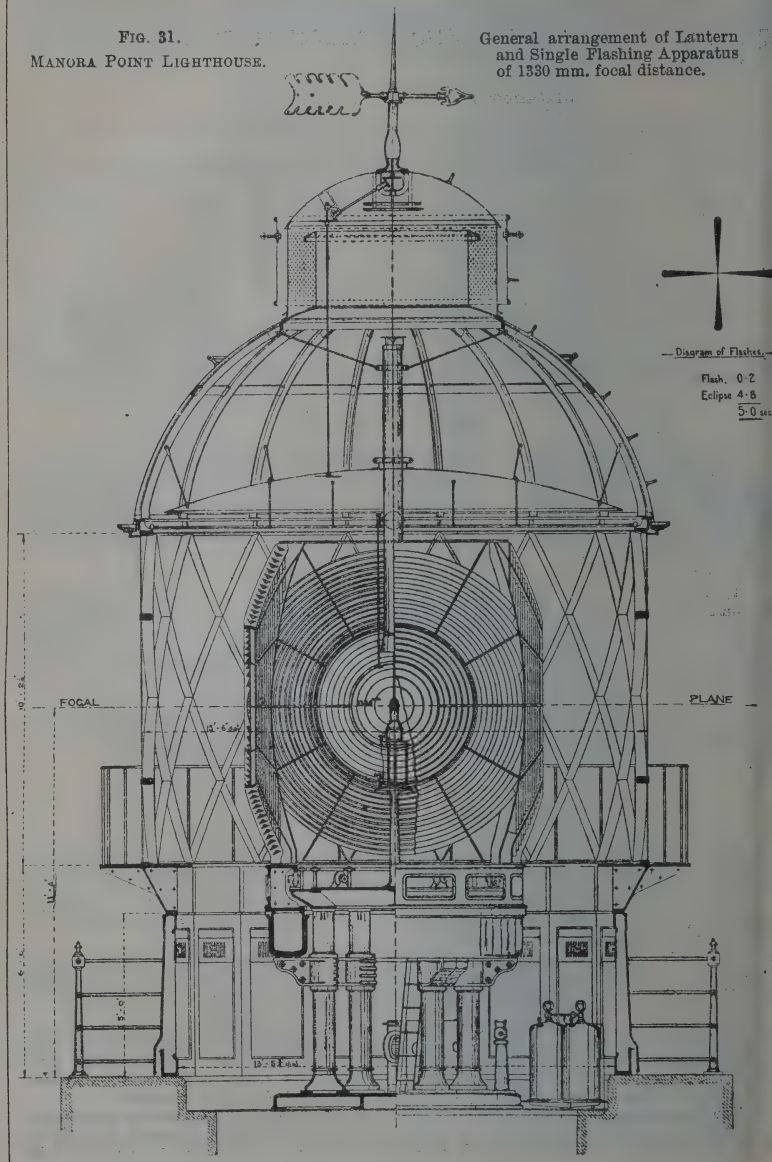
The luminary now in general use at lighthouses is the incandescent oil burner, to which paraffin oil is supplied under pressure, and is vaporised in a retort beneath the burner, being afterwards consumed in an incandescent mantle. The sizes of mantle usually employed vary from 35 mm. to 110 mm. in diameter with intensities up to 3,500 candles.

The latest burner of this type is the 'Hood' petroleum vapour burner designed by the late engineer-in-chief to the Trinity House, in which the mantle employed is of the autoform type, with an intrinsic brightness of 325 candles per sq. in. The burner is in four sizes, 35 mm., 50 mm., 75 mm., and 100 mm., with total intensities of 660, 1,150, 2,200, and 3,300 candles, and consumptions of 0·75, 1·25, 2·25, and 3·25 pints of oil per hour, respectively.

The substitution of incandescent oil burners for concentric wick burners has not only greatly augmented the intensity of the lights, but has resulted in a considerable economy in consumption, in addition to obviating excessive labour and expense of landing large quantities of oil

FIG. 31.
MANORA POINT LIGHTHOUSE.

General arrangement of Lantern and Single Flashing Apparatus of 1330 mm. focal distance.



at lighthouses, especially at rocks and isolated positions. The following may be cited as an example of the increased intensity and economy which are attained by the use of this luminary. At the Eddystone, which is a biform light having superimposed lenses and burners, the resultant beam with the former concentric six-wick burners was 79,250 candles, the consumption of oil being 2,500 gallons per annum; whilst with incandescent oil burners the resultant beam is nearly 600,000 candles and the consumption 1,200 gallons per annum.

For minor lighthouses and portlights (fig. 32, p. 1560) at the entrances to harbours, etc., the illuminant is sometimes a capillary wick lamp having one or more wicks, which can be left without attention for a single night. A distinctive character is given to such lights by means of revolving screens driven by a simple clockwork mechanism which will run for a night without rewinding; the screen occults the light at regular intervals. For the entrance to harbours where range is not a great consideration the light may be coloured red or green.

Many lights are now left unattended for long periods, and the illuminant is generally compressed oil-gas, stored in receivers, or acetylene gas, manufactured in generators on the spot or on the dissolved acetylene principle.

Dissolved Acetylene Light at Venice.

The following information respecting the cost of illumination by dissolved acetylene at the Lighthouse on the North-East breakwater of the Port of Lido, Venice, is extracted from a report by Sig. Carlo Duse in the 'Giornale del Genie Civile,' 1913.

The Lighthouse is fitted with a dioptric lens of 300 mm. diameter. The burner consists of three single elements aggregating 60 litres per hour capacity, equal to a white light, through the lens, of 800 Hefner candle-power, or 720 standard candle-power.

The light shown is a green flashing light with two flashes, each of 1½ seconds duration, the first followed by one second eclipse and the second by four seconds eclipse. The light is visible for a distance of nine miles, under conditions of average clearness. It is automatic and is controlled by a Dalen Sun-valve.

The gas magazine consists of 8 dissolved acetylene cylinders or accumulators, each of 5 cubic metres capacity. This supply suffices for an uninterrupted period of 115 days, during which no attention is given to the light.

The initial cost of the lighthouse was 2,960*l.* for the structure and 600*l.* for the light apparatus. A statement of the estimated annual working cost is as follows:—

	£	s.	d.
Three charges of gas, each of 10 cylinders of 5 cubic metres capacity at 4*s.* per cu. m.	30	0	0
Exchange of cylinders and carriage	10	10	0
Casual repairs, rectification and periodical visits	4	16	0
	£45	6	0

The dissolved acetylene was obtained from a local compressing station, but at the date of the report it was under contemplation to establish a compressing station as part of the lighting undertaking in the expectation that the price of the gas would be reduced to 2*s.* per cubic metre.

Relative Absorptive Powers of Coloured Glass.

With the best red glass the ratio between the powers of the red and white lights is as 2 to 5.

When colour is necessary in fixed dioptric apparatus the coloured beam can be strengthened by condensing prisms, whilst for revolving dioptric apparatus the red and white can be approximately equalised by giving to the red beam a greater breadth and a special arrangement of the lens and prisms.

A pink is better than a red tint.

During thick weather red lights are not so much absorbed by the atmosphere as white.

Glazing.

The glass of lighthouses is usually ⅜ in. thick, except in peculiarly exposed situations, where it is ½ inch.

The astragals are 1 in. in section, of gun-metal, having a tensile strength of 33,000 lbs. per square inch.

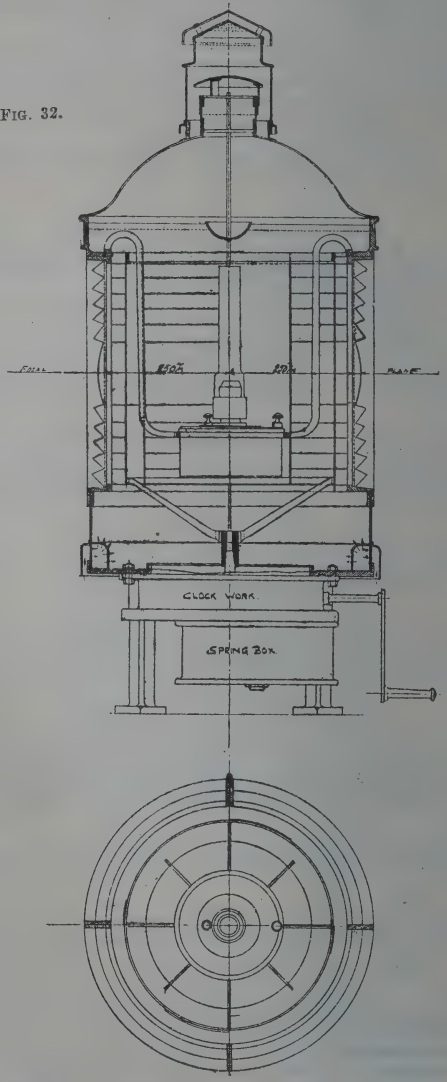
Diagonal astragals do not intercept light in any one azimuth throughout their whole height, and they secure great rigidity and strength.

Ordinary first-order lanterns are 12 ft. in diameter and 10 ft. high in the glazing.

The Bishop Lighthouse has a lantern of 14 ft. diameter and 15 ft. high; Fair Island, 14 ft. diameter, 6 ft. 2 ins. high; Tory Island, 14 ft. 9 ins. diameter, 18 ft. high; Sule Skerry, 16 ft. diameter, 12 ft. 2 ins. high.

FOURTH ORDER OCCULTING PORTLIGHT.

FIG. 32.



Lightning Conductors.

These should be of ¾-in. best quality copper rod, carried 18 ins. above highest part of ventilator of lantern, and then terminated in three branches with platinum caps or platinum wire No. 8 B.W.G., screwed and soldered into the rod; the latter should be put into metallic connection with all internal masses of metal. The earth connections should be made by copper plates, 20 ins. by 12 ins., and ⅛ in. thick. Conductors should be periodically inspected.

Audible Signals.

The types of sound signals in use by the Trinity House are:—(1) aerial and submarine bells; (2) explosive signals; (3) reeds; (4) sirens; and (5) diaphones.

Of the first of these, **Aerial Bells**, actuated by the motion of the ship or buoy carrying them, are well known, but a new method of operating the striking mechanism has been recently installed at the unattended lighthouse on the Menai Straits and on the Lune Deep unattended gas boat.

The bells in each case weigh 10 cwt. The striking hammer is interior to the bell, and the striking action is performed by the admission of carbonic acid gas under pressure to the underside of a diaphragm which actuates the hammer striking the bell; the gas is then exhausted into the atmosphere and the hammer returns to a vertical position preparatory to another impulse. A battery of 24 cylinders of CO_2 gas is capable of maintaining a bell signal with a character of 1 stroke every 15 seconds for twelve months without re-charging.

Submarine Bells are of several types, one of which is operated by the motion of the floating body to which it is attached, and another by a regulated pressure of air or CO_2 gas, in order to impart a definite character to the signal.

The bells used on Trinity House light-vessels are suspended outboard from a davit, and when lowered are approximately 18 feet below the water line. They are operated by compressed air at a pressure of 15 lbs. per sq. in., which is led from a receiver on board the vessel through a rubber pipe to the striking mechanism actuating the bell hammer.

The third type of submarine bell, of which only one exists in the Trinity House Service, is electrically operated, and is laid in twenty-four fathoms of water—three-quarters of a mile off South Stack lighthouse in North Wales. The bell is fixed to a tripod 21 ft. high, and is connected by a 4-core cable with the engine-room at the lighthouse, where a current of 3 amperes at a pressure of 200 volts is generated by a Crompton motor; this is pulley-driven by the 5-h.p. oil engines which simultaneously work the air-compressing plant for the reed fog signal.

Telephone lines connect a microphone in the electro-magnet casing and a receiver in the engine-house, so that the keeper on watch can ascertain if the bell is sounding properly or not.

Explosive Signals consist of the firing of a gun, explosion of acetylene gas, or the detonation of gun-cotton charges from a rising and falling jib on the lantern roof, of which last system there are seven instances in the Trinity House service, possessing a special feature in the safety gear by which premature firing is obviated while the jib is in its lowered position for loading. This is effected by leading the wires from the battery switch on the lantern pedestal to terminals outside the lantern roof, and fixing to the trunnion of the jib spring contact strips which make and break contact between the battery and detonator leads, when the jib is raised and lowered; by this means, after the jib has been moved through a small angle out of the vertical, no firing of the charge is possible until it is again raised, and consequently no danger to the keeper, or damage to the lantern glazing, can accrue.

Explosive signals are now fired by wireless. A recent representative installation on the Clyde consists of a gun which is charged with an admixture of air and acetylene gas and is fitted with wireless receiving apparatus. A synchronous transmitting set is installed on a pier 1½ miles distant. When fog is observed, the transmitting installation is put into operation and the impulses sent out are received on the apparatus attached to the fog signal gun. The synchronising arrangement renders the installations immune from atmospherics and interference from other wireless waves.

The three remaining and most important types of sound signals will be dealt with conjointly, as each is operated by compressed air, and the only difference lies in the type of instrument producing the sound.

Reed Signals are, as a rule, sounded at a pressure of 15 lbs. per sq. in. from a vertically fixed conical horn with a bent top. The reed tongues are of steel 3 ins. long by ⅛ in. wide, and are tuned to give a note of about 450 vibrations per second, with a consumption of ⅔ cu. ft. of free air per second of blast.

Manual reed signals are sounded at 5 lbs. per sq. in., and the character is produced by a hand-operated valve.

Siren Signals are sounded at a pressure of 25 lbs. per sq. in. from horizontal tapered elliptical trumpets, and from vertical conical horns with bent tops. In all cases, except at Trevose Head Lighthouse, the siren is automatic and produces a note of about 187 vibrations per second with a consumption of 11 cu. ft. of free air per second of blast.

The siren at Trevose Head is 12 ins. in diameter, with only one port to the trumpet, and is driven by a small Brotherhood air motor. In this instance there is only one trumpet, which is a specially constructed Rayleigh elliptical steel horn.

The modern form of sound signal is the 'Diaphone,' such as that installed by the Trinity House service at Caskets Lighthouse, off Alderney, one of the Channel Islands, and elsewhere. They are sounded at a pressure of 30 lbs. per sq. in. and have a consumption up to 45 cu. ft. of free air per second of blast.

Audibility.

Under favourable conditions a steam siren may be heard at a distance of 14 miles, but sometimes the range does not exceed 2 miles.

A compressed-air siren (0·125 metre in diameter) has been heard at a distance of 13 miles but the range is sometimes as low as 1·75 mile. A small-sized siren (0·042 metre diameter) cannot be heard at a greater distance than 1·85 mile under favourable conditions.

A 4-oz. charge of cotton powder can be heard under favourable conditions at a distance of 20 miles, and under unfavourable conditions at a distance of 2½ miles.

The distance traversed by the sound from submarine bells has reached 15 miles, but 1 to 2 miles is a serviceable distance.

Modern Navigational Devices.

See *The Engineer*, November 7, 1924, Abstract of lecture by F. E. Smith, F.R.S. (Director of Scientific Research, Admiralty), before the Royal Institution, February 29, 1924. Relates to navigational devices based on the acoustic and electro-magnetic properties of sea water and the directiveness of radio-telegraphy.

DIVING.

Forms and Limitations.—Diving is practised in three forms—either naturally, without any extraneous supply of air during submersion, or artificially, under pneumatic pressure (*a*) with a diving dress or (*b*) with a diving bell. The first is the most primitive method and, though still in vogue among natives in Eastern seas, is bound to be intermittent, in spells of short duration, as it causes great physical strain, leading not merely to acute discomfort, but at times to bleeding at the nose, mouth, and ears. When practised with the aid of pneumatic apparatus, the period of submersion may be greatly prolonged. The only practical limitation is in regard to depth. For every 33 ft. below water, the pressure on the lungs is increased by 1 atmosphere (14·7 lbs. per sq. in.) Thus, at 50 ft. below the surface the pressure is 22½ lbs. in excess of atmospheric pressure; at 100 ft it is 44½ lbs., and so on. Such pressures, though considerable, may be sustained with impunity, and even a depth of 150 ft. may be reached without ill effects. But greater depths necessitate considerable powers of resistance and are attended with risk. Until recently the maximum depth to which any diver had descended, as recorded by authentic testimony, was 210 ft., at which depth the pressure was rather more than 7 atmospheres absolute. But in August 1924 some trials, made in Walchensee Lake, Bavaria, with a deep-sea diving outfit prepared by a German firm, are reported to have indicated the possibility of executing work at much greater depths than this. One diver went to a depth of 140 metres. The apparatus proved water and pressure tight, and all turning joints could be moved. He could see for half a metre only. Then another diver went 160 metres below the surface of the water, but at that depth there was absolute darkness. He could walk on the bed of the lake without difficulty. Hoisting from this depth to the surface took only 4½ minutes. On the following day, work, such as fastening a shackle to a sunk piece, was done at a depth of 110 metres. At 160 metres, the maximum depth, the pressure amounts to 225 lb. per sq. in. Harbour work does not generally entail diving in water of more than 10 fathoms (60 ft.).

Caisson Disease.—After immersion under pressure the blood becomes more or less saturated with nitrogen in dissolved form, and when the pressure is relaxed the surplus gas is given off—if too rapidly, bubbles of gas form in the circulatory system, resulting in pains ('pins and needles'), asphyxiation, paralysis, and death, according to the intensity. To these symptoms is given the name of *Caisson Disease*, from its association with work carried on in caissons under pneumatic pressure. It is the most formidable antagonist of the diver, prostrating even the most powerful and robust. Fortunately the malady does not manifest itself at all under moderate pressures, viz., those less than 2 atmospheres absolute. For depths exceeding 35 or 40 ft., it is

necessary to use circumspection during the process of decompression, i.e., the ascent to the surface should be made slowly, with stoppages at intervals. By this means the evil effects can be neutralised.

The following table indicates the ordinary time limits in deep water, stoppages in ascent, and approximate air supply, in accordance with Prof. Haldane's recommendations and the latest British Admiralty practice:—

TABLE.

Depth.		Pressure, Lbs. per Sq. In.	Time under Water from Surface to Beginning of Ascent.	Stoppages in Minutes at different Depths.			Total Time of Ascent, Minutes.	No. of Cylinders needed.	Revolutions of Pump per min.
Feet.	Fathoms.			30 ft.	20 ft.	10 ft.			
0–36	0–6	0–16	No limit	—	—	—	0–1	1	15–20
6–42	6–7	16–18½	Up to 3 hours	—	—	—	1–1½	1	25–30
			Over 3 hours	—	—	5	6	1	25–30
42–48	7–8	18½–21	Up to 1 hour	—	—	—	1½	1	30
			1 to 3 hours	—	—	5	6½	1	30
			Over 3 hours	—	—	10	11½	1	30
48–54	8–9	21–24	Up to ½ hour	—	—	—	2	2	20
			½ to 1½ hours	—	—	5	7	2	20
			1½ to 3 hours	—	—	10	12	2	20
			Over 3 hours	—	—	20	22	2	20
54–60	9–10	24–26½	Up to 20 min.	—	—	—	2	2	25
			20 min. to ¾ hour	—	—	5	7	2	25
			¾ hour to 1½ hours	—	—	10	12	2	25
			1½ hours to 3 hours	—	5	15	22	2	25
			Over 3 hours	—	10	20	32	2	25
60–66	10–11	26½–29	Up to 15 min.	—	—	—	2	2	25
			¼ to ½ hour	—	—	5	7	2	25
			½ to 1 hour	—	3	10	15	2	25
			1 to 2 hours	—	5	15	22	2	25
			2 to 3 hours	—	10	20	32	2	25
66–72	11–12	29½–32	Up to 15 min.	—	—	2	4	2	25
			¼ to ½ hour	—	3	5	10	2	25
			½ to 1 hour	—	5	12	19	2	25
			1 to 2 hours	—	10	20	32	2	25
72–78	12–13	32–34½	Up to 20 min.	—	—	5	7	2	25
			20 to 45 min.	—	5	15	22	2	25
			¾ to 1½ hours	—	10	20	32	2	25
78–84	13–14	34½–37	Up to 20 min.	—	—	5	7	2	30
			20 to 45 min.	—	5	15	22	2	30
			¾ to 1½ hours	—	10	20	32	2	30
84–90	14–15	37–40	Up to 20 min.	—	3	5	10	2	30
			20 to 40 min.	—	5	15	22	2	30
			40 to 60 min.	3	10	15	30	2	30
90–96	15–16	40–42½	Up to 20 min.	—	3	5	11	2	30
			20 to 35 min.	—	5	15	22	2	30
			35 to 55 min.	5	10	15	32	2	30

Diving Bells.

As an alternative to the diving dress, the diving bell, a chamber constructed of mild steel plating, carefully riveted and securely caulked so as to be perfectly watertight, may be suspended over the place of operation and lowered or raised as required. The scope of movement by workers is naturally restricted to the area occupied by the bell, which may be 20 ft. by 10 ft. or thereabouts. Some submarine caissons are of much greater dimensions, but they are not diving bells in the true sense of the word. The interior is fitted with seats and footrests for the occupants, who may perhaps number a dozen. The bell is ballasted with cast-iron kentledge to enable it to sink without risk of overturning.

NOTE.

In the process of raising the United States submarine S 51, attempts were made to tunnel through the clay beneath her, by means of water jets, 2½ ins. in diameter, at a pressure of 50 lbs. per square inch, but the divers were unable to hold the jets against the reaction. To counteract this reaction, the nozzle had behind it five other smaller holes directed backwards. The reaction of these jets counterbalanced that of the main jet, and the diver could comfortably control the nozzle when working at even 200 lbs. pressure.

SECTION XXIX

NAVIGABLE WATERWAYS—VELOCITY OF RIVER FLOW—TREATMENT FOR EROSION—CHANNEL TRAINING WORKS—RIVER DREDGING—COST OF RIVER REGULATION—RIVER CANALISATION—COST OF CANAL CONSTRUCTION—CONTINENTAL CANALS—LOCKS AND MECHANICAL LIFTS—CANAL CURVES—LOSS OF WATER ON CANALS—TRACTION AND HAULAGE—SHIP CANALS.

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SECTION XXIX

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NAVIGABLE WATERWAYS.

Classification.

(1) **Natural Channels**, i.e., those rivers, or portions of rivers, including estuaries, the normal flow of which is not interfered with by artificial works;

(2) **Canalised Rivers**, frequently called 'Navigations,' the flow of which is more or less under artificial control and

(3) **Canals**, proper, entirely artificial in conception and construction.

The distinction between the three classes is fundamental and important. In the case of the natural channel, improvement works are limited to a rectification of the bed, and no attempt is made to control or augment the natural flow of water, which, being derived from the drainage of the basin, is normally sufficient for purposes of navigation, within the limits of the channel capacity. The canalised portions of rivers consist of sections in which the natural flow is conserved and controlled, as in the manner of a canal, but generally without extraneous sources of water supply. Canals, being works of an entirely artificial character, have to be fed with supplies obtained by the interception of streams, or from other external sources, frequently necessitating pumping and reservoir storage.

Internal Waterways in the United Kingdom.

According to the Report of the Royal Canal Commission, issued in 1909, the total mileage of Canals and Navigations in use in the United Kingdom is about 4,670. Of this total, about 1,639 miles lie in England and Wales, 183 in Scotland, and 848 in Ireland. The length of canals in existence in England and Wales is given as 1,927½ miles, and of navigations, 1,312½ miles. There are 812½ miles of open river and estuary.

IMPEDIMENTS TO NAVIGATION OF RIVERS.

In the seaward section the most pronounced disability, where it exists, is the bar. For its removal a very efficient means, producing immediate amelioration, is dredging; but the effect in the majority of cases is merely temporary, and operations must be continuous if the improvement is to be maintained. Where bars are not in evidence, or not very pronounced, a river mouth is often encumbered by shoals, due either to detritus brought down by the river itself or to coastal erosion and drift. In this case also, dredging may be resorted to with immediate advantage.

For permanent benefit it is requisite to supplement this temporary expedient by training works of a scope and magnitude dependent on circumstances. Such works comprise longitudinal training walls, or embankments, and groynes, dykes, or jetties, to be alluded to later.

In the upper sections of rivers the principal difficulties encountered are irregularities in flow due to floods in rainy seasons and depletion of water in periods of drought, excessive current velocity, instability of channels and the formation of shoals. In low-lying lands, it is often necessary as a protection against inundation to raise the river banks with impervious material well supported from behind. Insufficiency of water may be met by the introduction of weirs, or the formation of storage reservoirs. The remedy for excessive and irregular currents lies in training works of a suitable character.

Velocity of Flow in Rivers.

The velocity of river flow varies very considerably, as will be seen from the following table. As regards navigation, currents exceeding three to four miles an hour or four and a half to six feet per second make a serious deduction from the speed of propulsion of vessels proceeding upstream and render control difficult in the case of small craft travelling downstream. See also par. on Horse Traction, page 1587.

River Seine at Meulan .	2·45 ft. per second.	River Rhine at Basle .	6·36 ft. per second
„ „ at Paris. .	4·00 „ „ „	„ Aar at Berne . .	7·50 „ „ „
„ Thames at London Bridge . .	3·00 „ „ „	„ Durance, below Sisteron . . .	8·65 „ „ „
„ Tiber at Rome .	3·40 „ „ „	„ Maranon, S. America	13·00 „ „ „

Velocity Observations are taken by means of (*a*) Floats, (*b*) Current Meters, and (*c*) Pressure Tubes.

Floats.—For surface velocities an orange is excellent, floating almost wholly immersed. In the winter season, fragments of ice give similarly good results. The topmost layers of water, however, are frequently affected by the wind. To obviate this the float should extend some distance below the surface. A corked bottle, weighted at the bottom, has proved satisfactory for the purpose. Tube floats are also employed, consisting of tin cylinders about 1 in. diameter weighted so as to maintain perpendicularity, and leave two or three inches projecting above the surface. Double floats are sometimes used, consisting of a small surface float connected by means of a cord to a float of larger bulk below. In Mississippi experiments, the lower floats were kegs 9 ins. high and 6 ins. diameter, or 12 ins. high and 8 ins. diameter, according as depth was less or greater than 5 ft. They were without top or bottom, and ballasted with lead. The connecting cords were $\frac{3}{16}$ in. to $\frac{1}{2}$ in. diameter. The upper float was of light pine, $5\frac{1}{2}$ ins. square by $\frac{1}{4}$ in. thick, or of hollow tin, $5\frac{1}{2}$ ins. by $1\frac{1}{2}$ in.

Current Meters.—These record velocity by means of the revolution of a screw, being calibrated by drawing through still water at various speeds. Price current meter, used by United States Geological Survey, consists of six cups attached to a vertical shaft, which revolves on conical hardened steel point when immersed in moving water. Meter measurements can be made from a bridge, from a cable and car specially installed for the purpose, from boats or by wading. Current meters are affected by friction, and are not very suitable for low velocities; in fact, in feeble currents they cease to act.

Pressure Tubes.—Pitot tubes, which are ⌊ shaped with the lower horizontal limb pointing upstream, record the velocity by the height to which the water in the tube is forced above surface level by the pressure of the current. Darcy's adaptation consists of two tubes in communication, enabling the differential reading to be taken more accurately and eliminating the effect of ripples and oscillations. The apparatus gives good results in small channels with currents of fair velocity, but it is not suitable for large rivers or for very low rates of flow.

Position of Maximum Velocity may be taken generally at or about surface level, but is not infrequently below. The view is generally held that the velocity varies as the abscissa

of a parabola, whose axis is parallel to the surface. The equation for the parabola in the case of the Mississippi was found to be

$$v = -0{\cdot}79222\ d^2 + 3{\cdot}2611$$

where,
v = velocity in feet per second and d is distance from axis in fractional parts of whole depth considered as a unit.

Mean Velocity.—The position of mean velocity has been found by repeated experiments in U.S. Geological Survey to be located at about 0·6 of the total depth. The mean of velocities obtained at 0·2 and 0·8 of the depth gave the mean velocity of the stream very accurately.

In ordinary cases the least, mean and maximum velocities may be taken in the ratio 3 : 4 : 5. In very slow currents they are nearly as 2 : 3 : 4.

Prony's Formula:

$$\frac{\text{Mean velocity}}{\text{Maximum velocity}} = \frac{\text{Maximum velocity} + 7{\cdot}71 \text{ ft. per sec.}}{\text{Maximum velocity} + 10{\cdot}28 \text{ ft. per sec.}}$$

Computed Velocity.—A great number of formulæ have been published connecting the velocity with the hydraulic mean radius (R) = $\frac{\text{area of stream}}{\text{wetted perimeter}}$, and the sine of slope (S) = $\frac{\text{fall in level}}{\text{length of channel}}$. Most of these expressions can be reduced to the form

$$v = c\sqrt{RS},$$

where c is a coefficient varying with the class and nature of the channel, as well as with the personality of the observer. Some of the coefficients are very complicated, and the values are variable to a considerable degree. Mr. A. A. Barnes ('Hydraulic Flow Reviewed,' 1916) proposes to modify the powers of R and S so as to admit of a coefficient of constant value. His expression is

$$v = 58{\cdot}4\ R^{\cdot 694} S^{\cdot 496}$$

or, approximately,

$$v = 60\ R^{\cdot 7}\ S^{\cdot 5}$$

In nineteen observations with ranges in width of stream from ·26 ft. to 2,598 ft., in depth from ·19 ft. to 69 ft., in hydraulic mean radius from ·0786 ft. to 53·6 ft., and in slope from 1¾ to 241·2 ft. per mile, velocities of from 1 to 7½ ft. per second were computed and found to agree, within 1 per cent., with actual observation.

In the course of investigations made during three years in connection with the regulation of the Whangpoo and Yangtse Rivers, Dr. Herbert Chatley found that in fairly straight and uniformly sectioned reaches when the flow is steady the above exponential form $v = cR^{\cdot 7}\ S^{\cdot 5}$ gave consistent results. But when the flow was unsteady he found it more satisfactory to take the expression

$$v = cR^{\cdot 7}\left(S - \frac{a}{g}\right)^{\cdot 5}$$

where a is the acceleration. In other words, the effective slope was equal to the algebraic difference between the actual slope and an 'acceleration' slope determined by the ratio of the actual mean acceleration of the water to the gravitational acceleration.

Critical Velocities.—The following is a statement founded on the researches of Dubuat and Beardmore of velocities at which various materials in a river bed commence to be eroded:

Soft clay	3 ins. per second.	Rounded pebbles, 1 in. diam.	2 ft. per second
Fine sand	6 ,, ,, ,,	Rough gravel	2¼ ,, ,, ,,
Coarse sand and pea gravel	9 ,, ,, ,,	Pebbles 1¼ in. ,,	3¼ ,, ,, ,,
Gravel as large as French beans	12 ,, ,, ,,	Heavy shingle	4 ,, ,, ,,

TREATMENT FOR EROSION.

Protection of River Banks.—Water plants form a very efficient natural protection and they assist in retarding the current—sometimes not an unmixed advantage.

Earthen banks of a soft and erodable character may be artificially protected, where stone is procurable, by rubble pitching, laid at a slope of $1\frac{1}{2}$ or 2 to 1, from 8 to 12 ins. thick at the top and increasing in thickness downwards at the rate of 3 ins. per yard. The foot of the slope should be adequately secured to some firm abutment, such as piling, otherwise the pitching may be undermined and, in that case, it will subside.

Where stone is not procurable, fascine aprons or mattresses, formed of brushwood, may be utilised. These are bundles of branches and twigs (usually willow) from 9 to 12 ins. in diameter about 12 ft. long and bound with tarred rope at intervals of 4 ft. or so, laid side by side and tied together so as to produce a surface covering of the desired extent. The 'fascines,' as they are termed, should be secured by stakes or short piles to the bank upon which they are deposited.

A plantation of small willows above water level is useful in counteracting the more deleterious effects of floods.

Mississippi River Bank Protection.—The banks of the Lower Mississippi are protected where necessary from erosion below water surface level by means of brushwood mattresses loaded with stone. The portion of the bank above surface level is protected by a covering of stone only, 10 ins. thick, laid to a suitable slope.

The mattresses were deposited from a single barge, or from a couple of barges, placed end to end, so that the combined length of the barges exceeded the width of the mattress. The ordinary size for mattresses was 800 ft. by 250 ft., but some mattresses were 1,000 ft. long by 300 ft. wide. 'The mattresses are constructed on the mattress-barge by laying parallel to the shore, and 8 or 10 ft. apart, a series of poles, whose aggregate width equals nearly that of the proposed mattress. These poles are small trees from 3 ins. to 6 ins. diameter at the butt, and 25 ft. to 30 ft. long. Smaller poles are then placed at right angles to the larger series, so as to pass alternately beneath and above the successive larger poles, as in basket-work. These smaller poles when forced into close contact with each other and with the other series, form a tolerably compact web or mattress. When so many of the small poles have been added that they approach the ends of the larger series, whose poles are parallel to the shore, these larger poles are each continued by having another large pole spliced to it, and so on, for the length of the mattress. The brush in the mattress is fastened together frequently with iron wire and cross poles. The whole mattress is strengthened by wire cables about 20 ft. apart, and by $\frac{3}{4}$ in. to $\frac{5}{8}$ in. wire ropes running longitudinally the whole length of the mattress. Transverse cables of wire, about 16 ft. apart, also strengthen the mattress; and transverse wire ropes in addition are sometimes used.'

'As each mattress was woven it was allowed to be floated down stream off the barge by the current, and when a sufficient length had been accomplished it was loaded with stone and sunk, the upper end being sunk first. The customary under-water slope did not exceed 1 in 3, and the depth of the outer edge often ranged from 60 ft. to 100 ft. (*From Report by General C. B. Comstock, on Mississippi River Improvement, to Chicago International Congress*, 1893.)

Flexible mattresses of reinforced concrete are being experimented with on the Mississippi.

CHANNEL TRAINING WORKS.

The instability and eccentricity of channels is remedied by training works, comprising (*a*) projecting jetties and groynes, (*b*) longitudinal dykes and embankments, and (*c*) ground sills.

Groynes or Jetties project from the banks to the stream at right angles, or thereabouts (generally within 70° to 90°) to its course, and have the effect of reducing the channel and concentrating the scour of the current within certain bounds. The beneficial effect, however, is largely local, and, in the absence of restraint between the jetties, the stream tends to diffuse itself over a wider area, so that while the bed may be deepened and improved opposite the ends of the groynes it often becomes actually shallower in the intermediate spaces. To be effective groynes should be spaced apart not more than five times their own length, and this often renders them less economical than a system of longitudinal dyking, which, on the whole, will be found far more satisfactory and is often ultimately adopted. Groynes should, in fact, only be looked upon as of the nature of a temporary expedient. They may be formed of piling, fascine work or rubble.

Groynes on the River Waal.—These are so arranged as to point upstream with the axis of the groyne on the concave bank forming an angle of 80° with the projected channel, and that on the convex bank an angle of 70°. This system has been found favourable to the deposit of alluvium between the groynes.

The groynes themselves are formed of a core of sand extending to 11 ft. 6 ins. below ordinary low water. The core is covered with mattresses of fascine work, having a lateral slope of 6 to 4, surmounted by a layer of broken brick and rubble stone. The slope towards the river is 1 in 4. The width of the crown of the groynes is 11 ft. 6 ins., and their height along the boundary of the normal river bed 1 ft. 6 ins. above ordinary low water level, corresponding to about 1 ft. 6 ins. below mean water level.

It is stated that sand forms a satisfactory core if banked in large quantities at a time, and that no harmful results ensue from the slipping away of a certain amount during submergence. A few years after formation the groynes receive a protective covering of basalt.

The River Waal has a velocity varying between 2¼ and 3½ ft. per second. The discharge is about 21,000 cubic ft. per second at lowest water level, and 220,000 cubic ft. during highest floods. (*From Report by M. Baucke to Philadelphia Navigation Congress*, 1912.)

Longitudinal Dykes are walls or embankments of timber, stone, concrete, fascines, or other material built up so that the channel is rigidly confined within definite limits throughout the length treated. At the outlet of the Fen Rivers in the Wash, banks of fascine faggots and clay were constructed 22 ft. wide at the base, 17 ft. high, and 13 ft. wide at the top, at a cost of about 1*s.* 8*d.* per cubic yard. On the River Weser, stone and gravel embankments have been found preferable to fascines on the ground that the surface slopes may be rendered less steep than 45°, which is stated to be the limit for fascine work.

River Training Works at the Mouth of the Danube.—Operations for the improvement of the navigable channel at the Sulina mouth of the Danube have been in progress for more than half a century, under the direction of the European Commission of the Danube, an international body, constituted in 1856 by the Treaty of Paris.

There are three main arms, or branches, of the Danube delta, at its influx into the Black Sea. The Sulina arm, with the port of Sulina at its mouth, was chosen for treatment by reason of its greater depth and general use, despite the fact that its discharge was scarcely 10 per cent. of the total.

Rudimentary timber piers, consolidated by concrete mass-work and stone rubble, were constructed in the first instance, thus concentrating the outward current, and by the scour so occasioned, the depth across the bar of the river was increased from 9 ft. to 17 ft. rapidly; and subsequently more gradually to 20½ ft., at which figure it remained, naturally, for a period of 22 years until 1894, when dredging was commenced and a depth of 24 ft. obtained, necessitating, however, continuous maintenance work. In 1915 the depth of 24 ft. was lost and three dredgers proved incapable of re-establishing it. On account of the progressive advance of the delta, the action of natural forces, aided by artificial means, had become insufficient to cope with the deposit of alluvium, which, indeed, threatened to destroy serviceable access to the river for shipping.

In 1922 a prolongation of the piers or jetties was begun, and in 1925 was completed to a point of about 3,300 yds. from the Sulina Lighthouse, which is located at the port entrance. On July 25, 1925, the new channel, 200 ft. wide, was opened to traffic with a minimum depth of 20 ft., which within a month was increased to 23 ft. Deposit, however, continued to take place at the outer extremities of the piers, and a further prolongation is now in progress with the object of reaching deeper water for the pierheads.

Levees constitute a type of longitudinal dyke. They contract the river channel in its higher stages and protect the adjacent country from inundation. As used in American practice, they are generally banks of earth or spoil, well consolidated, with a central trench forming an impervious connection with the natural ground.

Channel Curves.—The natural tendency of river channels is to form a series of deep water pools on the concave sides of bends, with shoals at the intervening points where the current passes over from one side of the river to the other. A judicious system of training will maintain the natural sequence of these deep pools, at the same time suppressing any unduly sharp bends which might be awkward for navigation. Generally speaking, for vessels of 400 to 600 tons moving at a fair rate of speed a radius of 550 yards should be regarded as a minimum—at low speeds, 220 yards will suffice. The minimum for vessels of very small tonnage (say, 200 tons and under) may be as low as 66 to 88 yards.

Ground Sills are serviceable where there is excessive scour of the bed or undue restriction in width of channel. They have the effect of rendering the fall of the stream more uniform. In German practice they are set from 40 to 50 feet apart, and found to be better than continuous pitching or filling of the bed. They are laid across the river so that their highest levels at the bank are about 12 inches below the normal surface, and they slope downwards to the centre of the stream at an angle of about 1 in 40. On the Mississippi the ground sills consist of either rubble mounds or cribs filled with rubble, or, again, of brush mattresses and stone in alternate layers. Whatever form be adopted, the top should be finished off smoothly to prevent injury to passing vessels. Ground sills may be used where it is desired to raise the low water level or lengthen out a slope.

Storage Reservoirs.—For the augmentation of the flow in dry seasons storage reservoirs have been advocated, and in two instances—the Mississippi and the Volga—have been adopted. Circumstances, however, have to be favourable if they are to prove a satisfactory and economical arrangement. The Volga has its source in a lake and swamp region where land is cheap and unfit for agriculture. The dams required were only 17½ feet high, and a storage capacity of 35,000 million cubic feet was obtained. On the Upper Mississippi above St. Paul, five reservoirs were formed out of an extensive lake area of 480 square miles, with a storage capacity of 93,400 million cubic feet. It is stated that the increase in height obtained at St. Paul during the low water period—about 90 days—averages only 14 inches. The system is not regarded as sufficiently satisfactory to justify its extension elsewhere in the United States. Where there is no original headwater accumulation its adoption is out of the question.

RIVER DREDGING.

The improvement of river channels by means of mechanical dredging has received considerable impetus of late years by reason of the development in power and capacity of dredging plant. The various appliances are described in detail in connection with harbour dredging (*vide* p. 1542 *et seq.*). In some cases, as for instance the Volga, with its tributaries the Oka and the Kama, the application of dredging alone, without the assistance of artificial training works, has proved sufficient to ensure the maintenance of a serviceable channel, while in other cases, notably on the Mississippi and the Mersey, engineers employ both systems conjointly.

Dredging Plant on the Volga.—On the Volga, dredgers work from the shallowest depths up to 20 ft. and consist of both bucket dredgers and suction pumps.

One of the former has a hull 131 ft. by 26 ft. with a draught of 3 ft. 3 ins. It discharges about 300 cubic yards per hour by means of shoots, or 370 cubic yards per hour through a floating pipe-line. Two other dredgers have a length of 157 ft., a breadth of 31 ft. 2 ins., and a maximum draught of 4 ft. 11 ins. They are self-propelling with a speed of 4 knots. The pipe-line is 1,740 ft. in length. The buckets have a capacity of ½ cubic yard, and they are reinforced by centrifugal pumps of 5 ft. diameter. The pipe-line has a diameter of 19 ins. A still more recent dredger is 131 ft. long by 28 ft. wide, with a draught of only 2 ft. 4 ins , a dredging depth of 17 ft., and a working capacity of 196 cubic yards per hour in sandy material.

COST OF RIVER REGULATION.

Country.	River.	Depth.	Length.	Total Cost.	Average Cost per Mile.	Average Fall per Mile.
		Ft.	Miles.	£	£	Ft.
United States	Upper Mississippi (St. Paul to Missouri River)	4½	632	2,050,000	3,244	·44
France . .	Rhone (Lyons to Sea) .	4·1	205	2,689,000	13,000	2·5
Germany .	Rhine	4–10 3–4·1	214	2,636,400	12,200	1·14
Ditto .	Weser (near mouth) .	5–10 3·6–4·6	210	463,300	2,210	1·65
Ditto .	Elbe (near mouth) .	6–10 2·6–4·25	252	2,047,900	8,130	0·98
Ditto .	Oder (near mouth) .	5–8·7	337	1,229,600	3,650	1·29

(*Extracted from Report by Major Harts to Philadelphia Navigation Congress*, 1912.)

PARTICULARS OF DREDGING PLANT USED ON MISSISSIPPI RIVER.

All self-propelling, with two main pumping engines, each of horizontal tandem compound condensing type, and centrifugal pumps with water-jet sand agitators.

Details.	Dredger 'Iota.'	Dredger 'Kappa.'	Dredger 'Henry Flad.'	Dredger 'B. M. Harrod.'
Date when built	1900	1902	1902	1906
Cost, complete	20,296*l.*	27,080*l.*	27,080*l.*	48,000*l.*
Material of hull	Steel	Steel	Steel	Steel and iron*
Dimensions of hull	192′×44′×7′	192′×44′×7′	192′×44′×7′	210′×44′×8½′
Draught	4′	4′	4′	5′
Size of engines	16″×26″	15″×30″	15″×30″	20″×34″
Revolutions per minute	165	140	140	140
Stroke	20″	24″	24″	24″
Pumps:				
Diameter of runner	75″	84″	84″	90′
Peripheral velocity, ft. per sec.	53	51·3	51·3	55
Diameter of suction	Two 24″	Two 24″	Two 24″	Two 27″
Width of suction head	23′	23′	23′	32′
Diameter of discharge	32 1/16″	31⅞″	32″	36″
Maximum working depth	20′	20′	20′	20′
Nominal capacity, sand per hour	1,000 cu. yds.	1,000 cu. yds.	1,000 cu. yds.	2,000 cu. yds.
Sand agitators:				
Kind of pump	Duplex comp. cond.	Duplex comp. cond.	Duplex comp. cond.	Centrifugal
Size	16″×15″	16″×15″	16″×15′	Two 12″
Number and diameter of jets	Twelve, ¾″	Twelve, ⅜″	Twelve, ¼″	Eighteen, 2″
Pressure	50 to 80 lbs.	50 to 80 lbs.	50 to 80 lbs.	20 lbs.
Boiler:				
Kind	7 Miss. River	7 Miss. River	7 Miss. River	7 Miss. River
Size	44″×30′	44″×30′	44″×30′	47″×28′

* Iron used for hull plating, the piping, and the chimney stacks, as it was found by experience that the life of iron materially exceeds that of steel for such purposes.

(*Extracted from Report by Mr. J. A. Ockerson to Milan Navigation Congress*, 1905.)

RIVER CANALISATION.

The canalisation of rivers is effected by dividing their beds into a series of reaches separated by dams, or weirs, which are provided with a communicating lock, or locks, arranged generally at one side. Dams are either fixed or movable, and they may also be permeable or impermeable. Fixed, impermeable structures are generally resorted to as being more economical in construction and more convenient in action. Movable dams may be said to be required only in cases of excessive flood flow, or where the conditions admit of free navigation during appreciable periods. Fixed weirs are usually constructed of solid stonework, rubble, piling or concrete provided with the requisite sluices and overflows. Movable weirs are more often of timber or iron framework with mechanism for lowering and raising them, either wholly or in part by means of leaves or panels. They are of various types with distinguishing names, such as Needle, Chanoine, Boulé and Bear-trap.

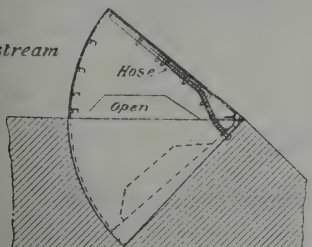

FIG. 1.—Section of Weir near Bremen.

Sector Weir near Bremen.—A notably large sector weir which constitutes a development of the bear-trap type, across the River Weser, near Bremen, is illustrated in cross sectional outline in fig. 1. The weir is in two lengths of 177 ft. each, and holds up the water on an average to a height of about 12 ft.; in winter, the height rises to 18 ft. The structure forms the hollow horizontal sector of a cylinder of 21½ ft. radius turning on a horizontal shaft, the angle of the sector being about 45 degrees. The weight of each sector is 129 tons. A description of the weir with the method of raising and lowering is contained in *Engineering* of July 7, 1916.

TYPES OF UNITED STATES RIVER REGULATION WORKS.

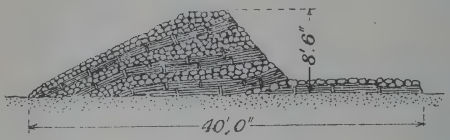

FIG. 2.—Brushwood and Stone Dam, Upper Mississippi.

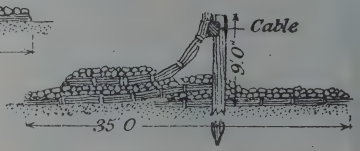

FIG. 3.—Pile and Brushwood Dam, Upper Mississippi.

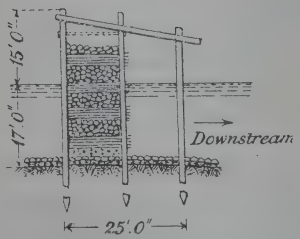

FIG. 4.—Pile, Brushwood, and Stone Dyke, Arkansas River.

FIG. 5.—Pile and Stone Dam, Alleghany River.

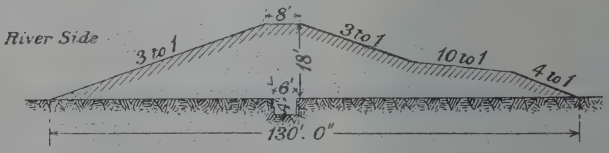

FIG. 6.—Levee on the Lower Mississippi.

COST OF RIVER CANALISATION.

River.	Length Canalised. Miles.	No. of Locks.	Depth. Feet.	Fall in Feet per Mile.	Total Cost.	Cost per Mile.	Operation and Maintenance. Total.	Operation and Maintenance. Per Mile.
FRANCE:					£	£	£	£
Saone	232	30	8·2	·85	1,755,000	7,550	12,100	52
Seine (Montereau to Paris)	61	12	—	·85	991,000	16,300	10,870	178
Seine (Paris to Rouen)	145	9	10 5	·85	3,500,000	24,200	18,450	127
Seine (New Works)	140	9	—	—	2,535,000	18,100	—	—
Yonne	67	26	—	2·43	1,118,000	16,700	6,730	100
Marne	113·5	19	7·25	1·16	1,047,000	9,250	7,980	70
Aisne	35·5	7	—	—	195,400	5,470	2,130	60
GERMANY:								
Saar	19·5	6	4·25- 7·9	2·15	354,400	18,170	6,410	330
Main	23·5	5	5·9- 8·9	1·40	448,200	19,070	8,010	340
Fulda	17·0	7	6·6-11 9	3·30	157,000	9,240	4,385	260
Salle	89·5	15	4·4- 8 8	1·27	383,400	4,280	9,080	100
Unstrut	40·5	12	2·5- 8·5	1·72	105,600	2,600	2,840	70
Oder	53·2	14	—	1·90	1,211,800	22,780	43,420	815
UNITED STATES:								
Black Warrior	91	7	6	2·76	508,680	5,583	25,207	275
Coosa	25	3	3	2·58	209,687	8,386	1,587	64
Allegheny	25	3	—	2·06	267,574	10,703	9,328	373
Monongahela	131	15	7-8	2·4	1,369,171	10,452	34,673	265
Muskingum	84	10	6	1·55	—	—	10,026	120
Great Kanawha	90	10	6	0·84	844,765	9,394	16,361	187
Kentucky	226	11	6	0·87	580,662	2,578	31,989	141
Green and Barren	190	7	5	0·49	327,682	1,725	15,177	80
Cumberland	131·4	8	6	0·67	525,076	3,996	6,611	50
Illinois	194	2	7	0 05	303,145	1,563	2,568	153

(*Extracted from Report by Major Harts to Philadelphia Navigation Congress*, 1912.)

Lateral Canals.

As an alternative to river canalisation and where the channel exhibits features which do not conveniently lend themselves to treatment, an independent lateral canal may be constructed, generally following the lie of the river, but also making use of any facilities which may offer themselves for straightening and rectifying the course.

The River Rhone, in the chequered history of its amelioration, has been furnished with three lateral canals to overcome the difficulties of navigation at its natural mouth. Each in turn of the earlier two became inadequate for dealing with the traffic which accrued from its construction, and now there is a recently constructed artificial waterway to the port of Marseilles which is described in detail at p. 1578.

COST OF LATERAL CANALS.

Locality.	Length in Miles.	Locks.	Total Cost.	Cost per Mile.	Maintenance and Operation. Total.	Maintenance and Operation. Per Mile.
FRANCE:			£	£	£	£
Loire, Digion to Briare	121·7	37	2,071,000	17,000	6,330	52
Garonne	120	53	2,484,000	20,700	7,500	62½
UNITED STATES:						
St. Mary's Falls	1·1	2	1,611,450	1,464,955	20,620	18,740
Des Moines Rapids	8	3	316,600	39,576	7,754	969
Muscle Shoals	18	11	638,345	35,463	10,280	571
Colbert Shoals	8	1	441,588	55,200	—	—
Cascades Canal	¼	2	764,065	1,528,130	2,877	5,751

(*Extracted from Report by Major Harts to Philadelphia Navigation Congress*, 1912.)

BRITISH CANALS.

The following summary of the conditions prevailing in Great Britain is extracted from the Report of the Royal Canal Commission (1909):

'On the whole, the waterways may be roughly divided into two classes, those having locks of more, and those having locks of less, than 14 ft. in width. Corresponding with these two classes of locks are two classes of vessels usually known respectively as barges and narrow boats, the latter being often called "monkey boats," and chiefly in use on the Southern and Midland canals of England. The barge usually measures from 60 to about 72 ft. in length by 14 ft. in width of beam; the narrow boat is about 70 to 72 ft. in length, but only 7 ft. in width. The narrow boat when loaded, and drawing about 3 ft. 3 ins. of water, will carry about 30 tons over many of the canals. The barge will carry about twice that weight, with the same draught. Both the narrow boat and the barge could carry a heavier cargo if the depth of water were increased sufficiently.

'The usual length of lock, both on the wider and the narrower waterways, in the South and the Midlands, is, accordingly, about 75 ft. But on the wider, or barge canals, the locks are usually between 14 and 15 ft. or more in width, and on the narrow canals between 7 ft. and 8 ft. In both classes of lock the depth of water on the sill varies, speaking very generally and with many exceptions, from 4 ft. to 5 ft.'

	Miles.	Chains
Canals with locks under 14 ft. (narrow)	1,165	5
„ „ „ over 14 ft. (barge canals)	762	29*
Navigations under 14 ft.	478	57
„ over 14 ft.	834	20

* Including the Manchester, Gloucester and Berkeley, and Exeter Ship Canals.

DEVELOPMENTS IN CANAL CAPACITY.

In France and South East Belgium the standard boat carries about 300 tons, while in Germany the newest canals are adapted to boats of 600 tons and upwards. In this country opinion as to future policy is divided between the adoption of the 300-ton type and the retention of the smaller class of boat in general use, not exceeding 100 tons. The following are the dimensions recommended for the two classes respectively by Sir J. Wolfe Barry and Partners, who were called in to advise the Royal Commission on the matter.

Dimensions.	100-ton Boat. Canal.	300-ton Boat. Canal.
Length of barge over all	80 ft.	115 ft.
Beam „ „	14 „	21½ „
Draught	5 „	6½ „
Area of immersed midship section of barge	69 sq. ft.	138 sq. ft.
Cross-sectional area of canal	350 „ „	690 „ „
Depth of canal	7 ft.	8½ ft.
Top width of waterway in open country	59½ „	92½ „
„ „ „ „ in towns	51½ „	83 „
Width of waterway at bridges	32 „	48 „
Minimum headway of new bridges	10 „	13 „
„ „ „ existing bridges	9 „	13 „
Ruling radius for bends of canal	12 chains	17 chains
Locks: Length, mitre to mitre of gates	253 ft.	266 ft.
„ Width between side walls	15 „	22½ „
„ Depth on sills	6½ „	8 „

GOVERNING DIMENSIONS OF LARGE BOATS AND CANALS AS DETERMINED BY FRENCH COMMISSION OF PUBLIC WORKS.

Tonnage of Boat.	Dimensions of Boats. Length.	Beam.	Draught.	Features of Navigable Waterway. Width at 6½ Ft. below Surface	Depth on Axial Line.	Curves. Increased Width.	Radius R.	Locks. Serviceable Length.	Width.	Depth on Sill.
	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
300	126·3	16·4	5·9	32·8	7·9	1,246 / R	984	132·8	19·7	8·2
600	196·7	23·3	5·9	51·3	7·9	3,018 / R	1,919	213·2	29·5	8·2
900	246·0	28·2	5·9	65·6	8·2	4,724 / R	2,690	262·4	34·4	8·2
1,200	295·2	32·8	5·9	77·7	8·4	6,888 / R	3,509	311·6	39·4	8·2

A boat, 24 to 25 ft. wide by about 200 ft. long, with 6½ ft. draught, has been recommended by experts as a suitable type for a 600-ton barge on the Canal du Nord.

On the Rhone, barges of the same width and 220 ft. long have been put into service, carrying 650 tons on a draught of 6 ft.

The type of boat on the Rhine is the lighter of 246 ft. by 36 ft., which with the same draught carries about 900 tons, but when immersed to 6½ ft. is capable of taking 1,200 tons, with a displacement coefficient of 0·75.

(*'Annales des Ponts et Chaussées,' March–April* 1920.)

Capacity of German Inland Waterways.

Inland waterways have reached a very high pitch of development in Germany. Certain inland harbours surpass important seaports in the amount of traffic handled The size of craft accommodated far exceeds anything attempted in this country. The following is a statement of the lengths of waterway available for successive grades of tonnage:—

	Tons.	Kilometres.
For vessels of	3,000 or more	615
,, ,, from	1,200–3,000	1,463
,, ,, ,,	600–1,200	2,064
,, ,, ,,	400– 600	2,607
,, ,, ,,	250– 400	1,705
,, ,, ,,	170– 250	1,565
Smaller vessels	—	4,515

An important project now in contemplation is the Rhine-Neckar-Danube Canal, which will complete the waterway connection right across Europe from the North Sea to the Black Sea. The length of the proposed canal will be about 165 miles, of which 125 miles come upon the Neckar section from Mannheim to Plochingen, and the remaining 40 miles on the section Plochingen-Ulm.

CONTINENTAL CANALS.

Canal du Nord, France, duplicating the St. Quentin Canal, which forms part of the navigable waterway connecting Paris with the Northern parts of France.—The ordinary cross-

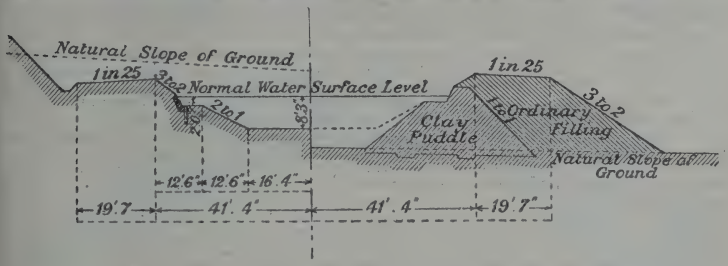

FIG. 7.—CANAL DU NORD.

Section in Excavation. Section in Filling on Impermeable Ground.

section has a minimum width of 33 ft. at the bottom and 39 ft. at a depth of 6½ ft., with a navigable depth of 8 ft. Towpaths, 13 ft. to 20 ft. wide on each bank, one for upstream and one for down-stream traffic. Locks provided to accommodate two 300-ton barges in tandem; dimensions, 279 ft. long by 19½ ft. wide by 8 ft. deep. Lifts, 13 ft. to 22 ft., with minimum reach of 1,100 yards between locks. Tunnels of two types: those for single train of boats are 33 ft. wide at springing of arch, and those for double trains of boats abreast are 52½ ft. wide at springing. Each type has two side platforms, 6½ ft. wide carried on piles. Largest tunnel at Ruyaulcourt, which is 2¾ miles long. Canal designed for mean speed of two miles per hour, with barges mechanically hauled. Fig. 7 gives typical sections.

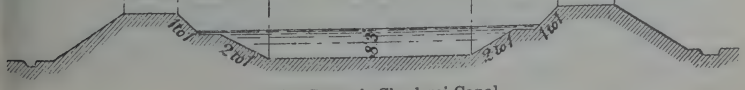

FIG. 8.—Brussels-Charleroi Canal.

The Rhone-Marseilles Canal.—Opened in 1926, the cross-section in the straight lengths gives a width of 82 ft. at a depth of 6½ ft., while the normal depth is 8 ft. 2 ins., and that in the outer portion approaching Marseilles 10 ft. Sills and inverts throughout are laid to this lower level, in order to admit of future deepening. The width of the canal is narrowed to 59 ft. where it passes through the Nerthe Mountain (Rove Tunnel). The canal section on the straight portion has been fixed at five times the immersed section of the present Rhone barges, when loaded to their maximum capacity of 600 tons on a 5 ft. 9 in. draught. These barges have a beam of 26 ft. 3 ins. The dimensions of the locks are 525 ft. internal length, by 52½ ft. in width. The lock at Arles has a lift of 23 ft. at low water. The total cost of the canal is stated to exceed 3,560,000*l.* The section of the Rove Tunnel shown in figs. 9 and 10 cost 52*l.* per ft. run of which the masonry work accounted for 16*l.* per ft. run.

Modern German Canals.—Herr Germelmann, in a Report to the Philadelphia Navigation Congress 1912, remarks that in Germany high economic value is attached only to large efficient canals, suitable for vessels of 213 ft. in length by 26¼ ft. in breadth (600 ton barges), or, at least, for vessels of 180½ ft. in length and 26¼ ft. in breadth (400-ton barges) with draughts of 5 ft. 9 ins. The cross-sectional area of canals recently constructed is as follows:—Spree-Oder Canal from 705 to 760 sq. ft.; Dortmund-Ems Canal, in cuttings, 640 sq. ft.; in embankment, 810 sq. ft.; Teltow Canal, 652 sq. ft.; Ems-Weser Hanover Canal, in cuttings, 662 sq. ft.; in embankment, 780 sq. ft.; Rhine-Ems Canal, 986 sq. ft.; Berlin-Stettin Canal, about 732 sq. ft.

Trollhätta Canal, Sweden.—This canal, first opened in 1607 and recently enlarged and extended at a cost of about 1,300,000*l.*, has a length of about fifty-two miles, and connects Lake Vänern with the Kattegat, between which there is, at ordinary water level, a vertical difference of 146 ft. The canal is built to accommodate vessels of 13 ft. 1½ in. draught, but with a view to future developments the locks are constructed to pass vessels of 16 ft. 5 ins. draught. The normal bottom width of the canal is 79 ft., but this, at passing places, is increased to 95 ft. and 115 ft. The maximum depth in rock cutting for vessels drawing 13 ft. 1½ in. is 14 ft. 5 ins., and in earth excavation, 18 ft. 3 ins. For the 16 ft. 5 in. vessel these dimensions are increased to 18 ft. and 19 ft. 7 ins. respectively. The lock chambers have a length of 295 ft. and a width of 45 ft., with 18 ft. of water over sills. The greatest change in level at any one lock is 26 ft.

New York State Barge Canal.—This canal, the inception of which dates back to the beginning of last century, has recently been enlarged so as to afford accommodation not only for the largest class of barges at present constructed, but also for those up to 3,000 tons which may be built in the future. A minimum depth of 12 ft. has been provided, with a minimum width of 94 ft. in rock cuttings and of 125 ft. in earth excavation. The locks, 57 in number, have chambers 310 ft. long and 45 ft. wide and are capable of passing vessels with maximum dimensions of 300 ft. by 42 ft. The lock at Little Falls has a range of 40½ ft., exceeding any single lift on the Panama Canal. The syphon lock at Oswego is the first of its type in the United States, and with a range of 25 ft. is probably the largest of its kind in existence. A description of it is as follows (*vide Engineering*, August 2, 1918). The general design of the culverts is not unlike that of an ordinary lock, except that at the upper and lower ends the culverts are curved upwards so as to form necks. These rise a little above the highest water level and are shut off from all communication with the outer air, except through the operating pipes. The flow of water in the syphon is started by means of tanks, one of which is built in each wall near the upper end, and communicates through pipes with the upper and lower levels and with both syphons in the same wall; they are shut off from all other communication with the outer air. The cycle of operations is as follows: The tank is first filled with water, then the intake valve is closed and the outlet valve opened. In consequence there is a body of water suspended by its weight, but tending to escape into the lower pool, and thus producing the necessary vacuum. Therefore, on opening the air valve, the air in the syphon rushes towards the vacuum, and water begins to flow up and over the crest in the neck. When using both syphons, the lock chamber can be filled in from 4½ to 5 mins., and it can be emptied in from 5½ to 6 mins. It has been found that the draught of the vacuum is such that, soon after the flow has started, the direction of the air is reversed and the vacuum is restored in the flask. The operating power is accordingly self-renewing except for a small amount of air leakage.

Cost of Canal Construction and Improvement in Great Britain.

In 1905 Mr. J. A. Saner estimated the constructional cost of new canal, suitable for two lighters of not less than 250 tons carrying capacity, or 200 tons when self-propelled, with locks 230 ft. by 22 ft. having 6½ ft. draught of water over sills, the canal itself being 40 to 45 ft. wide at bottom, 80 to 85 ft. wide at top, and 8 ft. deep in centre, at 30,000*l.* per mile, and the cost of improving existing routes to reach the same standard at 15,000*l.* 'These figures are based on the actual cost of the Weaver Navigation and the Manchester Ship Canal; the former has cost about 42,000*l.* per mile, and the latter about 440,000*l.* per mile, inclusive of docks in each case. The Worcester and Birmingham Canal originally cost 20,000*l.* per mile; and between 1879 and 1891 the French improved 2,500 miles of river, 2,250 miles of canal, and built 875 miles of new canal, for a total of 21,000,000*l.*, or an average of 3,734*l.* per mile; so that the foregoing figures should be ample.' (*Saner on Waterways in Great Britain, Min. Proc. Inst. C.E.*, vol. clxiii.)

RHONE-MARSEILLES CANAL. SECTIONS THROUGH ROVE TUNNEL.

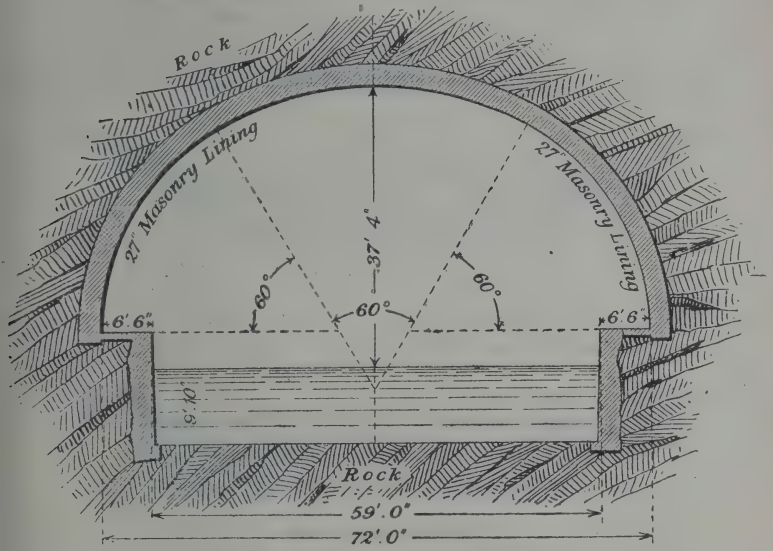

FIG. 9.—In Sections of Low Thrust.

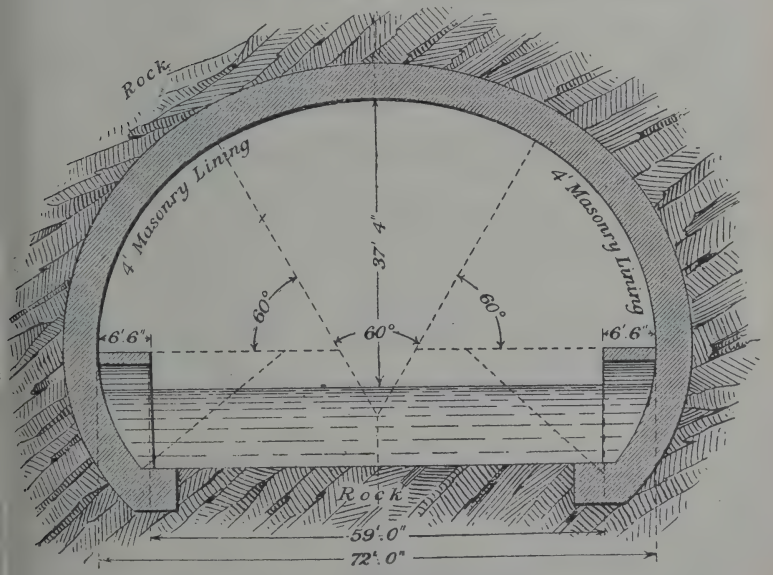

FIG. 10.—In Sections of High Thrust.

EXAMPLES OF MODERN GERMAN CANALS.

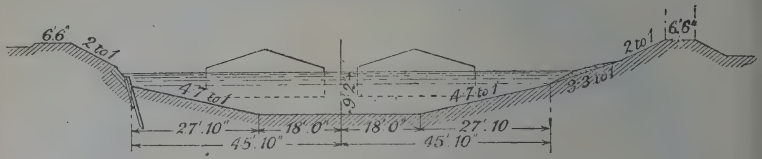

FIG. 11.—Spree-Oder Canal.

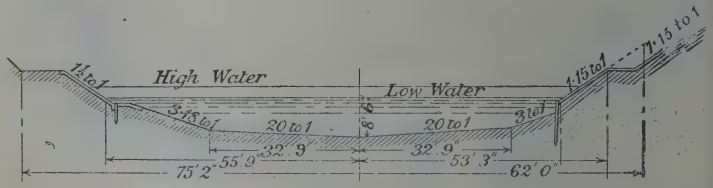

FIG. 12.—Teltow Canal.

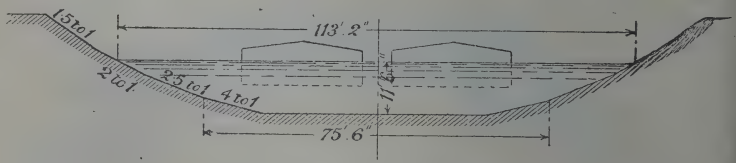

FIG. 13.—Rhine-Ems (Herne) Canal.

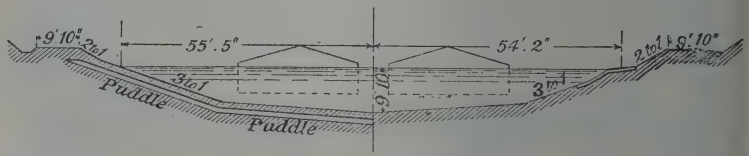

FIG. 14.—Berlin-Stettin Canal.

RELATIVE ADVANTAGES OF LOCKS AND LIFTS ON CANALS.

Changes of level in canals and canalised rivers are effected by (1) locks, and (2) mechanical lifts, the latter being either (*a*) vertical or (*b*) on an inclined plane.

Locks are the simplest and most stable means of attaining the desired object. There is no question of their superiority for all differences of level up to 12 or 15 ft., and circumstances are generally favourable for their adoption for differences up to 25 or 30 ft., and even more. Among

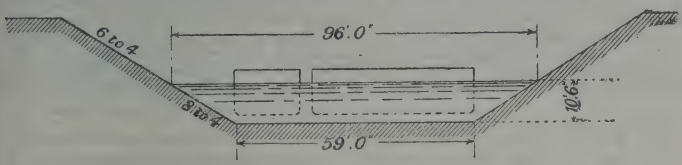

FIG. 15.—Bruges-Ghent Canal (General Section).

the older canals may be instanced a lock on the River Moldau, which has a lift of 29 ft., and another on the St. Denis Canal, which has a lift of 32½ ft. Such heights used to be considered as marking about the limit of the advantageous employment of locks over mechanical appliances. For

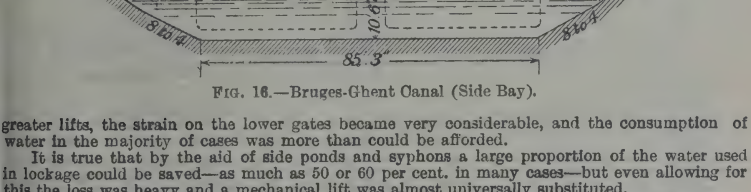

FIG. 16.—Bruges-Ghent Canal (Side Bay).

greater lifts, the strain on the lower gates became very considerable, and the consumption of water in the majority of cases was more than could be afforded.

It is true that by the aid of side ponds and syphons a large proportion of the water used in lockage could be saved—as much as 50 or 60 per cent. in many cases—but even allowing for this the loss was heavy and a mechanical lift was almost universally substituted.

In modern German practice, however, a very striking advance has been made owing to the development in size of vessels, which have now reached to a tonnage of 600 to 1,000 tons. A lock recently constructed at Henrichenburg has a lift of 46 ft. It is provided with five side ponds for the economisation of water, the saving amounting to about 76 per cent. The chamber (312 ft. long by 33 ft. wide with 9 ft. 10 ins. depth of water over sill) is built in concrete on a rock foundation, requiring an invert only 19¼ ins. thick. Other locks are being constructed which attain lifts of over 60 ft. The former limit therefore can no longer be said to apply, except in so far that, if it be exceeded, due provision will have to be made for the increase in strength of the gates and side walls, and for the economisation of water.

An appropriate test to apply to the serviceability of locks is the gradient or slope of the canal route. Where this is fairly regular and does not exceed 1 in 100 the rise lends itself to convenient subdivision into reaches of a quarter of a mile each, or more, separated by single locks of about 13 ft. lift. Under ordinary circumstances this is found to be a suitable standard for barge traffic, with barges of moderate tonnage, such as are customary in this country.

Where, on the other hand, the level of the ground changes abruptly, locks of higher lift or a series of locks may be employed, but only if an adequate supply of water is forthcoming to make good the loss from lockage. Where water is scarce it will be necessary to fall back upon some system of mechanical transfer.

Mechanical Lifts are generally more expeditious and time saving in action than locks, but they are also as a rule more expensive, and from their nature they are less durable and more liable to derangement.

From a number of examples of direct acting vertical lifts may be mentioned those at Anderton (Cheshire), Les Fontinettes (France), and Peterborough (Canada), *vide* figs. 17–19.

Lift at Anderton.—In this case the difference in level is 50 ft. The lift consists of two wrought-iron troughs, each 75 ft. long by 15½ ft. wide, originally worked hydraulically and counterbalancing one another, so that it was only necessary to reduce the depth of water in the lower trough by 6 ins. in order to set the apparatus in action. Owing to excessive wear and tear which developed in the hydraulic rams and cylinders, these were replaced in 1907–8 by a system of suspension gear passing over pulleys on an overhead gantry with counter weights at

the free ends of the ropes. The total weight so suspended is 1,000 tons, each of the caissons weighing 250 tons, of which 80 tons is iron and the remainder water. The reconstructed lift is worked electrically. The main 30 B.H.P. motor runs at about 750 revs. per min., and the large 6 ft. pulleys make about 1 revolution in 2 minutes.

Lift at Les Fontinettes, near St. Omer, France.—The lift consists of two iron troughs containing water and each capable of taking a boat of 300 tons. Each trough is bolted at its centre to the head of a ram or piston, working in an hydraulic press. The two presses are in intercommunication by means of a pipe and constitute an hydraulic balance, vertical movement being obtained by admitting a surcharge of water to the upper tank. The surcharge is 12 ins. in depth, equal to about 64½ tons weight. The difference in level is 43 ft. The troughs are 129 ft. 7 ins. long by 18 ft. 4½ ins. wide, with a minimum depth of water of about 7 ft. The ends are closed by lifting gates. The rams or pistons are 57 ft. long, 6 ft. 6¾ ins. diameter, and 2 ft. 8 ins. thick. They are formed in sections 9 ft. 2 ins. long, flanged inside, bolted together,

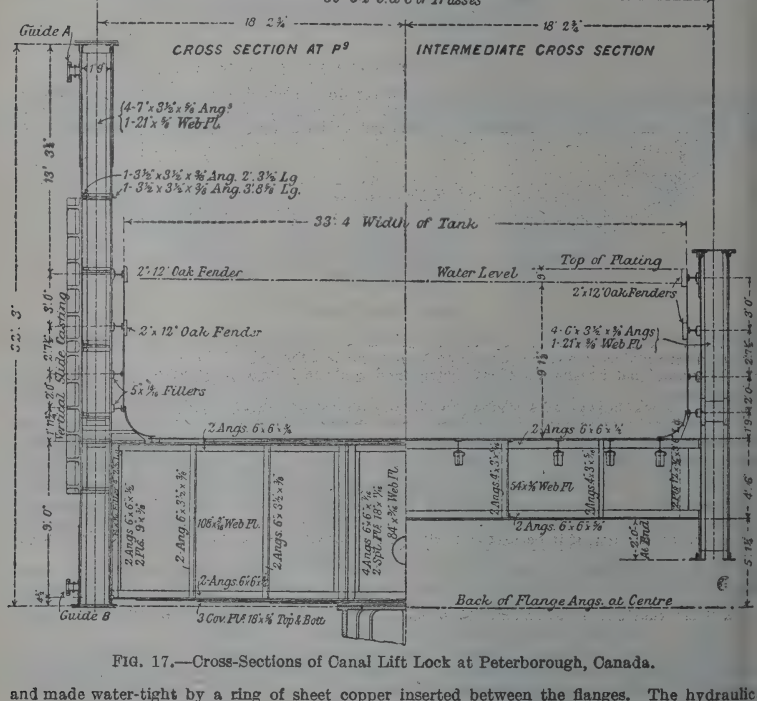

FIG. 17.—Cross-Sections of Canal Lift Lock at Peterborough, Canada.

and made water-tight by a ring of sheet copper inserted between the flanges. The hydraulic presses are 71 ft. high and 6 ft. 10 ins. diameter, resting upon concrete foundations at the bottom of excavated pits.

When one trough is raised to summit level there is a margin of 1¾ ins. between its upstream extremity and the downstream end of the canal aqueduct. At the moment of lifting the gates to allow of the passage of a boat in or out, the joint is made good by indiarubber hose running round the end of the aqueduct and protected by springs. This hose is inflated by air at a pressure of 1½ atmospheres. The same connection is made at the lower level.

The machinery consists of two turbines, one of 50 H.P. and the other of 15 H.P.

The actual time of descent and ascent of the troughs is five minutes. An entire operation, including entry and exit of barges, takes twenty minutes.

The total cost of the lift was about 74,800*l.*

Lifts on the Trent Canal, Canada.—There are two large lifts, one at Peterborough and the other at Kirkfield. The former consists of a pair of tanks, or chambers, 137 ft. long by

33 ft. 4 ins. wide, and with 9 ft. depth of water. Each tank is supported by a ram 7 ft. 6 ins. diameter worked hydraulically, so that the descent of one chamber automatically forces up the other. The range of lift is 65 ft. Under ordinary conditions the upper chamber is held in position at a level about 6 or 8 ins. below the limit of stroke, and this surcharge of water is sufficient, when the by-pass is open, to overcome friction and give the necessary movement. The tanks are supported by openwork lattice trusses, and the total load of water and steel is carried to the top of the ram by four plate girders 9 ft. deep. The following is a description of the gates, which are in pairs, one closing the chamber end and the other the canal reach. 'Each gate is made up of three main 15-in. channels, with a small plate and angle girder at the top, and is stiffened vertically by 10-in. I beams. In every space between these vertical I beams there are placed two galvanised iron air chambers about 11 ft. long. These have the effect of making the gates practically buoyant, and this decreases markedly the amount of work which has to be done in raising the gates from a horizontal to a vertical position. The water-tight plating is, in each case, on the outside of the gate, and the hinges are at the bottom. In the case of the lower reach gates and chamber gates, the hinge for the reach gate is 2 ft. 4 ins. below the hinge of the chamber gate, and 1 ft. 10 ins. separates them in a longitudinal direction. Consequently, the chamber gate is approximately 10 ft. deep, while the reach gate is about 12 ft. 6 ins. deep. As it is never necessary to operate any gate singly, the gates are arranged to work in pairs. At

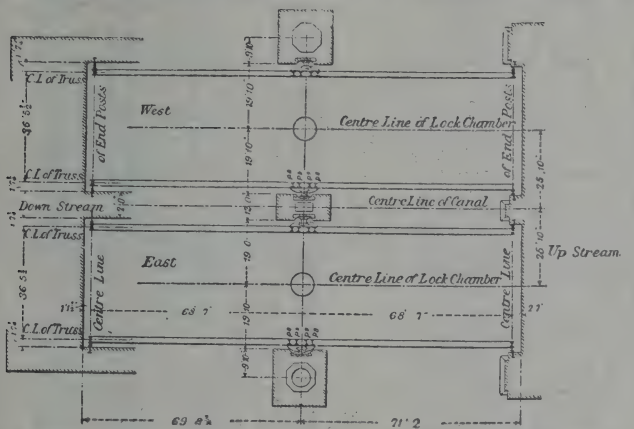

FIG. 18.—General Arrangement of Canal Lift Lock at Peterborough, Canada.

each end of the reach gate there is a pinion meshing into a circular rack set into the dock wall. The centre of the pitch circle of this rack is, of course, coincident with the centre of the hinge of the reach gate. The pinions above referred to are connected by a horizontal shaft running right across the gate, and power is applied to this shaft by means of a sprocket with chain, driven from another shaft, the centre of which is the same as that of the hinge. This shaft is actuated by one of the hydraulic gate engines provided.

'The seal between the reach-gate and the reach is accomplished by a small rubber strip, which lying over the adjacent surfaces is made water-tight by hydrostatic pressure. A similar arrangement is used for making the joints between chamber-gate and chamber water-tight. The seal between the end of the chamber and the end of the reach is accomplished by a collapsible rubber tube, which, when the chamber is away from the reach, lies almost flat against the end of the reach-gate frame. When, however, the chamber is in its proper position, the tube is inflated by compressed air at 90 lbs. per sq. in., and a water-tight joint is obtained.'

The hydraulic cylinders are plain steel castings, built up in flanged sections 5 ft. 3 ins. long. The inside diameter is 7 ft. 8½ ins., and the metal is 3½ ins. thick. The joint packing is of copper, ⅞ in. wide and $\frac{1}{16}$ in. thick, with $\frac{7}{16}$ in. diameter lead wire in press sections. The rams are of cast iron in flanged sections, also 5 ft. 3 ins. long, 30 ins. external diameter, thus giving a water space of 1½ in. completely round the rams. The jointing is the same as that for the cylinders, except that the lead ring is omitted.

A very full description of this lock appeared in *Engineering* of June 9 and 16, 1916, from which the above particulars were extracted.

Inclined Planes represent a class of mechanical appliances suitable for intermediate conditions, viz., a route gradient too steep for single locks with intermediate reaches, and not

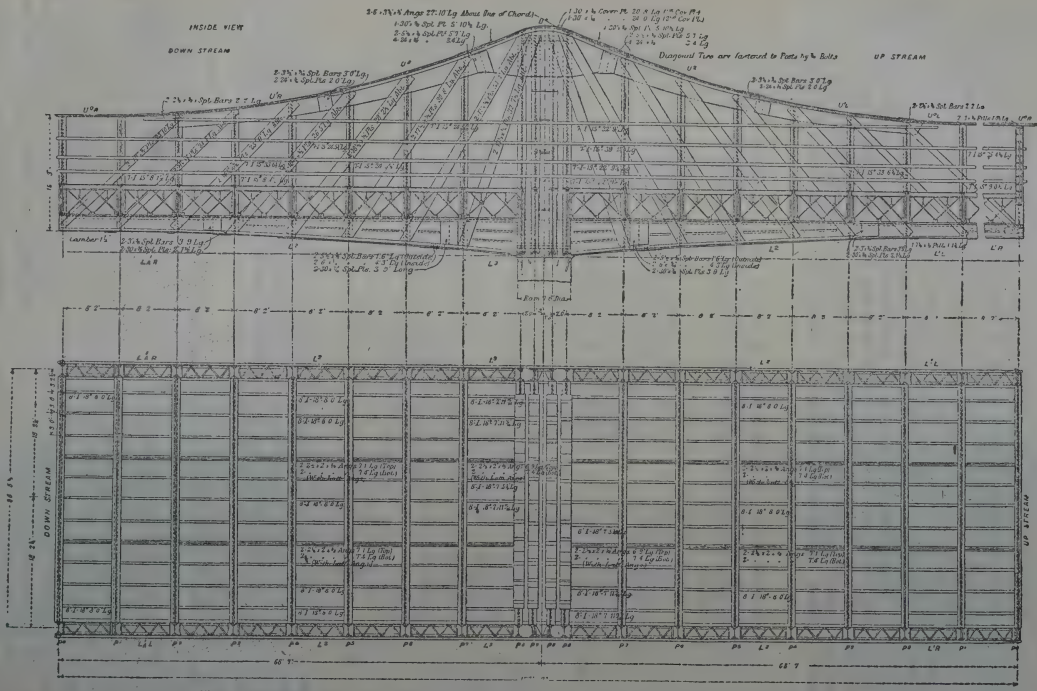

FIG. 19.—Internal View and Plan of Canal Lift Lock at Peterborough, Canada.

DIMENSIONS AND EQUIPMENT OF CERTAIN AMERICAN LOCKS.

	Length in feet.	Width in feet.	Depth at low water in feet.	Lift in feet.	Water Supply.	Valves.	Gates.	Gates operated by	Intermediate Gates.	Double Main Gates.	Means for bringing vessels into locks.
Allegheny River	287 to 298	55 to 56	8	7 to 12	Culverts in walls and under sills	Butterfly	Timber, steel	Hand, spar and cable	No	No	None.
Black Rock Harbour	650	70	22	5	Wall culverts	Stoney	Steel	Electric spar	Yes	No	Electric capstans.
Cascades of Columbia River	450	90	8	24	Wall culverts	Butterfly	Steel arched	Hydraulic cables	No	No	Hydraulic capstan.
Louisville and Portland (Old Lock)	310	80	—	11 to 22	Valves in gates	Butterfly	Timber	Steam chains	No	No	Winding engine.
Louisville and Portland (New Lock)	600	85	11	29	Culvert in walls	Butterfly	Steel	Air chain	No	No	Winding engine.
Monongahela River (New)	360	56	11	4 to 11½	Wall culverts	Butterfly	Steel	Air	No	No	None.
Ohio River	600	110	9½	9	Wall culverts	Butterfly	Steel rolling	Air or steam chain	No	No	None.
St. Mary's River (Weitzel Lock)	515	60 to 80	12½	17 to 20	Floor culverts	Butterfly	Timber	Hydraulic cables	No	No	None.
St. Mary's River (Poe Lock)	800	100	17·7	17 to 20	Floor culverts	Butterfly	Steel arched	Hydraulic cables	No	Yes	Hydraulic capstan.
St. Mary's River (New Lock)	1,350	80	24½	17 to 20	Floor culverts	Butterfly	Steel girder	Electric cables	No	Yes	Electric capstan.
St. Mary's River (Canadian Lock)	900	60	18	17 to 20	Floor culverts	Butterfly	Timber	Electric cables	No	Yes	None.
Panama Canal	1,000	110	40	30 to 60	Wall and floor culverts	Stoney and Cylindrical	Steel girder	Electric strut	Yes	Yes	Electric locomotive.

(From Report by Col. H. F. Hodges, U.S. Army, to 12th Int. Nav. Cong., Philadelphia, 1912.)

sufficiently abrupt at any one point for a vertical lift. Generally speaking, gradients of between 1 in 8 and 1 in 10 are most favourable, but they may run up to 1 in 75, or 1 in 80, and, on the other hand, inclined planes are sometimes adopted where the rise is much steeper, as, for instance, at Foxton on the Grand Junction Canal, where the gradient is 1 in 4. The Foxton incline is similar in character to the balanced vertical lift, consisting of two caissons travelling transversely, each maintaining a barge of 70 tons afloat. It is claimed for inclined planes that, in comparison with locks, they save water, and, in comparison with vertical lifts, they save time, since a boat is travelling forward simultaneously with its alteration in level. Moreover, they do not require such deep or expensive foundations as the lift proper. In spite of these advantages, inclined planes have not attained a very marked degree of acceptance among canal engineers.

Canal Curves.—The formula adopted in Belgium for the increased width at curves is

$$S = \frac{A^2 + a^2}{R}.$$

Where S is the increase in bottom width to be added to the normal semi-width on the convex side of the curve, R is the radius of the curve, and A and a are the half lengths of the boats which have to pass one another. The units are all in metres, and the value of S must therefore be multiplied by 3·28 to bring it to feet. The increased width is splayed into the straight length at a distance of 2 (A+a) from the commencement of the curve.

LOSS OF WATER ON CANALS.

Rankine summarises the sources of loss of water on canals as follows:

Waste of Water by leakage of the channel, repairs and evaporation *per day* = area of surface of canal × ¼ of a foot, nearly.

Current from the higher towards the lower reaches, produced by leakage at the lock gates, *per day*, from 10,000 to 20,000 cubic ft. in ordinary cases.

Lockage.—Single locks are more favourable to economy of water than flights of locks. At a single lock, single boats ascending and descending, alternately, cause less expenditure of water than equal numbers of boats in trains. On the other hand, at a flight of locks, boats in trains cause less expenditure of water than equal numbers of boats ascending and descending alternately. For this reason where a long flight of locks is unavoidable, it is usual to make it double, using one flight exclusively for ascending boats and the other exclusively for descending boats.

Loss by Percolation from Erie Canal.
In Cubic Feet per Second per Mile of Canal.

Location.	Material in Bank.	Cub. ft. per Sec. per Mile of Canal.
Near Dunsbach Ferry	Gravel	1·68
Near East of Schenectady	Sandy loam	1·50
Near West of Schenectady	Gravel	2·24
East of Amsterdam	Gravel	3·03
West of Amsterdam	Coarse gravel	12·89
Canajoharie	Gravel	2·00
Fort Plain	Gravel	6·85
East of Utica	Sandy loam	4·45
East of Rome	Sand and gravel	8·48
West of Rome	Clay loam and gravel	1·75

Note.—The Erie Canal has bottom widths of 52½ ft. and 42 ft. and depths of 7 ft. and 9 ft. in various portions.

Canal Bank Protection in Italy.—The sandy banks along the Candiano Canal in the province of Ravenna are strengthened with a row of reinforced concrete piling. The king piles, 10 to 16 ft. long and 8 ins. square, are driven at intervals of 10 ft. They are secured together at the top by a longitudinal runner 8 ins. by 8 ins., behind which is driven a row of sheet piling from 5½ to 6½ ft. long and 2 ins. thick. The length of the piles depends upon the nature of the ground and the depth of water, and, where necessary, further security is obtained by anchorage tie rods and bars to short piles in the rear. At points where it was possible to remove the water from the canal, or where the bottom was occasionally exposed, it was considered desirable and economical to revet the banks with a surfacing of reinforced concrete 2½ ins. thick in which the reinforcement consisted of expanded metal ·4 to 1·6 in. mesh and ·2 to ·32 lbs. per sq. ft. Where the canal bottom is not subject to erosion during floods, this revetment is continued down as far as 18 ins. above the level of the bottom, and the toe is protected by rubble. In cases of erosive action there is a concrete foundation or sill, sometimes supported by piling; and where the water level cannot be lowered sufficiently for the formation of a sill, the toe of the revetment rests against sheet piling.

TRACTION AND HAULAGE.

Means of Traction.—On ordinary small barge canals horse traction has hitherto remained the principal means of traction, although locomotives have been tried from time to time, generally without success. On the larger canals, principally those on the Continent and abroad, tug haulage is frequently employed and some vessels are self-propelled. Ship canals are navigated by vessels under their own steam, but for passage through the locks of the Panama Canal electric locomotives are provided.

Horse Traction on a straight reach is most effective at speeds between 2½ and 3 miles per hour. Within these limits a steady pull of between 100 and 125 lbs. can be maintained, which is sufficient for loads up to 60 tons. There is the further consideration that at higher speeds the wash against the banks becomes excessive for unprotected surfaces. Where tugs or locomotives are employed some form of bank protection becomes essential.

As regards river navigation Rankine gives the following formula as a rough estimate of the effect of the current of a stream on the load which one horse is able to draw against at a walk.

Load drawn against current = load drawn in still water $\times \left(\frac{3{\cdot}6}{3{\cdot}6 + v}\right)^2$: v being the velocity of the current in feet per second.

Cable Towage.—Lévy system, as adopted on St. Maur Canal between Paris and Joinville.—Cable weighs 2·45 lbs. per lin. ft. Set with permanent tension of five tons. Breaking strength 50 tons. Deflection due to haulage does not exceed 4 ins. Vertical supporting pulleys are 2 ft. 7½ ins. diameter, and have depth of groove of 7¾ ins. Circuit may cover distance of 10 to 11 miles, so that two driving machines may be set 20 to 22 miles apart. For a speed of 1½ miles per hour 2 H.P. is required to draw a barge loaded with 350 tons. For a speed of 2¼ miles an hour 4½ H.P. is required. Tractive force = $\frac{Wv'}{2gl}$, where W = weight of boat in lbs., v = velocity in ft. per sec., g = acceleration due to gravity = 32 ft. per sec. per sec., and l = length of towline in feet. For a boat of 300 tons a velocity of 3 ft. per sec. and length of line of 300 ft., the tractive force = 315 lbs. Estimated cost of plant, about 12*s.* 6*d.* per lin. yd. Cost of working ranges from ½*d.* to ¼*d.* per ton per mile.

(*Report of Dr. Watson to Water Commerce Congress at Chicago*, 1893.)

Electric Traction on an elaborate scale has been installed on the Teltow Canal in Germany since 1905. The tractors run on rails on both banks. The current is continuous at 550 volts, from overhead mains, and each locomotive is driven by two 8 h.p. motors, which are sufficiently powerful to haul two 600-ton barges at a speed of 2½ miles per hour. A similar system is in use on the Douai section of the Canal d'Aire, where the tractors are of 10 h.p. In 1918, some petrol locomotives of 20–25 h.p. were introduced on the Rhine-Rhone Canal in place of horses, but though the experiment was successful the system did not come into general use on the Canal because it would have entailed considerable alteration in the permanent works.

The following advantages among others have been claimed for the use of electric tractors in place of steam tugs:—

1. Assuming that the electric lines are laid on each bank, there will be greater regularity and uniformity of speed in the service than where tugs are used, and there will be less delay in despatching cargoes at short notice and at regular intervals.

2. The banks and bottom of a canal are not so much injured by electric-towing as by tug-towing. In the latter case the peculiar disturbance to the bottom, with consequential injury to the side banks, caused by the motion of the screw, is added to the wave from the moving boats common to each mode of transport.

3. In the case of electric towing there is considerable economy of space and water in locks and lifts, because tugs and steam boats, which, by reason of their machinery, have a smaller cargo-carrying capacity than barges of like dimensions, need not be taken through.

4. Electric power, when once installed along a line of waterway, can be utilised not only for traction, but also for operating locks and other works, and lighting the waterway at night, and can even, perhaps, be utilised for factories establishing themselves along the waterway.

(*Report of Royal Commission on Waterways*, 1909.)

In 1924 there was installed, on a short section of the canal from the Marne to the Rhine, a new system of electric traction known as the Chenean system. The underlying principle is the utilisation of an electric tractor, with proportional contact, travelling on an aerial cable. Owing to the light weight of the tractor (about 12 cwts.) it is possible to space the supports of the aerial cable, in general, at about 20 yards distance. The cable is of steel, 9 in. diameter, weighing ¾ lbs. per lineal ft. The speed of movement varies from 1 mile per hour in narrow cuttings, tunnels, etc., to 2 miles per hour and over in the open.

SHIP CANALS.

General Considerations.—It is desirable that the ratio of cross sectional area of the cana to the immersed section of ships, where the traffic is commercial, should not be less than 4 to 1 and it may with advantage be much higher. In the Suez Canal it is about 7 to 1. For vessel of war, the ratio may be slightly less, as, for instance, in the Kiel Canal, where the ratio is about 3½ to 1. The limiting value is, however, dependent on the speed at which vessels are permitted to travel. In the artificial portion of the Suez Canal the speed is limited to between 6 and 7 knots, and about 8 knots represents an approximate upper limit for narrow shallow waterways. In passing through such waters vessels sink to a lower level than in the open sea on account of the displacement. Thus pilots have a rough rule that when a ship is near the bottom her 'squat' or 'sinkage' in feet may be about one-fifth of her speed in statute miles per hour.

For curves, M. Quellenec, Consulting Engineer to the Suez Canal Commission, recommends widening the bottom so that the longest vessel may preserve in its own direction a free space equal to 1½ times its own length from the slope of the concave side. The formula used on the canal was:

$$W = \sqrt{R^2 + (2a)^2} - (R + b);$$

where,

W = amount of widening in feet;
R = radius of axis in feet;
a = length of ship in feet;
b = ½ bottom width (on tangent) of canal in feet.

Kiel, or North Sea and Baltic Canal.—This canal, which connects the North Sea and the Baltic, was originally constructed between 1887 and 1895 at a cost of about 7,800,000*l.*, including land purchase. It has a length of 61½ miles. The former dimensions have since been very considerably increased, viz., the bottom width from 72 ft. to 144½ ft., the surface width from 226 ft. to 334½ ft., the depth from about 30 ft. to 36 ft., and the cross-sectional area from about 4,500 sq. ft. to 8,868 sq. ft.

At the entrances at each end of the canal there are now twin locks of 1,083 ft. available length, by 147½ ft. clear width and 45 ft. 2 ins. sill depth at mean water level. These locks take the place of the earlier locks, which were 492 ft. long by 82 ft. wide with 32 ft. of water over sill. The new locks are constructed in concrete, and each has three pairs of caissons dividing the chambers into lengths of 725 ft. and 330 ft. The improvement works cost 11,000,000*l.*, and were completed in 1914, one month before the war.

Manchester Ship Canal.—The Manchester Ship Canal was constructed between 1887 and 1893. It has a total length of 36 miles and includes four sets of locks, with an average

MANCHESTER SHIP CANAL: TYPE SECTIONS.

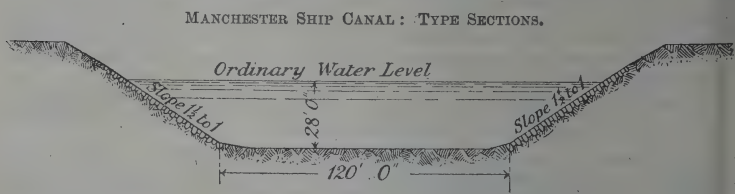

FIG. 20.—Ordinary Section.

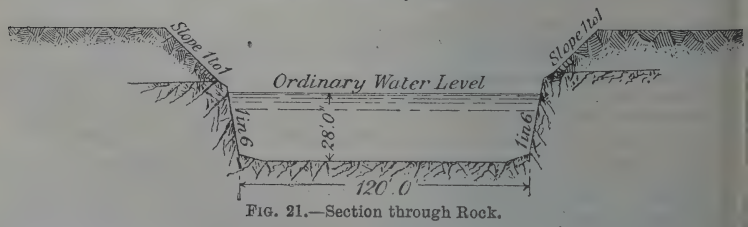

FIG. 21.—Section through Rock.

lift of 15 ft. each, about 160 acres of docks with warehouses and railway sidings, six high level bridges, seven swing bridges, and a swing aqueduct. The cost was 13,500,000*l.*, including land

purchase and promotion, the actual constructional cost being about 9,000,000*l.* The bottom width is 120 ft. The original depth was 26 ft., but this has now been increased to 28 ft. The average annual cost of maintenance is stated to be about 2,000*l.* per mile of canal.

Suez Canal.—The length of the Suez Canal is about 100 miles. It was opened in 1869, the cost of construction, apart from promotion, etc., having amounted to 10,680,000*l.* It has been progressively deepened so that the authorised maximum draught for ships in the canal has been as follows:—

From	1870 to 1890	7 m. 50	= 24 ft. 7 ins.
„	1890 to 1902	7 m. 80	= 25 ft. 7 ins.
„	1902 to 1906	8 m. 00	= 26 ft. 3 ins.
„	1906 to 1908	8 m. 23	= 27 ft. 0 ins.
„	1908 to 1914	8 m. 53	= 28 ft. 0 ins.
„	1914 to 1915	8 m. 84	= 29 ft. 0 ins.
„	1915 to 1920	9 m. 15	= 30 ft. 0 ins.
„	1921 to 1924	9 m. 45	= 31 ft. 0 ins.
„	1925	9 m. 75	= 32 ft. 0 ins.

The canal is in process of being deepened throughout to 12 metres, or 39 ft. 4 ins. A depth of 34 ft. has been attained.

Of the total length of 99·86 miles, 90·08 miles are in straight reaches; 3·48 miles in curves of 3,280 to 3,500 yds. radius; 4·97 miles in curves of 2,187 to 3,270 yds. radius; 1·11 miles in curves of 1,105 to 1,930 yds. radius; and ·22 mile with a curve of 321 yds. radius. These curves are in process of being modified so that the minimum radius shall be over 2,200 yds.

SUEZ CANAL.

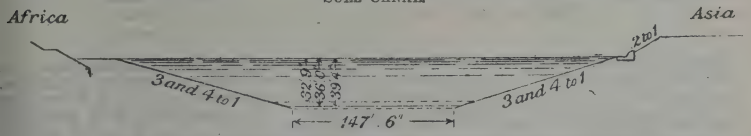

FIG. 22.—Section of Suez Canal, showing progressive deepening, as completed, in course of execution, and contemplated.

There are no locks, the canal being level throughout. At the Suez entrance there is a tidal range, amounting to about 6 ft. in the average at springs. The current flow does not exceed about 3½ ft. per second.

Panama Canal.—The total length of the Panama Canal, measured along its axis, is 50½ miles, but the portion actually within land area between coast lines is only 41½ miles. Of the total length, 14½ miles are at sea level, over 23½ miles in Gatun Lake, nearly 3 miles in locks or alongside approach walls, 1½ miles in Miraflores Lake, and 8 miles in the Gaillard Cut. The

DIAGRAMMATIC SECTIONS OF PANAMA CANAL. (Not to Scale.)

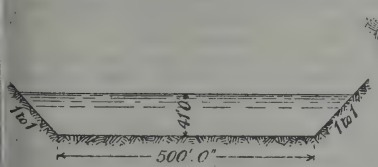

FIG. 23.—From Mindi River to Gatun Locks, and from Miraflores to Panama Bay.

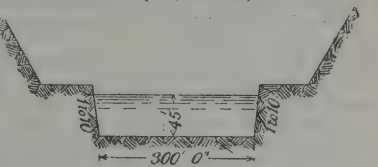

FIG. 24.—Gaillard (formerly Culebra) Cut.

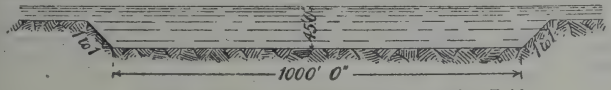

FIG. 25.—From Gatun Locks to Angle North of San Pablo.

summit level is 85 ft. above sea level. The depth lies between 40 and 45 ft. The bottom width varies as follows: For 16 miles the canal is 1,000 ft. wide; for 4 miles, 800 ft.; for 22 miles, 500 ft.; and for 8 miles, 300 ft. wide.

There are six pairs of locks with dimensions of 1,000 ft. in serviceable length and 110 ft. in width; three of these are at Gatun, one at Pedro Miguel, and two at Miraflores. The sills are laid so as to afford a depth of 40 ft. in salt water, and 41 ft. 4 ins. in fresh water. With the exception of the lower lock in the Miraflores flight, the chambers are provided with intermediate gates, dividing them into two sections of 600 ft. and 400 ft. The range of lift of the Pedro Miguel Lock is 30½ ft. All the locks are double, i.e. with parallel chambers, so that vessels may pass in opposite directions. At the Gatun flight the lift is 85 ft. divided among the three locks; the actual operating pressure between consecutive locks is therefore nearly 60 ft.

There are 46 pairs of lock gates, constructed of mild carbon steel with yokes and pintles of vanadium steel. The height of the gates varies from 46 ft. to 82 ft. The largest gate weighs about 700 tons.

The approximate cost of the canal, including purchase money, is 75,000,000*l.*

The following is a statement of the unit cost of excavating the Culebra (now Gaillard) Cut for the year 1912:

	Cost per cub. yd.
Transportation	$0·1331
Drilling and blasting	·1157
Tracks	·0885
Loading by steam shovels	·0681
General expenses and supervision	·0503
Dumps	·0479
Plant, arbitrary	·0395
Drainage, structures and clearing	·0045
Total unit cost	$0·5476

Bruges Ship Canal.—The canal connecting Bruges (Belgium) with the sea was constructed between 1896 and 1907. The works comprised an outer harbour with breakwater at Zeebrugge, and a sea-lock with a chamber 518 ft. long, 65½ ft wide, the sill being laid at 19 ft. 8 ins. below L.W.O.S.T., giving a depth of 31 ft. 8 ins. at H.W.O.N.T. The canal proper is 6¼ miles long, 72 ft. wide at the bottom, and 229 ft. wide at water surface level. There is a depth of 26 ft. throughout, and the side slopes are about 3 to 1. Two railway and three road bridges cross the canal. At Bruges there are two basins and a lock connecting with the internal barge canal system of Belgium.

Amsterdam, or North Sea Canal.—The distance from Amsterdam to the North Sea on the line of the canal is 15½ miles, and the route traverses two large shallow lakes. As originally constructed, the canal had a depth of 23 ft. and a bottom width of 88 ft. 7 ins. The entrance locks were three in number, the largest having an available length of 738 ft., a width of 82 ft., and a depth on sill of 33 ft. 6 ins. at ordinary low water. A new lock is now in course of construction, with a length of 1,313 ft., a breadth of 164 ft., and a depth of 49 ft. The canal itself is designed to be deepened to 49 ft., and to have a bottom width of 328 ft.

New Welland Canal, Canada.—The New Welland Canal was begun in 1913. Work was interrupted from 1917 to 1919 on account of the war. Completion may be expected about 1929. It is estimated that over $115,000,000 will be spent to complete the work.

The present Welland Canal locks overcome the 325·5 ft. difference in elevation between Lake Ontario (elevation 247) and Lake Erie (elevation 572·5) in 26 lifts. The locks have a usable length of 270 ft. and clear width of 45 ft. and depth over sills of 12–14 ft. The present canal cost $31,031,226 for construction, and $9,237,961 for maintenance to 1920.

The new canal project provides for seven locks to overcome the total lift of 325·5 ft., or 46·5 ft. lift per lock. Two additional guard locks are provided, one at each end of the canal, to provide for high and low water differences in the level of the lakes. These locks have a usable length of 800 ft., clear width of 80 ft., and depth over sills of 30 ft.

The new Welland Canal is to be excavated to 25 ft. in depth now, and later to 30 ft. When completed it will provide clearances, so that any ship passing through the lock at Sault Ste. Marie can continue to Lake Ontario. Later the Canadian Government expects to provide a waterway of equal dimensions from Lake Ontario down the St. Lawrence River. There is a difference of elevation between Lake Ontario and the river at Montreal of 221 ft.—(*Extract from Report by Edward H. Schulz to the 13th International Congress of Navigation, London*, 1923, *modified by later information.*)

SECTION XXX

STEAM ENGINEERING.

Revised by T. B. Morley, D.Sc., M.I.Mech.E.

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PART II

STEAM GENERATING PLANT . . . . . pp. 1605–1758

PART III

RECIPROCATING STEAM ENGINES . . . . pp. 1759–1819

PART IV

(Contributed by H. L. Guy, A.M.Inst.C.E.)

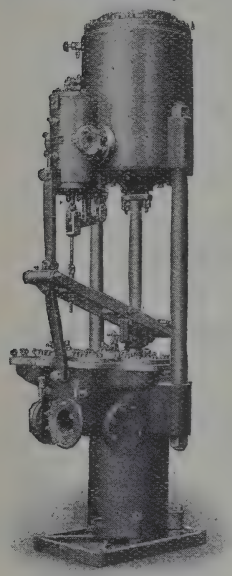
STEAM TURBINES . . . . . pp. 1819–1874

PART V

STEAM CONDENSERS—AIR PUMPS—FEED PUMPS—COOLING TOWERS—STEAM ACCUMULATORS . . . . pp. 1875–1904

CLARKE, CHAPMAN & CO. Ltd.

GATESHEAD.



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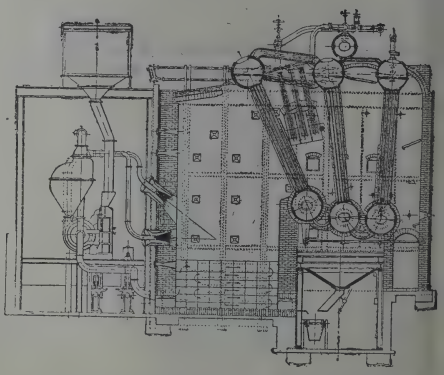
See also Advertisement facing page 2341 (Marine Engineering Section).



WOODESON PATENT WATER-TUBE BOILER FIRED WITH POWDERED FUEL BY CLARKE CHAPMAN TURBO-PULVERISER.

F. 1593

SECTION XXX

PART I

HEAT AND WORK—STEAM—PROPERTIES OF STEAM—FLOW OF STEAM—POWER PLANT THERMAL EFFICIENCIES.

(Revised by T. B. Morley, D.Sc., M.I.Mech.E.)

1 British Thermal Unit	= 778 ft.-lbs.	2,545 British Thermal Units	= 641 kg. cals.
	= 0·252 kg. calorie.		= 746 watts.
	= 107·7 kg. metres.	1·34 h.p. hours	= 1 k.w. hour
3·968 " " Units	= 1 kg. cal.		= 3,415* B.Th.U.
2,545 " " "	= 1 h.p. hour (British).		= 860·6 kg. cals.

STEAM.

When water is converted into steam by the addition of heat no steam is produced until the temperature of evaporation, or boiling point, is reached. This temperature increases with, and is determined by, the pressure. Whilst evaporation is taking place the temperature remains unchanged, and for this reason the heat required during this process is called the 'latent' heat. After the water has all been converted into steam, the addition of further heat raises the temperature and is said to superheat the steam. These general remarks apply to the vapours of all liquids, but the temperatures of evaporation at equal pressures vary widely with different liquids.

If steam contains liquid moisture mixed with it, it is said to be wet. The percentage of actual steam to total steam and moisture is the dryness fraction.

When the steam is not superheated, but yet contains no moisture, it is dry and saturated. The degree of superheat is measured by the rise of temperature above that of saturated steam.

The heat required to superheat steam varies with the pressure and temperature (see Table IV., p. 1597), but is roughly 0·55 B.Th.U. per pound of steam for each degree Fah. of superheat.

Superheating does not alter the pressure of the steam, but increases its volume in proportion (roughly) to the amount of superheat.

The volume of superheated steam may be determined approximately from the equation

$$V = v(1 + \cdot 0015 t_s)$$

where,

v = volume of dry saturated steam at the same pressure; t_s = degrees of superheat Fah.

For the mean specific heat, heat required to superheat, and total heat of superheated steam, see Tables III., IV., V., pp. 1596, 1597.

One cubic foot of water at 70° F. weighs 62·3 lb. At 212° the volume of this weight of water will be 1·04 cub. ft., an increase of 4 per cent. If the water is turned into saturated steam at 100 lb. gauge pressure, its volume will be 242 cub. ft. At 212° the volume of this weight of saturated steam will be 1,670 cub. ft., and at an absolute pressure of 1 in. of mercury it will be 11,000 cub. ft.

Steam Tables.

Prof. Callendar has established equations correlating the principal properties of steam, dry and saturated, superheated and supersaturated. His tables, based on these equations, agree well with the most reliable experimental observations and are also thermodynamically consistent.

In the following Table I., the total heat, volume, and total entropy of steam are abstracted from Callendar's Tables, published by Edward Arnold, London. The remaining data in Table I. and the other following tables have been calculated on the basis of Callendar's figures.

* British Engineering Standards Association 'Glossary of Terms used in Electrical Engineering.' The value 3,415 is based on the British Thermal Unit, which is defined as the quantity of heat required to raise the temperature of 1 lb. of water from 60° F. to 61° F., and is equal to 1·054 joules. See also p. 2192.

TABLE I.—PROPERTIES OF SATURATED STEAM (BASED ON CALLENDAR'S VALUES).

Absolute Pressure. Lbs. per Sq. In.	Temperature. ° F.	Water Heat from 32° F.	Latent Heat of Vapourisation.	Total Heat per Lb. B.Th.U.	Volume, Cub. Ft. per Lb.	Entropy of Water.	Total Entropy of Steam.	Absolute Pressure. Lbs. per Sq. In.
0·5	79·5	47·4	1045	1092	650·5	·092	2·0299	0·5
1	101·7	69·5	1032	1102	333·1	·133	1·9724	1
2	126·1	93·9	1020	1114	173·5	·175	1·9159	2
3	141·5	109·3	1012	1121	118·6	·201	1·8833	3
4	153·0	120·8	1005	1126	90·5	·220	1·8600	4
5	162·3	130·1	1000	1130	73·4	·235	1·8422	5
6	170·1	137·9	995	1133	61·9	·248	1·8277	6
7	176·9	144·9	991	1136	53·6	·258	1·8156	7
8	182·9	150·8	988	1139	47·3	·267	1·8049	8
9	188·3	156·2	985	1141	42·4	·276	1·7956	9
10	193·2	161·1	982	1143	38·4	·282	1·7874	10
11	197·8	165·7	979	1145	35·1	·290	1·7799	11
12	202·0	169·9	977	1147	32·4	·297	1·7731	12
13	205·9	173·9	974	1148	30·0	·303	1·7669	13
14	209·6	177·6	972	1150	28·0	·309	1·7611	14
14·7	212·0	180·0	970	1151	26·8	·312	1·7573	14·7
15	213·0	181·0	970	1151	26·2	·314	1·7557	15
16	216·3	184·3	968	1152	24·7	·319	1·7506	16
17	219·5	187·5	966	1154	23·4	·324	1·7458	17
18	222·4	190·5	964	1155	22·2	·328	1·7414	18
19	225·2	193·3	963	1156	21·1	·332	1·7373	19
20	228·0	196·1	961	1157	20·1	·336	1·7333	20
21	230·6	198·7	959	1158	19·19	·339	1·7294	21
22	233·1	201·3	958	1159	18·37	·343	1·7258	22
23	235·5	203·8	956	1160	17·62	·347	1·7223	23
24	237·8	206·1	955	1161	16·93	·350	1·7189	24
25	240·1	208·4	954	1162	16·29	·353	1·7157	25
26	242·2	210·5	952	1162·5	15·70	·356	1·7126	26
27	244·4	212·8	950	1163	15·17	·359	1·7097	27
28	246·4	214·8	949	1164	14·67	·362	1·7069	28
29	248·4	216·8	948	1165	14·19	·365	1·7042	29
30	250·3	218·7	947	1166	13·74	·367	1·7016	30
35	259·3	228	941	1169	11·90	·381	1·6897	35
40	267·2	236	936	1172	10·50	·392	1·6792	40
45	274·4	243	931	1174	9·40	·402	1·6702	45
50	281·0	250	926	1176	8·52	·411	1·6620	50
55	287·0	256	922	1178	7·79	·420	1·6547	55
60	292·6	262	918	1180	7 18	·427	1·6479	60
65	297·9	268	914	1182	6·66	·434	1·6417	65
70	303·0	273	911	1184	6·22	·441	1·6359	70
75	307·5	278	907	1185	5·82	·447	1·6304	75
80	312·0	282	904	1187	5·49	·453	1·6256	80

TABLE I.—PROPERTIES OF SATURATED STEAM (*continued*)

Absolute Pressure. Lbs. per Sq. In.	Temperature. ° F.	Water Heat from 32° F.	Latent Heat of Vapourisation.	Total Heat per Lb. B.Th.U.	Volume, Cub. Ft. per Lb.	Entropy of Water.	Total Entropy of Steam.	Absolute Pressure. Lbs. per Sq. In.
85	316·2	286	901	1187	5·18	·459	1·6209	85
90	320·2	290	899	1189	4·91	·464	1.6165	90
95	324·1	294	896	1190	4·67	·469	1 6123	95
100	327·7	298	893	1191	4·45	·474	1·6082	100
105	331·3	302	890	1192	4·25	·479	1·6044	105
110	334·7	306	887	1193	4·07	·483	1·6007	110
115	338·0	309	885	1194	3·90	·487	1·5972	115
120	341·1	312	883	1195	3·75	·491	1·5938	120
125	344·2	316	880	1196	3·61	·495	1·5906	125
130	347 2	319	878	1197	3·48	·499	1·5875	130
135	350·1	322	875	1197	3·36	·503	1·5846	135
140	353·0	325	873	1198	3·24	·507	1·5818	140
145	355·7	328	871	1199	3·14	·511	1·5791	145
150	358·4	330	869	1200	3·04	·514	1·5765	150
155	361·0	333	867	1200	2·95	·517	1·5740	155
160	363·5	336	865	1201	2·86	·520	1·5715	160
165	366·0	339	863	1202	2·78	·523	1·5691	165
170	368·4	341	861	1202	2·70	·527	1·5666	170
175	370·7	344	859	1203	2·63	·530	1·5643	175
180	373·1	346	857	1203	2·56	·533	1·5620	180
185	375·3	348	855	1204	2·50	·535	1·5598	185
190	377·6	351	853	1204	2·43	·538	1·5577	190
195	380	353	851	1205	2·38	·541	1·5557	195
200	382	356	849	1205	2·32	·544	1·5538	200
205	384	358	848	1206	2·266	·546	1·5520	205
210	386	360	846	1206	2·216	·549	1·5502	210
215	388	362	845	1207	2·167	·551	1·5483	215
220	390	364	843	1207	2·120	·554	1·5465	220
225	392	366	842	1208	2·076	·556	1·5447	225
230	394	368	840	1208	2·034	·559	1·5429	230
235	396	370	839	1209	1·993	·561	1·5412	235
240	398	372	837	1209	1·954	·564	1·5395	240
245	399	373	836	1209	1·916	·566	1·5379	245
250	401	375	835	1210	1·880	·568	1·5362	250
265	406	382	829	1211	1·780	·574	1·5317	265
315	422	399	815	1214	1·511	·594	1·5179	315
365	436	415	802	1217	1·315	·611	1 5063	365
415	449	429	790	1219	1·165	·627	1·4961	415

It has been established that under certain conditions of expansion, as in turbine nozzles steam may for a time not be in stable thermal condition, continuing to behave like a vapour although for equilibrium at the prevailing pressure and temperature a portion of it must become condensed. In other words, condensation is temporarily delayed. Steam in this condition is said to be 'supersaturated,' or, since its temperature is lower than the saturation temperature corresponding to the pressure, to be 'supercooled.' This condition is important in connection with the study of steam turbines.

Atmospheric pressure in this country is taken as 14·69 lbs. per square inch. At this pressure water boils at 212° Fahr., and has a latent heat of 970 British Thermal Units (B.Th.U.) per pound.

Steam at a pressure of 459 lbs. per sq. in. absolute, has a temperature of 459° F.

Gauge pressures are measured above atmospheric and are approximately 15 lbs. per square inch below the absolute pressures.

One inch of mercury column at 32° Fahr. is equal to 0·491 lb. per sq. in. Reduce one hundredth per cent. for each extra degree Fahr. of mercury column temperature.

TABLE II.—TEMPERATURES OF STEAM AT HIGH VACUA.

Ins. mercury .	29·6	29·5	29·4	29·3	29·2	29·1	29·0	28·9	28·8
Absolute pressure	0·196	0·244	0·293	0·342	0·391	0·440	0·489	0·538	0·587
Temp. Fah. .	52·5	58·5	63·7	68·2	72·1	75·7	78·9	81·8	84·5
Ins. mercury .	28·7	28·6	28·5	28·4	28·3	28·2	28·1	28·0	27·9
Absolute pressure	0·636	0·685	733·0	0·782	0·831	0·880	0·829	0·978	1·027
Temp Fah. .	87·0	89·3	91·5	93·6	95·6	97·5	99·3	101·0	102·5
Ins. mercury .	27·8	27·7	27·6	27·5	27·4	27·3	27·2	27·1	27·0
Absolute pressure	1·076	1·125	1·174	1·222	1·271	1·320	1·369	1·418	1·467
Temp. Fah. .	104·1	105·6	107·1	108·5	110·0	111·3	112·6	113·8	115·0
Ins. mercury .	26·9	26·8	26·7	26·6	26·5	26·4	26·3	26·2	26·0
Absolute pressure	1·516	1·565	1·614	1·663	1·711	1·760	1·809	1·858	1·956
Temp. Fah. . .	116·1	117·2	118·3	119·4	120·4	121·3	122·3	123·3	125·2

NOTES.—Mercury column at 60° F. Referred to a 30-in. barometer. Pressure in lbs. per sq. in. absolute. Height of mercury gauge at a given pressure increases one-hundredth per cent. per deg. F. of mercury temperature above 60. At 60° F. 1 lb. per sq. in. pressure = 2·045 ins. mercury, and 1 in. mercury = 0·489 lbs. per sq. in.

TABLE III.—MEAN SPECIFIC HEATS OF SUPERHEATED STEAM FROM SATURATION TEMPERATURE.

Pressure, Lbs. per Sq. In. Absolute.	Superheat, degrees Fahrenheit.						
	50	100	150	200	250	300	350
20	·503	·500	·497	·495	·494	·492	·491
30	·512	·507	·503	·501	·499	·497	·495
40	·519	·514	·509	·506	·503	·501	·499
50	·525	·519	·515	·511	·508	·505	·502
60	·532	·525	·519	·515	·511	·508	·505
70	·537	·529	·524	·519	·515	·512	·509
80	·542	·534	·528	·523	·519	·515	·512
90	·547	·538	·532	·527	·522	·518	·515
100	·549	·542	·535	·530	·525	·521	·517
120	·560	·551	·543	·536	·531	·526	·522
140	·568	·558	·549	·542	·537	·531	·527
160	·575	·565	·555	·548	·542	·536	·531
180	·580	·570	·561	·553	·546	·540	·535
200	·587	·577	·566	·558	·551	·545	·540
250	·604	·591	·579	·570	·562	·555	·550
300	·618	·603	·591	·581	·572	·563	·556

Table IV. gives the extra heat, above the total heat of saturated steam given in Table I. contained in superheated steam from water at 32° Fahr. The heat added to the water and steam from any higher temperature is less than the value in the table by the number of degrees above 32 from which the heating of the water commences (approximate).

TABLE IV.—HEAT REQUIRED TO SUPERHEAT ONE POUND OF STEAM.

Pressure, Lbs. per Sq. In. Absolute.	Superheat, degrees Fahrenheit.						
	50	100	150	200	250	300	350
20	25·17	50·02	74·62	99·02	123·3	147·5	172·0
30	25·59	50·73	75·54	100·2	124·7	148·9	173·2
40	25·94	51·35	76·43	101·2	125·7	150·2	174·6
50	26·26	51·93	77·20	102·1	126·9	151·4	175·8
60	26·62	52·47	77·92	103·0	127·9	152·5	177·0
70	26·82	52·90	78·55	103·8	128·8	153·5	178·1
80	27·10	53·39	79·20	104·5	129·7	154·5	179·1
90	27·35	53·82	79·76	105·3	130·5	155·4	180·1
100	27·44	54·25	80·33	106·0	131·3	156·2	181·0
120	28·00	55·06	81·43	107·3	132·8	157·9	182·8
140	28·41	55·78	82·42	108·4	134·2	159·4	184·5
160	28·75	56·52	83·31	109·5	135·4	160·8	186·0
180	29·09	57·05	84·17	110·6	136·6	162·1	187·5
200	29·36	57·66	85·0	111·6	137·8	163·5	189·0
250	30·2	59·07	86·9	114·0	140·5	166·4	192·5
300	30·9	60·3	88·6	116·1	142·9	169·0	195·0

Example.—The total heat of steam at 160 lbs. absolute, superheated 150 degrees, from water at 102° F., is approximately as follows. (There is a slight inaccuracy owing to the specific heat of water varying a little, which can be discovered and checked from the third column of Table I.)

Total heat of saturated steam from 32°	=	1201 B.Th.U.
Deduct 102° − 32°	=	70 ,,
Net heat of saturated steam from 102°	=	1131
Add heat of 150° of superheat	=	83
Total heat as required	=	1214 ,,

TABLE V.—TOTAL HEAT OF SUPERHEATED STEAM.

Pressure, Lbs. per Sq. In. Absolute.	Superheat, degrees Fahrenheit.						
	50	100	150	200	250	300	350
20	1182·2	1207·1	1231·7	1256·1	1280·4	1304·6	1329·1
30	1191·2	1216·3	1241·1	1265·8	1290·2	1314·5	1338·8
40	1197·6	1223·1	1248·1	1272·9	1297·5	1321·9	1346·3
50	1202·7	1228·4	1253·7	1278·6	1303·4	1327·9	1352·3
60	1207·0	1232·9	1258·3	1283·4	1308·3	1332·9	1357·4
70	1210·5	1236·6	1262·2	1287·5	1312·5	1337·2	1361·8
80	1213·6	1240·0	1265·8	1291·0	1316·2	1341·1	1365·7
90	1216·4	1242·9	1268·8	1294·3	1319·5	1344·4	1369·1
100	1218·7	1245·5	1271·6	1297·2	1322·6	1347·5	1372·5
120	1223·1	1250·1	1276·5	1302·3	1327·8	1352·9	1377·9
140	1226·6	1254·0	1280·7	1306·6	1332·4	1357·6	1382·7
160	1229·7	1257·4	1284·3	1310·5	1336·4	1361·8	1387·0
180	1232·4	1260·4	1287·5	1314·0	1340·0	1365·5	1390·8
200	1234·8	1263·1	1290·4	1317·0	1343·2	1368·9	1394·4
250	1239·9	1268·8	1296·6	1323·7	1350·2	1376·1	1402·2
300	1244·0	1273·4	1301·7	1329·2	1356·0	1382·2	1408·1

Steam at Very High Pressures.

Increasing attention is now being directed to the use of steam generated at very high pressure and temperatures, and researches are being carried out to gain more accurate information i reference to the same.

TABLE VI.—PROPERTIES OF STEAM AT HIGH PRESSURES.

(Abstracted from Callendar's ' Enlarged Steam Tables.')

P = absolute pressure lbs. per sq. inch ; H = total heat, B.Th.U. per lb. ; V = volume of 1 lb steam in cub. feet ; ϕ = entropy ; t_s = saturation temperature ° F.

Temperature. ° F.	P = 400. t_s = 445·5.			P = 500. t_s = 468·6.			P = 600. t_s = 488·3.		
	H	V	ϕ	H	V	ϕ	H	V	ϕ
Saturation	1,218·3	1·206	1·4991	1,222·2	0·977	1·4814	1,225·0	0·822	1·4667
500	1,253·2	1·315	1·5362	1,243·2	1·029	1·5033	1,233·2	0·839	1·4755
550	1,283·4	1·409	1·5672	1,275·0	1·109	1·5359	1,266·6	0·909	1·5094
600	1,312·4	1·499	1·5952	1,305·3	1·185	1·5651	1,298·2	0·974	1·5398
650	1,340·5	1·587	1·6211	1,334·5	1·257	1·5920	1,328·4	1·037	1·5679
700	1,367·9	1·672	1·6452	1,362·7	1·327	1·6170	1,357·5	1·097	1·5933
750	1,394·6	1·756	1·6677	1,390·1	1·397	1·6401	1,385·6	1·157	1·6171
800	1,420·8	1·837	1·6889	1,417·0	1·463	1·6619	1,413·1	1·213	1·6393
850	—	—	—	1,443·4	1·528	1·6824	1,440·0	1·268	1·6603

Temperature. ° F.	P = 700. t_s = 505·5.			P = 800. t_s = 520·9.			P = 900. t_s = 534·7.		
	H	V	ϕ	H	V	ϕ	H	V	ϕ
Saturation	1,227·2	0·710	1·4541	1,229·0	0·626	9·4434	1,230·1	0·559	1·4333
550	1,258·2	0·765	1·4856	1,249·8	0·657	1·4642	1,241·4	0·575	1·4484
600	1,291·1	0·824	1·5174	1,284·0	0·711	1·4973	1,276·9	0·625	1·4791
650	1,322·4	0·879	1·5463	1,316·4	0·761	1·5272	1,310·3	0·670	1·5099
700	1,352·4	0·932	1·5728	1,347·2	0·810	1·5544	1,342·0	0·714	1·5377
750	1,381·2	0·984	1·5970	1,376·7	0·856	1·5793	1,372·3	0·757	1·5634
800	1,409·2	1·034	1·6198	1,405·4	0·901	1·6026	1,401·5	0·797	1·5871
850	1,436·7	1·083	1·6412	1,433·3	0·946	1·6243	1,430·0	0·837	1·6092
900	—	—	—	1,460·6	0·986	1·6448	1,457·7	0·875	1·6298

Temperature. °F.	P = 1000. t_s = 547·3.			P = 1200. t_s = 569·7.			P = 1400. t_s = 589·3.		
	H	V	ϕ	H	V	ϕ	H	V	ϕ
Saturation	1,230·9	0·506	1·4244	1,232·2	0·425	1·4086	1,232·8	0·366	1·3951
600	1,269·8	0·554	1·4620	1,255·6	0·447	1·4311	1,241·4	0·372	1·4034
650	1,304·3	0·597	1·4938	1,292·2	0·487	1·4650	1,280·1	0·407	1·4391
700	1,336·8	0·637	1·5225	1,326·5	0·522	1·4950	1,316·2	0·440	1·4709
750	1,367·8	0·677	1·5488	1,358·9	0·557	1·5226	1,350·0	0·470	1·4995
800	1,397·7	0·714	1·5729	1,390·0	0·589	1·5478	1,382·3	0·500	1·5257
850	1,426·6	0·749	1·5954	1,419·9	0·619	1·5711	1,413·2	0·527	1·5499
900	1,454·8	0·784	1·6166	1,448·9	0·649	1·5929	1,443·0	0·554	1·5723
950	—	—	—	1,477·2	0·679	1·6132	1,472·0	0·579	1·5932

Temperature. ° F.	P = 1600. t_s = 606·7.			P = 1800. t_s = 622·4.			P = 2000. t_s = 636·8.		
	H	V	ϕ	H	V	ϕ	H	V	ϕ
Saturation	1,232·8	0·322	1·3834	1,232·7	0·288	1·3731	1,232·3	0·260	1·3635
650	1,268·0	0·348	1·4155	1,256·0	0·303	1·3938	1,243·9	0·264	1·3738
700	1,305·8	0·378	1·4489	1,295·5	0·331	1·4284	1,285·2	0·289	1·4098
750	1,341·0	0·406	1·4790	1,332·1	0·356	1·4594	1,323·2	0·314	1·4420
800	1,374·6	0·431	1·5060	1,366·8	0·381	1·4877	1,359·1	0·339	1·4713
850	1,406·5	0·456	1·5309	1,399·8	0·406	1·5133	1,393·1	0·359	1·4978
900	1,437·2	0·481	1·5538	1,431·4	0·426	1·5370	1,425·5	0·379	1·5220
950	1,466·9	0·506	1·5753	1,461·8	0·446	1·5591	1,456·7	0·399	1·5446
1000	1,495·8	0·527	1·5954	1,491·3	0·466	1·5795	1,486·8	0·419	1·5655

At about 3,160 lbs. per sq. in. absolute, steam is in the 'critical' state, there being then no urface of separation between liquid and vapour; the latent heat is zero, the total heat (at aturation) is about 890, and the volume about 0·052 cub. ft. per lb. The generation of steam at he critical pressure (followed by throttling to a lower pressure for use in a turbine) is the charac- eristic feature of the recently invented 'Benson' boiler.

Equivalent Evaporation.

The factor of equivalent evaporation 'from and at 212°' is found by dividing the actual otal heat of steam as calculated or found from foregoing tables, by 970, which is the latent eat of steam, or heat of evaporation, at atmospheric pressure.

Example.—If the actual total heat is 1067, the factor is 1·1. This means that if the actual vaporation of a boiler is 8·0 lbs. of water per lb. of coal, the 'equivalent evaporation from nd at 212°' is 8·0 × 1·1 = 8·8 lbs. This basis is widely used because it renders the performance boilers accurately comparable on a uniform basis.

To Calculate the Amount of Steam required to Heat a given Quantity of Water.

G = gallons of water; T and t = temperatures, Fah., after and before heating; 10 × G × $(T - t)$ = B.Th.U. added to the water; H = total heat per lb. of steam (column 5, Table I., 1594); H − T + 32 = heat given to water by each lb. of steam; W = lbs. of steam required; en,

$$W = \frac{10 \times G \times (T - t)}{H - T + 32}$$

Note.—One cubic foot of water contains 6·24 gallons. The volume of each lb. of steam is ven in Table I.

Flow of Steam from an Orifice or Nozzle.

A jet of steam issuing from a vessel under pressure first contracts in section, and then expands the drop in pressure is more than about 42 per cent. of the absolute pressure in the vessel. The solute pressure at the narrowest section, which corresponds to the neck of a turbine nozzle, ries a little, but averages about 58 per cent. of the initial pressure for saturated steam, and out 55 or 56 per cent. for superheated steam. The velocity of the steam at this narrowest ction is nearly constant except at very low pressures.

For typical values of velocity and discharges, see Part IV., Steam Turbines, p. 1819.

When the drop in pressure is less than 42 per cent. of the absolute initial pressure, the full locity and contraction of section do not occur, and the above data do not hold (see Part IV., eam Turbines, p. 1819).

Or the quantity discharged per minute may be approximately found by Napier's formula

$$W = 6\,a\,p + 7,$$

where,

W = weight in pounds; a = area in square inches; p = absolute pressure.

The theoretical flow requires to be multiplied by $k = 0{\cdot}93$ for a short pipe, or 0·63 for a thin opening, as in a plate or a safety valve.

Where the steam flows into a pressure more than two-thirds the pressure in the boiler, then

$$W = 1{\cdot}74\,a\,k\,\sqrt{p_2\,(p_1 - p_2)}, \text{ approximately,}$$

where a, k are as above, and p_1, p_2 are initial and final pressures.

Power Plant Thermal Efficiencies.

In the diagram (p. 1601) the steam pressure is in *absolute* pounds per square inch, and the object is to divide up the over-all thermal efficiency of a power plant between the boiler plant (which includes superheater and economiser) and the turbo-generator plant.

Take, for instance, the 80 per cent. boiler efficiency line, which is about as high as can be expected in year-in and year-out working. From this it will be seen that 1,595 B.Th.U. must be applied to the boiler furnace to obtain 1 lb. of steam at a total heat of 650° F.

The best thermal efficiency practicable year in and year out, and even then only obtainable on a very high load factor, is a turbo-generator consumption of 11 lbs. per k.w.hr. (See Curve B.) This, combined with the boiler efficiency, gives a thermal efficiency over all of 19·4 per cent., or 17,550 B.Th.U., applied at the boiler furnace per kw.hr. It is questionable whether better results than this can be obtained until higher total temperatures than 650° F. can be worked to.

It is quite easy to arrive at a boiler efficiency and the efficiency of a turbo-generator separately, but these data do not give the power station engineer the year-in and year-out over-all thermal efficiency of a power plant from the fuel to the switchboard. This over-all figure, which has now reached 17 per cent. in some large power stations in this country, working on a load factor of about 60 per cent., is likely to be increased in the near future; it must take into account *all losses*, that is to say, the power required for operating a power station itself. These losses include lighting, motors, pumps (whether steam or electrically driven), condensing plants, cooling tower equipments, etc., also leakages due to blow-down of boilers, traps, drains and so on. The station may have a high boiler efficiency, and a high turbo-generator efficiency while the over-all efficiency may be very low, and very often is, because the consumption of power for driving the power station is frequently overloaded.

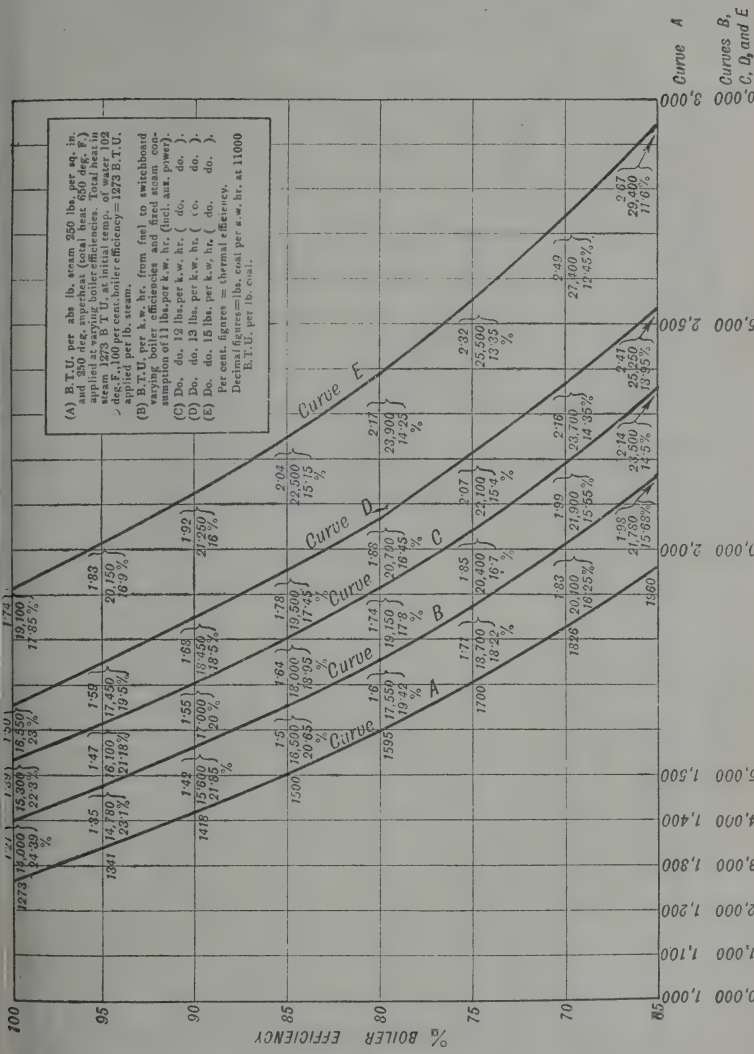
(*A. Hugh Seabrook, A.M.Inst.C.E.*)

At a discussion on Power Station Design at I.M.E.A. Convention, June 1920, the view was expressed by Selvey that 17,500 B.Th.U. per unit generated was then in sight, or 19·5 per cent over-all efficiency; and Mr. Ferranti was of the opinion that 28 per cent. would be attained with steam plant, eventually.

It is claimed that during October and November 1926 the station thermal efficiency at Columbia Power Station, U.S.A., attained 27 per cent. In this station pulverised coal is used, there are economisers and air pre-heaters, boiler pressure is 600 lbs. per sq. inch, and the steam is superheated to 730° F. The power units are two 45,000 kw. turbines, with four Babcock and Wilcox boilers for each. Steam is bled from the turbines at three stages for feed heating. Steam leaving the H.P. turbines at 80 lbs. per sq. in. is reheated to 700° F. before it passes to the L.P. turbines.

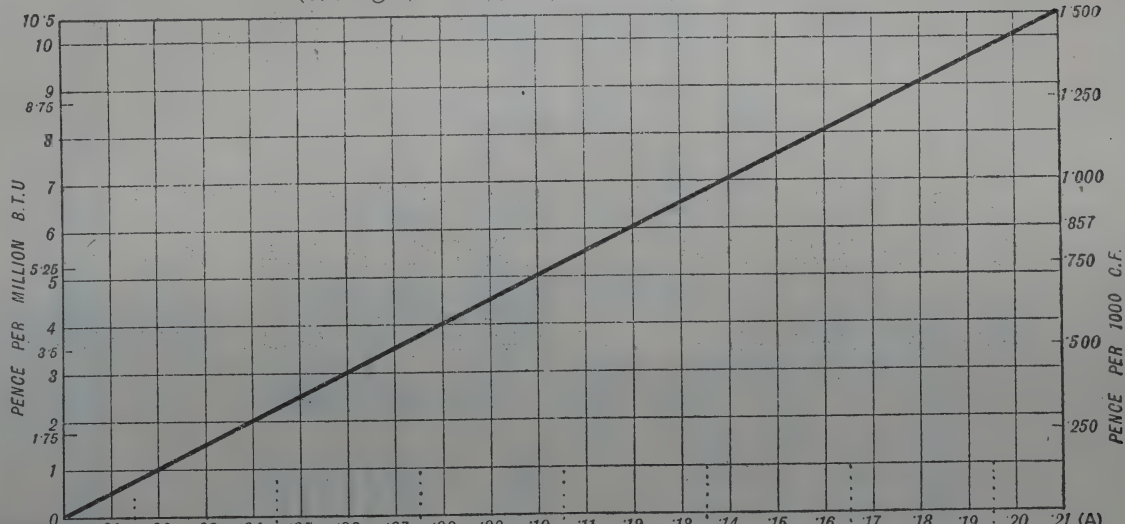
The boiler plant efficiency is over 89 per cent, and the load factor is exceptionally high, from 60 to over 80 per cent.

(*The Engineer*, Sept. 23, 1927.)


(A) B.T.U. per abs lb. steam 250 lbs. per sq. in. and 250 deg. superheat (total heat 650 deg. F.) applied at varying boiler efficiencies. Total heat in steam 1273 B.T.U. at initial temp. of water 102 deg. F., 100 per cent. boiler efficiency = 1273 B.T.U. applied per lb. steam.
(B) B.T.U. per k.w. hr. from fuel to switchboard varying boiler efficiencies and fixed steam consumption of 11 lbs. per k.w. hr. (incl. aux. power).
(C) Do. do. 12 lbs. per k.w. hr. (do. do.).
(D) Do. do. 13 lbs. per k.w. hr. (do. do.).
(E) Do. do. 15 lbs. per k.w. hr. (do. do.).
Per cent. figures = thermal efficiency.
Decimal figures = lbs. coal per k.w. hr. at 11000 B.T.U. per lb. coal.
Curve A
Curve B
Curve C
Curve D
Curve E
% BOILER EFFICIENCY
Curve A
Curves B, C, D, and E

RATIO BETWEEN GASEOUS FUEL AND K.W.H.

CURVE SHOWING—1. Pence per K.W. Hour (A) and £ per K.W. Year (B) with varying costs per million B.Th.U.
2. " " " " " with varying costs per thousand C.F. Gas
Assuming :—17 per cent. Thermal Efficiency. 143 B.Th.U. per C.F.
50 K.W. Hours per million B.Th.U. 8,000 Hours per annum.
3. Ratio between pence per K.W. Hour and £ per K.W. Year (A and B).
(Pence per K.W. Hour × 3·3 = £ per K.W. Year.)
(C) Coal @ 12/6 T. and 11,000 B.Th.U. per lb. (B) ÷ 2·22 = (C).



(Seabrook.)

FUEL CONSUMPTION AND THERMAL EFFICIENCY OF STEAM ELECTRIC POWER STATIONS.*

The reports on the output and fuel consumption of steam electric power stations in Great Britain, published by the Electricity Commissioners, classify the stations into thirteen groups according to output. For four of these groups, representing the largest, the smallest, and two intermediate sizes of station, the following figures are abstracted from the report for the year ending March 31, 1926 :—

Output of Station Units in Year.	Over 200,000,000.	Between 10,000,000 and 25,000,000.	Between 500,000 and 1,000,000.	Under 50,000.
Number of stations in group . .	5	63	26	10
Total units generated by steam plant .	1,241,324,725	1,036,661,966	19,260,935	302,143
Total fuel consumed . . . tons	1,048,135	1,289,205	63,901	1,797
Average fuel consumption per unit generated . . . . lbs.	1·89	2·77	7·37	12·96

	1926 Report.	1925.
Total output of all steam stations . units	7,804,482,933	7,090,756,650
Total coal . . . . . tons	8,396,872	8,001,087
Over-all average fuel consumption. lbs. per unit	2·40	2·53

* *Generation of Electricity in Great Britain, Year ending March* 31, 1926. Electricity Commission, H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.

SECTION XXX

PART II

STEAM GENERATING PLANT.

BOILER DESIGN—TRANSMISSION OF HEAT IN BOILERS — BOILER EFFICIENCY — BOILER SHELLS — STANDARD CONDITIONS FOR THE DESIGN AND CONSTRUCTION OF MARINE BOILERS — BOILER TUBES — TYPES OF BOILERS — BOILER SETTING — CHIMNEYS AND FLUES—SUPERHEATERS — SCALE AND CORROSION — FEED-WATER SOFTENING — FEED HEATERS — ECONOMISERS — AIR HEATERS — INSPECTION AND LEGISLATION — BOILER FITTINGS — DAMPERS — INJECTORS — SAFETY VALVES — GAUGES—REGULATORS — CLEANERS — STEAM PIPES—STEAM TRAPS.

BOILER DESIGN.

General Considerations.

Simplicity and accessibility for cleaning, favour the tank type of boiler, of which the Lancashire is the best known. The ratios of heating surface to weight and space occupied are, however, necessarily low, and for large units or intensive generation of steam, the tubular boiler has advantages. In order that these advantages may be fully developed, certain problems must be recognised and dealt with, namely—

(*a*) Boiler deposits must be reduced to a minimum, and these constrained in suitable mud drums and other parts.

(*b*) Water and steam spaces must be accessible for cleaning and inspection with a minimum of time and labour for joint breaking and making.

(*c*) Combustion of coal (or oil or gas) in large bulk must be arranged for.

(*d*) As much as possible of the heating surface should be exposed to direct radiation from the furnace and combustion chamber. The remaining heating surface should be large in relation to length of path of gases.

(*e*) The boiler must be capable of dealing with overloads.

The first two, (*a*) and (*b*), used to receive more attention than the other points, but (*c*) and (*d*) are now recognised to be of very great importance.

The efficient combustion of fuel requires that the particles of combustible, whether solid, liquid, or gaseous (including the products of the volatilisation of coal or oil), should be brought into intimate contact with air in the furnace.

In general this requires a large combustion chamber and a long path for the flame before it reaches the tubes or plates of the boiler, so that ample space and time for combustion are ensured.

Large water-tube boilers were at one time unduly limited in combustion space, and in recent years combustion chambers and flame paths have been much increased. A tendency is now showing itself to avoid further increase, and even to reduce combustion space as compared with recent designs, and to secure efficient combustion by turbulence or agitation of the gases in the furnace.

Ample heating surface exposed to the combustion chamber and high combustion temperature increase the heat transmitted by direct radiation, the importance of which is increasingly recognised.

As regards that part of the heating surface which receives heat by contact with the gases, the area required depends largely on the speed of the gas flow, high speeds resulting in high transmission rates. Restricted gas passages, however, while they lead to high gas speeds, are apt to be troublesome to keep free from deposit, and also require more draught (and hence usually the consumption of power for driving fans).

The tank type of boiler, such as the Lancashire or the cylindrical marine, has the advantage that the large amount of hot water contained enables it to respond quickly to sudden increases in demand for steam.

The Lancashire type is relatively free from breakdowns, the wear and tear are low, so that maintenance is cheap, it is easy to operate with semi-skilled labour, and is better suited than water-tube boilers to deal with impure feed water.

For burning low-grade fuels the water-tube boiler has advantages on account of its large brick-lined combustion chamber and adaptability for fitting with mechanical stokers and ash handling plant. The water-tube boiler can be constructed for very high pressures.

Boiler Output.

The steam generated per hour depends on the amount of fuel that can be properly burned on the grate per hour, and on the extent and efficiency of the heating surface.

For a particular type of boiler fuel, and draught, the steam-raising capacity is thus proportional to the grate area, though it is obvious that by control of the stoking, and particularly of the draught, the rate of combustion, and hence also the steam generated per hour, may be varied very widely.

Rate of Combustion and Draught.

With natural or chimney draught the air pressure at the grate depends on the height of the chimney, the temperature of the gases in the chimney, and the lay out of the flues. A typical figure is 0·65 in. of water per 100 ft. of chimney height, above the grate. The effective draught at the grate for a Lancashire boiler battery with economiser will be about one-third of this figure, and rather less for a water-tube boiler installation with economiser.

The coal burnt per hour per square foot of grate will be about :—

20 lbs. average steam coal; 5-10 lbs. anthracite very thinly spread.

For other chimneys and draughts the rate of combustion increases not quite in proportion to height.

The draught at the base of the chimney is due to the difference of the weight of the column of hot gases in the chimney and the weight of a similar column of external air.

If t_1 = temperature of external air; t_2 = mean temperature of gases in chimney; h = height of chimney in feet; d = draught in inches of water, measured at foot of chimney; density of gases (of typical composition) at 32° F. and atmospheric pressure = ·084 lb. per cu. ft.; density of air = ·0807 lb. per cu. ft., then,

$$\text{Mean density of gases at chimney temperature} = \cdot 084 \times \frac{493}{t_2 + 460} = \frac{41 \cdot 4}{t_2 + 460};$$

$$\text{Density of external air} = \cdot 0807 \times \frac{493}{t_1 + 460} = \frac{39 \cdot 8}{t_1 + 460};$$

$$\text{Pressure difference at base of chimney in lbs. per sq. foot} = h\left(\frac{39 \cdot 8}{t_1 + 460} - \frac{41 \cdot 4}{t_2 + 460}\right);$$

or

$$d \text{ in inches of water gauge} = h\left(\frac{7 \cdot 64}{t_1 + 460} - \frac{7 \cdot 95}{t_2 + 460}\right).$$

This is the 'theoretical' draught. The actual available draught is less than the theoretic by that required to produce the velocity of flow of the gases and by that required to overcon friction in the flues, economiser, and chimney. The loss due to velocity (in inches w.g.)

$$= d_v = 0 \cdot 10 \times \text{density of gases} \times \text{pressure} \times \frac{V^2}{t_2 + 460}$$

$$= \text{for typical gases } 0 \cdot 123 \frac{V^2}{t_2 + 460}$$

where

V = velocity of gases in chimney.

The friction loss (in inches w.g.) in the chimney

$$= d_f = 0{\cdot}40 \times f \times \text{density} \times \text{pressure} \times \frac{V^2}{t_2 + 460} \times \frac{L}{D}$$

where

f = friction coefficient = 0·016 say;
L = length of gas path in feet;
D = diameter of chimney in feet;

$$\therefore \text{ friction loss } d_f = 0{\cdot}0079 \frac{V^2}{t_2 + 460} \frac{L}{D}$$

It is convenient to relate the losses in the chimney to the weight of gas flowing rather than to the velocity.

If W = rate of flow of gas in lbs. per sec., the velocity loss d_v becomes

$$d_v = 0{\cdot}000117 \frac{W^2 (t_2 + 460)}{D^4}$$

and the friction loss

$$d_f = 0{\cdot}0000075 \frac{W^2 (t_2 + 460)\, L}{D^5}$$

Example.—A boiler battery consists of six boilers with a grate area of 38 sq. ft. each. What will be the draught at the foot of a chimney 150 ft. high and 7 ft. diameter, when the rate of combustion is 25 lbs. per hour per sq. ft. of grate area and the mean chimney temperature is 600° F.?

The coal burned per hour is 6,700 lbs.

The flue gases will amount to about 19 lbs. per lb. coal, or 108,000 lbs. per hour = 30 lbs. per sec.

The 'theoretical draught' (with external air at 60° F.)

$$= 150 \left(\frac{7{\cdot}64}{520} - \frac{7{\cdot}95}{1060}\right) = 1{\cdot}08 \text{ inches w.g.}$$

$$\text{Loss due to velocity} = 0{\cdot}000117 \times \frac{30^2 \times 1060}{7^4}$$

$$= 0{\cdot}046 \text{ inches w.g.}$$

$$\text{Loss due to friction} = 0{\cdot}0000075 \times \frac{30^2 \times 1060 \times 150}{7^5}$$

$$= 0{\cdot}064 \text{ inches w.g.}$$

$\therefore$ available draught at foot of chimney

$$= 1{\cdot}08 - (0{\cdot}046 + 0{\cdot}064)$$
$$= 0{\cdot}97 \text{ inch w.g.}$$

From this, the friction losses at flues, economiser (if any) and dampers must be deducted in order to find the draught at the boiler furnaces. Note, in the above example, if there were an economiser, the chimney temperature would be lower than 600° F., and hence the 'theoretical draught' itself would be less. The economiser thus reduces draught both by reducing chimney temperature and by its additional frictional resistance.

Effect of Altitude on Draught.

At high altitudes, the barometric height is less than at sea-level, and hence the density of the atmosphere is less. Hence also the 'theoretical draught' of a given chimney is reduced.

In order to obtain the same draught the height of the chimney must be increased.

The approximate ratio of the height required to the height required at sea-level is given in the following table:

Altitude above sea-level (ft.)	500	1,000	1,500	2,000	3,000	4,000
Ratio of heights	1·02	1·04	1·06	1·08	1·12	1·16

The diameter of the chimney at altitudes should also be increased by about 1½ per cent. for each 1,000 ft. of altitude.

Draught and Rate of Combustion.

Even if the draught at the grate is accurately known, this alone does not fix the rate of combustion, which is influenced by the kind of fuel and thickness of fire; the following tables, due to W. S. Hutton, must therefore be regarded as approximate only.

RATE OF COMBUSTION FOR DIFFERENT DRAUGHT PRESSURES.

Height of Chimney above Grate, in Feet.	Total Draught Pressure, in Inches of Water.	Rate of Combustion, in Pounds per Square Foot of Grate per Hour.	Height of Chimney above Grate, in Feet.	Total Draught Pressure, in Inches of Water.	Rate of Combustion, in Pounds per Square Foot of Grate per Hour.
25	·182	10	130	·948	30
50	·364	16	140	1·029	34
60	·437	17	150	1·095	40
70	·512	18	180	1·313	50
80	·583	19	200	1·459	60
90	·657	20	225	1·641	70
100	·729	22	250	1·825	80
110	·802	24	300	2·189	90
120	·875	27	400	2·553	112

TOTAL DRAUGHT REQUIRED FOR EFFICIENT COMBUSTION OF DIFFERENT KINDS OF FUEL.

Fuel.	Total Draught, in Inches of Water.	Fuel.	Total Draught, in Inches of Water.
Straw	0·20	Slack, very small	0·7 to 1·1
Wood	0·30	Coal-dust	0·8 to 1·1
Sawdust	0·35	Semi-anthracite coal	0·9 to 1·2
Peat, light	0·40	Mixture of breeze and slack	1·0 to 1·3
Peat, heavy	0·50	Anthracite, round	1·2 to 1·4
Sawdust, mixed with small coal	0·60	Mixture of breeze and coal-dust	1·2 to 1·5
Steam coal, round	0·4 to 0·7	Anthracite slack	1·3 to 1·8
Slack, ordinary	0·6 to 0·9		

In hand-fired plants, using coal for fuel, the rate of combustion should not be permitted to fall below 15 lbs. per sq. ft. of grate surface per hour. With stokers the rate of combustion may be as high as the design of the plant will permit. When firing with fine steam-size coal, the rate should not be less than 10 lbs. per sq. ft. of grate area per hour.

A typical working figure for the rate of combustion in stationary boilers with good natural or moderate assisted draught is 25 lbs. coal per hour per sq. ft. of grate area. For locomotives the rate is about 60 to 70, but may rise to 200.

USE OF DRAUGHT GAUGES ON STEAM BOILERS.

(*Chas. F. Wade, A.M.I.Mech.E., A.M.I.E.E.*)

The weight of oxygen or of air required to produce a given number of B.Th.U., using almost any fuel, is approximately constant, so that a measure of the air supplied to a boiler furnace is a good guide to the amount of fuel being consumed. If, therefore, the boiler is fitted with a steam flow indicator or meter as a measure of the heat transmission taking place, there will be a constant relation between air and steam flow under all conditions of steaming rate for a given efficiency, so that by careful initial tests of the waste gases under best conditions of operation this relation can be established once for all. Air flow may be gauged either by the difference in reading of two separate simple draught gauges connected sufficiently far apart in the path of the gas travel to obtain a large enough difference in air pressure or, preferably, a differential draught gauge may be connected across the two points; so long as the boiler and baffling, etc., remain in good condition the reading of such a gauge will provide a measure of the gas and air flow. The draught scale may with advantage have a second scale added giving the rate of steam flow corresponding to the most efficient conditions for the amount of pressure difference indicated and as established by the preliminary tests of the waste gas composition. Deterioration in the physical state of the boiler and its settings will be shown by inability to maintain the correct relation of steam and air flow, and the cause of the irregularity may be deduced from readings of the temperature of the waste gases.

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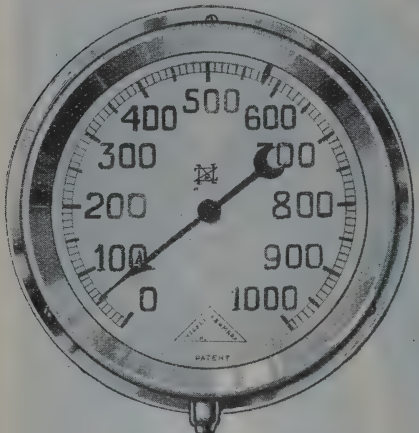

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A single draught gauge connected to one point of the gas circuit affords no indication of efficiency of combustion by itself, as a similar reading may be obtained under very widely differing conditions of fire thickness, initial draught, physical state, relation of forced to induced draught, etc.; thus mere working to a given reading on a simple draught gauge will inevitably lead to serious inefficiency from time to time.

Plain **U** tube gauges are not sufficiently sensitive to obtain close readings, and in addition cannot be arranged to give bold and distinct indications. Inclined tube gauges are much to be preferred, as each inch of height of liquid may be extended over a much longer scale. Open-scale, dial-type instruments are best of all, as they can be arranged to give a reading which can be observed clearly at a considerable distance, which cannot be done with any existing form of liquid column gauge.

Transmission of Heat in Boilers.

The transfer of the heat developed by the combustion of the fuel in the furnace to the water in the boiler takes place in two ways: (1) by radiation from the incandescent fuel and the hot gases; and (2) by convection and conduction—i.e. conduction through the materials in the path of the heat flow and by the contact of the gases and water with the metal separating them.

The transmission of heat to that part of the heating surface which is directly exposed to the fire is practically entirely by radiation, and that to the remainder of the heating surface practically entirely by convection.

Transmission by Radiation.

The heat transmitted by direct radiation in most boilers is strikingly large, so that the fire-box surface is much the most powerful evaporating surface.

The amount of heat radiated from a fire of temperature T_1 (° F. absolute) to the fire-box surface at T_2 is

$$1{,}600 \times \frac{T_1^4 - T_2^4}{1{,}000^4} \text{ B.Th.U. per hour per sq. ft.}$$

or practically, since T_2^4 is always negligible in comparison with T_1^4,

$$\text{Radiant heat} = 1{,}600 \left(\frac{T_1}{1{,}000}\right)^4.$$

Whether the radiating surface to be taken into account in calculating the total heat radiated is the grate area, or a larger amount, is debatable. The formula indicates, however, the importance of the direct heating surface, and also the importance of high combustion temperature for high rates of transmission.

Transmission through Plates or Tubes.

The transmission of heat from a fluid to another fluid on the other side of a metal tube depends on a large number of factors, including, as well as the area of tube surface and the temperatures, the velocities of the fluids, the diameter of the tube, and the nature of the fluids and of the tube surfaces. The change of temperature of the fluid passing through the tube is, of course, itself dependent on the factors named, so that the factors are not all independent. Differences of conductivity and thickness of the metals of the tube are negligible, the resistance to the passage of heat through the metal being a very small portion of the total resistance from fluid to fluid.

The coefficient of heat transmission is the number of heat units transmitted per unit time per unit area per degree of mean temperature difference (see p. 1877, and for determination of mean temperature difference see p. 1878).

For the conditions prevailing in the tubes of fire tube boilers, such as boilers of the locomotive type, waste-heat boilers, and air heaters, that is, where the current of hot gas—and for an air heater, the current of air being heated—is along the tubes, the coefficient of heat transmission can be related approximately to $\frac{w}{a}$, where w is the rate of gas flow in lbs. per sec., and a the cross section of the gas path in sq. ft. The results of investigations on different boilers vary widely, but for values of $\frac{w}{a}$ between 1 and 4, mean values of the transmission coefficient h are given by the equation $h = 0{\cdot}00077 \frac{w}{a} + 0{\cdot}00085$, where h = B.Th.U. transmitted per second per sq. ft. of heating surface per degree F. of temperature difference *between the gas and the metal.*

If, as in a boiler, one side of the tube metal is in contact with water, the temperature difference between metal and water is negligible compared with that between gas and metal, and in this case the temperature difference between gas and water may be used instead of that between gas and metal.

When both the substances separated by the tube wall are gaseous, the temperature differences on *each* side of the tube must be considered, or else the overall coefficient of transmission calculated.

The procedure that may be adopted is illustrated by the following examples:

Example 1.—A tubular boiler, in which the gases pass through the tubes at the rate $\frac{w}{a} = 2$, temperature of water (and of steam) = 350° F., gas temperatures 1,000° F. at inlet to 450° F. at outlet.

Mean temperature difference (M.T.D.) between gas and water

$$= \frac{(1{,}000 - 350) - (450 - 350)}{\log_e \frac{1{,}000 - 350}{450 - 350}} = 294.$$

This may also be taken as the M.T.D. between the gas and the tube metal.

Coefficient $h = 0{\cdot}00077 \times 2 + 0{\cdot}00085$
$= 0{\cdot}00239$, say 0·0024 B.Th.U. per sec. per sq. ft. per ° F.

$\therefore$ heat transmission rate $= 0{\cdot}0024 \times 294 = 0{\cdot}706$ B.Th.U. per sec. per sq. ft. (the heating surface being measured on the *gas* side of the tube).

If the tube is 2 ins. internal diameter, $a = 3{\cdot}14$ sq. ins. $= 0{\cdot}0218$ sq. ft.

$$\therefore \quad w = \frac{w}{a} \times a = 2 \times 0{\cdot}0218 = 0{\cdot}0436 \text{ lbs. per sec.}$$

Taking 0·25 as the mean specific heat of the gases, the heat given up in each tube
$= 0{\cdot}0436 \times 0{\cdot}25 \times (1{,}000 - 450) = 6$ B.Th.U. per sec.

$$\therefore \text{ tube surface required (internal)} = \frac{6}{0{\cdot}706} = 8{\cdot}5 \text{ sq. ft.}$$

$$\therefore \quad \text{tube length} = \frac{\text{surface}}{\text{perimeter}} = \frac{8{\cdot}5 \times 12}{6{\cdot}28} = 16{\cdot}2 \text{ ft.}$$

Evaporation (from and at 212° F.) per tube

$$= \frac{6 \times 3{,}600 \text{ (B.Th.U. per hour)}}{970 \text{ (B.Th.U. per lb. steam)}} = 22{\cdot}2 \text{ lbs. steam per hour.}$$

$\therefore$ for 2,000 lbs. steam per hour

Number of tubes required = 90
Total tube heating surface = 765 sq. ft.
Evaporation per sq. ft. of heating surface = 2·62 lbs. per hour (from and at 212° F.).

Example 2.—A tubular air heater, with tubes 2 ins. internal and 2¼ ins. external diameter; gas flowing inside tubes, air flowing in counter current direction outside tubes: $\frac{w}{a}$ for gas = 2; $\frac{w}{a}$ for air = 1·86; gas temperatures 700° F. and 450° F. at inlet and outlet; air temperatures 60° F. and 334° F.

h_g = coefficient of heat transmission on gas side = 0·0024.
h_a = do. on air side = 0·00228.

Mean temperature difference between gas and air

$$= \frac{(700 - 334) - (450 - 60)}{\log_e \frac{700 - 334}{450 - 60}} = 378.$$

It would be incorrect to take either h_g or h_a multiplied by 378 as the heat flow per sq. ft. per sec., since h_g and h_a refer respectively to the transmission between gas and *metal*, and *metal* and air only.

It can be shown that the mean temperature difference (M.T.D.) between gas and metal

$$= \text{M.T.D. between gas and air} \times \frac{1}{1 + \frac{h_g \times A_g}{h_a \times A_a}}$$

where A_g, A_a are the metal surfaces exposed to gas and air respectively.

In the example, $\frac{Ag}{Aa} = \frac{\text{internal diameter of tube}}{\text{external diameter of tube}} = \frac{2}{2 \cdot 25}$

$$\therefore \text{ M.T.D. gas to metal} = 378 \frac{1}{1 + \frac{0 \cdot 0024 \times 2}{0 \cdot 00228 \times 2 \cdot 25}} = 195 \cdot 3$$

$$\text{Similarly, M.T.D. metal to air} = 378 \frac{1}{1 + \frac{0 \cdot 00228 \times 2 \cdot 25}{0 \cdot 0024 \times 2}} = 182 \cdot 7$$

$\therefore$ heat transmitted per sec. $= 0 \cdot 0024 \times 195 \cdot 3$ B.Th.U. per sq. ft. of surface exposed to gas $= 0 \cdot 469$ B.Th.U. per sq. ft.

Also heat transmitted per sec. $= 0 \cdot 00228 \times 182 \cdot 7 = 0 \cdot 416$ B.Th.U. per sq. ft. of surface exposed to air.

These heat transmission rates must be inversely proportional to the areas on the gas and air sides, *i.e.* $\frac{0 \cdot 469}{0 \cdot 416}$ should be $\frac{2 \cdot 25}{2 \cdot 00}$, which is fulfilled very closely.

The length of tube required may be calculated as follows:

Rate of flow of gas in tube $= \frac{w}{a} \times$ area of tube

$$= 2 \times \frac{3 \cdot 1416}{144} = 0 \cdot 0436 \text{ lbs. per sec.}$$

Specific heat of gas $= 0 \cdot 25$.

$\therefore$ heat given up by gas in tube

$$= 0 \cdot 0436 \times 0 \cdot 25 \times (700 - 450) \text{ B.Th.U. per sec.}$$
$$= 2 \cdot 725 \text{ B.Th.U. per sec.}$$

$\therefore$ heating surface required (on gas side) $= \frac{2 \cdot 725}{0 \cdot 469} = 5 \cdot 81$ sq. ft.

Internal perimeter of tube $= 3 \cdot 1416 \times 2 = 6 \cdot 283$ in. $= 0 \cdot 5236$ ft.

$\therefore$ tube length $= \frac{5 \cdot 81}{0 \cdot 5236}$ ft. $= 11 \cdot 1$ ft.

The temperature differences are the chief factors in determining the length of tube (for usual values of $\frac{w}{a}$).

The number of tubes is determined from the total gas flow compared with the flo w per tube.

Thus if the gas flow is 4·4 lbs. per sec., the number of tubes for the above example would be $4 \cdot 4 \div 0 \cdot 0436 =$ say 100.

Example 3.—An alternative method of finding the heat transmission rates in the previous example is as follows:

If the overall coefficient of heat transmission from gas to air (neglecting the relatively small resistance of the metal) $= H$,

then $$\frac{1}{H} = \text{resistance to heat flow}$$

$$= \frac{1}{ha} + \frac{1}{hg} = \frac{1}{0 \cdot 0024} + \frac{1}{0 \cdot 00228}$$

therefore $$H = 0 \cdot 00117.$$

The overall mean temperature difference is 378°.

$\therefore$ rate of heat transmission

$$= 0 \cdot 00117 \times 378 \text{ B.Th.U. per sec. per sq. ft. of mean area}$$
$$= 0 \cdot 443 \text{ B.Th.U. per sec. per sq. ft. of mean area.}$$

The ratio of the areas on the gas and air sides is 2 : 2·25, or the areas are respectively 6 per cent. below and above the mean area.

The transmission rates are thus $0 \cdot 443 (1 - 0 \cdot 06) = 0 \cdot 416$ and $0 \cdot 443 (1 + 0 \cdot 06) = 0 \cdot 469$ B.Th.U. per sec. per sq. ft. of the respective areas, agreeing with the former calculation.

General Remarks on Tubular Heaters.

For a given range of temperatures, and a given value of $\frac{w}{a}$, the required tube length is proportional to tube diameter.

Hence if the length for a particular diameter has been calculated, the lengths for other diameters can be very readily found.

The tube length is *not* proportional to the drop of temperature of the heating medium; the extra tube length for each additional ten degrees say of temperature reduction at the outlet end becomes successively greater. Thus, if in a waste heat boiler, with water at 350° F., and initial gas temperature 1,000° F., the tube length is 12·2 ft. for outlet temperature 450° F., it will be 13·7 ft. for 430° F., and 15·5 ft. for 410° F. (the rate $w \div a$ and the diameter remaining the same).

The loss of pressure in the tubes, in inches of water gauge, may be taken as approximately

$$\left\{ 0{\cdot}0000216 \frac{l}{d} T_m + 0{\cdot}000075 \left(\frac{T_1}{2} + T_2 \right) \right\} \left(\frac{w}{a} \right)^2$$

where

l = tube length in ft.;

d = internal diameter of tube in ins.;

T_m = mean gas temperature, ° F. absolute $= \frac{T_1 + T_2}{2}$;

T_1 = inlet gas temperature, ° F. absolute;

T_2 = outlet gas temperature, ° F. absolute;

$\frac{w}{a}$ = lbs. of gas per sec. ÷ area of section of tube in sq. ft.

In this formula, the pressure of the gas is assumed to be atmospheric within a few ins. water gauge.

Fry's Empirical Formula.

In the case of boiler tubes with flue gases passing through them, the change of temperature of the gases, and thus also the heat transferred, can be calculated from the following equation (Lawford H. Fry, *Engineering*, Aug. 27, 1920):—

$$\text{lolog.} \frac{T_1}{t} - \text{lolog.} \frac{T_2}{t} = Mx \quad . \quad . \quad . \quad (1),$$

in which T_1, T_2 are the mean flue gas temperatures, ° F. absolute, at two sections of the tube x feet apart, t the mean temperature (absolute) of the tube wall, and 'lolog.' means 'logarithm of the logarithm.'

M is given by $\log. M = B - m \log. \frac{W}{p}$. (2) $\log. (B + 1{\cdot}3) = 1{\cdot}71 - 0{\cdot}54 \log. d$ . . (3)

$$\log. m = 1{\cdot}36 + 0{\cdot}37 \log. d \quad . \quad . \quad . \quad (4)$$

where,

d = internal diameter of tube in inches; p = perimeter of tube $(= d \times 3{\cdot}1416)$; W = rate of flow of gas in lbs. per hour.

Having determined the fall of temperature of the gases from the above, the heat given up —*i.e.* the heat transferred—is equal to

$$W \times (T_1 - T_2) \times \text{mean specific heat of gases.}$$

The following table gives the values of M for a number of tube diameters and rates of flow. These values may be used directly in equation (1).

Values of M.

d inches.	W in lbs. per hour.				
	100	200	400	800	1,600
0·5	0·133	0·117	0·104	0·092	0·081
1·0	0·074	0·063	0·054	0·046	0·039
2·0	0·050	0·040	0·033	0·027	0·022
4·0	0·040	0·030	0·023	0·018	0·014
8·0	0·037	0·026	0·019	0·013	0·009

EXAMPLES.

(1) To find fall of temperature in flue tube 2 ins. diameter and 12 ft. long, with rate of gas flow of 400 lbs. per hour, boiler pressure 180 lbs. per sq. in., and temperature of gases 2,000° F. at entrance of tubes.

The temperature of the metal of the tube is nearly that of the water in the boiler—i.e. nearly that of steam at 180 lbs. per sq. in.; thus $t = 380°$ F., about. (Slight differences in t have very little influence as a rule.)

From the table, for 2-in. tube, and W = 400 lbs. per hour, M = 0·033

$$\therefore \text{ lolog. } \frac{2{,}000 + 460}{380 + 460} - \text{lolog. } \frac{T_2}{380 + 460} = 0{\cdot}033 \times 12$$

$$\therefore \text{ lolog. } \frac{T_2}{840} = \bar{1}{\cdot}273;$$

$$\therefore \text{ log. } \frac{T_2}{840} = 0{\cdot}1875.$$

$\therefore T_2 = 1{,}293°$ F. abs., or 833° F.

(2) To find the heat transferred.

The mean specific heat of flue gases at the temperature in question may be taken as 0·31. Then the heat transferred in B.Th.U. per hour

$$= 400 \times (2{,}000 - 833) \times 0{\cdot}31 = 145{,}000.$$

The tube surface is 6·29 sq. ft., and heat transferred per sq. ft. = 23,100 B.Th.U. per hour.

(3) To find length of tube required to reduce the gas temperature to 700° F., rate of flow and diameter being as before:

$$\text{lolog. } \frac{2{,}000 + 460}{380 + 460} - \text{lolog. } \frac{700 + 460}{380 + 460} = 0{\cdot}033 \times \text{length.}$$

From which, length = 15·8 ft.

GRAPHIC CALCULATION OF HEAT TRANSMISSION THROUGH BOILER TUBES.

Fig. 1 (p. 1614) replaces equations (2) (3) and (4), and gives directly, without calculation, the value of M for any given values of W and d, or if required the value of any one of the three quantities W, M, d when the other two are known. In Fig. 1 any straight line will cut the three scales graduated in terms of W, M, d at graduations which satisfy equations (2) (3) (4).

Fig. 2 enables equation (1) to be solved graphically. The values of $\frac{T_1}{t}$ and $\frac{T_2}{t}$ are marked on the two end scales and values of Mx on the middle scale. Any straight line cuts these scales at graduations which satisfy equation (1).

Example 1:—To find the length of flue necessary for a temperature drop from 2,000 deg. F. to 720 deg. F. in a half-inch flue, with a wall temperature of 380 deg. F. and where 100 lb. of gas are passing per hour.

In Fig. 1 draw a straight line joining the points W = 100 and $d = 0{\cdot}5$. This line cuts the M scale at the required value of M = 0·132.

Since

$$\frac{T_1}{t} = \frac{2000 + 460}{380 + 460} = 2{\cdot}93, \text{ and } \frac{T_2}{t} = \frac{720 + 460}{380 + 460} = 1{\cdot}41,$$

therefore a straight line drawn in Fig. 2 joining these graduations on the $\frac{T_1}{t}$ and $\frac{T_2}{t}$ scales, will cut the Mx scale, at the required value of Mx, which is seen to be 0·50. Therefore, since $M = 0{\cdot}132$, $x = \frac{0{\cdot}50}{0{\cdot}132} = 3{\cdot}78$ ft., *i.e.*, a flue 3·78 ft. in length will be required for the given temperature drop.

Example 2:—To find what drop in temperature will take place in a half-inch flue, 5 ft. in length, when 1,600 lb. of gas are passing per hour and the temperature of flue gas at entry is 2,000 deg. F., the flue wall temperature being 420 deg. F.

From Fig. 1, by joining W = 1,600 and $d = 0{\cdot}5$, we get M = 0·081, therefore,

$$Mx = 0{\cdot}405.$$

But $\frac{T_1}{t} = \frac{2{,}000 + 460}{420 + 401} = 2{\cdot}80$, therefore, joining $\frac{T_1}{t} = 2{\cdot}80$ and $Mx = 0{\cdot}405$, in Fig. 2, we get

$$\frac{T_2}{t} = 1{\cdot}50,$$

therefore,

$$T_2 = 1{\cdot}50 \times 881 = 1{,}322° \text{ C.} = 861° \text{ F.}$$

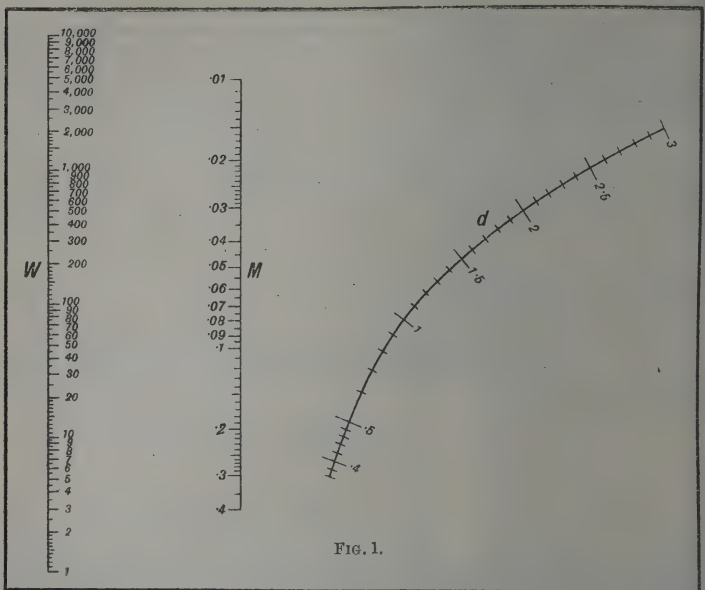


FIG. 1.

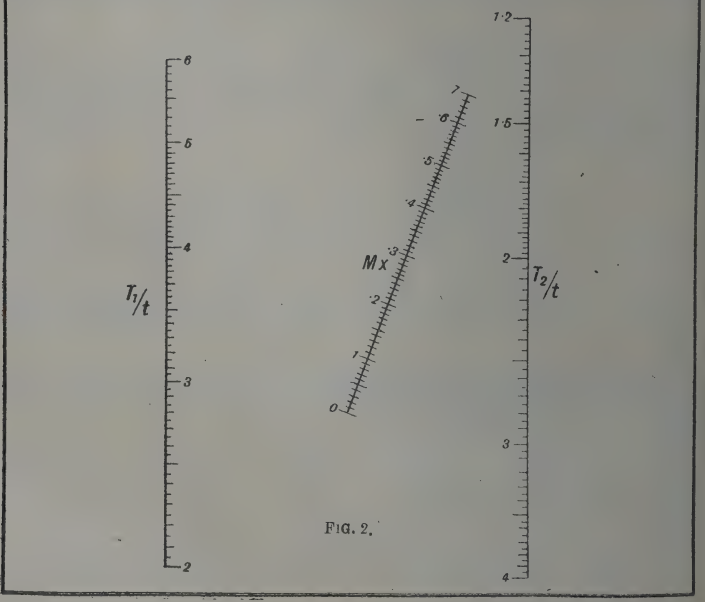


FIG. 2.

Actually, lines need not be drawn on the diagrams, as it is sufficient to lay a rule on the scales through the required points.

(A. J. V Umanski, M.Sc., *Engineering*, June 10, 1921.)

Very high rates of heat transmission have been attained in water-tube boilers when heavily forced. Spyer (Brit. Assoc., 1922) states that rates of working giving an average heat transmission of 24,000 B.Th.U. per hour per sq. ft. of heating surface have been attained on test without causing damage. With a single horizontally inclined tube a rate of 140,000 has been obtained experimentally.

Heating Surface.

The amount of heating surface required for efficient operation is much influenced by its arrangement, the proportion of it receiving heat by direct radiation, the velocity of flow of the gases through the flues or tubes, the circulation of the water, etc. While the ratio of heating surface to grate area thus varies widely, typical approximate values are as follows :—

Lancashire boiler	22–26
Water-tube	50–60
Water-tube, marine	35
Locomotive	60–70
Scotch boiler, marine	35–40
American tubular	50–80

The economiser surface should be about equal to the boiler surface for a Lancashire boiler and less, down to 50 per cent., for a water-tube boiler with ample heating surface.

For superheater surfaces see p. 1676.

As evidence of the effect of high gas speeds, cases are on record in which half the tubes in a tubular boiler have been plugged and yet the same total evaporation per hour obtained.

Recent Progress in Evaporation Rates.

Improvements in design which have raised the proportion of heat transferred by direct radiation have led to great increases in the rate of evaporation. This is illustrated by the following table relating to boilers installed at different dates at Bradford :—

Year.	Lbs. water evaporated per hour per sq. ft. heating surface.
1900	3·0
1902–11	3·25
1916	3·45
1926	6·0
1926 (on order)	12·0

Still higher rates have been achieved ; at Hell Gate Power Station, New York, boilers equipped with Murray fin-tube furnace walls have evaporated 14·7 lbs. per sq. ft. (see also p. 1620). It is reported that boilers are now being built for 69 lbs. per sq. ft., and that a still higher rate is claimed for a boiler at work in an industrial plant at Manchester.

(T. Roles, quoted in *Engineering*, June 3, 1927.)

Efficiency and Evaporation Rate.

The efficiency of a boiler depends not only upon good design, but is very much dependent upon good maintenance, cleanliness, prevention of air leakages in flues, and skilful stoking.

The actual evaporation in lbs. of steam per lb. of coal is a common, but somewhat unscientific, standard of efficiency. It obviously varies with the heat value of the coal, the steam pressure, and the superheat. When stated as the equivalent evaporation 'from and at 212° F.' it is a better basis, but is still dependent upon the quality of the coal. Thus, best Welsh coal will evaporate 25 per cent. more than an inferior slack with the same boiler efficiency. To convert actual evaporations into 'from and at 212' multiply by the B.Th.U. given to each lb. of water in heating, evaporating and superheating it, and divide by 970. Thus starting with water at 102° and superheating to 150° at 160 lbs. absolute, the B.Th.U. is 1214, so that the equivalent evaporation factor is 1·255.

If the calorific value of the coal is 11,800 B.Th.U. per lb., then an efficiency of 60 per cent. corresponds to an evaporation 'from and at 212°' of $\frac{11{,}800 \times \cdot 6}{970} = 7 \cdot 25$ lbs. water per lb. coal.

The evaporation per sq. ft. of heating surface depends on the fuel-combustion rate and the ratio of heating surface to grate area as well as on the efficiency.

Thus, in a Lancashire boiler burning 25 lbs. coal per hour per sq. ft. of grate, and having heating surface 25 times the grate area, if 7 lbs. water are evaporated per lb. coal, then the evaporation per sq. ft. of heating surface is 7 lbs. Similarly for a water-tube boiler 5 lbs., and for a locomotive 10 to 12 or more lbs. steam per sq. ft. heating surface are fair average figures.

By increasing the draught and thus increasing the rate of combustion, the output of the boiler can be much increased, but it should be noted that at high combustion rates the efficiency falls off.

For example, the series of trials of a Babcock and Wilcox boiler recorded on page 1660 show a maximum efficiency when burning 25 lbs. coal per sq. ft. of grate per hour. For rates of combustion between 30 and 70 these results correspond roughly to

$$w = \frac{78}{C} + 8{\cdot}3,$$

where C is the rate of combustion, and w the equivalent evaporation per lb. coal.

Typical figures for boilers in good condition, but without specially elaborate technical supervision, are :—

	Per cent.		Per cent.
Small cylindrical boiler, no economiser	50–55	Large water-tube boiler with economiser	70
Large cylindrical boiler with economiser	60–70	Do. highest class	70–80
Do. well fired and maintained	75	Locomotive boiler, moderately fired	65–70
Small water-tube boiler with economiser	50–60	Marine boiler, well fired	60–70

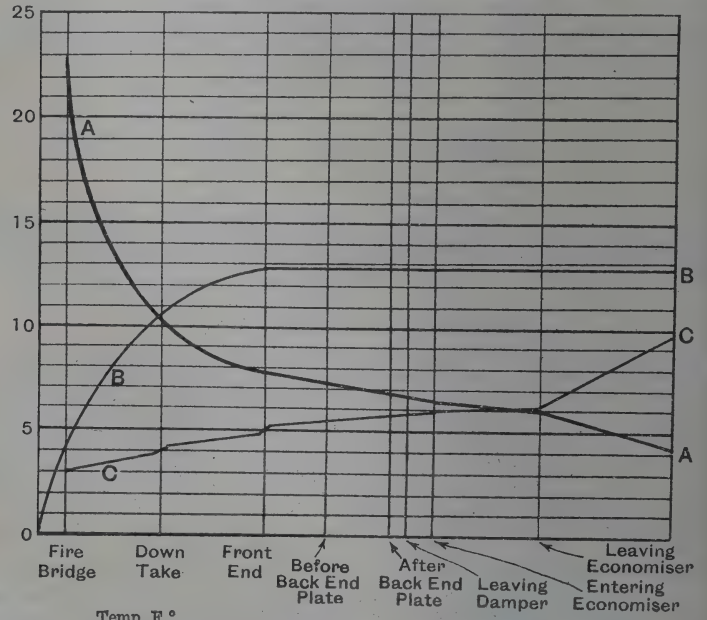
In the modern large power stations with large water-tube boilers and highly skilled technical supervision, efficiencies of 80 to 92 per cent. have been obtained.

That the efficiency of many boiler plants is much lower than the results which can be attained by greater care and skill in maintenance and supervision, is evidenced by the reports of Brownlie (p. 1617).

Maintenance of Boiler Efficiency.

(Chas. F. Wade, A.M.I.Mech.E., A.M.I.E.E.)

The arrangement advocated, and which has been adopted in several important modern power-stations with satisfactory results, consists in providing means of testing the CO_2 percentage, gas



Curve A = $\frac{\text{Temp. F.°}}{100}$; Curve B = CO_2%; Curve C = Draught ins. W.G. × 10.

FIG. 2A.

temperature, and draught pressure at regular intervals at a series of points situated at each consecutive stage in the gas travel through the boiler. Standard conditions being established with the newly overhauled boiler in as perfect a state of air-tightness, soundness of baffles, etc., with,

say, full rate of steaming, then readings are obtained of the three values mentioned, and are plotted to a suitable scale as three curves on a chart, as shewn in fig. 2A. The curves shown are ideal ones, and those obtained in practice will deviate more or less, even with a boiler in the best possible condition, both as to physical state and combustion conditions. The significance of the variations which may occur in the various curves for individual defects in state or operation are given in the following table, while combinations of two or more defects will produce modifications of the curves to correspond. The chart may be taken as an equivalent to the indicator diagram of a steam-engine, and is used to check the operation of the boiler and its state in an analagous manner.

INTERPRETATION OF WADE'S BOILER CONTROL CHARTS.

Fault.	I. Temperature Curve.	II. CO_2 Curve	III. Draught Curve.	Remarks.
Forcing boilers beyond economical capacity	High throughout	Low at A " " B Normal at D	*Induced and natural draught*—high throughout *Forced draught*—low throughout	
Over-heavy firing beyond air capacity	A low B and D possibly high	High throughout CO present Smoke	High throughout	
Thin fires and bare patches	Low throughout	Low throughout Excess O_2	Low throughout	
Leaky seating blocks or buffles	A and B normal D high	A and B normal D low	A normal or high B onwards low	
Short-circuiting at side walls of downtake or at superheater cross-box wall	A, B and D normal E higher than D	A, B and D normal E rather low	A high. Fall of draught less than normal	
Leakage through back wall into flue	A normal B to E low F high	CO_2 not materially affected; possibly low	Draught not appreciably affected	
Air leakage into flues	A normal B normal or low * D low	A normal B normal or low *	A and B normal* C slightly low	*Marked variations in all curves at point of leakage.
Air leakage around dampers.	E normal F low	E normal F low	E and F (difference too small to measure)	
Dirty plates internally.	High throughout, with reduced fall A to D	Normal throughout	Normal throughout	
Dirty flues and gas passages.	Low throughout	Low throughout CO present	Low A to C High from D onwards	

Efficiency of Steam-Boiler Plant.

(*Contributed by David Brownlie, B.Sc. Hons. (Lond.), F.C.S., A.M.I. Mech.E.*)

(1)

The following are the true average figures for the performance of 250 steam-boiler plants in 17 different industries, comprising 1,000 boilers with an annual coal bill of 2,166,000 tons. Each test, comprising a day test and a check test of one week, was carried out with the greatest care

on the plant as actually working from week to week all the year round. Nearly 2,000 boiler plants were inspected and it was found that all were being worked on the same general lines—that is to say, these average figures apply to the burning of 75–100 million tons of coal burnt per annum in Great Britain for steam generation :—

AVERAGE WORKING FIGURES OF 250 TYPICAL BOILER PLANTS.

TESTS.

Average of 250 *Typical Boiler Plants.*

(A) *Working Day's Test.*

Type of boiler	'Lancashire'	Water evaporated per sq. ft. of grate area per hour	137·4 lbs.
Number of boilers	4	Water evaporated per lb. of fuel	6·56 lbs.
Grate area	152·6 sq. ft.	Equivalent evaporation from and at 212° F., per lb. of fuel	7·46 lbs.
Duration of test	9·43 hours	Equivalent evaporation from and at 212° F., per 1,000,000 British thermal units	631·0 lbs.
Amount of fuel used	30,131·72 lbs.	Temperature of feed-water before economisers	116° F.
Analysis of fuel used :		Temperature of feed-water after economisers	193° F.
British thermal units	11,822	Percentage of fuel bill saved by economisers	7·1 per cent.
Ash	11·5 per cent.		
Fuel burnt per boiler per hour	798·8 lbs.		
Fuel burnt per sq. ft. of grate area per hour	20·9 lbs.		
Water evaporated	197,776·0 lbs.		
Water evaporated per boiler per hour	5,243 lbs.		

(B) *Long Check Test* (one week of 7 days).

Duration	167·5 hours	Water evaporated per lb. of fuel	6·42 lbs.
Amount of fuel used	128·25 tons		
Water evaporated	184,435·0 galls.		

DETAILS.

Draught in side flue	0·40 in. W.G.	Temperature of superheated steam	346·5° F.
Draught in main flue at exit of economisers or chimney base	0·80 in. W.G.	Steam or power used as auxiliary to the production of steam	2·4 per cent.
Temperature of flue gases before economisers	598° F.	Thermal efficiency :	
Temperature of flue gases after economisers	478° F.	(A) Net working efficiency complete, after deducting 2·4 per cent. steam or power used as auxiliary to the production of steam	60·09 per cent.
Percentage of CO_2 in flue gases from side flue of boilers by means of combustion recorder	7·6 per cent.	(B) Boilers only	56·71 ,,
Steam pressure :		(C) Economisers only	4·35 ,,
Pounds per sq. in. (gauge)	89	(D) Superheaters only	0·51 ,,
Pounds per sq. in. (absolute)	104		
Temperature of saturation of steam	330·5° F.		

The installations from which the above average is derived comprise all sizes of plants with annual coal bills of from 750 tons to 70,000 tons ; whilst the average working pressure varied from 12 lbs. to 200 lbs. per sq. in. The fuels used were of every possible description, from the highest qualities of washed nuts, beans, peas, and fine slack, and large and small screened coal, down to interior fuels of all qualities, including refuse coal mixed with shale, pit sweepings, washer settlings, etc., as well as coke and coke breeze.

The 250 plants had a total of 1,000 boilers, comprising 935 'Lancashire' boilers, 36 modern 'tubular' boilers, 17 'egg-ended' boilers, 6 'Cornish' boilers, 1 'marine' boiler, 2 'vertical' boilers, and 3 'patent' boilers. The plants varied in size from one small 'vertical' boiler to 35 'Lancashire' boilers, 30 ft. by 8 ft.

The total grate area of the 250 boilers was 38,158·6 sq. ft., corresponding to 152·6 sq. ft. per plant, or 38·1 sq. ft. per boiler, which, on the assumption that all the boilers were 'Lancashire,' would give an average grate-area length of approximately 6 ft.

The average figure shows 20·9 lbs. of fuel per square foot of grate area per hour, referring to the average amount burnt per hour per working day, and not to the amount for any particular hour. This figure is considerably below what is possible on a boiler plant run on modern lines which would give something like 25 lbs. to 30 lbs. per square foot grate area per hour with the average quality of fuel. The boiler plants of the country are working under very easy conditions

in this respect, and much more fuel could be burnt per boiler. Figures for fuel consumption depend very largely on the quality of the fuel. Thus a good quality washed coal of, say, 13,000 British thermal units and 7 per cent. to 8 per cent. ash could easily be burnt economically at the rate of 35 lbs. per square foot per hour, whereas purely refuse coals would only give about 15 lbs. Coke of good quality can be burnt at the rate of 22 lbs. per square foot grate area per hour and coke breeze about 15 lbs.

The average for the 250 plants shows 11,822 British thermal units and 11·5 per cent. ash, which includes almost every description of coal and coke varying in quality from 7,000 British thermal units to 14,000 British thermal units.

As regards coke, a good average sample of coke shows about 12,000 British thermal units to 12,500 British thermal units with 12 per cent. ash, whilst a good sample of coke breeze shows 9,000 British thermal units to 10,000 British thermal units and 15 per cent. to 20 per cent. ash. The great trouble with coke and coke breeze is the amount of moisture contained in them. Good samples should only contain about 5 per cent. and certainly not over 8 per cent. Many samples, however, contain regularly 20 per cent., which is a most serious matter from the point of view of economy.

In a well-managed plant with average quality of coal a 'Lancashire' boiler, 30 ft. by 8 ft., can evaporate easily 850 gallons per boiler per hour, an increase of 62 per cent. of steam output as compared with average figures.

(2)

The following are the figures for two separate industries, namely, collieries, and chemical works:—

(1) *Collieries.*—Representing average figures for the complete investigation of 100 boiler plants, 570 boilers, annual coal bill 1,250,000 tons.

(2) *Chemical Works.*—Representing average figures for the complete investigation of 60 boiler plants, 236 boilers; annual coal bill, 620,000 tons.

Essential Figures of the Tests.	100 Colliery Plants.	60 Chemical Works Plants.
1. Duration of test	9·68 hrs.	9·20 hrs.
2. Amount of coal used	39,815·0 lbs.	38,025 lbs.
3. Analysis of coal. B.Th.U. per lb.	10,500	11,350
4. " " Ash	15·5 per cent.	12·0 per cent.
5. Coal burnt per boiler per hour	721·5 lbs.	1,059·8 lbs.
6. Coal burnt per sq. ft. grate area per hour	18·9 lbs.	26·6 lbs.
7. Amount of water evaporated	216,900 lbs.	23,358 lbs.
8. Water evaporated per boiler per hour	3,931 lbs.	6,510 lbs.
9. Water evaporated per lb. coal	5·44 lbs.	6·10 lbs.
10. Water from and at 212° F. evaporated per lb. coal	6·07 lbs.	7·00 lbs.
11. Temperature of feed-water. Before economisers	137° F.	103° F.
12. " " After economisers	154° F.	215° F.
13. Percentage of coal bill saved by economisers	1·6 per cent.	10·1 per cent.
14. Draught in side flue	0·60 in. W.G.	0·38 in. W.G.
15. Draught in chimney base (or equivalent)	0·95 in. W.G.	0·70 in. W.G.
16. Temperature of flue gases. Before economisers	690° F.	650° F.
17. " " After economisers	650° F.	500° F.
18. Percentage of CO_2 in flue gases	7·5 per cent.	8·0 per cent.
19. Steam pressure. Gauge lbs. per sq. in.	86 lbs.	102 lbs.
20. Temperature of saturated steam	328·4° F.	339·2° F.
21. Temperature of superheated steam	350·0° F.	384·2° F.
22. Steam or power used auxiliary to the production of steam	1·8 per cent.	6·1 per cent.
Efficiency.		
23. (A) Net working efficiency of plant after deducting steam or power used auxiliary to steam production	55·52 per cent.	57·9 per cent.
24. (B) Due to boiler only	55·02 "	54·2 "
25. (C) Due to economiser only	0·90 "	6·1 "
26. (D) Due to superheater only	0·62 "	1·3 "

Reference No.		1	2	3
1. Source of data		Inst. Mech. Eng., 1904	Insurance Co. test	Colville Magazine, 1923
2. Duration of test		4 hours	8 hours	—
PARTICULARS OF BOILER.				
3. Type		Lancashire	Lancashire	Lancashire
4. Size		8′ 0″ × 30′ 0″	8′ 0″ × 30′ 0″	8′ 0″ × 30′ 0″
5. Heating surface of boiler	sq. feet	920	954	1,000
6. Heating surface of superheater	sq. feet	217	312	—
7. Heating surface of economiser	sq. feet	2,240 (for 3 boilers)	None	2,560 (for 4 boilers)
8. Grate area	sq. feet	38	34·8	—
9. Method of stoking		Hand	Hand	Terbeek burners
10. Nature of draught		Natural 140 ft. chimney	Natural	—
DRAUGHT (IN INCHES), W.G.				
11. Over fires		0·2	0·45	—
12. Over leaving boiler		—	0·85	—
13. Over leaving economiser		0·52	—	—
14. Pressure of air supply		—	—	—
FUEL.				
15. Description		North Wales coal	Anthracite and slack mixed	Blast-furnace gas
16. Calorific value, B.Th.U. per lb. (higher)		14,040 (dried)	14,038 (dried)	120 (per cub. foot)
17. Moisture	per cent.	4·6	1·35	—
18. Ash	per cent.	4·97	—	—
FUEL CONSUMED.				
19. Weight burnt per hour, lbs. (per boiler)		705	399·9	About 100,000 cub. ft
20. Weight burnt per hour, per sq. ft. of grate		18·52	11·49	—
21. Ash and clinker removed, per cent. of fuel fired		8·3	13·6	—
STEAM.				
22. Pressure, lbs. per sq. in., boiler		—	—	—
23. Pressure, lbs. per sq. in., superheater		158·9	150	120
24. Temperature leaving superheater	° F.	481·6	547	470
WATER EVAPORATED.				
25. Water temperature entering economiser	° F.	61	—	90
26. Water temperature entering boiler	° F.	245	110	220
27. Feed water, lbs. per hour (per boiler)		5,481	3,035	6,500
28. Water evaporated, lbs. per hour per sq. ft. H.S. from and at 212°		5·24	4·03	—
29. Water evaporated, actual per lb. fuel, lbs.		7·78	7·59	—
30. Water evaporated equivalent from and at 212° F. per lb. fuel		8·45	9·62	—

TEST RESULTS.

4	5	6	7	8
Engineering 1/8/24	Engineer 5/3/26	Engineering 2/1/25	Amer. Soc. Mech. Eng., Jan. 1925	Amer. Soc. Mech. Eng., Oct. 1926
—	—	5 hrs. 50 mins	—	—
Yarrow Water-tube	Yarrow Water-tube	Stirling Water-tube	Stirling Duplex	Springfield Water-tube
—	—	—	—	—
3,255	7,016	8,282	30,600	12,560
410	2,005	1,120	4,520	4,000
1,550	—	4,100	22,080	10,692
88·7	—	182	—	378
Underfeed chain grate	—	Bennis mech.	Lopulco system	Taylor mechanical stokers
Balanced	—	Forced	—	Forced and induced
—	—	0·22	0·18 0·20 0·58	0·02 0·02 0·03
—	—	0·74	0·06 0·22 1·54	— — —
—	—	—	0·06 0·82 5·15	0·21 1·48 3·41
—	—	—	6·4 6·5 9·9	3·0 3·2 5·1
Washed pearls	Oil	Washed slack	Pulverised coal	Slack
11,000	17,913	12,080 (as fired)	12,590 12,545 12,717	13,840 13,940 13,938
11·5	—	11·21	22·6 2·6 2·0	5·87 5·05 5·48
12·5	—	6·14	10·7 12·2 10·7	6·01 6·41 5·66
1,638 2,390 2,886	—	4,284	5,244 13,561 27,445	5,512 10,430 18,200
18·0 27·0 32·5	—	23·54	— — —	— — —
—	—	6·71	— — —	6·64 7·86 8·15
— — —	—	—	253 254 270	277 281 291
194 201 220	258	208	251 253 265	277 278 281
543 586 622	638	575	571 630 681	560 627 663
108 91 87	—	127	125 157 153	149 140 142
202 219 213	102	211	205 242 265	245 264 268
12,400 17,050 20,300	41,252	34,983	47,582 131,438 254,357	59,957 105,940 161,580
4·9 6·9 8·2	—	4·81	— — —	4·76 9·2 12·85
7·57 7·13 7·0	11·9	8·17	9·07 9·69 9·27	10·87 10·15 8·88
9·55 9·26 9·29	15·49	10·56	— — —	— — —

Reference No.	1	2	3
GASES.			
31. Temperature leaving boiler . . . °F.	635	594	600
32. Temperature leaving economiser . . °F.	299	—	500
33. Temperature of boiler-house . . .	—	—	—
34. Vol. analysis of gases leaving economiser, if economiser is used, CO_2, per cent.	6·57	9·5	14·2
35. " " CO, per cent.	Nil	Nil	—
36. " " Oxygen, per cent.	12·30	9·5	—
EFFICIENCY			
37. Efficiency of boiler alone (based on higher cal. value where stated) . per cent.	58·0	62·0	—
38. Efficiency of boiler and superheater per cent.	61·0	67·1	—
39. Efficiency of boiler, superheater, and economiser . . . . per cent.	71·6	—	58·2
HEAT ACCOUNT.			
40. Heat absorbed in boiler . . per cent.	58·0	62·0	—
41. Heat absorbed in superheater . per cent.	3·0	5·1	—
42. Heat absorbed in economiser . per cent.	10·6	—	—
43. Heat lost as unburnt fuel in ash . per cent.	3·23	4·7	—
44. Heat lost by incomplete combustion per cent.	—	—	—
45. Heat lost in dry products of combustion . . . . . per cent.	4·05	10·4	—
46. Heat lost in excess air . . . per cent.	8·3	8·9	—
47. Heat lost by moisture in fuel . per cent.	0·47		—
48. Heat lost due to steam formed by combustion of hydrogen . . per cent.	2·8	2·8	—
49. Heat balance, radiation, error, etc. . per cent.	9·55	6·1	—

Notes or Additional Data in connection with some of above tests.

No. 4.—The efficiency stated is evidently based on the *lower* calorific value of the coal.

No. 5.—The oil-fired Yarrow boiler was afterwards provided with an air heater, and about 5 per cent. additional efficiency was obtained, at an evaporation of 40,000 lbs. per hour. Air entering heater at 1110° F., leaving at 240° F. Gas entering at 556° F., leaving at 435° F. Furnace temperature, 2530° F. Suction before heater, $\frac{5}{16}$ in., after $\frac{7}{8}$ in. Air pressure before, 0, after $1\frac{1}{4}$ in. The combustion chamber volume was 2,790 cub. ft.

No. 7.—Boilers at Lake Shore Power Station, Cleveland, U.S.A. Each boiler has a water screen with 835 sq. ft. heating surface. Sixteen fuel burners. The tests quoted are from a series of twenty-four published in the journal of the Amer. Soc. Mec. Eng. (*Mechanical Engineering*), Jan. 1925, which show the efficiency and distribution of losses at a wide range of loads, and at starting and banking conditions.

No. 8.—Boilers at Hell Gate Power Station, New York, U.S.A. The tests shown are selected from a large series showing the performance at different rates of evaporation. The boiler-heating surface includes 460 sq. ft. of water-cooled side walls.

From the above table the losses of heat in a boiler plant may be assigned to their respective causes.

CONSTRUCTION OF BOILERS

Boiler Shells.

Mild steel is now almost invariably used for boiler shells. As a rule, in order to provide a margin for wear and tear, plates below $\frac{3}{8}$ in. thick should never be used.

The bending of plates should be done by rolls, and not by hammering. Rivet holes should be drilled and the rough edge removed by a countersinking tool.

RESULTS—*continued.*

4			5	6	7			8		
—	—	—	—	579	409	509	646	458	576	659
295	354	397	—	281	169	229	318	186	268	300
76	81	77	—	72	—	—	—	77	63	76
15·2 mean			13·8	10·8	13·0	14·7	14·0	13·2	14·0	14·9
—	—	—	—	—	Nil	Nil	Nil	0·1	0·0	0·3
—	—	—	—	—	—	—	—	5·8	5·2	3·7
—	—	—	—	—	75·8	79·0	73·0	—	—	—
—	—	—	83·8	—	81·1	86·4	81·5	84·6	79·5	70·5
89·4	87·0	86·2	—	84·8	86·9	92·9	89·8	92·2	88·6	78·6
—	—	—	—	69·00	75·8	79·0	73·0	77·1	70·6	61·1
—	—	—	—	6·95	5·3	7·4	8·5	7·5	8·9	9·4
—	—	—	—	8·85	5·8	6·5	8·3	7·6	9·1	8·1
—	—	—	—	0·71	—	—	—	0·2	1·1	2·6
—	—	—	—	—	—	—	—	0·4	—	1·1
—	—	—	—	6·77	1·8	3·6	5·8	2·8	5·0	4·9
—	—	—	—					0·6	0·5	0·6
—	—	—	—	4·77	3·6	3·8	3·6			
—	—	—	—					3·1	3·2	3·9
—	—	—	—	2·95	7·7	—0·3	0·8	0·7	1·6	8·3

Steel for Boilers.

The steel is usually required to be made by the open-hearth acid process. The tensile trength is about 26 to 30 tons per sq. in. for shell plates, and 24 to 28 tons per sq. in. for plates or furnaces, flue tubes, and endplates.

Strength of Boiler Shells.

let
P = working pressure in lbs. per sq. in.;
t = thickness of plate in inches;
D = diameter (internal) of boiler in inches;
E = efficiency of longitudinal joint—i.e. proportionate strength of joint to plate;
F = factor of safety;
f = tensile strength of plate in lbs. per sq. in.;

hen,

$$P = \frac{2Ef}{DF}, \text{ or } t = \frac{PDF}{2Ef}.$$

The factor of safety is usually between 4 and 6. Frequently rules are used in which the ife working stress is substituted for $\frac{f}{F}$ in the above.

For permissible values of f, F, or $\frac{f}{F}$, the rules of the Boiler Survey or Insurance Society con- rned should be consulted.

For 'Standard Conditions for Marine Boilers,' see page 1625.

The proportionate strength of joint to plate—i.e. the efficiency of the joint—depends upon he type of joint, and also on the pitch and diameter of the rivets, and thickness of plate.

Typical percentage figures for single riveted lap joints are 40 to 58; for double riveted lap 5 to 70; for double butt (a butt strap each side of the plate and double riveted) 72 to 77; for reble riveted butt, each alternate rivet in outer rows being omitted, 82 to 85.

For the method of calculating the efficiency of riveted joints, see page 1629.

There is a strong tendency now in favour of butt joints for the longitudinal seams, by which the circular form of the shell is maintained, and there is less liability to grooving. The butt strap also protects the joint from corrosion.

All longitudinal seams break joint, as it is termed—that is, the seam in one ring of plates comes opposite to the solid plate in the next ring.

The efficiency of a riveted joint depends on the combination of dimensions as well as on the type of the joint, and there is no fixed relation between efficiencies of the different types of joints. However, for strength and sizes of material used in present-day boiler construction, the relative efficiencies obtainable with different types of joints are approximately as follows: Single-riveted lap joints, 57 per cent.; double-riveted lap joints, 74 per cent.; butt and double-strap joint, double-riveted, 82 per cent.; butt and double-strap joint, triple-riveted, 87 per cent.; and butt and double-strap joints, quadruple-riveted, 94 per cent.

(*'Power,'* Feb. 22, 1927.)

Working Strength of Boiler Flues.

(*Modern Dimensions.*)

P = working pressure, in lbs. per sq. in.
D = diameter, in inches.
L = length, in ft., between seams or hoops.
t = thickness of plate, in inches.

$$P = \frac{806300t^{2\cdot19}}{D \times L} \div \sqrt{\frac{300}{L}} \quad (Harrison).$$

$$P = \frac{50t^2}{D\sqrt{L}} - \frac{D}{L} \quad (M.\ Longridge).$$

(t being in 32nds of an inch.)

$$P = \frac{6149t^2}{\sqrt{DL}} \quad (W.\ H.\ Booth).$$

$$P = \frac{48000t^{2\cdot3}}{D\sqrt{L}} \quad (W.\ H.\ Booth).$$

TABLE OF 2·19 POWER FROM ¼ TO ½ INCH.
(*For Harrison's and Booth's formulæ.*)

Details.	In.	In.	In.	In.	In.
Thickness of plate . .	·25	·312	·375	·437	·500
Power, 2·19 . . .	·04802	·07829	·116715	·16358	·21915

Every case ought to be finally examined to see that the actual pressure on each square inch of section of plate must not exceed the safe crushing resistance of the material, or $P = 30000t \div Df$. This rule may need applying to test the cases of thick furnaces. The value of f is 3 to 4. The strength of flues can be indefinitely increased by the employment of flanged seams, or corrugations.

See also page 1629.

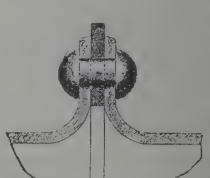


FIG. 3.—Flanged Seam.

The first form of joint in flue and furnace work was ordinary riveting, both transversely and longitudinally, but as weakness developed, the T iron hoop was tried; this, however, though strong, was found to be too rigid, and to lead to leakage in the seams. The flange out of the solid plate (fig. 3) was then designed by Daniel Adamson, and rapidly made its way to the front. The longitudinal joints are now welded, so that when the flange is adopted, no rivets whatever are exposed to the fire in the furnaces.

Pressures Required for Riveting and Flanging.

The pressure required for riveting is 75 to 125 tons per sq. in. of rivet area, preferably the lower value. Excessive pressure causes local deformation of the plate. The riveting pressure should be maintained for a short period, so that the rivet may cool down a little, otherwise the spring of the plate may stretch the rivet while it is still hot.

The pressure required for flanging boiler plates may be found from the formula:

$$F = \frac{2\cdot5(L \times t^2)}{L + 10},$$

where,

F = press load in tons; L = length run of flange in feet; t = thickness of plate in sixteenths of an inch. (*Mechanical World Year Book.*)

Welded Seams in Boilers.

The efficiency of welding depends essentially upon the skill and care of the workman who makes the weld; and in view of the uncertainty of the efficiency in practice as compared with tests, it is not advisable to use welds in parts of boilers subjected to tension, though parts in compression, such as furnaces and flue tubes, may be welded.

For particulars of oxy-acetylene and electric welding, see Section XL., Part II, p. 2747.

Many successful boiler repairs have been effected by welding, particularly in the making up of parts that have been wasted away, and the filling up of grooving.

Welded parts should be hydraulically tested to double the working pressure, the material at and around the weld being hammered while under test.

BOILER RULES AND REGULATIONS.

'Standard Conditions for the Design and Construction of Marine Boilers' have been recommended by a committee of representatives of the Board of Trade, British Corporation, Lloyd's Register, and Bureau Veritas. An abstract of the rules drawn up is given in the following pages. For boilers constructed to the requirements of a particular surveying body or boiler insurance company, the rules of the body concerned should be consulted.

Standard Conditions for the Design and Construction of Marine Boilers.*

(*Abstract.*)

MATERIALS OF CONSTRUCTION.

(*Based on British Standards.*)

Process of Manufacture.—Structural steel for marine boilers shall be made by the open-hearth process, acid or basic.

Freedom from Defects.—The finished material shall be free from cracks, surface flaws, and lamination. It shall also have a workmanlike finish, and must not have been hammer-dressed.†

Tensile Tests: Plates.—The tensile breaking strength of steel plates for shells and girders, determined from Standard test pieces, shall be between the limits of 28 tons and 35 tons per square inch, but a range of not more than 4 tons per square inch shall be permitted in any one case. For plates intended for flanging or welding, and for combustion chambers and furnaces, the tensile breaking strength shall be between the limits of 26 tons and 30 tons per square inch. The elongation, measured on a Standard test piece having a gauge length of 8 ins., shall be not less than 20 per cent. for material of $\frac{3}{4}$ in. in thickness and upwards, required to have a tensile breaking strength between the limits of 28 tons and 35 tons per square inch; and not less than 23 per cent. for material of $\frac{3}{4}$ in. in thickness and upwards, required to have a tensile breaking strength between the limits of 26 tons and 30 tons per square inch.

Stay Bars.—The tensile breaking strength of longitudinal stays shall be between the limits of 28 tons and 35 tons per square inch, with an elongation of not less than 20 per cent. measured on the Standard Test Piece B, but a range of not more than 4 tons per square inch shall be permitted in any one case. For steel bars for combustion chamber stays the tensile breaking strength shall be between the limits of 26 tons and 30 tons per square inch, with an elongation of not less than 23 per cent. measured on the Standard Test Piece B.

Where stay bars are tested on a gauge length of 4 times the diameter (Test Piece F), the elongation shall be 24 per cent. and 28 per cent. respectively.

The tensile breaking strength of angle and tee bars shall be between the limits of 28 and 32 tons per square inch, with an elongation of not less than 20 per cent. measured on the Standard Test Piece A.

For material under $\frac{3}{4}$ in. in thickness the elongation may be 3 per cent., but not more than 5 per cent., below the above-named elongations.

Wherever practicable the rolled surfaces shall be retained on two opposite sides of the test piece.

Rivet Bars.—The tensile breaking strength of rivet bars shall be between the limits of 26 tons and 30 tons per square inch of section, with an elongation of not less than 25 per cent. measured on the Standard Test Piece B or 30 per cent. measured on the Standard Test Piece F. The bars may be tested the full size as rolled.

Bend Tests: Cold Bends.—Test pieces shall be sheared lengthwise or crosswise from plates or bars, and shall not be less than $1\frac{1}{2}$ ins. wide, but for small bars the whole section may be used. For rivet bars bend tests are not required.

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* Published by His Majesty's Stationery Office.

† The Board of Trade have more detailed instructions which they propose to retain.

Temper Bends.—The test pieces shall be similar to those used for cold bend tests. For temper bend tests the samples shall be heated to a blood-red colour and quenched in water at a temperature not exceeding 80° F. The colour shall be judged indoors in the shade.

In all cold bend tests, and in temper bend tests on samples 0·5 in. in thickness and above, the rough edge or arris caused by shearing may be removed by filing or grinding, and samples 1 in. in thickness and above may have the edges machined, but the test pieces shall receive no other preparation. The test pieces shall not be annealed unless the material from which they are cut is similarly annealed, in which case the test pieces shall be similarly and simultaneously treated with the material before testing.

For both cold and temper bends the test piece shall withstand, without fracture, being doubled over until the internal radius is equal to 1½ times the thickness of the test piece, and the sides are parallel.

For small sectional material these bend tests may be made from the flattened bar.

Bend tests may be made either by pressure or by blows.

Tests for Manufactured Rivets.—Rivets selected by the Inspector from the bulk shall withstand the following tests:—

(*a*) The rivet shanks are to be bent cold, and hammered until the two parts of the shank touch, without fracture on the outside of the bend.

(*b*) The rivet heads are to be flattened, while hot, in the usual manner, without cracking at the edges. The heads are to be flattened until their diameter is 2½ times the diameter of the shank.

FORMS OF BRITISH STANDARD TENSILE TEST PIECES.

For Plates and other Structural Material.

TEST PIECE A.

X.—For thicknesses over ⅝ths in.: Maximum width allowed = 1½ ins. Y.—For thicknesses ⅜ths in. to ⅝ths in. Maximum width allowed = 2 ins. Z.—For thicknesses under ⅜ths. in. Maximum width allowed = 2½ ins.

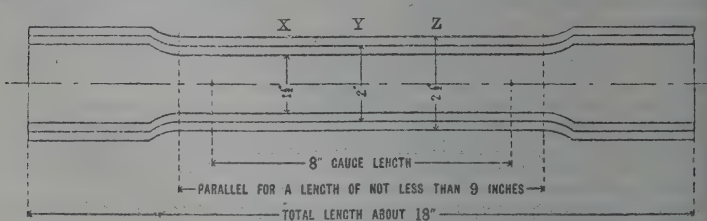

FIG. 4.

NOTE.—It will be observed that the widths given above, being maxima, do not exclude the use of the usual 1½ ins. by 8 ins. test pieces.

TEST PIECE B.

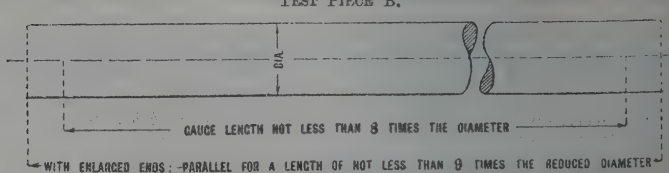

FIG. 5.

TEST PIECE F.

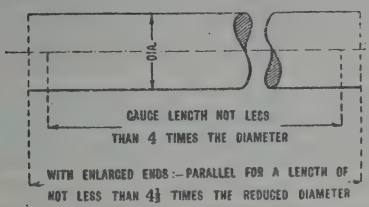

FIG. 6.

SPECIAL IRON FOR SCREW STAYS FOR COMBUSTION CHAMBERS.

In order that iron screw stays may be approved of the same size as would be required for mild steel, the iron must withstand the following tests:—

Tensile Tests.—The tensile breaking strength shall not be less than 21½ tons per square inch, with an elongation of not less than 25 per cent. measured on the Standard Test Piece B, or of 20 per cent. measured on the Standard Test Piece F.

Bend Tests.—Test pieces either of the bar as rolled, or turned down to 1 in. diameter, shall stand bending cold until the sides are parallel and the space between the two sides is not greater than the diameter of the test piece.

Diameters and Thickness of Plain and Stay Tubes.—The following table may be worked to:—

Outside Diameter in Inches.	Standard Thicknesses in L.S.G.				Suitable for Working Pressures of Lbs. per Square Inch.			
Inches.	A	B	C	D	A	B	C	D
2	—	11	10	9	—	155	215	300
2¼	11	10	9	8	140	190	260	315
2½	11	10	9	8	125	175	230	300
2¾	11	10	9	8	110	160	215	275
3	10	9	8	7	140	190	250	300
3¼	10	9	8	7	130	180	230	280
3½	10	9	8	7	120	165	215	260

The minimum thickness of stay tubes measured under the threads shall be ¼ in. for marginal stay tubes, and $\frac{4}{16}$ in. for other stay tubes.

Thickened Ends.—If stay tubes are required to have their thickness increased at the screwed ends, so that the thickness at the bottom of thread is practically the same as in the body of the tube, the thickening is to be attained by upsetting and not by any welding process, and the tubes are to be annealed after the upsetting.

Screwed Threads to be Continuous.—Stay tubes must be screwed at both ends with a continuous thread, which should not be finer than 10 threads per inch. It is desirable, however, that they should be screwed to the standard 9 threads per inch, therefore, after 30th June, 1921, this should be the rule.

MAIN BOILERS, CYLINDRICAL TYPE.

GENERAL CONDITIONS AS TO DESIGN, WORKMANSHIP, HYDRAULIC TEST, ETC.

In the design and construction of marine boilers the following conditions should be observed:—

Riveting of End Seams.—The riveting of the seams joining the end plates to the cylindrical shell shall be not less than 42 per cent. of that of the solid plate. Where the shell plates exceed ½ in. in thickness the seams connecting the shell plates to the end plates are to be double riveted.

Other Circumferential Seams.—The circumferential seam at or near the middle of the lengt of single-ended boilers should have a strength of joint not less than 60 per cent. of the solid plate The inner circumferential seams of double-ended boilers should have a strength of joint no less than 62 per cent. of the solid plate. In any case there shall be three rows of rivets whe single-ended boilers have shell plates over $1\frac{3}{8}$ ins. in thickness, and when double-ended boiler have shell plates over $1\frac{3}{8}$ ins. in thickness. Where the shell plates exceed $\frac{1}{2}$ in. in thickness the intermediate circumferential seams of double-ended boilers are to be at least double riveted

Welding and other Treatment of Plates.—No steel plates subject to a direct tensional stres are to be welded except where the weld is covered by a butt strap or straps. For small stean domes, by special permission where the welding is done by hammer and the plates do not exceed $\frac{1}{2}$ in. in thickness, the straps may be omitted. The strength shall, in such cases, be assume to be 50 per cent. of that of the solid plate. All steel plates which are welded, dished, flanged or locally heated, are to be afterwards efficiently annealed.

Butt Straps.—Butt straps must be cut from plates, and not from rolled strip.

Rivet Holes.—All rivet holes must be drilled 'fair,' and as far as possible they should b drilled in place. After drilling the plates the burrs should be removed and the faying surface of the plates cleaned, and the sharp outer edges of holes removed also.

Stays not to be Welded. Annealing of Fire-worked Stay Bars.—No steel stays are to be welded If plus threads are desired, the ends of the stay bars may be upset or the bars may be drawn down in the central portions from bars originally of the size of the ends. In either of these tw cases the bars must be subsequently annealed throughout.

In double-ended boilers the through longitudinal stays must be supported at or near th middle of their length.

Threads of Screw and other Stays.—All longitudinal stays and also screw stays should hav threads in accordance with the British Standard Specification, and true to pitch, viz. :—

After the 30th June, 1921, all screw stays $1\frac{1}{4}$ ins. in diameter and upwards should have threads per inch, and all stays 2 ins. in diameter and above passing through plates and secure by nuts on each side of the plate should have not more than 6 threads per inch.

Compensation Rings to Manholes.—Where the cylindrical shell is cut for a manhole, com pensation must be provided and must be such that the strength in way of the hole is not les than that required for the longitudinal joint.

Hydraulic Tests of New Boilers.—In all new boilers working at pressures up to 100 lbs. pe square inch the hydraulic test must be twice the working pressure. For boilers working a pressures greater than 100 lbs. per square inch the hydraulic test pressure must be $1\frac{1}{2}$ time the working pressure plus 50 lbs. per square inch.

RULES FOR DETERMINING THE WORKING PRESSURE TO BE ALLOWED ON VARIOUS PARTS OF CYLINDRICAL MARINE BOILERS.

Cylindrical Shells.

Formula for Working Pressure of the Shell.—For the cylindrical shells of steel marine boile the maximum working pressure (which is designated by W.P. and is in lbs. per square inch to be allowed shall be calculated from the following formula :—

Where the thickness of the shell plates does not exceed $1\frac{1}{4}$ ins.,

$$\text{W.P.} = \frac{(t - 2) \times S \times J}{C \times D}$$

Where the thickness of the shell plates exceeds $1\frac{1}{4}$ ins. and double butt straps are fitted,

$$\text{W.P.} = \frac{t \times S \times J}{2{\cdot}85 \times D}$$

where,

t is the thickness of the shell plates in 32nds of an inch,

S is the minimum tensile strength of the steel shell plates in tons per square inch,

J is the percentage of strength of the longitudinal seams calculated by the methods describe on page 1629.

C is a coefficient, which is 2·75 when the longitudinal seams are made with double butt straps; 2·83 when the longitudinal seams are made with lap joints and are treble riveted; 2·9 when they are made with lap joints and are double riveted; and 3·3 when they are made with lap joints and are single riveted.

D is the inside diameter of the outer strake of plating of the cylindrical shell measured in inches.

N.B.—The factor of safety must be in no case less than 4.

Methods of Calculating the Strength of Riveted Joints.—The percentage of strength of a riveted joint (J) is found from the following formulæ (I), (II), (III): (I) and (II) are applicable to any type of joint; (III) is applicable only to that type of joint in which the number of rivets in the inner rows is double that in the outer row. The lowest value given by the application of these formulæ is to be taken as the percentage of strength of the joint.

(I) Percentage of strength of plate at joint as compared with solid plate $= \dfrac{100\,(p-d)}{p}$

(II) Percentage of strength of rivets as compared with the solid plate $= \dfrac{100\,(S_2 \times a \times n \times C)}{S_1 \times p \times T}$

(III) Percentage of combined strength of the plate at the inner row of rivet holes and of the rivets in the outer row

$$= \frac{100\,(p-2d)}{p} + \frac{100\,(S_2 \times a \times C)}{S_1 \times p \times T},$$

where,

p = pitch of rivets at outer rows in inches;
d = diameter of rivet holes in inches;
a = sectional area of one rivet in square inches;
n = number of rivets which are fitted in the pitch p;
T = thickness of plate in inches:
C = 1·0 for rivets in single shear as in lap joints;
C = 1·875 for rivets in double shear as in double butt-strapped joints;
S_1 = minimum tensile strength of plates in tons per square inch;
S_2 = shearing strength of rivets, which is taken generally to be 23 tons per square inch, and may be 85 per cent. of the minimum tensile strength of the rivet bars.

Thickness of Butt Straps.—Where the longitudinal seams are fitted with double butt-strapped joints, the outer butt strap should have at least 0·625 of the strength of the plate, and should be of sufficient thickness to permit of efficient caulking of its outer edges. The inner butt strap should be $\frac{4}{32}$ in. thicker than this.

In cases where the number of rivets in the inner rows is double the number in the outer row, this will require the thickness of the outer strap to be

$$t = \frac{5 \times (p-d)}{8 \times (p-2d)} \times T,$$

and that of the inner strap to be at least

$$t_n = \frac{5 \times (p-d)}{8 \times (p-2d)} \times T + \tfrac{4}{32} \text{ in.}$$

Distances between rows of Rivets and between Rivets and Plate Edges.—In all cases the clear space between a rivet hole and the edge of a plate should not be less than the diameter of the rivet hole—i.e. the centre of the rivet hole should be at least $1\frac{1}{2}$ diameters distant from the edge of the plate.

In joints, whether lapped or fitted with butt straps, in which there are more than one row of rivets and in which there is an equal number of rivets in each row, the distance between the rows of rivets should be not less than $0{\cdot}33p + 0{\cdot}67d$, with zigzag riveting, or $2d$ with chain riveting.

In joints in which the number of rivets in the outer rows is one-half of the number in each of the inner rows, and in which the inner rows are chain riveted, the distance between outer rows and the next rows should be not less than $0{\cdot}33p + 0{\cdot}67d$ or $2d$, whichever is the greater, and the distance between the rows in which there are the full number of rivets should be not less than $2d$.

In joints in which the number of rivets in the outer rows is one-half of the number in each of the inner rows, and in which the inner rows are zigzag, the distance between the outer rows and the next rows should be not less than $0{\cdot}2p + 1{\cdot}15d$, and the distance between the rows in which there are the full number of rivets should be not less than $0{\cdot}165p + 0{\cdot}67d$.

In the above p is the pitch of the rivets in the outer rows.

Maximum Pitch of Rivets in Longitudinal Joints.—The maximum pitch of the rivets in th longitudinal joints of boiler shells is to be—

$$\text{Maximum pitch in inches} = C \times T + 1\tfrac{5}{8} \text{ ins.}$$

where T is the thickness of the plate in inches and C is a coefficient as given in the followin table:—

Number of Rivets per Pitch.	Coefficients for Lap Joints.	Coefficients for Double Butt-strapped Joints.
1	1·31	1·75
2	2·62	3·50
3	3·47	4·63
4	4·14	5·52
5	—	6·00

FURNACES.

Plain Furnaces.—The working pressure to be allowed on plain furnaces or furnace strengthened by Adamson or other joints, and on the cylindrical bottoms of combustion chambers is to be determined by the following formulæ, the least pressure obtained by either formul being taken:—

$$\text{W.P.} = \frac{C\,(t-1)^2}{(L+24)\times D}, \text{ or W.P.} = \frac{C_1}{D} \times [10\,(t-1) - L].$$

where D is the external diameter of the furnace or combustion chamber bottom in inches;

t is the thickness of the furnace plate in 32nds of an inch;

L is the length of the furnace or of combustion chamber bottom or the length betwee points of substantial support, in inches, measured from the centres of rive rows or from the commencement of flange curvature, whichever is applicable

C = 1,450 where the longitudinal seams are welded, and 1,300 where they are riveted

C_1 = 50 where the longitudinal seams are welded, and 45 where they are riveted.

W.P. = working pressure in lbs. per square inch.

Corrugated Furnaces.—The working pressure to be allowed on corrugated furnaces is to b determined by the following formula:—

$$\text{W.P.} = \frac{C\,(t-1)}{D},$$

where D is the external diameter measured at the bottom of the corrugations in inches;

t is the thickness of the furnace plate in 32nds of an inch, measured at the bottom o the corrugation or camber;

C is a coefficient which is 480 for the Fox, Morison, Deighton, Purves, and other simila furnaces, 510 for the Leeds Forge Bulb Suspension furnace.

N.B.—No furnace, plain or corrugated, should exceed $\frac{13}{16}$ in. in thickness.

FLAT PLATES SUPPORTED BY STAYS SECURED IN VARIOUS WAYS.

Flat Plates supported by Screwed Stays.—The working pressure to be allowed on flat plate supported by stays is to be calculated by the following formula:—

$$\text{W.P.} = \frac{(t-1)^2 \times C}{a^2 + b^2},$$

but if steel of less tensile strength than 26 tons per square inch is used the working pressur allowed shall be correspondingly reduced.

In this formula,

W.P. is the working pressure in lbs. per square inch;

t is the thickness of the flat plate in 32nds of an inch;

a is the distance apart of the rows of stays in inches;

b is the pitch of the stays in the rows in inches;

C is a coefficient which varies with the method of fixing the stays as follows:—

Where the plates are exposed to flame and the stays are screwed into the plate and thei ends are riveted over, C = 50.

Where the plates are not exposed to flame and the stays are screwed into the plate and their ends are riveted over, C = 57.

In these cases the thickness of he plate must be at least half the diameter of the stay required by the rule.

Where stay tubes are screwed into tube plates and expanded, C = 52. If they are fitted with nuts, C = 72.

Where the plates are exposed to flame and the stays are screwed into the plate and fitted with nuts on the outside, C = 75. Where the plates are not exposed to flame, C = 86.

Where the stays pass through the plates not exposed to flame and are fitted with nuts inside and outside, C = 96.

Where plates are stiffened by flanging, the inner radius of which is not greater than $2\frac{1}{2}$ times the thickness of the plate, for the support thus given C = 110 when the plates are not exposed to flame, and C = 96 where they are exposed to flame. The pitch is to be reckoned from the commencement of the curvature.

GIRDERS.

Girders Supporting Combustion Chamber Tops.—For girders supporting the tops of combustion chambers the following formula is to be used :—

$$\text{W.P.} = \frac{\text{C} \times d^2 \times t}{(\text{L}-\text{P}) \times \text{D} \times \text{L}} \times \frac{\text{S}}{28},$$

where,

d is the depth of the girder at centre in inches ;

t is the thickness of the girder at centre, when this is a forging, or the sum of the thicknesses of the plates when the girder is made of two plates, measured in 32nds inch ;

L is the length of the girder in inches, measured between the tube plate and back chamber plate inside, or between tube plates in chambers common to two opposite furnaces ;

P is the pitch of stays supported by the girder, in inches ;

D is the distance apart of the girders, centre to centre, in inches ;

S is the minimum tensile strength of the steel plates forming the girder, in tons per square inch. In the case of forged girders S is to be taken as 24 for iron and 28 for steel ;

C is a coefficient as follows :—

$$\text{C} = \frac{n}{n+1} \times 495,$$

when the number of stays in each girder is odd, and

$$= \frac{n+1}{n+2} \times 495,$$

when the number of stays in each girder is even, n being the number of stays to each girder.

STAYS.

Iron or Steel Screw Stays to Combustion Chambers.—For screw stays with threads not coarser than 9 threads per inch, made of steel or of special wrought iron tested to the requirements, the following formula is to be used :—

$$\text{W.P.} = \frac{(d - 0{\cdot}267)^2 \times 8{,}250}{a},$$

where,

d is the diameter of the stay over the thread in inches ;

a is the area in square inches supported by one stay.

But in no case must the stress exceed 9,000 lbs. per square inch of section.

Steel Longitudinal Stays.—For steel longitudinal stays with threads not coarser than 6 thread per inch, the working pressure is to be calculated from the following formula :—

$$\text{W.P.} = \frac{(d - 0{\cdot}340)^2 \times 9{,}500}{a} \times \frac{S}{28},$$

where d is the diameter of the stay over the thread in inches;

a is the area in square inches supported by one stay;

S is the minimum tensile strength of the steel in tons per square inch.

But in no case must the stress exceed 11,000 lbs. per square inch of section, when steel of minimum tensile strength of 28 tons per square inch is used.

In cases where longitudinal stays are made with enlarged ends, and the body of the stay smaller in diameter than at the bottom of the thread, and in cases where coarser threads tha 6 per inch are used, the working pressure is to be calculated from the following formula :—

$$\text{W.P.} = \frac{(d_1 - 0{\cdot}125)^2 \times 9{,}500}{a} + \frac{S}{28},$$

where d is the diameter of the stay at the bottom of the thread or at the smallest part the body.

Stay Tubes.—On stay tubes, whether of wrought iron or of lap-welded steel, a working stre of 7,500 lbs. per square inch of the net sectional area at the bottom of the thread is permitted.

Dished Ends (Convex Outside).—For ends of steam chests, etc., dished to partial spheric form, the following formula is to be used :—

$$\text{W.P.} = \frac{15 \times S\,(t - 1)}{R},$$

where

W.P. is the working presures in lbs. per square inch;

t the thickness in 32nds of an inch;

R the inner radius of curvature of the end in inches, which shall not exceed the diamet of shell;

S the minimum tensile strength of plates in tons per square inch.

Safety Valves.—At least two safety valves must be fitted to each boiler. They must l arranged so that the springs and valves are cased in, that the valves cannot be overloaded wh steam is up, that they can be lifted by easing gear, and turned round on their seats by han and in case of fracture of springs they cannot lift out of their seats.

The easing gear must be arranged to lift all the safety valves on a boiler together, and mu be workable from some accessible place free from steam danger.

All the safety valves of each boiler may be fitted in one chest, which must be separate fro any other valve chest and which must be connected direct to the boiler by a strong and st neck, the passage through which should have a cross-sectional area at least equal to one-h the aggregate area of the safety valves in the chest.

Each safety valve box shall have a means of draining it; the pipe shall lead to the bilge tank clear of the boiler.

Size of Safety Valves.—The minimum aggregate area of the safety valves of the ordina type in each boiler, whether coal-fired or oil-fired, and whether working under natural, force or induced draught, shall be found by the following formula :—

Aggregate area of safety valves in square inches

$$= \text{Total heating surface of boilers in square feet} \times \left(\frac{K}{p + 15}\right),$$

where p is the working pressure in lbs. per square inch.

For coal-fired boilers K is 1·25, for oil-fired boilers and boilers with closed stokehold forc draught K = 1·5.

Accumulation Test of Safety Valves.—All safety valves must be set to the required pressure under steam. During a test of 15 minutes with the stop valves closed, and under full firing conditions, the accumulation of pressure must not exceed 10 per cent. of the loaded pressure. During this test no more feed-water should be supplied than is necessary to maintain a safe working water level.

Superheater Safety Valves and Drains.—Where a superheater is fitted which can be shut off from the boiler it must have a separate safety valve fitted with easing gear, etc. The valve as regards construction must comply with the regulations for ordinary safety valves, but the easing gear may be fitted to be workable from the stokehold only.

The superheater must be fitted with a drain cock or valve to free it from water when necessary.

BOILER TUBES.

Approximate Weight of Iron Boiler Tubes.

PER FOOT RUN.

External Diameter.	11 S.W.G.	10 S.W.G.	9 S.W.G.	8 S.W.G.	¼-inch	$\frac{5}{16}$-inch.
Ins.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
$2\frac{1}{8}$	2·89	3·18	3·55	3·92	5·89	7·16
$2\frac{3}{4}$	3·20	3·51	3·93	4·34	6·54	7·97
3	3·50	3·85	4·30	4·75	7·20	8·79
$3\frac{1}{4}$	3·80	4·18	4·68	5·17	7·85	9·61
$3\frac{1}{2}$	4·11	4·52	5·06	5·59	8·50	10·4
$3\frac{3}{4}$	4·41	4·85	5·43	6·01	9·16	11·2
4	4·72	5·19	5·81	6·43	9·81	12·0
$4\frac{1}{4}$	5·02	5·52	6·19	6·85	10·4	12·8
$4\frac{1}{2}$	5·32	5·86	6·57	7·27	11·1	13·7
$4\frac{3}{4}$	—	6·19	6·94	7·69	11·7	14·5
5	—	6·53	7·32	8·11	12·4	15·3
$5\frac{1}{4}$	—	6·86	7·70	8·52	13·0	16·1
$5\frac{1}{2}$	—	—	8·07	8·94	13·7	16·9
$5\frac{3}{4}$	—	—	8·45	9·36	14·4	17·8
6	—	—	8·83	9·78	15·0	18·6

Surface of Boiler Tubes.

PER FOOT RUN.

External Diameter.	Surface.	External Diameter.	Surface.	External Diameter.	Surface.
Ins.	Sq. Ft.	Ins.	Sq. Ft.	Ins.	Sq. Ft.
$\frac{3}{4}$	·1964	$1\frac{3}{4}$	·4582	$3\frac{1}{4}$	·8509
$\frac{7}{8}$	·2291	$1\frac{7}{8}$	·4909	$3\frac{1}{2}$	·9163
1	·2618	2	·5236	$3\frac{3}{4}$	·9818
$1\frac{1}{8}$	·2945	$2\frac{1}{8}$	·5563	4	1·047
$1\frac{1}{4}$	·3273	$2\frac{1}{4}$	·5891	$4\frac{1}{2}$	1·178
$1\frac{3}{8}$	·3600	$2\frac{3}{8}$	·6545	5	1·307
$1\frac{1}{2}$	·3927	$2\frac{3}{4}$	·7200	$5\frac{1}{2}$	1·440
$1\frac{5}{8}$	·4254	3	·7584	6	1·571

BRITISH STANDARD SPECIFICATION FOR CHARCOAL IRON LAPWELDED BOILER TUBES.*

(No. 43—1927.) (*Abstract.*)

1. The tubes shall be lapwelded and shall be made from genuine charcoal iron of the best ality. 2. The tubes shall be sound, clean, smooth and well finished, free from surface defects, st and longitudinal grooving, both internally and externally, and the ends shall be clean and uare. 3. The tubes shall be carefully annealed at both ends. 6. The tubes or strips cut from e tubes shall show a tensile strength between the limits of 19 and 24 tons per square inch clusive, with a contraction of area of the metal of not less than 45 per cent. 7. The tubes

* By permission of the British Engineering Standards Association.

shall stand bulging both hot and cold with a parallel drift (fig. 7) without showing either crack or flaw, until the diameter of the bulged end exceeds the original diameter of the tube by not less than 15 per cent. when tested hot and by not less than 10 per cent. when tested cold. 8. A piece

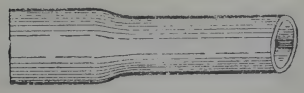

FIG. 7.

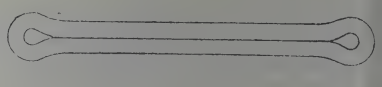

FIG. 8.

of tube 2 ins. long shall be placed on end and shall stand hammering down until it is reduced to 1⅛ in. high, without showing crack or flaw. 9. The tubes shall, when cold, stand flattening (fig. 8) without showing crack or flaw until the interior surfaces of the tubes meet. 10. Each tube shall be tested by an internal hydraulic pressure of at least 750 lbs. per sq. in., and any tubes failing to stand this test shall be rejected.

BRITISH STANDARD SPECIFICATION FOR COLD DRAWN WELDLESS STEEL TUBES FOR LOCOMOTIVE BOILERS.*

(No. 53—1927.) (*Abstract*).

Quality of Material.

1. The tubes shall be cold drawn and weldless, and shall be manufactured from steel of the best quality made by the Open-Hearth process. They shall not show on analysis more than 0·035 per cent. of sulphur or more than 0·030 per cent. of phosphorus. The manufacturer shall supply an analysis when required to do so.

Freedom from Defects.

2. The tubes shall be perfectly sound, clean, smooth, and well finished, free from surface defects, rust and longitudinal grooving, both internally and externally, and the ends shall be clean and square.

Annealing.

3. The tubes shall be carefully annealed throughout their length after the operation of drawing and the ends shall be carefully annealed after the process of enlarging or decreasing the diameter.

Permissible Variation in Weight.

4. The actual weight of each tube shall not differ from the calculated weight by more than 5 per cent. above or 2½ per cent. below the weight calculated from the specified dimensions allowing 489·6 lbs. per cubic foot of metal in the tubes.

Tensile Test.

6. The tubes or strips cut from the tubes shall, without further annealing, show a tensile strength of not less than 20 tons per sq. in. nor more than 26 tons per sq. in. with an elongation of not less than 28 per cent. in 8 ins. for tubes, and not less than 22 per cent. in 8 ins. for strips cut from the Tubes. If strips are cut for testing from tubes over 2¼ ins. diameter they may be annealed before testing.

Crushing down Test.

8. A piece of tube 2 ins. long shall be placed on end and shall, when cold, stand hammering down until it is reduced to 1⅛ ins. high, without showing either crack or flaw.

Flattening Test.

9. The tubes shall, when cold, stand flattening (fig. 8), without showing either crack or flaw until the interior surfaces of the tubes meet or, when the tubes are over 11 S.W.G. in thickness until the interior surfaces are brought to a distance apart equal to the thickness of the wall of the tube.

Hydraulic Test.

10. Every tube shall be tested by an internal hydraulic pressure of at least 1,000 lbs. per sq. in., and any tubes failing to stand this test shall be rejected.

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TYPES OF BOILERS.

LANCASHIRE AND CORNISH BOILERS.

The distinction between these two general types is that the Cornish has one and the Lancashire two internal flues.

These boilers were originally made with iron plates, and had flat ends (often in two or three pieces), the flat surfaces being strengthened with rod and gusset stays.

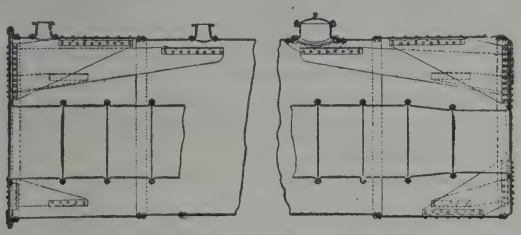


FIG. 9.—Lancashire Boiler (ordinary type, with flat end plates).

When steel took the place of iron, and boiler makers were able to obtain larger plates, the end plates of the largest boilers were then made in one piece, and the shells constructed of seven or nine belts, each in one plate. Fig. 9 shows a section of one of these Lancashire boilers as it is still being made by some firms.

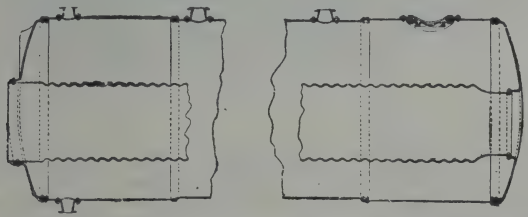


FIG. 10.—John Thompson Type, with dish end plates and corrugated flue tubes.

All internally-fired boilers are subjected to straining due to unequal expansion and contraction, the flue tubes and furnace tubes becoming hotter than the shell while the boiler is at work.

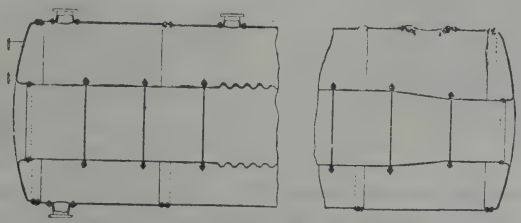


FIG. 11.—John Thompson Type, with flue tubes corrugated for part of their length.

Makers of boilers having flat end plates provide for expansion by the flexibility of the end plates.

Some makers avoid the staying required in the case of flat end plates by using dish-end

plates (fig. 10), and provide for the relief of expansion stresses by making the flue tubes corrugated, either for their whole length (fig. 10), or for part of their length (fig. 11).

A length of corrugated flue tube is used by makers of flat end boilers also, for high pressures.

THE GALLOWAY BOILER.

The general design and details of the Galloway Boiler (*Galloways, Ltd., Manchester*) are shown by fig. 12. The boiler has two furnaces at the front, joining behind the bridges into one flue of special shape, containing the well-known Galloway cone tubes, and side pockets; otherwise, and in general appearance, it is somewhat similar to the two-flued or Lancashire boiler.

The advantages claimed for the Galloway boiler are:—

Increased heating surface—about 10 per cent. additional.

Improved circulation, giving more uniform temperature and reduced expansion strains. This circulation, also, largely prevents the deposit of solid matter upon the furnaces and adds to the durability of the boiler.

Improved heat transmission, owing to good circulation and to sinuous path of flue gases past the cone tubes.

Increased output and higher efficiency.

DETAILS OF STANDARD 'GALLOWAY' BOILERS

Size. Length × Diam.	No. of Cone Tubes.	Heating Surface.	Normal Grate Area.	Outside Diam. of Furnace.	Steam Evaporated per Hour, Lbs.			Approximate Net Weight.	
					Coal burnt per Sq. Ft. Grate per Hour.			Working Pressure.	
					20 lbs.	25 lbs	30 lbs.	120 lbs.	160 lbs.
Ft. Ft.In.		Sq. Ft.	Sq. Ft.	Ft. In.	Lbs.	Lbs.	Lbs.	Tons.	Tons.
14×5 6	6	300	14·5	2 1	2,500	3,100	3,700	7	—
16×5 6	8	350	16	2 1	2,700	3,400	4,100	7·5	—
18×5 6	8	395	17·2	2 1	2,900	3,600	4,400	8	—
16×6 0	8	395	19·5	2 4	3,300	4,100	5,000	8	—
18×6 0	11	445	21	2 4	3,500	4,400	5,300	8·75	—
20×6 0	11	495	22·5	2 4	3,800	4,800	5,700	9·5	—
22×6 0	14	555	22·5	2 4	3,800	4,800	5,700	10·3	—
20×6 6	15	570	23·2	2 7	3,900	4,900	5,900	10·5	12·5
22×6 6	15	605	25	2 7	4,200	5,300	6,400	11	13·25
24×6 6	18	675	27·5	2 7	4,600	5,800	7,000	11·8	14·5
26×6 6	18	725	30	2 7	5,100	6,400	7,600	13	15
24×7 0	18	735	29·7	2 9	5,100	6,300	7,600	14·5	17
26×7 0	20	795	32	2 9	5,400	6,800	8,200	15·5	18
28×7 0	20	850	32	2 9	5,400	6,800	8,200	16·5	19
30×7 0	25	925	32	2 9	5,400	6,800	8,200	17·5	20
28×7 6	20	925	35	3 0	5,900	7,400	8,900	17·75	22
30×7 6	25	1,000	35	3 0	5,900	7,400	8,900	19	23·5
28×8 0	25	1,070	38	3 3	6,500	8,100	9,700	20	25
30×8 0	25	1,120	38	3 3	6,500	8,100	9,700	21	26
30×8 6	25	1,220	40	3 5	6,800	8,500	10,200	23·5	28·3
30×9 0	25	1,310	43	3 8	7,300	9,100	11,000	25·5	31·5

BASIS.—8·5 lbs. of water evaporated per lb. of coal. Boiler supplied with hot feed as from a Green's economiser.

On page 1638 are results of tests made by the British Engine, Boiler, and Electrical Insurance Co., Ltd., on two adjacent boilers working into the same chimney, one being a Lancashire boiler and the other a Galloway patent boiler, but otherwise of similar size and seated in similar manner.

GALLOWAYS
LIMITED

HEAD OFFICE: KNOTT MILL IRONWORKS, MANCHESTER.

Telegrams: 'GALLOWAY, MANCHESTER.' Telephone: 6312 CENTRAL.

LONDON OFFICE: 11 QUEEN VICTORIA STREET, E.C.4.

Telegrams: 'GALLOWNEER, CANNON, LONDON.' Telephone: 0834 CITY.

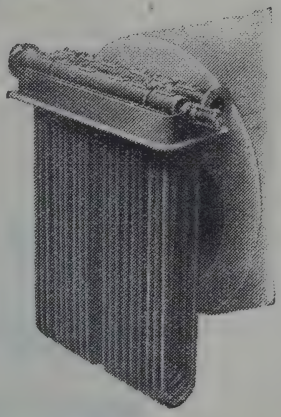
LANCASHIRE AND GALLOWAY BOILERS.

BOILERS.

LANCASHIRE GALLOWAY
WATER-TUBE
MULTI-TUBULAR DRY BACK

STEAM VALVES
AND
BOILER FITTINGS

GALLOWAYS'
SUPERMISER
LEEK'S PATENTS
Ensures 80% Boiler Efficiency.



MULTIPLE FLOW
ACCESSIBLE SUPERHEATER
(COVER REMOVED).

G.S.19/915

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GALLOWAYS

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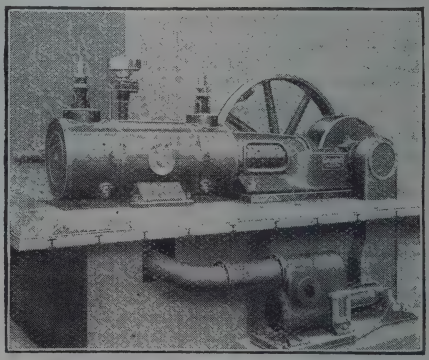
TANDEM DROP-VALVE ENGINE. ARRANGED FOR STEAM EXTRACTION.

ENGINES.

ROLLING MILLS, WINDING, FACTORIES, SEWAGE, TOWN'S WATER, ELECTRIC POWER.

LARGE GAS ENGINES.

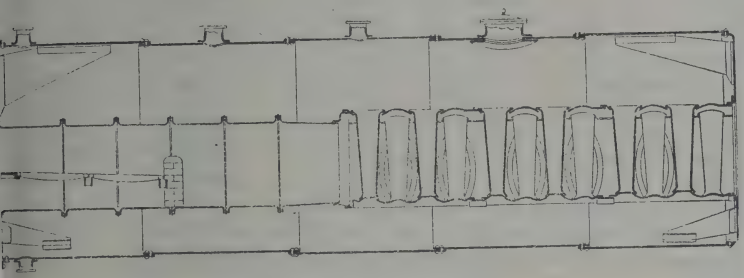


PATENT UNI-FLOW STEAM ENGINE.

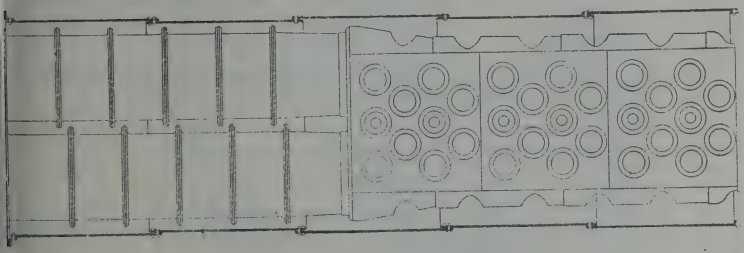
G.S.19/915

F. 1637

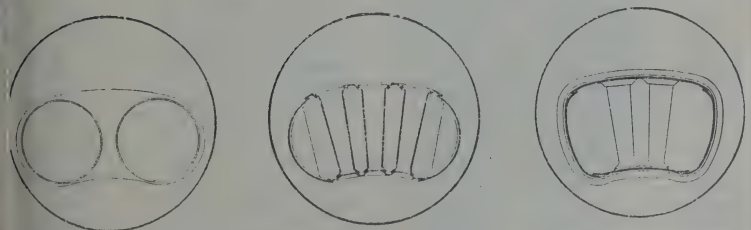
THE GALLOWAY BOILER.



Longitudinal Sectional Elevation.



Longitudinal Sectional Plan.



Cross Section behind Fire Grates.

Cross Section through Galloway Flue.

Cross Section at Back End.

FIG. 12.

TESTS OF LANCASHIRE AND GALLOWAY BOILERS.

Details.	Lancashire Boiler.	Galloway Boiler.
Diameter of boiler	8 ft.	8 ft.
Length of boiler	30 ft.	30 ft.
Total heating surface	985 sq. ft.	1,164 sq. ft.
Fuel fired per hour	1,421 lbs.	1,424 lbs.
Combustible burnt per hour	1,348 lbs.	1,317 lbs.
Water evaporated per hour	10,565 lbs.	11,485 lbs.
Dried fuel fired per sq. ft. grate per hour	31 lbs.	31 lbs.
Water evaporated per lb. combustible from and at 212° F.	9·39 lbs.	10·39 lbs.

THE JOHN THOMPSON LANCASHIRE BOILER.

(*John Thompson (Wolverhampton), Ltd., Wolverhampton.*)

This is a boiler (fig. 13, p. 1640) of the dish-end type (figs. 10, 11). The end plates are dished to a convex form and increased in thickness to give the same factor of safety (as obtained with the stayed surface), thereby dispensing with all gusset and longitudinal rod stays. The inside, being free from stays, can be easily cleaned, particularly over the fire-boxes, where the steam is so largely generated.

The table on page 1639 gives some particulars of these boilers, which have been made for working pressures up to 230 lbs. per sq. in.

MULTITUBULAR BOILERS, LOCOMOTIVE TYPE.

THE ROBEY BOILER.

Fig. 14 shows a boiler, locomotive type, by Messrs. Robey & Co. Ltd. of Lincoln. It is rated at 8 h.p. nominal, with enlarged grate suitable for burning inferior fuel, having a grate area of 6·43 sq. ft., and a total heating surface of 164·8 sq. ft. Its working pressure is 150 lbs per sq. in. The tubes are of steel solid drawn.

The figure shows Messrs. Robey & Co.'s patent roof fire-box girders, which, being supported by the archplate of external fire-box, take all compressive strains off the fire-box front plate and tube plate.

DIMENSIONS OF 8 H.P. LOCOMOTIVE BOILER.

Length of external fire-box	3 feet 5 inches	Height of internal fire-box	3 feet 4 inches
Length of boiler barrel	6 „ 1 „	Height of external fire-box	4 „ 4½ „
Length of smoke-box	1 „ 11 „	Diameter of boiler barrel	2 „ 9¼ „
Width of external fire-box	2 „ 10 „	Number of tubes	32
Width of internal fire-box	2 „ 3⅜ „	Diameter of tubes	2½ „
Length of internal fire-box	2 „ 10 1/16 „		

THICKNESS OF PLATES.

Boiler barrel	0 ft. ⅜ in.	Tube plates	0 ft. ⅝ in.
External fire-box	0 „ 7/16 „	Total length of boiler	11 „ 5 „
Internal fire-box	0 „ 5/16 „		
Heating surface in tubes	132·5 sq. ft.	Working pressure	150 lbs. per sq. in.
Heating surface in fire-box	32·3 „	Hydraulic test	250 „ „
Total heating surface	164·8 „	Steam test	150 „ „
Grate area	6·43 „		

Fig. 15 (p. 1642) shows a Great Northern Railway locomotive boiler for a 6-ft. 6-in. 4-wheel coupled bogie engine.

SHOP No. 3719, YEAR 1908.

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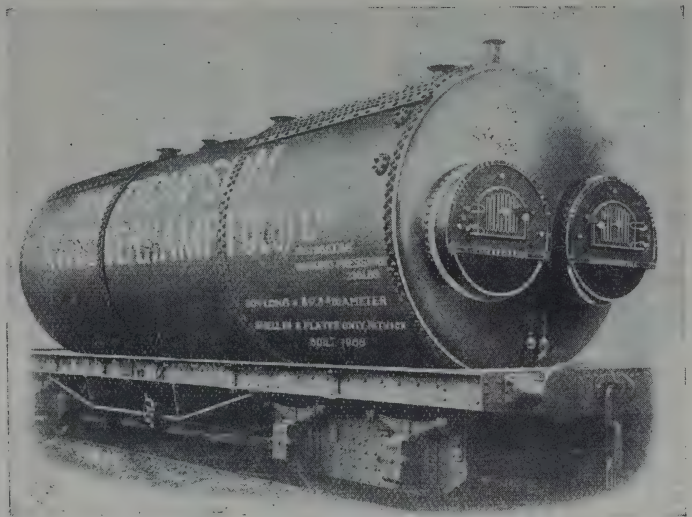

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Diameter of Boiler.	Length of Boiler.	Working Pressure, in Lbs. per Sq. In.	Heating Surface, in Sq. Ft.	Grate Area, in Sq. Ft.	Approximate Evaporation, in Lbs. of Water per Hour.	I.H.P., based upon 20 lbs. of Steam per I.H.P. per Hour.	Diameter of Flues.	Thickness of Shell, in Inches.	Thickness of Flues, in Inches.	Thickness of Dish End, in Inches.	Thickness of Flat End, in Inches.
Ft. Ins.	Feet.						Ft. Ins.				
6 6	24	100	640	28	5,000	250	2 6	15/32	8/8	3/4	1/2
6 6	24	120	640	28	5,000	250	2 6	1/2	13/32	3/4	9/16
6 6	24	160	640	28	5,000	250	2 6	5/8	15/32	13/16	21/32
7 3	24	100	680	30	5,500	275	2 9	1/2	8/8	3/4	17/32
7 3	24	120	680	30	5,500	275	2 9	9/16	13/32	8/8	9/16
7 3	24	160	680	30	5,500	275	2 9	21/32	15/32	13/16	21/32
7 3	30	100	875	30	6,000	300	2 9	1/2	8/8	3/4	17/32
7 3	30	120	875	30	6,000	300	2 9	9/16	13/32	8/8	9/16
7 3	30	160	875	30	6,000	300	2 9	21/32	15/32	13/16	21/32
8 3	30	100	1,050	42	7,250	365	3 3	9/16	7/16	13/16	9/16
8 3	30	120	1,050	42	7,250	365	3 3	5/8	7/16	15/16	21/32
8 3	30	160	1,050	42	7,250	365	3 3	23/32	1/2	1	3/4
8 6	30	100	1,100	45	9,000	450	3 5	19/32	7/16	13/16	9/16
8 6	30	120	1,100	45	9,000	450	3 5	21/32	15/32	15/16	23/32
8 6	30	160	1,100	45	9,000	450	3 5	3/4	17/32	1	3/4
9 3	30	100	1,175	49	9,500	475	3 9	5/8	7/16	7/8	9/16
9 3	30	120	1,175	49	9,500	475	3 9	11/16	15/32	15/16	21/32
9 3	30	160	1,175	49	9,500	475	3 9	13/16	17/32	1 1/16	25/32

The above evaporations assume the use of mechanical stokers.

MODERN TYPE OF 'JOHN THOMPSON LANCASHIRE BOILER.' DISHED ENDS—SHELL IN FIVE RINGS—CORRUGATED FLUES THROUGHOUT.
(*John Thompson (Wolverhampton) Ltd., Wolverhampton.*)

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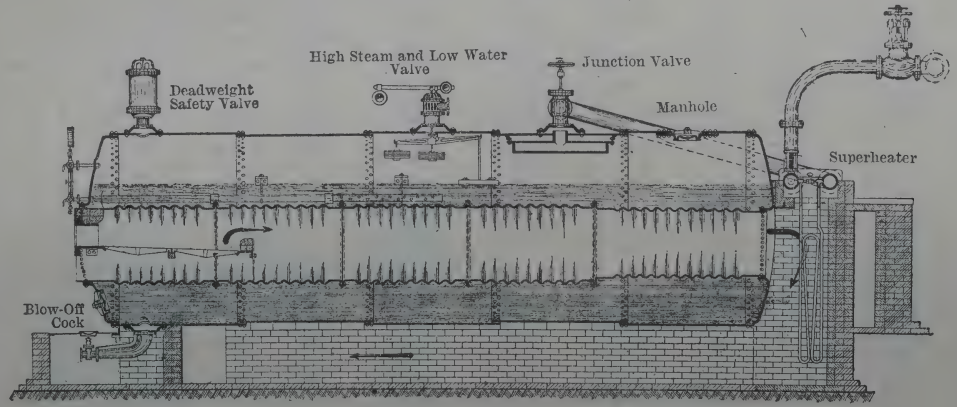
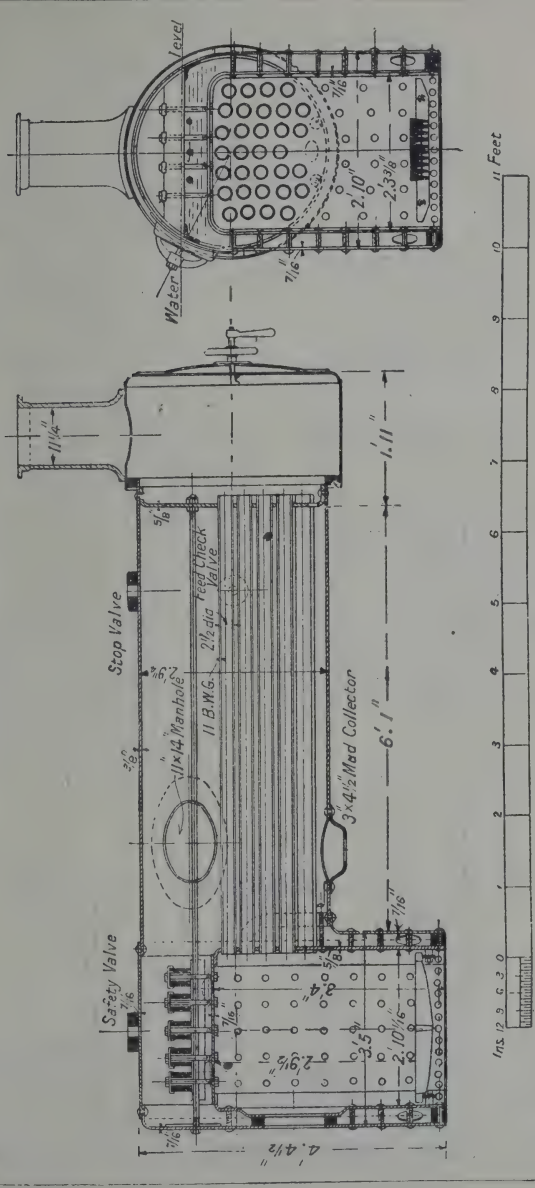
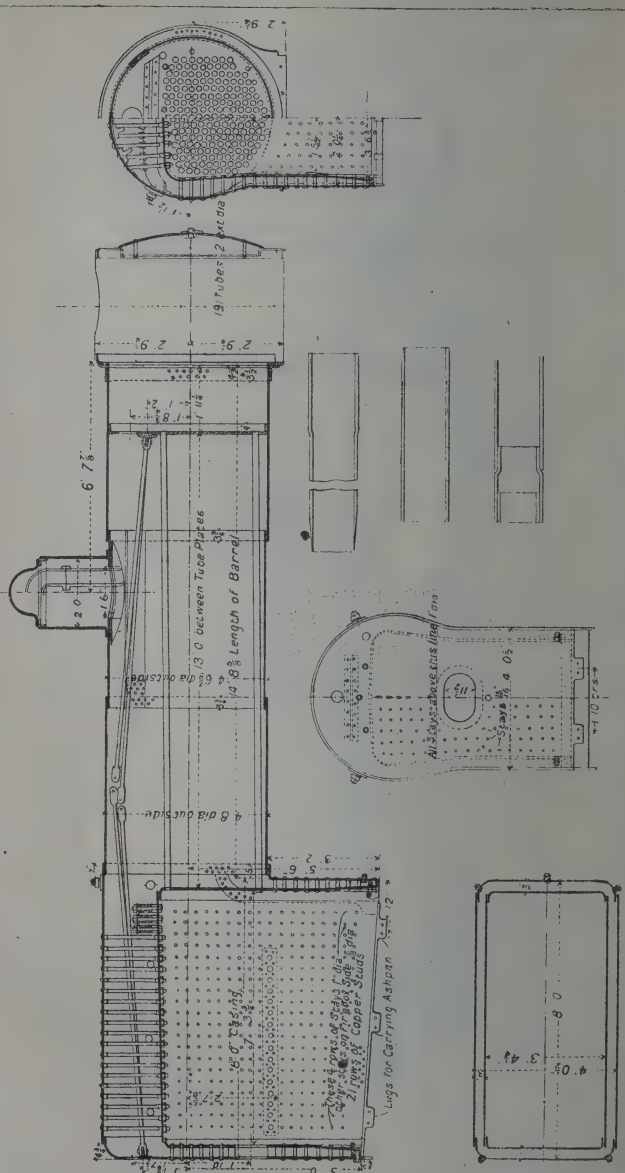


FIG. 13.



ROBEY MULTITUBULAR BOILER, LOCOMOTIVE TYPE.

FIG. 14.



LOCOMOTIVE BOILER FOR 6 FT. 6 IN. 4-WHEEL COUPLED BOGIE ENGINE, GREAT NORTHERN RAILWAY.

FIG. 15.

Paxman Boilers.

(Davey, Paxman & Co., Ltd., Colchester.)

The Paxman Vertical Multitubular Boiler.

(Prov. Prot.)

This type of boiler has been designed to supply the demand for a boiler which occupies a minimum of space, does not require any brickwork setting, and at the same time does not sacrifice its economy in achieving these objects. Owing to the design a greater heating surface and consequent evaporation can be obtained than with any other design of vertical boiler of the same diameter, without in any way interfering with the accessibility for inspection and cleaning. The special features of the design, which have made it possible to achieve these results, are as follows:—

The general construction of the boiler is shown by sectional views figs. 16 and 17. A straight neck C, secured to the top of the firebox B, conveys the products of combustion into a chamber to the left G, from whence they pass through the horizontal smoke tubes A, to a similar chamber on the other side H, provided with door and uptake, constituting a smokebox. The first chamber or combustion chamber G is lined with firebrick, which, retaining the heat, ensures complete combustion of the gases before they enter the tubes. This chamber is also provided with a door, so that the tubes are easily accessible for cleaning purposes.

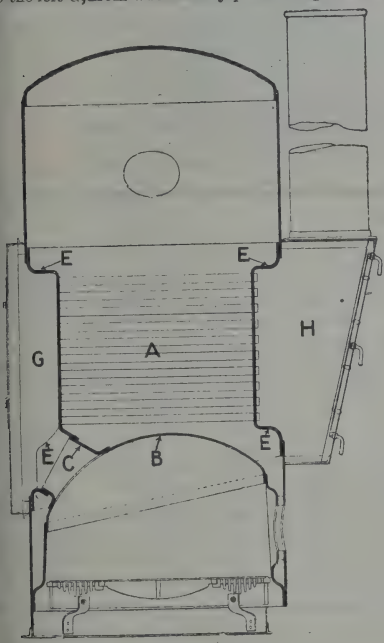


Fig. 16.

The construction of the firebox forms one of the special features of the design, the inclination of the joint of the crown B enabling the neck C to be so placed as to allow of more tubes being inserted without increasing the height of the boiler.

Another very important feature is the design of the pockets forming the tube plates. Unlike the usual practice using deep independent pockets riveted to the shell, these are pressed out of the solid shell plate, thus allowing them to be of a

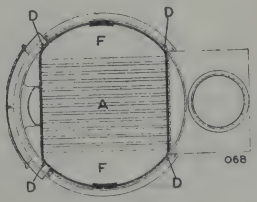


Fig. 17.

minimum depth and dispensing with any riveted joints beyond those in the shell plates themselves.

The advantages of this form of construction are considerable: the absence of loose riveted pockets increases the strength of the boiler shell, does away with all chances of trouble with leaky seams and rivets, and at the same time the reduction in the depth of the pockets allows of a considerable increase in the length of the tubes, and consequently in the heating surface, without increase in the diameter of the boiler, thus improving the proportion of heating surface to grate area, with the result that the efficiency is sensibly increased.

The reduction in the depth of the pockets has the additional advantage of doing away with the necessity of staying the tops or bottoms of these pockets.

The additional heating surface obtained by increasing the length and number of the tubes in no way affects the accessibility of the boiler for cleaning purposes. As will be seen in fig. 17, the spaces F, through which access to the tubes and crown of firebox is obtained, will remain unaltered by the length or depth of the complete nest of tubes.

The advantages of this boiler can be briefly summarised as follows:—

1. Ease of erection owing to absence of brickwork setting or special foundations.
2. Increased evaporation per square foot of floor space occupied.
3. Greater economy owing to better proportion between heating surface and grate area.
4. Ample accessibility for cleaning and inspection of all internal parts.
5. Elimination of riveted joints round pockets.
6. No staying required in any part of the boiler.

The boiler can be supplied for evaporation up to 6,000 lbs. per hour, and for working pressure between 80 and 160 lbs. per square inch

PRINCIPAL DIMENSIONS OF PAXMAN VERTICAL MULTITUBULAR BOILERS.

(For working pressures up to and including 140 lbs. per square inch.)

No.	Boiler.							Economical Evaporation in Lbs. per Hour.
	Shell.			Tubes.		Heating Surface.	Grate Area.	
	Diameter.		Height, including Ashpan.	No.	Diameter			
	Ft.	Ins.	Ft. Ins.		Ins.	Sq. Ft.	Sq. Ft.	
1	3	0	7 6	49	2	82	5	380
2	3	4	8 5	56	2	103	6	550
3	3	9	8 7	56	2	121	7·75	660
4	4	0	9 6	64	2¼	153	8·75	770
5	4	3	9 9	64	2¼	170	10·25	860
6	4	6	10 3	81	2¼	210	12	1,090
7	4	9	10 9	81	2¼	225	13	1,180
8	5	0	11 6	90	2¼	260	14·75	1,350
9	5	3	12 3	110	2¼	320	16	1,660
10	5	6	12 6	110	2¼	355	18	1,900
11	5	9	13 0	120	2¼	406	21	2,030

THE PAXMAN ECONOMIC BOILER.

This boiler (fig. 18) consists of a cylindrical shell, with one or more internal flues, and a number of small return tubes running from end to end. A combustion chamber of brick receives the products of combustion at the back of the boiler; they then pass through the small tubes to the smokebox in front, and finally return to the back, outside the boiler shell, through the brick flues in the setting, to the chimney.

Whilst the temperature of the waste gases which leave the boiler on their way to the chimney ranges from 600° to 700°F. with many boilers of the Cornish, Lancashire, or similar types, it is

only from 450° to 475°F. in the case of the Paxman 'Economic'; with the latter boiler, on account of its large heating surface, there is about 30 per cent. less waste of heat, the temperature named being just sufficient to create a natural draught, indicating that the utmost possible degree of heat has been abstracted from the fuel burnt, and rendering an Economiser unnecessary.

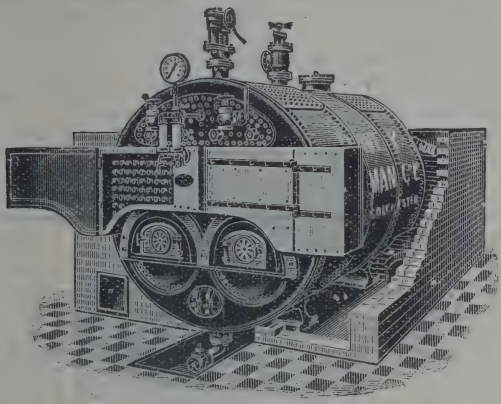


FIG. 18.

An independent test of this boiler by Sir Alexander W. B. Kennedy showed an evaporation of 12·2 lbs. of water from and at 212°F. per lb. of coal.

The operation of sweeping the tubes (preferably daily) can be effected by the stoker, using an ordinary wire tube brush, during any interval of thirty minutes; or, if there is no such interval, a steam cleaning device can be supplied, enabling the operation to be completed in two minutes.

A Paxman 'Economic' boiler being only about half the length of a Lancashire boiler of corresponding capacity, a very considerable saving is effected in the boiler setting and buildings; and in case of shipment the freightage cost may be only one-third of that for a Lancashire boiler.

PRINCIPAL DIMENSIONS OF STANDARD SIZES OF PAXMAN ECONOMIC BOILERS WITH SINGLE OR DOUBLE FLUES.

No.	Length	Diam.	Flues. No.	Flues. Diam.	Internal Heating Surface.	Evaporation per Hour.*	No.	Length	Diam.	Flues. No.	Flues. Diam.	Internal Heating Surface.	Evaporation per Hour.*
	Ft.Ins.	Ft.Ins.		Ft.Ins.	Sq. Ft.	Lbs.		Ft.Ins.	Ft.Ins.		Ft.Ins.	Sq. Ft.	Lbs.
8	6 5	4 9	1	2 3	140	840	30	11 0	6 3	1	3 2	478	2,860
10	7 0	5 0	1	2 4	174	1,044	35	12 6	6 6	1	3 2	565	3,400
12	8 0	5 0	1	2 6	234	1,400	40	12 6	7 0	2	2 3	665	3,990
14	8 6	5 0	1	2 6	248	1,480	45	12 6	7 6	2	2 4	772	4,530
16	9 0	5 3	1	2 6	276	1,650	50	14 0	7 6	2	2 6	890	5,220
20	9 6	5 6	1	2 9	324	1,940	60	14 0	8 0	2	2 8	1,180	6,960
25	9 6	6 0	1	3 0	393	2,350							

* The figures given for the evaporative capacity of each boiler are with feed at 212°F., when burning good coal, and with good draught and stoking. It is of course possible to obtain a much greater evaporation when the draught is ample, and the user is prepared to sacrifice economy to increase the evaporation.

The Cochran Boiler.

(Cochran & Co., Annan, Ltd., Annan, Scotland.)

The boilers (fig. 19, p. 1647) are used very largely both ashore and afloat; the advantage which they present over other kinds for land use and export consists, principally, in great economy of space, in not requiring any brickwork setting, in having a large amount of highly effective heating surface, in obtaining plenty of steam, and in being very economical in fuel, besides being perfectly accessible for cleaning and repairs outside and inside.

For winch boilers this type combines the advantage of the cross-tube boiler and the horizontal boiler without their disadvantage, and has been found the most suitable for large passenger, mail, and cargo steamers running to all parts of the world.

The boilers are made in a range of standard sizes, as per following Table, which gives full particulars of their standard dimensions.

Evaporation of Cochran Boilers.

Particulars of Boiler.					Heavy Steaming.						Easy Steaming.				
					Coal.		Evaporation.				Coal.		Evaporation.		
Diam. of Boiler.	Height of Boiler.	Grate Area.	Heating Surface.	Ratio H.S./G.A.	Lbs. per hour.	Lbs. per sq. ft. of Grate per hour.	Per lb. Coal.	Per sq. ft. H.S. per hour.	Total per hour by Formula.	Evaporation in lbs. (maximum) nearest round figures.	Lbs. per hour.	Lbs. per sq. ft. of Grate per hour.	Per lb. Coal.	Per sq. ft. H.S. per hour.	Total per hour (calculated).
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ft. In.	Ft. In.														
3 0	6 9	4·75	60	12·6	72	15·1	5·0	6·0	360	360	43	9·5	6·2	4·5	270
3 3	7 6	5·75	80	14·0	98	17·0	5·1	6·2	500	500	58	10·0	6·4	4·6	375
3 9	8 6	7·50	100	13·3	144	19·3	5·0	7·2	720	700	86	11·5	6·2	5·4	540
4 0	9 0	8·50	120	14·1	170	20·0	5·1	7·2	868	850	102	12·0	6·3	5·4	651
4 3	9 6	9·25	140	15·1	188	20·4	5·2	7·1	996	1,000	112	12·0	6·6	5·3	747
4 6	10 0	9·75	160	16·4	202	20·8	5·4	6·8	1,098	1,100	121	12·4	6·8	5·1	823
4 9	10 3	11·75	200	17·0	253	21·6	5·5	7·0	1,401	1,400	151	12·5	6·9	5·2	1,050
5 0	11 3	12·50	220	17·6	273	21·8	5·6	6·9	1,531	1,520	163	13·0	7·0	5·2	1,148
5 3	11 9	14·00	250	17·8	312	22·4	5·6	7·0	1,760	1,760	187	13·3	7·0	5·2	1,320
5 6	12 3	16·75	300	17·9	383	22·7	5·6	7·2	2,160	2,160	229	13·6	7·0	5·4	1,620
5 9	13 0	18·75	350	18·7	435	23·3	5·7	7·1	2,504	2,500	261	13·9	7·1	5·3	1,878
6 0	12 6	18·75	350	18·7	435	23·3	5·7	7·1	2,504	2,500	261	13·9	7·1	5·3	1,878
6 0	13 6	18·75	350	18·7	435	23·3	5·7	7 1	2,504	2,500	261	13·9	7·1	5·3	1,878
6 0	14 0	18·75	400	21·4	435	23·3	6·1	6·6	2,667	2,600	261	13·9	7·6	5·0	2,002
6 6	13 6	22·50	450	20·0	533	23·7	5·9	7·0	3,144	3,100	319	14·1	7·3	5·2	2,358
6 6	14 0	22·50	450	20·0	533	23·7	5·9	7·0	3,144	3,100	319	14·1	7·3	5·2	2,358
6 6	14 6	22·50	500	22·2	533	23·7	6·2	6·6	3,304	3,300	319	14·1	7·7	4·9	2,478
7 0	14 0	26·75	500	18·7	643	24·0	5·7	7·3	3,665	3,600	385	14·3	7·1	5·4	2,748
7 0	15 0	26·75	600	22·4	643	24·0	6·3	6·7	4,021	4,000	385	14·3	7·8	5·0	3,015
7 6	16 3	31·50	750	23·8	767	24·3	6·5	6·6	4,939	4,900	460	14·6	8·0	5·0	3,705
8 0	16 6	37·00	850	23·0	966	24·5	6·3	6·7	5,760	5,700	543	14·6	7·9	5·0	4,320
8 6	17 0	41·00	1,000	24·4	1,004	24·5	6·5	6·6	6,610	6,600	602	14·6	8·2	4·9	4,957

Messrs. Cochran's formula for evaporation is :—

$$E = 26\,(G - 2)\left(5 + \frac{\frac{H}{G} - 13}{7{\cdot}5}\right)$$

where,

E = Evaporation in lbs. per hour; G = Grate area in sq. ft.; H = Heating surface in sq. ft. The first expression of the formula represents the coal burnt per hour; the second expression represents the water evaporated per lb. of coal.

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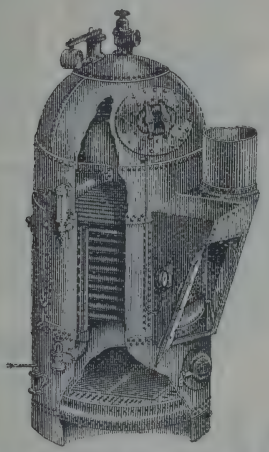

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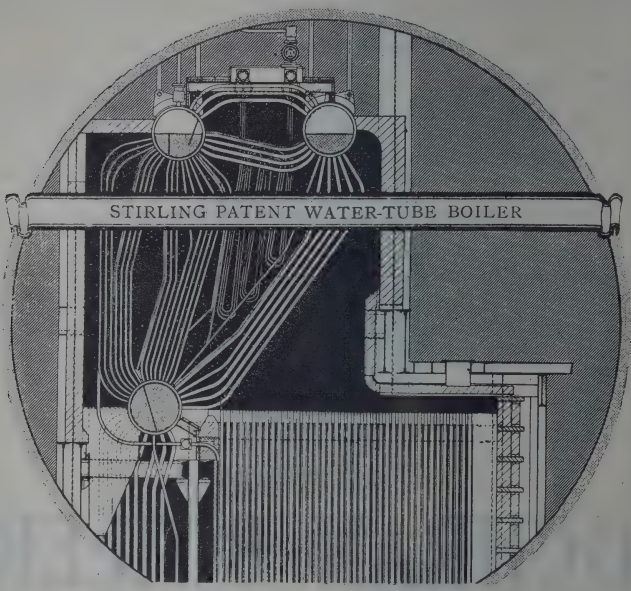

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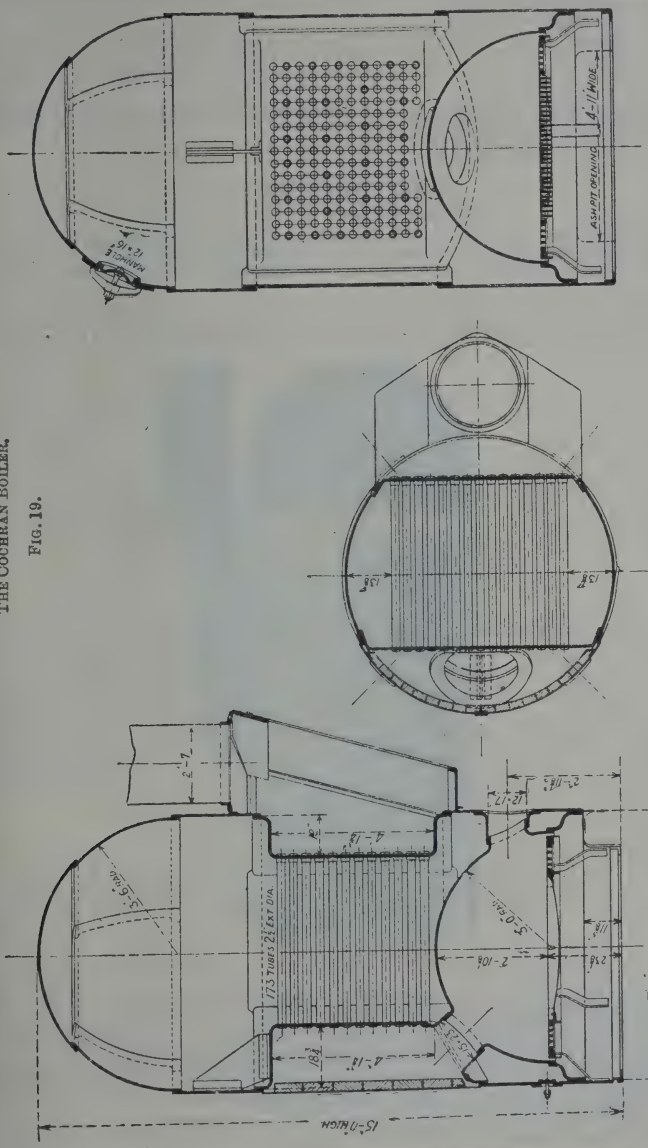


THE COCHRAN BOILER.

FIG. 19.

The evaporations given by this formula can be obtained under favourable conditions, but the makers' practice is to recommend that about 75 per cent. of this maximum evaporation should be relied upon for continuous working.

In the Evaporation table (p. 1646) it will be noticed that there are two sets of figures, showing coal consumption and evaporation. Under 'Heavy Steaming' are given the evaporations as per formula, and under 'Easy Steaming' the evaporations are calculated at 75 per cent. of this amount.

An adaptation of the standard Cochran boiler recently introduced to meet the requirements of hot-water service and heating schemes has met with a considerable measure of success. For particulars of this boiler, see p. 2498.

The Beardmore-Blake Boiler.

(William Beardmore & Co., Ltd., Glasgow.)

This boiler, fig. 20, is specially adaptable for use as an auxiliary boiler for steamers, coal or oil fired, steam cranes, and for utilising the waste heat from furnaces, etc.

The boiler is simply installed, occupies very little ground space, no brick settings being required.

Special features are the following:—

There are no flat surfaces; the circularity of the shell and combustion chamber is not broken into by the introduction of flat tube plates, consequently neither stays or stay tubes are required.

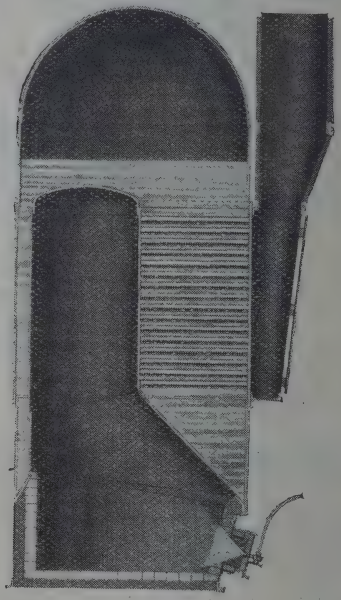


Fig. 20.

A large 'wet back' circular combustion chamber is provided having from 25 to 80 sq. ft. of heating surface, according to size of boiler, every square foot of same being equivalent to 3 sq. ft. of tube surface, thereby greatly increasing the evaporative power and efficiency of the boiler.

The tube plates are truly circular, the tube holes being drilled to provide a true bearing and ensuring a perfectly tight joint by rolling with an ordinary tube expander.

There is no undue stress on the ends of the tubes as in boilers with flat tube plates (which the tubes have to support), a number being screwed into the flat tube plates to act as stays.

Accessibility to all parts for cleaning and examination.

The wide spaces between the tubes facilitates the passage of steam, promoting rapid circulation with maximum generation of steam.

The heating surface is so effective that the maximum heat is absorbed in the generation of steam, the temperature of the gases leaving the tubes being only what is necessary to provide the requisite draught for combustion.

The large cubical capacity of the firebox and combustion chamber, which is so essential for oil fuel to obtain the highest efficiency and maximum evaporation, is provided in this type of boiler.

For utilising waste heat, provision can be made on the boiler for auxiliary hand firing, and this is generally desirable in connection with forge furnaces which may be intermittent in working, or, if at any time a furnace is out of operation, complete coal firing may be resorted to.

STANDARD SIZES, BEARDMORE-BLAKE OIL FIRING BOILERS.

(For working pressures up to 180 lbs. per sq. in.)

Height.	Inside Diameter.	Approximate Heating Surface.	Approximate Evaporation.	Approximate Weight.	Diameter of Funnel.
Ft. Ins.	Ft. Ins.	Sq. Ft.	Lbs./hr.	Cwts.	Ins.
11 6	4 6	160	1,200	80	15
13 0	5 0	220	1,650	95	16
14 6	5 6	280	2,100	110	18
16 0	6 0	400	3,000	145	21
16 6	6 6	460	3,450	165	22
17 0	6 6	500	3,750	180	22
17 0	7 0	550	4,125	210	24
17 6	7 0	600	4,500	215	24
18 0	7 6	650	4,875	220	27
18 6	7 6	700	5,250	235	27
19 0	8 0	825	6,190	300	30
19 6	8 6	1,000	7,500	350	32

WATER-TUBE BOILERS FOR LAND SERVICE.*

THE NICLAUSSE BOILER.

This boiler consists of a compact nest of large, straight, short solid drawn tubes, closed at each end and mounted at the front end in solid drawn pressed steel headers, upon the top of which is mounted a capacious steam and water drum. There is thus only a single row of headers. The heating surface of the outer tube is rendered highly efficient by the provision of an inner tube to carry the water to its back end, whereby the circulation must always be in only one, and that the correct, direction. The tubes are closed by a tapered screwed pressed steel cap at the back end, and at the front end by a tapered screwed pressed steel plug, to which is attached the inner tube by a swivelling connection, whereby it can be readily withdrawn. Both plugs and caps can be easily removed for inspection and cleaning. It is generally sufficient to remove the front plug and withdraw the inner tube once a year for washing out by means of a hose applied to the outer end of the inner tube *in situ*.

THE VICKERS WATER TUBE BOILERS.

(Vickers Boiler Co., Ltd.)

These boilers (figs. 21 and 22) comprise the 'Bent' Spearing 'Header' type and Tube type.

The Vickers 'Bent Tube' type boilers comprise both three-drum and five-drum patterns.

The Spearing 'Header' type boiler may comprise three drums, viz. the main drum at the rear with mud drum and circulating drum at the front, or alternatively two drums only, viz. main steam and water drum and mud drum. Boilers of this type may be arranged either with the two drums at the front or the rear. A further design of the header type boiler is a patent double-circulation boiler which is specially designed for giving a very high rate of evaporation per sq. ft. of heating surface.

All 'Header' type boilers embody the special features associated with the Spearing type of boiler, viz. a mud drum usually of 2 ft. 6 in. internal diameter, downcomer pipes of large area connecting the main steam and water drum with the mud drum, straight solid drawn weldless steel headers of large area with staggered tubes, and also connecting nipples of large area.

These special points in design have been embodied with a view to ensuring positive circulation under all operating conditions, and also to ensure the precipitation of all solids in the mud drum for blowing off. In practice it has been found that the downcomers are of the utmost practical

* See Section XXXVI, p. 2388, for Marine Service.

THE VICKERS BOILER.

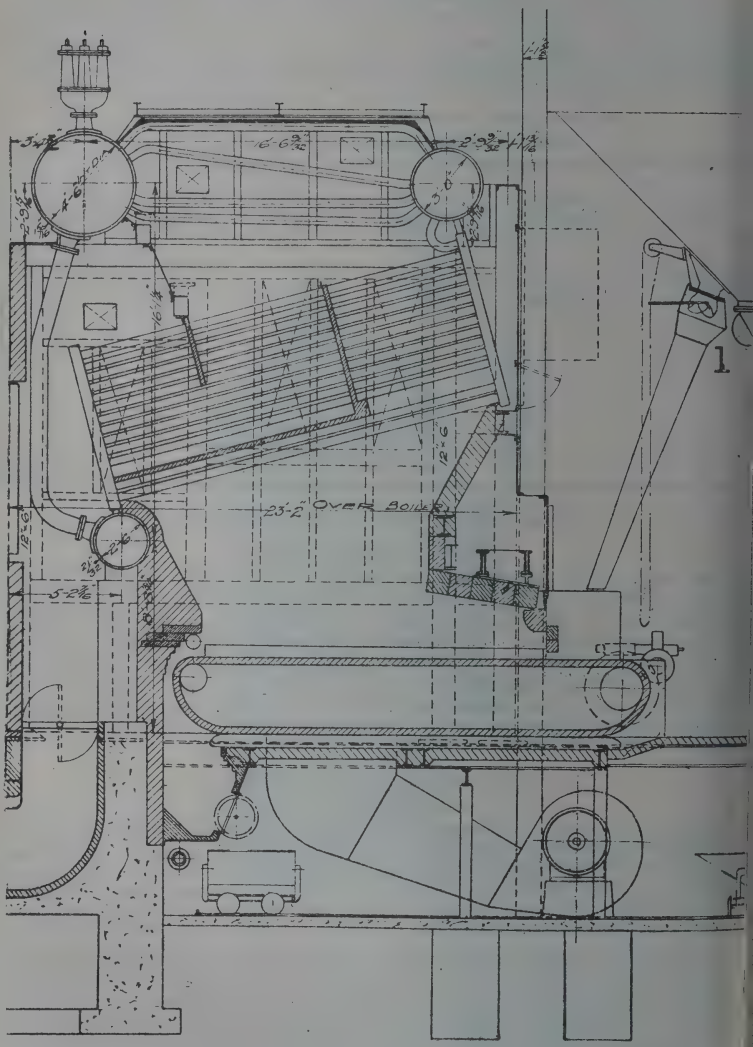
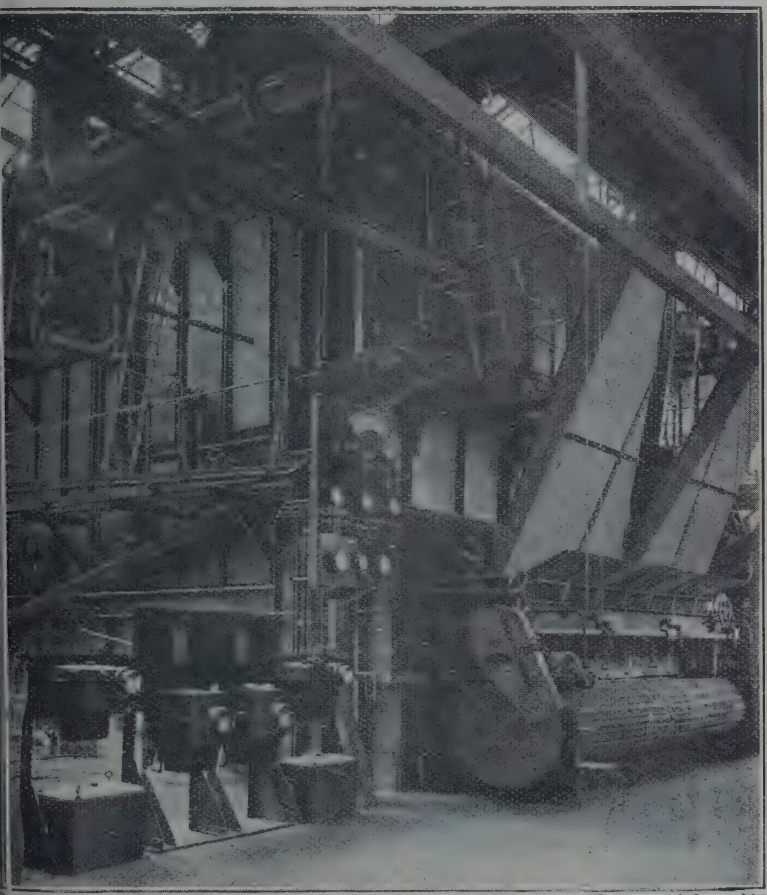


FIG. 21—Three-drum cross-headed type boiler.

WATER TUBE BOILERS



ot a battery ot three Vickers Header Type Boilers fitted with Illinois Stokers 16 feet wide installed at West Ham Generating Station. Evaporation 90,000 lbs. per hour.

VICKERS BOILER CO., LTD.,

50-64 BROADWAY, WESTMINSTER, S.W.1

Telephone : VICTORIA 6845. Telegrams : ARCTURUS, SOWEST, LONDON.

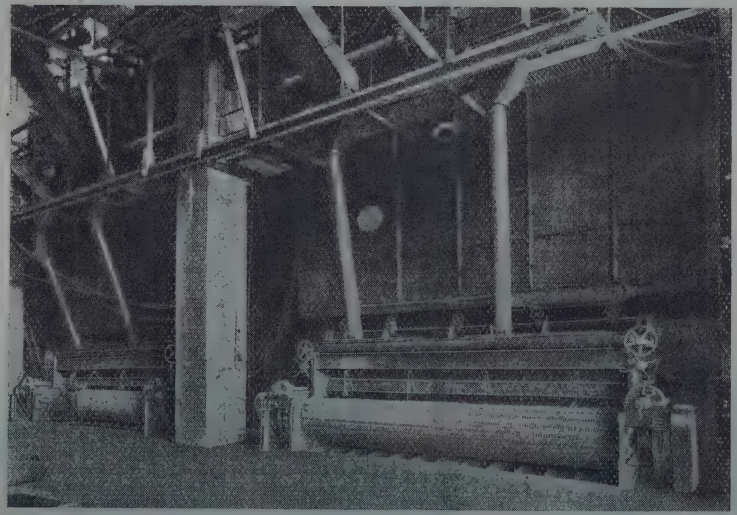
F. 1650

ILLINOIS CHAIN GRATE STOKERS

SINGLE UNITS IN ANY SIZE.

CAST-IRON COMPARTMENTS FOR FORCED DRAUGHT.

LINKS replaceable while Stoker is running.



Automatic ignition for high ash or low volatile coals.

ILLINOIS FLAT SUSPENDED ARCHES.

ILLINOIS WATER BACK.

Two of a battery of eight "Illinois" Chain Grate Stokers installed with Vickers Header Type Boilers at Copenhagen Electricity Works. Each 20 feet wide.

(*See Editorial pages 2101 and 2104.*)

SOLE MANUFACTURING LICENSEES FOR GREAT BRITAIN AND THE COLONIES:—

Vickers Boiler Co., Ltd.,

50-64 Broadway, Westminster, S.W.1.

Telephone: VICTORIA 6845.

Telegrams: ARCTURUS, SOWEST, LONDON.

F. 1651

THE VICKERS BOILER.

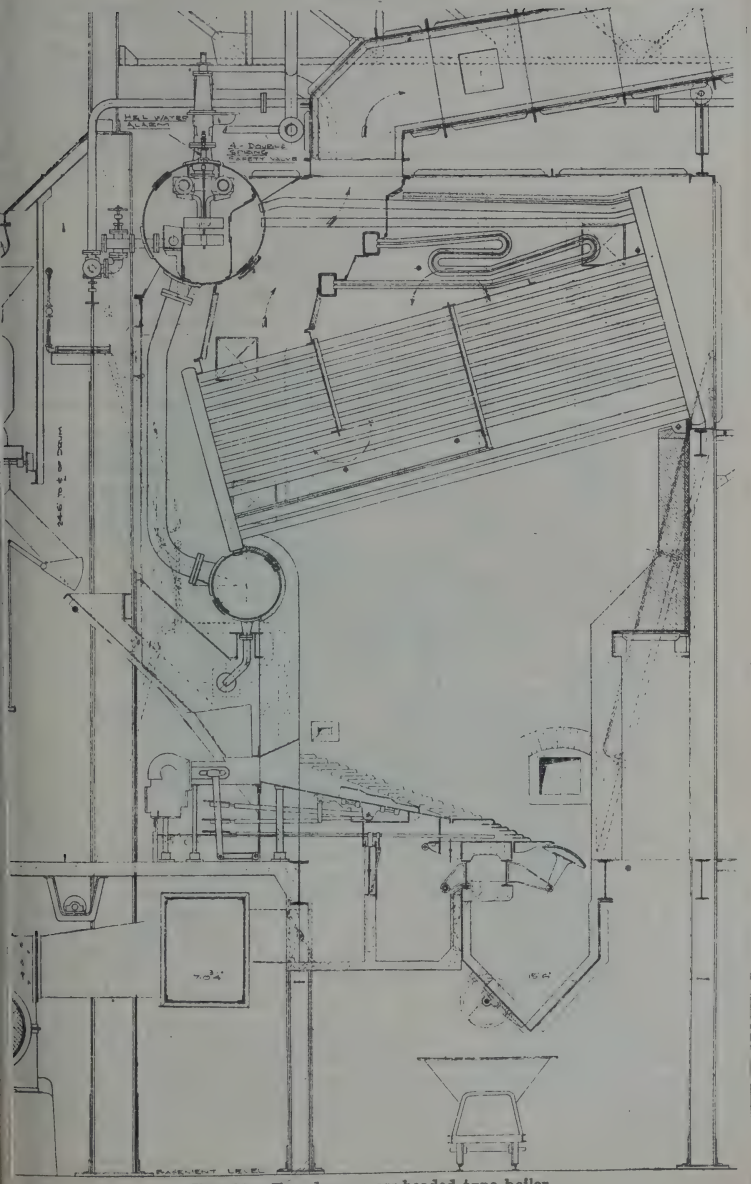


FIG. 22.—Two-drum cross-headed type boiler.

value from the point of view of effective circulation, and in ensuring an uninterrupted supply of feed water in a proper cycle from the main steam and water drum through the mud drum to the bottom rows of tubes first. This positive circulation also makes this type of boiler an extremely efficient and satisfactory steam generator under overload conditions.

The value of the large mud drum in conjunction with the downcomer circulating system, and the precipitation of suspended solids in the water in the mud drum has enabled this boiler to be efficiently used with extremely unsatisfactory feed water without any detrimental effect upon the boiler tubes, and it is very rarely indeed that any deposit whatever is found in these tubes.

Figs. 21 and 22 show: (1) The Vickers three-drum cross-header type boiler; (2) the Vickers two-drum cross-header type boiler.

Boiler units of the header type have been made up to an evaporative capacity of 100,000 lbs. per hour, and of the bent-tube type up to an evaporative capacity of 60,000 lbs. per hour.

The Clarke-Chapman Water-Tube Boiler.

(Woodeson's Patent.)

(Clarke, Chapman & Co., Ltd., Gateshead-on-Tyne.)

The 'Woodeson' Patent Water-tube Boiler, as shown by figs. 24–26, consists of three sections, each comprising steam drum, water drum, and a number of groups of tubes expanded into same; these tubes are nearly vertical and perfectly straight, and manholes are arranged on steel drums immediately over each group through which any tube can be withdrawn.

A spacious steam dome is arranged over the steam drums to ensure a supply of dry steam and to maintain a steady water level. The bottom drums are absolutely hanging so that expansion and contraction can take place without effecting any damage to boiler.

The boiler as shown is also fitted with a Clarke-Chapman Patent Superheater between the front and centre sections.

In the design of the 'Woodeson' boiler, a special feature is the ease of access for purposes of examination or repairs, the time which has to be expended on same being practically reduced to a minimum; thus in a boiler of, say, 6,100 square feet of heating surface, containing 456 tubes, the

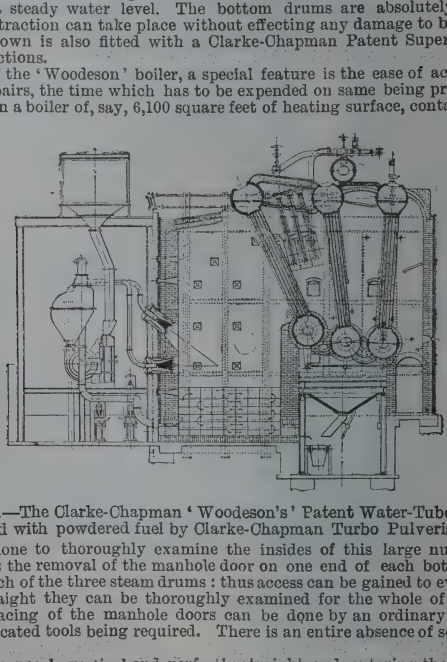


Fig. 23.—The Clarke-Chapman 'Woodeson's' Patent Water-Tube Boiler fired with powdered fuel by Clarke-Chapman Turbo Pulveriser.

only work to be done to thoroughly examine the insides of this large number of tubes for their total length is the removal of the manhole door on one end of each bottom drum and one manhole door off each of the three steam drums: thus access can be gained to every tube, and these being perfectly straight they can be thoroughly examined for the whole of their length. The removing and replacing of the manhole doors can be done by an ordinary fireman, no skilled mechanic or complicated tools being required. There is an entire absence of screwed joints in the boiler.

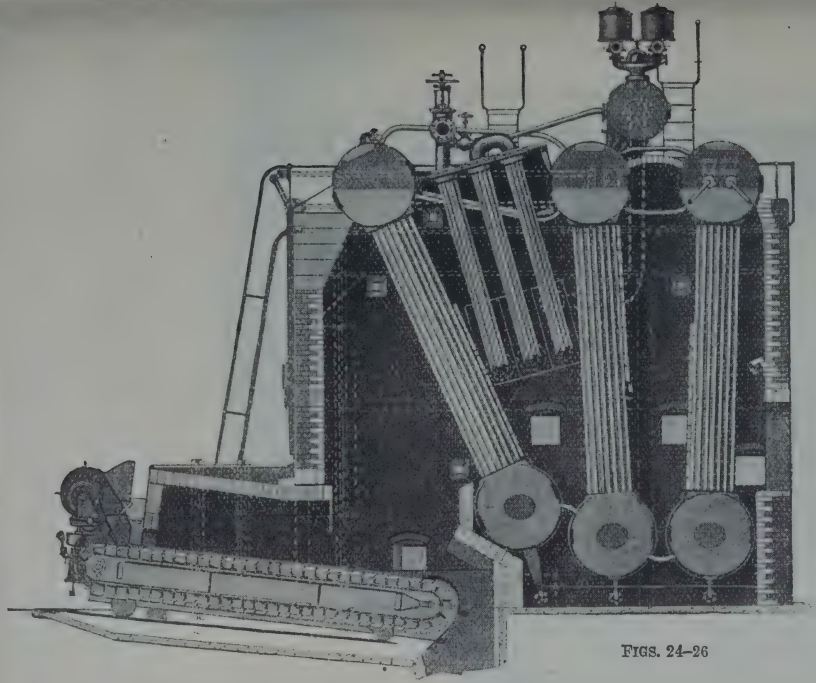
Each tube being nearly vertical and perfectly straight and entering the steam drum direct without intervention of any headers, ensures a perfect steam release, and so adds to the efficiency of the boiler, as there are no sharp turns to retard flow of the steam globules to the steam space. Also, deposits are not retained in the tubes, but are collected in the large mud-drums: thus over-heating and destruction of tubes are reduced to a minimum. The Woodeson Patent Water-Tube Boiler is also eminently suitable for firing with Powdered Fuel as shown in fig. 23.

See also p. 2392.

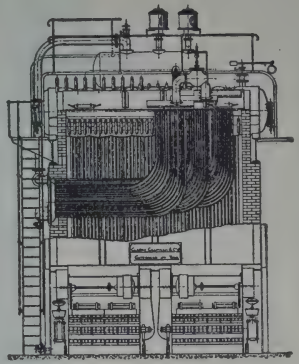
THE CLARKE-CHAPMAN WATER-TUBE BOILER.

(Woodeson's Patent.

Fitted with Patent Superheater and Stoker; Underfeed Type.



Front Elevation.



Side Elevation.

(Showing Superheater in Position.)

FIGS. 24–26

THE STIRLING WATER-TUBE BOILER.

(*The Stirling Boiler Company, Ltd.*, 32–33, *Farringdon Street, London, E.C.* 4.)

This boiler consists of two or more upper drums, containing water and steam, connected by banks of tubes to one or more lower water drums, the upper drums being further connected by several rows of steam and water circulating tubes.

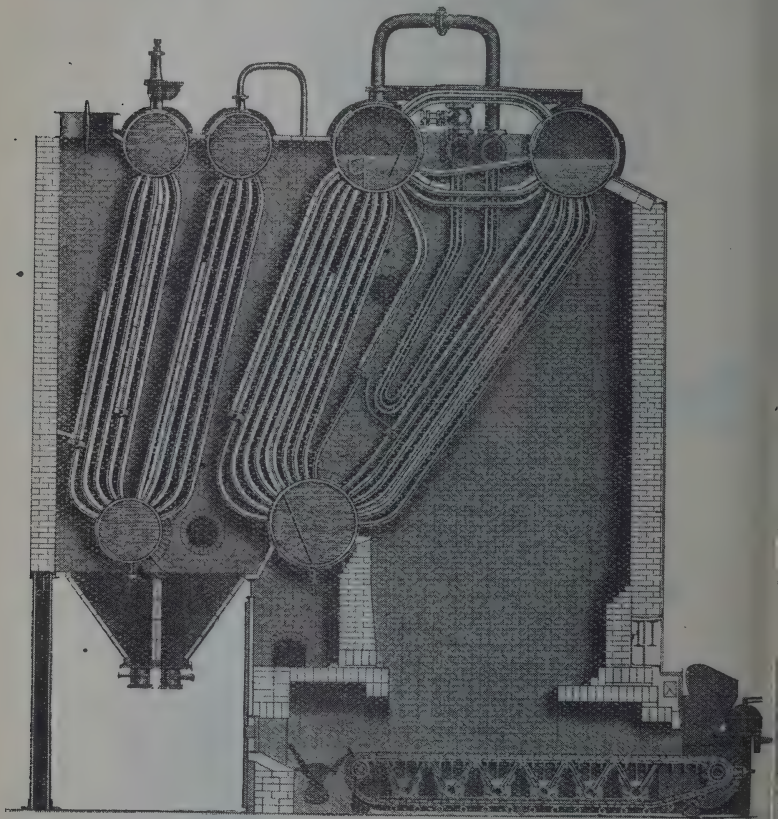


FIG. 27.—The Stirling Boiler.

The type of Stirling boiler shown in fig. 27 is termed the 'Tri-drum' boiler. It is the latest type of this generator, and is essentially a high duty boiler, with a rapid circulation, quick steam generation and a large evaporative capacity, the products of combustion being brought directly into intimate contact with the outer surfaces of the tubes, and directed by a system of baffles to secure the maximum heat interchange between these gases and the water.

The tubes are of solid drawn steel, and are 3¼ in. external diameter. As will be seen from the figure, the Stirling tubes are curved at the ends, permitting them to enter the drums radially, thereby allowing not only for a maximum number of tubes to be connected to the drum, but also for a natural expansion and contraction in each individual tube, thus ensuring tightness and at the same time flexibility.

The tubes are expanded into the tube plates, the projecting tube ends within the drums being either belled or beaded over; thus each tube has a discharge outlet of its full area for the escape of the steam as generated, so obviating steam pocketing in the tubes, with its attendant risks of blistering, etc. The Stirling boiler tubes are slightly inclined to the vertical to enable the front bank tubes to absorb much radiant heat and to receive from the gases the maximum heat by convection.

The drums are made of best quality open-hearth steel and undergo hydraulic test pressures before leaving the makers' works.

All portions of the boiler are circular in form, eliminating any tendency to deformation of any part owing to internal pressure, and certain types of this boiler are already operated at a working pressure of 1,400 lbs. per square inch.

The boiler is entirely independent of the brickwork, the upper steam and water drums being either carried on a steel framework or suspended by slings from overhead beams, while the lower drums are supported by the tubes from the upper drums, leaving the whole boiler freedom of movement with changes of temperature.

The water circulation, practically throughout the whole course of its progress through the boiler, is travelling in a direction opposite to that taken by the gases, thus securing throughout the whole surface of the boiler a very high efficient heat transmission rate. The feed water is introduced into the rear drum and becomes highly heated before reaching the front bank, scale forming matter, if present, being thrown down in the rearmost banks of tubes and preserving cleanliness in the main front bank generators.

By means of patent diaphragms in the rear drums, incoming feed water has to traverse two passes in the rear bank of tubes before joining the main body of water already in circulation, giving a gradual rise in the temperature of the water throughout the boiler, with the corresponding gradual approach to the greatest temperature of the gases, *i.e.* the combustion chamber.

A patent separating baffle is also fitted into the upper rear drum to intercept the mixture of steam and water issuing from the ends of the water cross tubes. This mixture is separated into its components within the confined space of the baffle, the water flowing quietly into the water space of the drum, while the steam is discharged above the water level. By directing the steam port downwards there is a tendency to throw down into the water space the last trace of residual moisture left in the steam. The presence of this baffle produces a state of quiescence in the drum a necessary condition for dry steam), an unusual high dryness factor for the steam (essential for a high degree of superheat), and the cleanliness of the superheater, valves and entire steam circuit.

The overall sizes of the Stirling boiler of a given heating surface can be arranged to suit varying conditions, the design of boiler being adaptable equally well for boiler houses with low roof and ample width as for those having little width and ample height.

A marine type of this boiler is also supplied, which may be used for landwork when the space available is very limited.

Stirling boilers are designed for all evaporations between 4,000 lbs. and 500,000 lbs. of water per hour, and working pressures between 100 lbs. and 1,400 lbs. per square inch.

The boiler is easily cleaned, this being effected on the tubes on the external sides by a system of steam soot blowers, or by hand-operated steam lances; the internal sides (access to which is made by the simple operation of removing three manhole doors) are cleaned by means of water-driven turbine cleaners. This water, supplied through a flexible hose, rotates small cutters, varying in form according to the nature of the scale to be removed. The exhaust water from the turbine washes the refuse into the lower water drum, from which it is easily drained off through the blow down pipes.

All other parts of the boiler are easily accessible by the conveniently placed access and sooting doors. The rare occurrence of a renewal of Stirling tubes is provided for by any tube being able to be removed without sacrificing the neighbouring good tubes.

Taking a great number of tests extending over a period of many years, the efficiency of the Stirling boiler averages from 80 to 85 per cent.

This boiler will give the highest satisfactory results with all classes of fuel and methods of firing, whether pulverised fuel, mechanical stokers, or oil burners, while it is largely in use for the utilisation of waste heat, whether in the form of blast-furnace gas, waste heat from coke ovens, or heating and puddling furnaces. It is a boiler much used in power stations, paper works, gas works, etc.; it is also largely employed on sugar estates abroad, fired with bagasse in special furnaces.

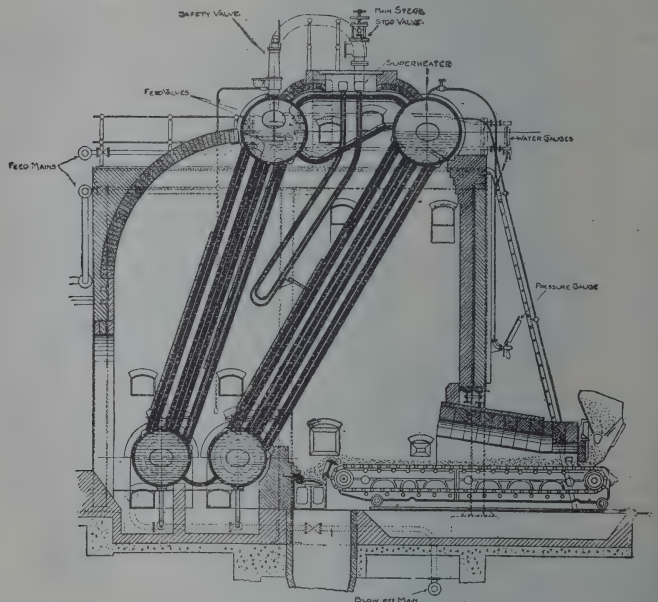
The Galloway Five-Drum Water-Tube Boiler.

This is generally similar to the 'Stirling' type boiler, and has been designed for large units and high efficiencies. The arrangement is easy to keep clean internally.

The 'John Thompson' Patent Straight Tube Water-Tube Boiler.

(John Thompson Water Tube Boilers Ltd., Ettingshall, Wolverhampton.)

This boiler (fig. 28) consists of either two, four, or six drums, one, two, or three at the top for steam and water, and a corresponding number at the bottom. Each series of drums is brought into communication one with the other by a number of short circulating tubes, whilst large straight tubes, set nearly vertically, connect the top drums with those at the bottom. By this means the water, which is fed into the boiler from the back of the steam and water drums, passes down the back row of tubes, each of which has a discharge outlet equal to its full area, and thus affords a free, rapid, and continuous circulation which in its turn prevents the deposit of scale on the heating surface of the tubes.



Patent

Fig. 28.

The six-drum type of boiler is known as the Integral Economiser Boiler, the back or third bank of tubes being the Economiser.

The drums shown in fig. 29 are of mild steel and longitudinally divided into halves, the portion which receives the tubes being hydraulically formed into a series of impressions, enabling the tubes to enter the tube plate at right angles.

The following points are special features:

1. *Tubes.*—The tubes are so arranged, as to spacing, that any one tube may be removed and replaced without in any way disturbing any others.

The tubes are all passed in and out of the boiler by way of the fire-door opening, thus saving the necessity for extra head room.

Each tube can be examined throughout its whole length by holding a lamp at one end.

YARROW
PATENT
WATER TUBE BOILERS
FOR
POWER STATIONS, FACTORIES, &c.

YARROW GLASGOW

THE YARROW BOILER IS FLEXIBLE AND
CAPABLE OF THE HIGHEST OVERLOADS.

FOR PULVERISED FUEL
OR
MECHANICAL
STOKERS.

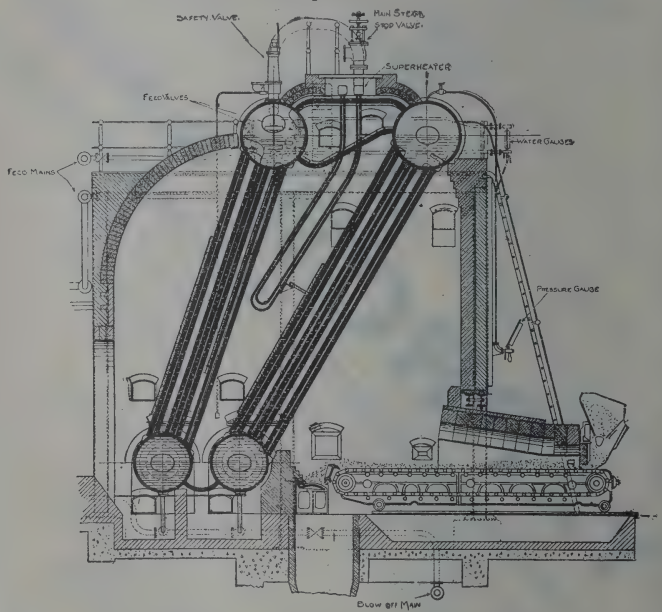
YARROW BOILERS

"JOHN THOMPSON" BOILERS

(Patent Vertical Straight Tube Type)

STRAIGHT TUBES. LARGE OVERLOAD CAPACITY
GREATEST SIMPLICITY. NO CAPS
LARGE COMBUSTION AREA. LOW MAINTENANCE
HIGH EFFICIENCY

As Boiler Makers we also manufacture Watertube Boilers of various Types to meet all requirements.



PATENT

Complete Boilerhouse Plants, including Superheaters, Economisers, Air Preheaters, Reheaters, Piping, Brickwork, Mechanical Stokers, Steel Chimneys, Coal and Ash Handling Plants, Water Softeners and Sand Filters, etc.

A CENTURY OF EXPERIENCE.

John Thompson Water Tube Boilers Limited

IMPERIAL HOUSE, KINGSWAY, LONDON, W.C.2

Works : WOLVERHAMPTON, DUDLEY and BILSTON

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F. 1657

2. *Drums.*—The steam and water drums are of a large and ample capacity, so essential for the obtaining of dry steam, and thus giving large thermal storage.

Any scale that may be deposited in the boiler falls into the mud-drums at the bottom.

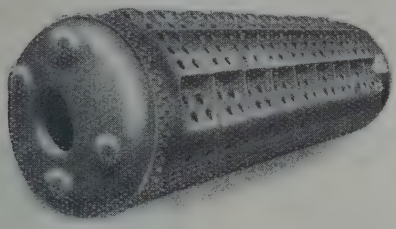


FIG. 29.

3. *Boiler.*—The boiler is suspended from steel girders which rest on steel columns based in cast iron; it is thus entirely independent of the brickwork, ensuring freedom for expansion in every part, and enabling the brickwork to be removed and replaced, if necessary, without in any way disturbing the boiler or its connections.

The largest size of these boilers can be cleaned and restarted in full work within the period of three days, there being only one manhole joint in each drum to be made.

PARTICULARS OF 16 'JOHN THOMPSON' WATER-TUBE BOILERS, VERTICAL TYPE, GIVING WEIGHTS.

(*For working pressures up to 250 lbs. per sq. in.*)

Evaporation per Hour from and at 212° F.	Heating Surface.	Grate Area.	Stokers.	Approximate Total Weight Packed for Shipment.	Space Occupied over Brickwork.		Stop Valves.	Height from Floor Line to Centre of Stop Valve Outlet.		Tubes Wide.	Vertical Centre.	
					Width over Side Walls.	Length from Back to Front.						
Lbs.	Sq. Ft.	Sq. Ft.	Ft. Ins.	Tons.	Ft. Ins.	Ft. Ins.	Ins.	Ft.	Ins.		Ft.	Ins.
8,000	1,905	40	10 × 4	30	8 11	20 0	3	21	7	10	16	0
12,000	2,665	60	10 × 6	38	11 4	20 0	4	21	9	14	16	0
14,300	3,050	72	12 × 6	42	12 6½	20 0	4	21	9	16	16	0
16,800	3,500	84	12 × 7	46	13 9	20 0	5	21	10	18	16	0
19,200	3,940	96	12 × 8	49	13 9	22 0	5	23	10	18	18	0
22,500	4,380	112	8 × 14	54	14 11½	22 0	5	23	10	20	18	0
25,000	4,820	126	2/4½ × 14	66	16 2	22 0	6	23	11	22	18	0
28,000	5,100	140	2/5 × 14	69	16 2	23 0	6	24	11	22	19	0
30,800	5,580	154	2/5½ × 14	71	17 4½	23 0	6	24	11	24	19	0
33,600	6,030	168	2/6 × 14	74	18 7	23 0	6	24	11	26	19	0
36,300	6,500	182	2/6½ × 14	77	19 9½	23 0	7	25	0	28	19	0
39,200	6,970	196	2/7 × 14	80	21 0	23 0	7	25	0	30	19	0
42,000	7,440	210	2/7½ × 14	85	22 2½	23 0	7	25	0	32	19	0
44,600	7,900	224	2/8 × 14	91	23 5	23 0	7	25	0	34	19	0
51,000	8,830	256	2/8 × 16	97	25 10	23 0	8	25	1	38	19	0
61,000	10,200	306	2/8½ × 18	106	29 5½	23 0	8	25	1	44	19	0

The Babcock & Wilcox Patent Water-Tube Boiler.

STANDARD LAND TYPE.

The structure of this boiler (figs. 30, 31), composed entirely of wrought steel, may be practically considered as having three distinct parts, namely:

A series of inclined water tubes placed over the furnace, in which the water, being divided into small volumes, is quickly raised to a high temperature and rises, at the front end, through vertical connecting boxes or headers (into which the tubes are expanded).

A horizontal steam and water drum, up to which the water rises from the headers, and where the steam separates from the water, the remaining body of water returning through the vertical tubes and headers at the back end into the inclined water-tubes, where it is again subjected to the action of the fire, and again passes into the steam and water drum; thus, a continuous and rapid circulation is kept up, and a uniform temperature maintained throughout the boiler.

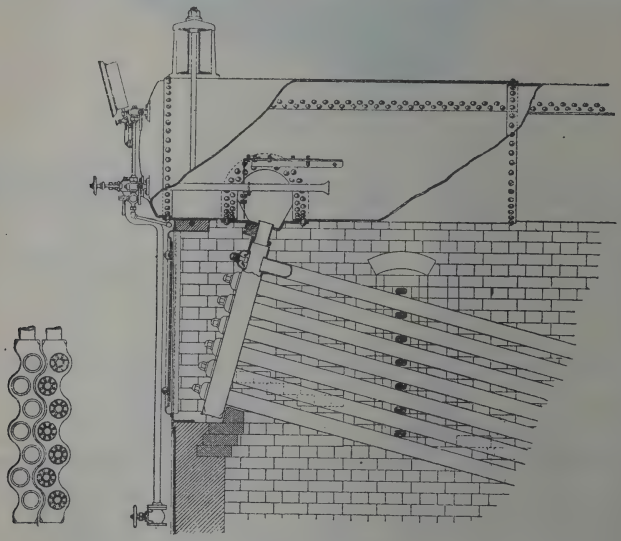


FIG. 30.—Vertical Section showing details.

A *mud-collector* is attached to the lowest point of the inclined water-tubes, into which the matter held in suspension in the water is, to a large extent, precipitated by its specific gravity.

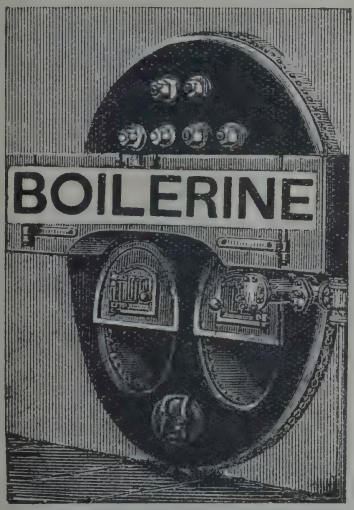
The inclined water-tubes are of steel and the headers at each end into which they are expanded are sinuous (or staggered) and of mild steel, each complete section consisting of one zigzag row of tubes, expanded into a rear and front header. The headers are provided with handholes placed opposite the ends of each tube to permit of cleaning, and, in case of need, the removal of a tube, each handhole being provided with a cap fastened with a wrought steel bolt and clamp and a cap nut, the handhole covers being placed metal to metal. The top ends of each section are connected to the steam and water drum, not directly, but are first expanded into specially designed cross-boxes, which are riveted to and extend from the underside of the drum at each end. The steam and water drum is made of the best selected mild steel double riveted for ordinary purposes; the mud drum is made of mild steel, and is provided with ample facilities for cleaning.

The entire boiler, except the furnace, is suspended by wrought iron slings, from iron girders resting on wrought iron columns, to allow the boiler to expand or contract without straining the brickwork. The boiler and furnace are enclosed in masonry lined with firebrick, the furnace being arranged below the tubes, and firebrick baffles compel the hot gases to pass upwards, then downwards, then upwards again before escaping to the chimney. These hot gases strike the tubes at right angles, thus intercepting the radiant heat from the fuel as effectively as possible; the tubes being zigzagged, the gases are thoroughly broken up as they rise, and, passing into the

PURVEYORS OF BOILERINE

TO HIS MAJESTY THE KING.

BY



Boilerine

is a complex carbon compound, the ingredients of which are exactly apportioned to suit each particular water.

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FOR ECONOMY

The Babcock & Wilcox Water-tube Boiler gives a maximum evaporation per square foot of floor space. At the Barton Power House, belonging to the Manchester Corporation, which is exclusively equipped with B. & W. Boilers, the coal consumption is only 1.36 lbs. per unit generated.

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An analysis of the last published returns issued by the Electricity Commissioners for the year ending March 31st, 1926, shows that all the Power Houses with the highest overall Thermal efficiency, i.e. from 21.5% to 17%, are equipped with Babcock & Wilcox Boilers.

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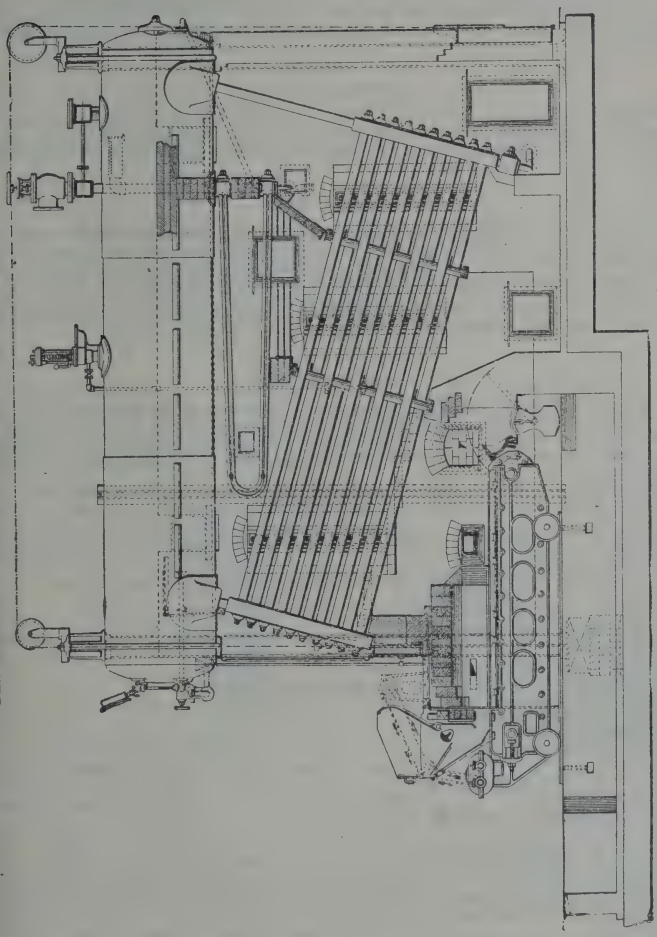
F. 1659

THE BABCOCK & WILCOX PATENT WATER-TUBE BOILER.



(FIG. 31.—Boiler fitted with Superheater and Stoker.

combustion chamber under the drum, they expand and combine before again passing the secon and third time through the tubes and on to the flue; thus complete combustion, rapid steamin and consequent economy are secured.

The damper for regulating the draught and flow of the gases is placed in the back chambe whilst doors for cleaning the tubes and removing soot are placed on one side of the brickwork.

A comparison of space is afforded by a works, where six Lancashire boilers, evaporatin 48,000 lbs. of water per hour, are placed beside four Babcock & Wilcox boilers of the abov type, evaporating 40,000 lbs. of water per hour under the same conditions. The ground spac occupied by each range of boilers is in the ratio of 10 for Lancashires to 4½ for Babcock Wilcox boilers.

CROSS-TYPE BOILER.

The general construction of this form of boiler is the same, but the drum is placed transversel instead of longitudinally, with the tubes, and the whole boiler is constructed in pieces of compara tively light weight suitable for transport in countries where ordinary means of carriage are no available.

PORTABLE BOILER.

This form is similar to the last described, but is still further sectionalised in the drum portion which is arranged to be riveted up on site. The boiler is also provided with an iron casing line with firebrick, and is thus self-contained and independent of the brickwork. This type is also used for countries where transport and facilities in the matter of construction are not available.

In addition to the above types, the boilers are arranged with special furnaces for burning saw dust, lignite, rice husks, bagasse, coke breeze, refuse, coal, gas, and oil fuels.

MARINE TYPE BOILER.

In general construction this boiler (see page 2389) is similar to the foregoing, but with the steam and water drum placed transversely and brought to the front. The principal difference between this boiler and those already described is the largely increased grate area, enabling the boiler to give a greatly increased evaporation per square foot of heating surface compared with the other types.

The 'O T' marine type of boiler, of large evaporative capacity, is fitted with a superheater chain-grate stoker, and superposed economiser, for evaporating up to 250,000 lbs. of water per hour.

Batteries of these boilers are now installed working at pressures up to 1,200 lbs. per square inch.

ACTUAL PERFORMANCES WITH BABCOCK AND WILCOX MARINE BOILERS.

(*Date of Trial, June* 1910.)

Heating surface in sq. ft.	2,571					
Firebar surface in sq. ft.	57·89					
Kind of fuel used	Pocahontas hand-picked.					
Duration of trial—hours	24·06	24·5	24	24	6	3
Amount of draught in stokehole, inches of water	—	—	1·41	1·95	1·78	3·0
Average observed gauge pressure, lbs. per sq. in.	202	201·4	202·8	201·6	200·6	200·4
Average observed temperature of water fed to boiler	211·6	211·4	207·8	204·1	200·9	194·4
Pounds coal consumed per sq. ft. grate per lb.	15·22	24·81	35·48	41·53	43·81	70·24
Pounds water evaporated per sq. ft. heating surface from and at 212° F.	3·88	6·43	9·53	10·52	10·52	14·76
Pounds water evaporated per sq. ft. firebar surface from and at 212° F.	172	286	401	468	467	656
Pounds of water evaporated per lb. of coal per hour (actual)	10·76	10·95	10·71	10·64	10·09	8·77
Pounds of water evaporated from and at 212° F.	11·32	11·52	11·3	11·26	10·67	9·37
Number of boilers	1	1	1	1	1	1

THE HOWDEN H.P. BOILER.

(*James Howden & Co., Ltd.*, 195 *Scotland St., Glasgow.*)

A few of the leading features of this boiler (fig. 32) are as follows :—

1. Reduced weight of boiler and of the water in comparison with Marine Cylindrical Boiler of similar output, approximately 40 per cent.

2. Reduced diameter of shell and thickness of plate.

3. Simplicity of construction.

4. No flat combustion chamber surfaces requiring staying.

5. Shipment of boiler could be made in sections, involving lighter weights to be handled, and also reduction in the spaces left open for the shipping of boilers.

6. In this design the most valuable features of the ordinary cylindrical boiler have been retained.

7. There is ample steam space and steam liberating surface, which will avoid any tendency to priming.

8. A minimum amount of brickwork, and as brickwork and casings are not exposed to high furnace temperatures, the losses by radiation are reduced and the temperature of the stokehold would not be any higher than in the case of a cylindrical boiler.

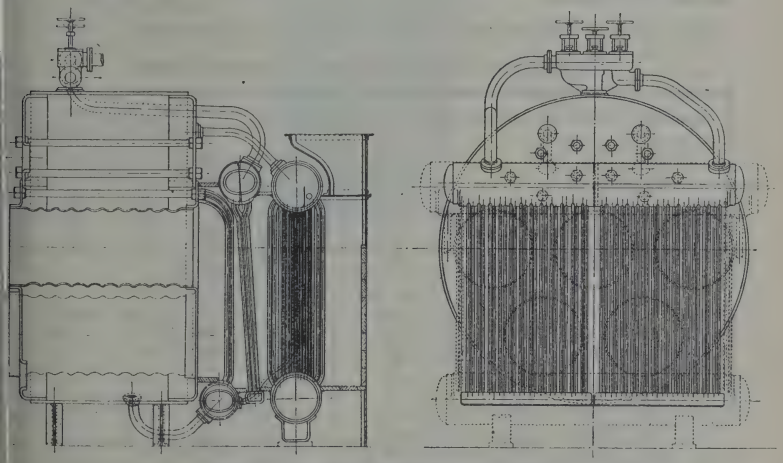


FIG. 32.—Typical Howden H.P. Boiler.

9. The water tubes are subjected only to the comparatively low temperature of the combustion chamber gases, without radiation effect from the fuel. They are, therefore, from the point of view of temperature, in the same condition as the middle and back row tubes of a water tube boiler, so that trouble by overheating should not occur and the life of the tube should be correspondingly prolonged.

10. Any mud introduced with feed water or scale would be deposited in the lower water tube drum, which is not subjected to flame, and where it could be readily removed.

11. The boiler is readily accessible for cleaning and inspection, both in combustion chamber and internally.

The 'Spencer-Hopwood' Patent Boiler.

This, a vertical boiler with inclined water-tubes (manufactured by *Messrs. Spencer-Hopwood Ltd., Hitchin, Herts*), has the tubes spread immediately over the fire, making it extremely rapid in steam raising); 100 lbs. pressure per sq. in. can be obtained from cold water in the boiler in thirty-five minutes from the time of lighting the fire. A number of mandoors of the McNeil type are provided opposite both ends of the nest of tubes, giving easy access to them and also to the entire interior of the boiler for cleaning and renewal purposes.

The standard 'Spencer-Hopwood' patent boiler will evaporate from 25 to 50 per cent. more steam than a vertical cross-tube boiler of the same dimensions.

This boiler is also made in a squat pattern for use where head room is limited, and most modern railway breakdown cranes are fitted with it.

Recently a new and improved 'Spencer-Hopwood' patent boiler has been put on the market for standard pattern sizes Nos. 16 to 24. These have a much deeper nest of tubes than before resulting in a higher thermal efficiency and still smaller space required for the output. In the smaller sizes this is done by arranging the major axes of the manholes in a vertical direction instead of the usual horizontal one, and using more than two, thus deepening the nest of water-tubes 33 per cent. In the larger sizes there are two or three rows of manholes, which enables the nest to be deepened as much as 100 per cent. Further, by the use of more than two manholes per row of manholes, the width of the tube nest can be increased to anything desired, enabling these boilers to be made up to 6 ft. diameter and over, to evaporate up to 5,000 lbs. of steam from and at 212° F. per hour, so that they can be installed to do the work of a small Lancashire boiler and to give as high an efficiency, without the floor space, without the brick setting, without the chimney, and without the necessity of taking hours to raise steam.

Where superheated steam is required, a superheater can be supplied for all sizes, which is arranged in the uptake.

Stock boilers are built for working pressures up to 120 lbs. per square inch.

Evaporation of 'Spencer-Hopwood' Patent Boilers.

Standard Pattern for General Purposes.						Squat Pattern for Railway Breakdown Cranes and other Purposes where Headroom is limited.					
Number of Boiler.	Evaporation lbs. per hour. Natural Draught.	Evaporation lbs. per hour. Induced Draught.	Height.	Diameter.	Approximate Weight.	Number of Boiler.	Evaporation lbs. per hour. Natural Draught.	Evaporation lbs. per hour. Induced Draught.	Height.	Diameter.	Approximate Weight.
			Ft. Ins.	Ft. Ins.	Cwts.				Ft. Ins.	Ft. Ins.	Cwts.
2	261	300	5 3	2 6	18	2	257	320	4 0	2 6	17
3	376	480	6 3	2 9	21	3	336	460	4 6	2 9	19½
4	453	550	6 6	3 0	25	4	418	550	4 9	3 0	24
5	537	650	6 9	3 3	32	5	480	600	5 0	3 3	26½
6	625	760	7 6	3 6	36	6	545	690	5 0	3 6	29
8	748	960	8 0	3 9	44	8	656	880	5 6	3 9	34½
10	903	1,160	9 0	4 0	52	10	736	970	6 0	4 0	39½
12	1,053	1,360	9 9	4 3	60	12	867	1,160	6 9	4 3	49
16	1,500	2,000	10 9	4 9	77	14	1,055	1,400	7 6	4 6	56
18	1,700	2,200	11 0	5 0	94	16	1,235	1,650	8 3	4 9	70
20	2,000	2,700	11 6	5 3	125	18	1,400	1,860	9 0	5 0	85
22	2,350	3,100	12 0	5 6	130	20	1,550	2,100	9 0	5 3	94
24	3,000	4,000	12 6	6 0	160	22	1,700	2,500	9 0	5 6	100

The evaporations given are based on actual tests with 5 ft. of chimney only, feed water at 60° F., steam at 100 lbs. pressure per sq. in., and good steam coal.

Induced draught is obtained from a steam jet included with the boiler mountings.

These boilers fired with oil evaporate 25 per cent. to 30 per cent. more than the (natural draught) figures given above for coal.

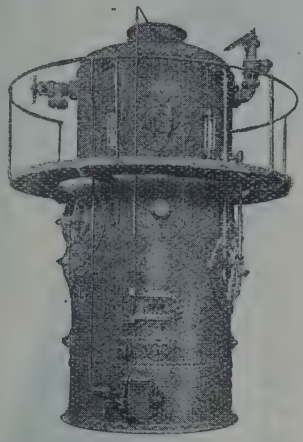
SPECIFY
SPENCER-HOPWOOD PATENT WATER-TUBE VERTICAL BOILERS

IF you are intent on obtaining the maximum results from a Donkey Boiler which costs the least to run and the least to maintain, read the following eleven points about the Spencer-Hopwood Vertical Boiler:

I.
Costs no more than other boilers of the same output.

II.
Raises steam from cold in HALF-AN-HOUR day after day without any injurious effects.

III.
Occupies less floor space than any other boiler for the same output.



IV.
Has no rivet heads subject to high flame temperatures.

V.
Is the most accessible for cleaning and inspection.

VI.
The tubes are immediately accessible for renewal, inspection, or internal cleaning, by removing the easily-handled mandoors at the side.

VII.
The tubes can be cleaned on the fire side with a lance while the boiler is working.

VIII.
33% Overload Capacity.

IX.
Lowest Maintenance Costs.

X.
Highest Evaporation for size.

XI.
Greatest Heating Surface for size.

SPENCER-HOPWOOD PATENT WATER-TUBE VERTICAL BOILERS ARE USED ALL OVER THE WORLD.

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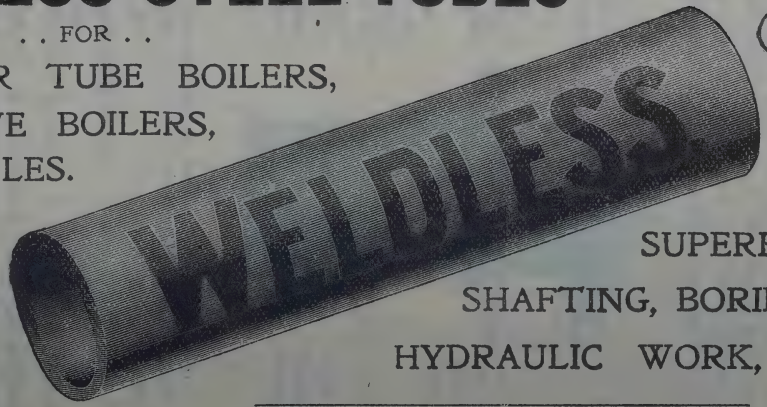

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WEDNESFIELD, Nr. WOLVERHAMPTON.

F. 1663

The 'Sulzer' Water-tube Boiler.

This boiler (*Sulzer Bros., London*), shown in fig. 33. is constructed in the single and double bank type. Its main features are:—

Perfectly straight and nearly vertical tubes, preventing 'hogging,' and minimising the amount of deposit on same, resulting in the intimate contact of the tubes with the products of combustion, therefore larger heating surface than would be obtainable with slanting water-tubes.

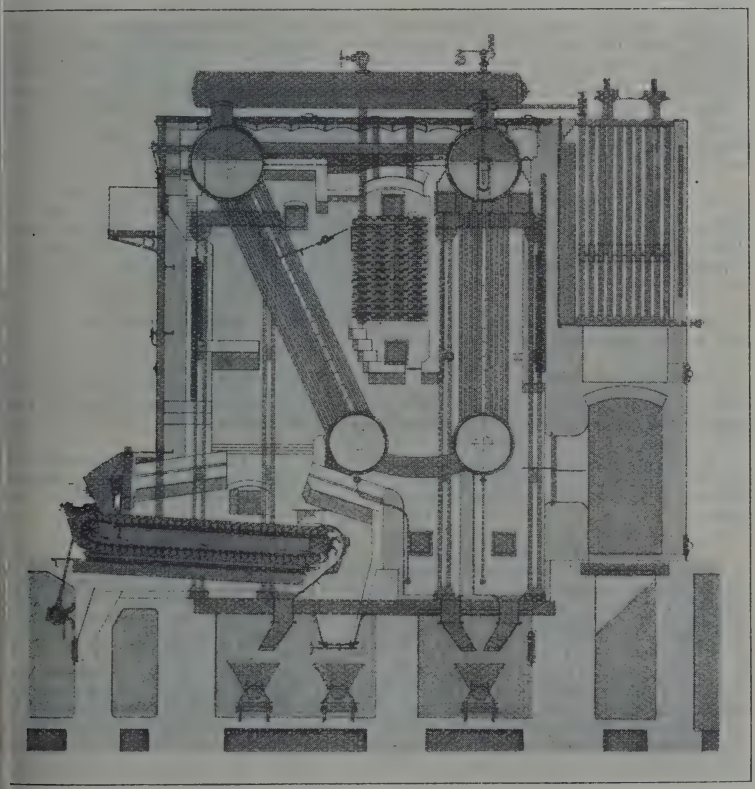


Fig. 33.—Sulzer Double-bank Four-pass Vertical Water-tube Boiler.

The tube-plates are shaped so as to reduce the strain on the material to a minimum.

Free suspension of the boiler permitting free expansion, thus avoiding leakage at the joints.

Brisk circulation of water promoted by upright tubes and suitably arranged return tubes, steam bubbles escaping freely to the upper drum.

Perfect control of the amount of superheat.

General simplicity in design, and therefore great reliability.

The Yarrow Land Boiler.

This boiler (manufactured by *Messrs. Yarrow & Co., Ltd., Glasgow*), fig. 31, consists of three or more drums, including a saturated steam drum of large capacity, which is connected to each of the water-drums by straight tubes. The drums are of circular section, built up of pressed steel parts, the shell generally being in one ring, so that no intermediate circumferential joint is required. The drum ends are of partial spherical form, and no stays are necessary. For higher pressures, as in the case of Yarrow Boilers adopted in many recent installations, the drums are made from hollow forgings, either entirely seamless, or with riveted joints only where separate ends are attached. The tubes in both the superheater and the boiler are expanded into thickened tube plates and bell-mouthed at their ends. The tube plates on the inside of the drums are, where necessary, recessed out in way of the tube holes, to enable the expanding of the tubes to be perfectly carried out. The Yarrow boiler is supported by the steam drum being slung from a strong steel structure, which leaves the tubes and water-drums perfectly free to expand independently.

As one of the water-drums is placed at the front of the furnace and another at the back of the furnace, the tubes joining these drums to the steam drum are adjacent to the furnace. It is well known that, owing to direct radiation, by far the greater part of the heat utilised in a boiler is transferred in the tubes nearest the fire. From the above it will be realised that as so large a proportion of the heating surface is adjacent to the fire, the total heating surface of the Yarrow boiler for the same output and efficiency can be considerably less than is usual.

Another characteristic of the Yarrow boiler is the very rapid circulation through the tubes due to their being straight and nearly vertical.

An outstanding feature of this boiler is the complete absence of any form of baffle or obstruction in the path of the gases where dirt could collect. This feature can be readily seen from fig. 34, which shows the cross section of a Yarrow boiler with superheater as arranged when the flue gases are discharged into a common flue at the back of the boiler.

The Yarrow type of superheater consists of a single mild steel drum into which inverted **U** tubes are expanded. Suitable internal divisions are fitted in the drum so that the required number of passes through the **U** tubes can be obtained. This form of superheater is self-draining.

The Yarrow boiler is often arranged with a damper in the flue above the side of the boiler on which the superheater is situated (see also description of Yarrow marine type boiler, page 2391), and by means of this damper all the gases can be made to pass up the side of the boiler remote from the superheater. This arrangement forms a convenient method of controlling the degree of superheat which can be reduced almost to a minimum without causing a serious falling-off in the steam-raising capacity or efficiency of the boiler.

In order to clean the interior of the boiler it is only necessary to remove the manhole door from each drum end (each is secured by two bolts). A man has ample room in the saturated steam drum for operating the tools for cleaning the inside of the tubes. For cleaning the outside of the tubes where this cannot be conveniently done from the furnace, access doors are provided in the side and end casings.

Owing to the great height of the furnace and to the large area between the tubes in the furnace rows, or, in other words, the low velocity of gases passing out of the furnace, the Yarrow boiler is found to remain comparatively clean after long periods of steaming. This, coupled with the fact that there are no places on which dirt can lodge, are the chief reasons why the efficiency of the Yarrow boiler does not fall off as in some other types.

For Electric Power Stations where peak loads have to be provided for, the Yarrow boiler is particularly suitable, as it cannot be damaged by too quickly increasing the rate of evaporation, and it can be forced to almost any extent without fear of damage. It is sometimes fitted with feed-water economisers or air-heaters, and sometimes with both. The general design of the boiler lends itself to making a compact and accessible unit when combined with these adjuncts.

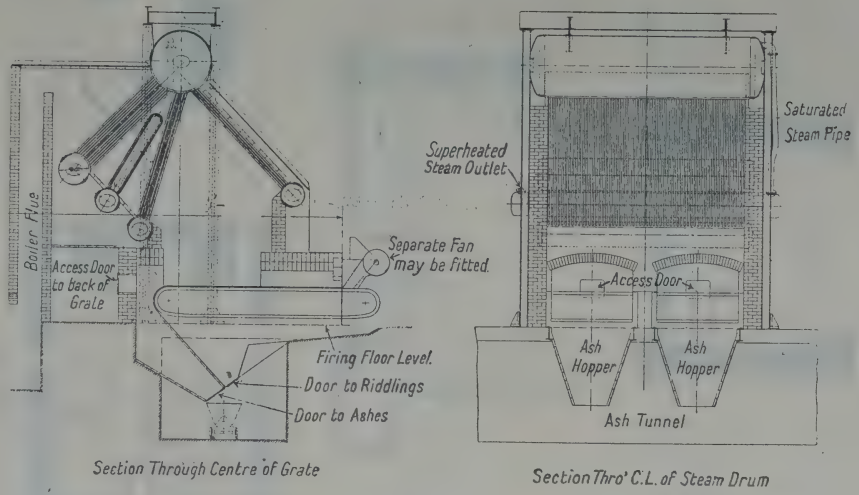

Boiler Flue
Access Door to back of Grate
Separate Fan may be fitted
Firing Floor Level
Door to Riddlings
Door to Ashes
Section Through Centre of Grate
Superheated Steam Outlet
Saturated Steam Pipe
Access Door
Ash Hopper
Ash Hopper
Ash Tunnel
Section Thro' C.L. of Steam Drum

FIG. 34.

BOILER SETTING.

In ordinary practice, as developed by long experience, a boiler (figs. 35, 36, 37) is set upon two longitudinal walls, parallel to one another, and distant apart over half the diameter of the boiler. On these walls are laid specially formed seating blocks (fig. 38) of firebrick, the seating edge of which should not exceed 3 inches in width, and may advantageously be convex in

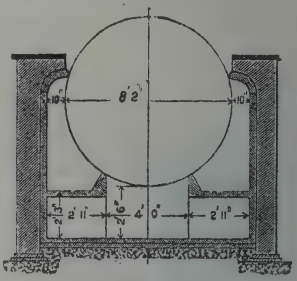


FIG. 35.

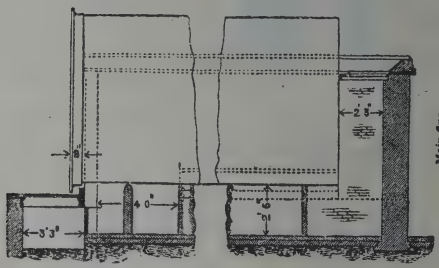


FIG. 36.

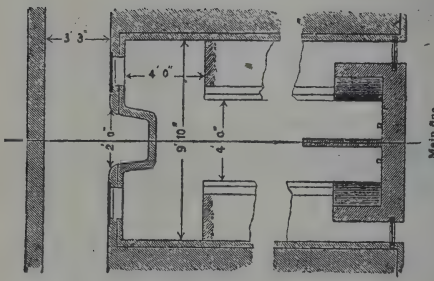


FIG. 37.

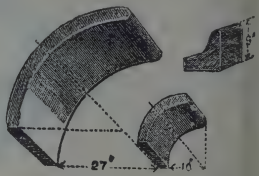


FIG. 38.—Flue Covers and Seating-block.

profile so as to touch the boiler plate along a line only. Where the ring seams cross the seating blocks, a rectangular gap should be cut across the seating for purposes of inspection, and specially formed wedge pieces ought to be provided to close these gaps. These are removed for inspection and at once replaced.

Properly designed fireclay blocks for the seating and downtake allow for expansion and contraction, and minimise air leakage. This is important, as air leakage often accounts for 5 per cent. of the coal bill. Lancashire boilers can be made to work practically airtight.

Foundations.

In preparing the foundations, a matter of great importance is that good drainage should be ensured, as it is found that serious damage often occurs to boilers owing to dampness which arises from the foundation, such outside wasting not being caused by leakages from the boiler itself, but simply from being built either on wet ground or where surface water is allowed to accumulate. Care should also be exercised that the foundations are built in hard well-burned bricks.

It is often advisable to concrete the whole area under the boiler and flues.

It is frequently specified that the internal parts of the flues should be lined with firebricks. For boilers of the Lancashire type, experience shows that this is an unnecessary expense. Good quality hard bricks are satisfactory, the only firebricks used being the specially shaped seating blocks in contact with the boiler shell and those for the bridge at the back of the grates.

Where in contact with the boiler shell, the bricks must be set in fireclay. Elsewhere ground mortar (three parts of ashes to one of lime) may be used.

The boiler should be set having a fall of about 1 in 240 towards the front end, so as to ensure its being thoroughly drained of its contents when it is emptied for its periodical cleaning. The top of the side flues also should be made up by flue covers (fig. 38) of fireclay, in such a form as generally to allow a flue of about 10 inches at each side of the boiler, the flues themselves being of such dimensions as will allow of a man getting thoroughly round for the purpose of cleaning and examining the boilers from time to time.

The following materials are required to seat a boiler 7 feet in diameter by 30 feet long :—

Firebricks and bricks for flue lining, including breakage	6,000
Downtake covers 6 inches wide	14
Seating blocks	52
Flue covers, 12-inch wide	64
Fireclay and ground mortar	3 tons
Common bricks for external walls	Quantity varies according to thickness.

Mortar for laying up firebrick is too often made of fireclay alone. This is very bad practice for the reason that a mortar made of fireclay alone has no permanent body, and after it has been subjected to heat for some time it crumbles from between the bricks. A satisfactory mortar for this purpose may be made by mixing ½ ton of fireclay and 1 ton of firebrick dust (crushed firebrick) to the proper consistency, for each 1,000 firebricks laid. The brick dust, or crushed firebrick, should be the size of a pea and smaller. This mortar, when set, forms a compact refractory binding that is as strong as the brick itself.

Some Modern Improvements.

When preparing the foundations for a boiler or battery of boilers, it is essential that the position chosen be carefully examined, for if the situation is at all damp or there is a liability of the surrounding ground getting soaked with surface water or floods, a proper system of drainage must be adopted. For this purpose an experienced engineer should be consulted. Also where the ground is of a sandy or shaley nature it may be necessary to resort to piling, and as there is no general rule to follow, experience can alone decide the laying out of the work. It is essential that there should be no sinking or warping of the foundations, which not only hastens the formation of cracks in the settings, but induces strains in the pipe work and causes other serious inconveniences.

Most boiler makers supply a general plan of the brickwork setting, which is usually of the old type, and shows broad-faced blocks and semi-circular covers in contact, with two or three courses of brickwork on top. It is far better, however, to have one's own carefully prepared drawing made for the specific installation, prepared by some firm of repute which makes a speciality of this class of work and approved by the engineers and the Boiler Insurance Co.

After the foundations are laid and brought up to the level ready for commencing the boiler setting proper, it is well sometimes to allow several days to elapse to ensure that there will be no further settlement, especially where concrete has been employed.

In the ordinary type of Lancashire boiler the path of the gases, after leaving the boiler flues, is along the bottom flues to the front, and then dividing to the side flues they pass thence into the main flue through separate dampers. There are many instances in which the gases pass first through the side flues and then along the bottom flue to the main. This system is not to be recommended, as the hottest gases should first pass under the boiler. As to the dimensions of the flue passages, these are a compromise, small flues giving difficulty when inspecting, while large

flues add too much useless surface. The back downtake should not exceed 2 ft. 6 ins. from back to front, the sides tapering from the width over the furnace tubes to about 3 ft. 6 ins., and not exceeding 4 ft., with a depth of from 3 ft. to 4 ft., depending upon the size of the boiler. It is usual now to give a greater width in the downtake in order to accommodate if necessary a superheater without requiring too much reconstruction. The side flues are made with vertical sides giving 9 to 12 ins. clear from brickwork to boiler plates at the centre line of diameter, and the floor level being about on a level with the bottom of the boiler gives a convenient chamber for an inspector to crawl through, while providing ample space for the accommodation of soot.

With the Paxman 'Economic' type of boiler (page 1644) the arrangement is somewhat different. The gases pass from the main iron flues into the back chamber where they divide right and left and return through the internal boiler tubes into two front smoke boxes from whence they pass downwards to two underneath flues separated by a mid feather upon which the boiler rests. These flues meet at the back, and the products of combustion pass out through a single damper or dampers to the main flue.

A number of firms make special firebrick blocks for boiler setting. These include mid feather and side seatings, large and small segment blocks for the top of the side flues and back chamber, besides flat blocks and other shapes less commonly employed but often required. However well the brickwork, as constructed on the older plan, may be cemented together, the constant movement of the boiler under steam and the changes of temperature soon begin to cause cracks and crevices to appear, especially between the boiler shell and the brickwork. The result is a loss of draught and short circuits in parts of the flue causing a considerable reduction of thermal efficiency. Further, the blocks being cemented in position the work of the boiler inspector, who has to thoroughly examine the boiler plates on the outside, is not an easy one, and to remove the permanent brickwork entails a very considerable amount of trouble and expense.

Cushioned Seating Blocks and Covers.

The 'Pearson Patent' Asbestos Cushioned Seating Blocks and Flue-Covers (*E. J. & J. Pearson Ltd., Stourbridge*) have been specially designed to remedy sources of waste caused by (*a*) corrosion of the plates, due to the presence of moisture in the brickwork; (*b*) short circuiting of the hot flue-gases; (*c*) leakages of cold air into the flues; and at the same time to be readily removable and replaceable when an inspection has to be made.

The arrangement, as shown by figs. 39 and 40, consists of a specially prepared cushion of hard asbestos, compressed into a groove formed on the face of the blocks, in such a way that the boiler-plates are completely insulated from all contact with the blocks themselves.

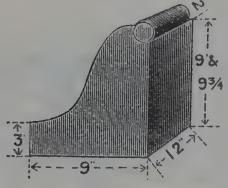


Fig. 39.—Patent 'Asbestos Cushioned' Seating Block.

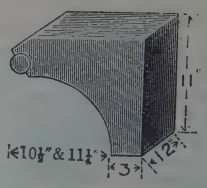


Fig. 40.—Patent 'Asbestos Cushioned' Flue-Cover.

The plates are thus secured against the rubbing caused by the expansion and contraction of the boiler, and also against any risk of corrosion through contact with damp brickwork or blocks which alone has been the cause of very many serious explosions.

Owing to the non-absorbent nature of the material, and also to the high pressure to which it is subjected, the hard asbestos-cushion does not take up moisture, as is the case with ordinary clay blocks, consequently there is no possibility of corrosion. No corrosion has ever been found in boilers set with these seatings, and boilers can be inspected which have been running for several years. In addition to this advantage, the presence of the compressed asbestos cushion ensures an absolutely gas-tight joint between the boiler plates and the blocks, so that not only is there no risk of any short circuiting of the flue-gases, but (an even more important consideration) no danger of cold air finding its way into the flues from the outside, there being no necessity to fill up large spaces with ashes or sand in order to ensure air-tightness. The arrangement gives a

specially large heating surface. Under the old system, 10 per cent. of the external surface of the boiler was covered up by, and in contact with, brickwork; while in a boiler set with the Patent Asbestos Cushioned Blocks, less than 1 per cent. of the external surface is covered, and at no point are the seating blocks or covers in contact with the boiler plates.

The 'Patent Asbestos Cushioned Seam-Inspection Blocks and Covers' (figs. 41 and 42) are designed to meet the requirements of the Board of Trade and the insurance companies. The Board of Trade now require a proper inspection at least once in fourteen months, and the removal of the brickwork, wherever necessary, is compulsory. These blocks enable complete examination of the ring-seams, without any need to remove more than the block or cover opposite the seam. This means a great saving of time and expense at each inspection. The lower half of the block is built and bonded into the side wall of the flue, rendering it a part of the permanent structure, and enables the upper half to be removed with utmost ease, admitting daylight to the flues and

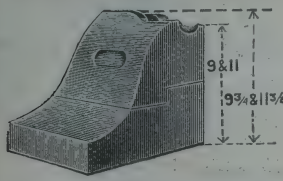


FIG. 41.—Patent 'Asbestos Cushioned' Seam-Inspection Seating Block.

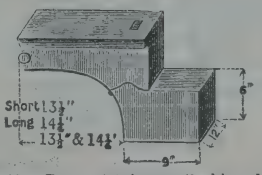


FIG. 42.—Patent 'Asbestos Cushioned' Seam-Inspection Flue Cover.

facilitating inspection. The upper part of the block turns slightly on the knuckle joint, and is thereby safe from cracking under boiler expansion. Handholes are inserted in upper half of each cover for lifting purposes.

It is probable that no part of a boiler setting of the old types gives more trouble than the back downtake. The constant expansion and contraction of the boiler causes the blocks or slabs, used to cover in the downtake flue, to crack and fall down into the flue. The 'Pearson Patent Interlocking Downtake Arch' (fig. 43) is an arrangement of great simplicity and reliability. It consists of an arch, of the required span, built up of interlocking bricks, so shaped that while

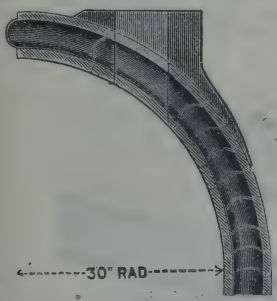


FIG. 43.—'Pearson Patent Interlocking Downtake Arch.'

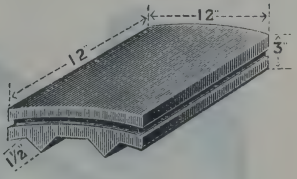


FIG. 44.—'Angular Contact Slab.'

they are as easily built up as an ordinary brick, when once in place they cannot be dislodged, and however much the arch may give to the movements of the boiler, no displacement of the brickwork can occur. Each set is fitted with two manhole blocks with lids, by means of which easy access is obtained to the flues, without disturbing the brickwork.

For the covering in of the boiler the 'Angular Contact Slabs' (fig. 44) may be used. In these coverings, advantageous use is made of the well-known fact that an envelope of stationary air is one of the best non-conductors of heat known.

Recent tests, of which particulars are given below, show the efficiency of this method of covering, there being a difference of over 90° C. between the temperature under the covering and the external air temperature.

Tests.

(1.) Report on test of Angular Contact Boiler Covering Slabs with layer of hair felt between slabs and boiler plates :—

Type of boiler, 'Lancashire'	30 ft. × 7 ft. dia.
Working pressure at time of test	40 lbs.
Temperature of atmosphere	8° C.
Shaded temperature taken 3 ins. above surface of bare boiler shell	83° C.
Shaded temperature taken 3 ins. above surface of covering slabs	21° C.
Temperature under covering slabs	107° C.

Boiler housed in shed open both ends.

(2.) Report on test of Angular Contact Boiler Covering laid on boiler shell without felt or silicate cotton :—

Type of boiler, Cylindrical	26 ft. × 6 ft. 6 ins. dia.
Working pressure at time of test	40 lbs.
Temperature of atmosphere	10° C.
Shaded temperature taken 3 ins. above surface of bare boiler shell	81° C.
Shaded temperature taken 3 ins. above surface of covering slabs	15° C.
Temperature under covering slabs	109° C.

Boiler set in the open and not housed.

The covering slabs are quite distinct, and have no connection with the flue-covers, the compressed asbestos cushion preventing any leakage of flue-gases : consequently while radiation of heat from the boiler is prevented, there is also no possibility of the temperature under the slabs being raised by the infiltration of hot flue-gases.

The covering slabs form a surface hard enough to be worked on, and can easily be removed for the inspection of the boiler plates at any time, and as easily replaced, the covering being in no way damaged by the removal.

The 'Karrena' Furnace Roof.

(*A. B. Cleworth & Co., Ltd.*, 118 *Queen Victoria St., London, E.C.* 4.)

The principle of the 'Karrena' roof, fig. 45, consists of specially shaped refractory blocks, suspended between hollow prismatic girders, arranged either transversely or longitudinally to

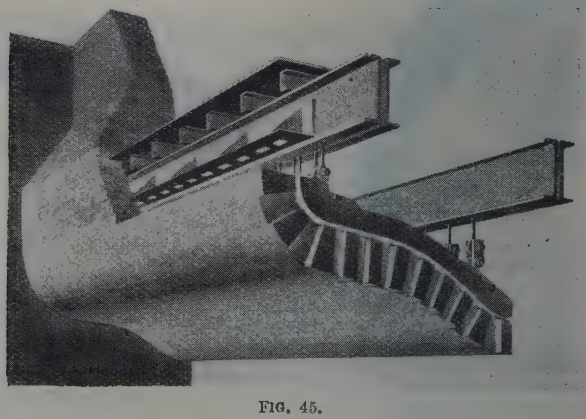
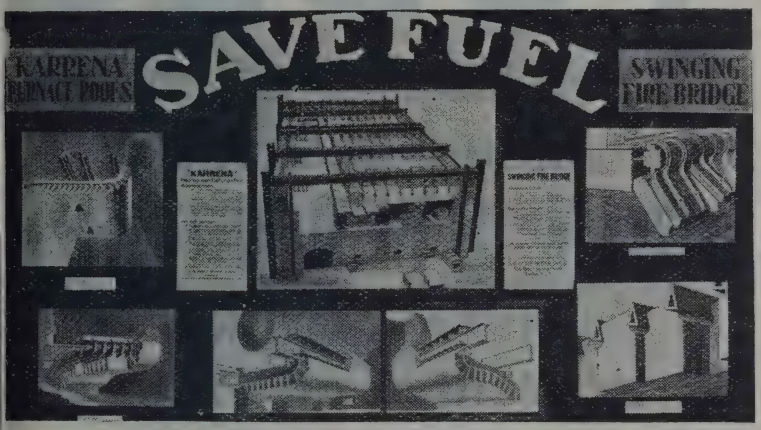


Fig. 45.

the grate. The shape of the girders and the necks of the blocks renders it impossible for the latter to slip or subside, and all sharp corners (which may be the cause of cracks) in these blocks are avoided.

"KARRENA"

PATENT FLAT SUSPENDED FURNACE ROOFS



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F. 1671

The refractory blocks in the 'Karrena' roof, being suspended, there is no outward pressure exercised on the side walls, as is the case with a sprung arch, and consequently the side walls need not be of such heavy construction. Further, owing to the absence of pressure between the suspended blocks themselves, their life is considerably increased.

The construction of the 'Karrena' roof enables it to be erected in practically all furnaces in one span, thus, in two stoker boilers, eliminating the middle wall, and thereby increasing the volume of the furnace, giving more even heat distribution throughout the whole width of the combustion chamber. Furthermore, the 'Karrena' roof being flat, the radiation of heat over the grate is evenly distributed over its whole width, which ensures best utilisation of fuel and improved combustion.

An important advantage possessed by the 'Karrena' system of roof is that the sweep or curve in the longitudinal section of the roof can be designed to suit any conditions, and the incline in the roof can be altered, *i.e.* raised or lowered, without any dismantling.

The 'Liptak' Flat Furnace Arches.

(*Liptak Furnace Arches, Ltd.*, 38 *Victoria Street, London, S.W.* 1.)

The Double Suspension system of constructing Flat Furnace Arches (fig. 45A) as patented and supplied by Liptak Furnace Arches, Ltd., provides a renewable working face with ample protection for the ironwork.

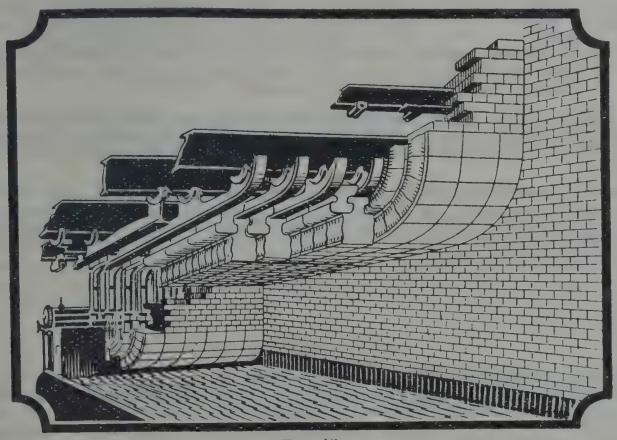


FIG. 45A.

The blocks of the working face are readily renewable, as the lower blocks are suspended from an upper arch of refractory material, so that if the whole of the lower blocks were burned away there would still be refractory protection between the furnace heat and the ironwork.

The arches have been supplied in large numbers in this country and in widths up to 26 ft. between walls.

Liptak Furnace Arches, Ltd., are also makers of air-cooled refractory walls for combustion chambers, and single suspended arches for industrial furnaces.

Leaky Boiler Settings.

Leakage through boiler settings of brick can be lessened by giving the walls two coats of Portland cement wash and then one coat of cold water paint to brighten them up. Or the brick settings may be sealed by applying cement with a covering of canvas pasted over and then painted.

Another method is to build with mortar in which a certain quantity of cement has been mixed, the amount to be gauged by the tenacity of the mortar, which must not hold bricks so that they will be destroyed if it is found necessary to take the brickwork down : a 5 per cent. cement will give this, but may be increased or decreased ; the greater the percentage of cement the tighter the setting, but with the above disadvantage.

Washing the bricks with the liquid cement when building will give best results ; the brickwork should then be coated with the thin pure cement liquid afterwards, the cement being used as a wash. (*Horobin.*)

Bramwell Automatic Expansion Joints for the Fronts of Boilers.

When a boiler which is seated on brickwork, such as a Lancashire boiler, expands, the brickwork is crushed to a certain extent. In time slight crevices appear where the boiler is in contact with the brickwork. At the front of the boiler these crevices admit cold air into the side and bottom flues, lowering the flue gas temperature and reducing the efficiency of the boiler.

The Bramwell expansion joints are designed to stop this leakage without interfering with the structure of the boiler or its working in any way.

An 'L' section casing is fitted to the brickwork round some two-thirds of the circumference of the boiler, and an airtight joint is made between this casing and the brickwork.

Inside this casing is a ring of asbestos, which is made to maintain an airtight joint with the boiler shell by means of a wire rope, passing all round inside the casing, pressing against the back of the asbestos, and held tight by weights acting through a lever and pulleys. A joint is then made between the asbestos and the casing by screws at intervals, which draw the asbestos against the casing, tight enough to make a joint, but not tight enough to prevent the wire rope forcing the asbestos forward when the boiler contracts.

The whole device is flexible, and not affected by any irregularity of the circumferential expansion of the boiler, nor is the joint broken by the longitudinal expansion. Moreover, the sliding joints are made between metal and asbestos, and a fixed joint only is made with the brickwork.

The second part of the joint is an airtight door over the blow-off chamber. The door is split vertically to provide for the blow-off pipe, and is screwed down against asbestos packings when in position. It can readily be removed for inspection, but when in place the door completely excludes cold air, not only from the bottom flue by stopping leakage, but also from the surface of the boiler shell in the chamber.

Fusible Boiler Plugs.

There are six primary causes for the rejection of fusible plugs, which may be roughly divided into two classes. Under the first class, rejections are included due to mechanical defects of casing material. The second class includes rejections due to lack of purity in the tin filling. The impurities in the latter case may be those either present in the original tin or those introduced during the manufacture of the plug.

The following conclusions have been reached as to the precautions to be taken in the manufacture of fusible plugs :

1. The pig tin should be at least 99·7 per cent. pure, containing not more than 0·1 per cent. lead, or 0·1 per cent. zinc, which are the requirements of the Steamboat Inspection Service.

2. The casing should be of bronze, an alloy the major constituents of which are copper and tin. Small amounts of zinc and lead increase the ease of casting and machining, and are not objectionable if not present in greater amounts than in the following compositions :

	I.	II.
Copper	88	87
Tin	10	7
Zinc	2	5
Lead	—	1

3. The pot or crucible for melting the tin should not be used for melting other metals, thus doing away with the liability of contaminating the good tin when these are not thoroughly cleansed.

4. Casings should be tinned on the inside with the same grade of tin used for filling, but the tin left over from this process should not be added to the filling to be used. Zinc-chloride flux may be used, although hydrochloric acid is preferred, though no flux need be used during the filling process.

5. The casing should be preheated to not above 250° to 275° C. (482° to 527° F.), and tin should be poured at a temperature not above 275° to 300° C. (527° to 572° F.).

('*Bulletin of the American Institute of Mining and Metallurgical Engineers.*')

In order that fusible plugs may fulfil the important function of safeguarding boiler flues from collapse in the event of shortness of water, it is essential the following conditions should be complied with:—

1. The fusible plug should be of an efficient and approved type. Common plugs are of little or no service.

2. The fusible plug should be kept clean both on the fire and water side.

3. As the nature of the fusible alloy is affected by prolonged service, the fusible alloy should be renewed after it has been in service for twelve months. Spare caps should be kept to facilitate this operation and the used cap returned for refilling.

4. When used plugs are refilled, the old fusible alloy should be removed and the surface of the shell scraped bright, and properly tinned and refilled with new alloy. Fusible plugs should not be refilled with used metal.

5. The fusible alloy must be a properly graded mixture such as research and experience has shown to be necessary. ('*Vulcan*,' *Oct.* 1920.)

CHIMNEY AND FLUE DIMENSIONS.

Apart from any consideration of production of draught, the height of a chimney must be such that the smoke and noxious gases are discharged at a level at which they will not be a nuisance. The minimum height is usually fixed by the bye-laws of local authorities.

For relation between draught in inches of water gauge and chimney height see page 1606.

The area of the chimney depends on the amount of coal burned per hour on the grates of the boilers which it serves, and on the velocity of the gases in the chimney, and their temperature.

The gas velocity again depends on the draught pressure, and on the frictional resistances in the flues and chimney. Thus the area of the chimney for a given size of boiler or battery of boilers should take into account many factors, some of which are not capable of exact determination. This accounts for the empirical character of the rules given by various authorities, and for the variations in them.

For typical conditions, say about 600° F. chimney temperature, flues not abnormal in length, and of area about 20 to 40 per cent. greater than chimney area, and 25 to 28 lbs. of coal burned per sq. ft. of grate area per hour, the following rules give suitable areas:—

H = height of chimney in feet; A = area at top of chimney in sq. ft.; G = grate area.

$$A = \frac{k\,G}{\sqrt{H}};$$

where $k = 1{\cdot}5$ for one boiler, $1{\cdot}0$ for two, $0{\cdot}8$ for three, $0{\cdot}7$ for four, $0{\cdot}5$ for five or more.

At 28 lbs. coal per sq. ft. of grate area per hour this corresponds to

$$A = \frac{k\,W}{28\sqrt{H}};$$

where W = lbs. coal burned per hour.

For a 100-ft. chimney, and $k = 1{\cdot}4$,

A = 0·5 sq. ft. per 100 lbs. coal burned per hour.

Other formulæ are:

(*a*)
$$A = \frac{W}{14\sqrt{H}}$$

evidently for lower rate of combustion than the above, as it would agree with $k = 1{\cdot}5$ and rate of combustion 21).

TABLE OF SIZE OF CHIMNEYS FOR BOILERS.

Diameter. Inches.	Area A in sq. feet.	E.	Height of Chimney in Feet.														Side of Equivalent Square Chimney.
			50	60	70	80	90	100	110	125	150	175	200	225	250	300	
			Pounds of Coal burned per Hour.														
18	1·77	0·97	115	125	135	145											16
21	2·41	1·47	175	190	205	220											19
24	3·14	2·08	245	270	290	310	330										22
27	3·98	2·78	325	360	390	415	440										24
30	4·91	3·58	420	460	500	535	565	595									27
33	5·94	4·48		575	625	665	705	745	780								30
36	7·07	5·47		705	760	815	865	910	955	1,020							32
39	8·30	6·57			915	980	1,040	1,095	1,145	1,225							35
42	9·62	7·76			1,080	1,155	1,225	1,290	1,355	1,445	1,580						38
48	12·57	10·44				1,555	1,650	1,740	1,825	1,945	2,130						43
54	15·90	13·51					2,135	2,245	2,360	2,515	2,755	2,975					48
60	19·64	16·98					2 680	2,825	2,965	3,160	3,460	3,740					54
66	23·76	20·83						3,470	3,640	3,880	4,245	4,590	4,905				59
72	28·27	25·08						4,175	4,380	4,670	5,115	5,525	5,905	6,265			64
78	33·18	29·78							5,190	5,535	6,060	6,550	7,000	7,425	7,825		70
84	33·48	34·76							6,070	6,470	7,090	7,655	8,180	8,680	9,150	10,025	75
90	44·18	40·19								7,480	8,195	8,850	9,465	10,040	10,580	11,590	80
96	50·27	49·01								8,560	9,380	10,135	10,835	11,490	12,115	13,270	86
102	56·75	52·23								9,720	10,650	11,500	12,290	13,045	13,750	15,060	91
108	63·62	58·83								10,450	11,995	12,960	13,855	14,695	15,490	16,965	96
114	70·88	65·83									13,425	14,500	15,500	16,440	17,330	18,985	101
120	78·54	73·22									14,930	16,130	17,240	18,285	19,275	21,115	107
132	95·03	89·18									18,185	19,645	21,000	22,275	23,480	25,720	117
144	113·10	109·72									21,760	23,505	25,130	26,655	28,090	30,775	128

(*b*) Area in sq. in. $= \dfrac{\text{lbs. coal per hour} \times 12}{\sqrt{H}}$ . . . . (*Bourne*).

or $A \text{ (sq. ft.)} = \dfrac{W}{12\sqrt{H}}$.

(*c*) Area in sq. ins. = 1·5 per lb. coal per hour . . . (*Bourne*).

or $A = \dfrac{1{\cdot}5}{144} W$

(corresponding to $k = 1{\cdot}5$ if H = 100 and combustion rate = 14·4).

(*d*) Area in sq. ins. $= \dfrac{\text{Area of grate}}{\sqrt{H} \times 1{\cdot}58}$ . . . . . (*Elswick*).

or $A = \dfrac{1}{1{\cdot}58} \dfrac{G}{\sqrt{H}}$

(corresponding to $k = 0{\cdot}63$).

(*e*) Kent gives formulæ which correspond to the following :—

$$\text{Effective area } E = A - 0{\cdot}6\sqrt{A};$$

$$W = 16{\cdot}65\, E \sqrt{H}; \qquad D = 13{\cdot}54\sqrt{E} + 4;$$

$$E = \frac{0{\cdot}06\, W}{\sqrt{H}} \qquad S = 12\sqrt{E} + 4$$

where,

D = diam. of round chimney in inches ; S = side of square chimney in inches.

The table on page 1674 has been calculated from the foregoing formulæ of group (*e*).

(*f*) Sometimes the area of the chimney top is taken as $\frac{1}{8}$ to $\frac{1}{10}$ that of fire grate, the height not being taken into account.

Flue areas should be about 20–40 per cent. greater than chimney area.

For stability of chimneys see Section XII, page 623.

SUPERHEATERS.

Separately fired superheaters are not often used ; the superheaters are usually integral with the boiler in the case of water-tube boilers, or placed close to the boiler, in the downtake flue, in the case of the Lancashire type.

The steam may pass through the tubes in parallel—single-flow—or some of the tubes may be in series with the rest—multiple-flow type. The multiple-flow type gives a higher rate of flow of steam in the tubes for the same tube surface. The heat transmission is thus increased, and a higher degree of superheat obtained. There is, of course, a slightly greater drop of pressure in the multiple-flow type.

The superheat added to the steam depends upon :—

1. The heating surface per pound of steam per hour.
2. The temperature difference, gas to steam.
3. The velocity of the steam in the superheater.
4. The velocity of the hot gases past the tubes.
5. The pressure of the steam.

Factor 2 is very difficult to predetermine accurately, and hence superheaters are still mainly designed by rule-of-thumb. Modern superheaters are frequently so made that the steam velocity can be altered, thus permitting an adjustment if an incorrect estimate has been made. There are two principal methods of altering the velocity : by plugging up tubes, or removing them, and by rearranging the proportion of tubes in parallel to those in series. The first method is of practically no value.

Factors 2, 3 and 4 change with the amount of steam used, as with the load. The effect of load on factor 2 (temperature) is more marked the farther the superheater is from the grate,

and is very marked if in the downtake of a Lancashire boiler for instance. Factor 2 is also very much dependent on the normal rate of firing and the quality of coal used. Thus with poor coal a superheat of 100° F. at full load may fall to 30° F. at half load. If the normal rate of firing is high or the quality of coal good, the change of loading has less effect.

Superheaters are designed chiefly with regard to practical considerations, such as standardisation of tube lengths, convenience of access to individual tubes or elements, and ease of repair.

Heating Surface of Superheaters.

As a rough approximation, the heating surface may be calculated on the assumption that the heat transmission is at the rate of 5 B.Th.U. per hour per sq. ft. of heating surface per °F. of the difference of the arithmetical mean temperatures of gas and steam.

If W = steam generated in lbs. per hour;

H = heat required to superheat 1 lb. of steam (see Table IV, p. 1597);

T = mean gas temperature;

t = mean steam temperature;

then heating surface in sq. ft.

$$= \frac{W \times H}{(T - t) \times 5}$$

For example:—Let W be 6,000 lbs. per hour, the pressure 160 lbs. per sq. in., and superheat 200° F. The saturation temperature is 371° F., and final steam temperature 571° F., so that $t = 471°$ F. H (from Table IV) = 110 B.Th.U.

Assuming a Lancashire boiler, with the superheater placed in the downtake, the value of T may be 950° F., the heating surface $= \frac{6{,}000 \times 110}{(950 - 471) \times 5} = 276$ sq. ft.

The ratio of the heating surface of the superheater to that of the boiler varies very widely, even for boilers of the same type. It is difficult, therefore, to give typical figures. The following are taken from examples of actual practice, the ratio being expressed as a percentage of the boiler heating surface (excluding the economiser).

The ranges shown do not necessarily give the limiting values.

Lancashire boiler, superheat	150° F.	17 to 24 per cent.
,, ,, ,,	200° F.	25 to 28 ,,
Water-tube, Babcock . . .		15 to 40 ,,
,, ,, Stirling . . .		13 to 15 ,,
,, ,, Yarrow . . .		12 to 28 ,,
Locomotive		about 22 ,,

Boilers with superheaters require a smaller heating surface to give a desired efficiency.

Even if the amount of heating surface is calculated with due allowance for the effect on the heat transmission rates of the actual steam and gas velocities, it will be found that different rates of steam flow do not greatly alter the calculated heating surface. It is important to recognise, however, that at low steam rates the tube temperature becomes higher.

Sectional superheaters are arranged so that individual tubes or small groups of tubes may be readily removed without putting the whole superheater out of action.

The McPhail & Simpson Patent Superheater.

(*McPhail & Simpson, Wolverhampton.*)

The headers and tubes of these superheaters (fig. 46, p. 1677) are of solid drawn wrought steel.

The simple construction, and high-class material and workmanship used in their construction, render the superheaters absolutely steam tight, and at the same time ample means are provided for getting at the tubes should they by any chance require attention. This is made possible by the provision in the headers of the patent stoppers opposite the ends of each tube, whereby easy access to the tubes is obtained for expanding, examination, etc., and any individual tube can be

THE MCPHAIL & SIMPSON PATENT SUPERHEATER.

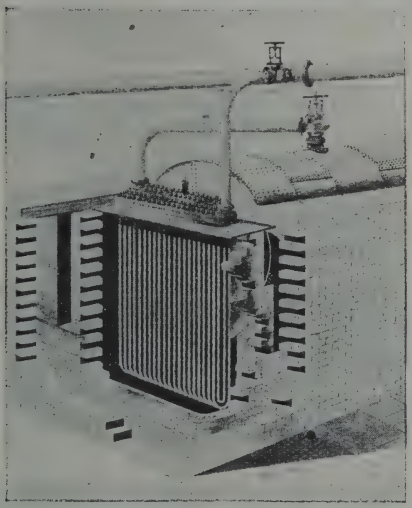


FIG. 46.

THE 'GALLOWAY' SUPERHEATER.

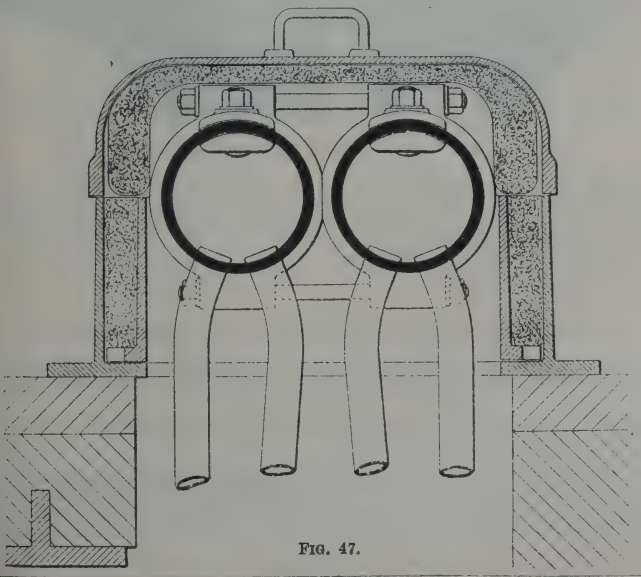


FIG. 47.

removed and replaced in a very short time, without disturbing the other tubes or pipe connections and without breaking a large joint.

There are no studs and no large joints used in these superheaters.

The substantial nature of the tubes entirely prevents warping.

The superheaters are adaptable to any type of boiler—Lancashire, Cornish, Babcock—and all types of water-tube boilers, both land and marine, and for independent firing.

Flooding of the superheaters, or the use of dampers, is not recommended.

Galloway Superheaters.

(Galloways, Ltd., Knott Mill Ironworks, Manchester.)

The Galloway Patent Multiple-Flow Superheater.

This superheater (figs. 47 and 48) is made entirely from mild wrought steel. All parts are of circular cross-section and therefore of maximum strength. There are three headers—two short ones, with the inlet and outlet branches, and one long one closed at both ends. The headers are rigidly stayed together to prevent movement and vibration, and are connected by the tubes, which are of seamless steel. The tubes are in groups of four or five, each group commanded by an internal cap so as to facilitate inspection and cleaning. The steam passes from the short inlet header through the first set of tubes into the long header, and then through the second set of tubes to the short outlet header. The headers (fig. 47) are carried in a double-walled box resting on the brickwork and covered by a cast-iron cover, thus minimising radiation losses and protecting the superheater from weather and damage.

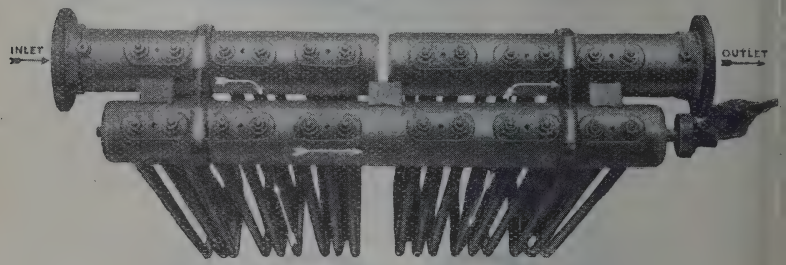


Fig. 48.—Plan view of Superheater showing direction of Steam Flow.

The joints between the superheater and the main steam piping are vertical, thus enabling the superheater to be removed for inspection without disturbing the steam pipes. If it is desired to work with the superheater removed, a straight connection or cross-over pipe is inserted in its place.

The superheat usually attained is 150° F. to 200° F. with ordinary firing.

The Galloway Patent Sectional Wrought Steel Steam Superheater.

To meet the demand for a superheater with tubes arranged so that they may be readily and quickly detached without disturbing the other tubes, *Galloways Ltd.* have designed and patented a sectional type superheater of simple and durable form.

The sectional type superheater is for use in the downtake flue at the rear of Lancashire and Galloway boilers, or for independent firing.

As shown (fig. 49) the superheater consists of two horizontal steel headers placed parallel to each other. A series of holes are drilled and faced for joints on the upper walls of the headers, to which the small steel boxes or hollow connecting chambers are secured by means of two studs of ample strength.

The superheater tubes are solid-drawn weldless steel of loop type or U shape, and the outside diameter of the tubes is 1½ ins. The ends of the tubes, which are straight and not bent over (thus maintaining full thickness and strength), are expanded into the under walls of the connecting chambers, usually in groups of three.

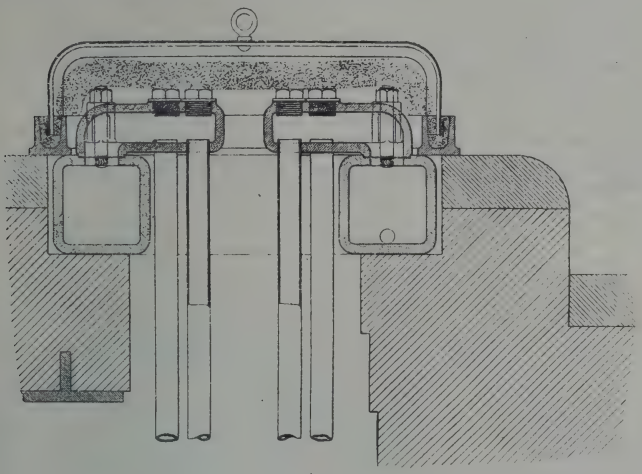


FIG. 49.

The upper walls of the connecting chambers are provided with screw plugs disposed in alignment with the ends of the several tubes, so as to give free access to the end of any tube for the purpose of examination or expanding without interference with or obstruction from the studs securing the connecting chambers to the headers.

Any of the groups or elements of superheater tubes, which are interchangeable, can be readily removed and replaced, or alternatively 'blanked-off,' by simply unscrewing the four securing studs of the two connecting chambers, and without disturbing any of the other groups of tubes or the main steam headers.

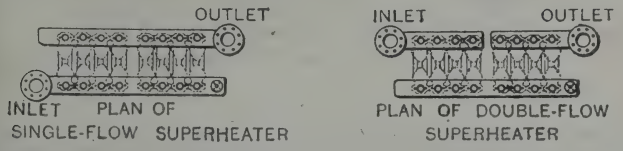


FIG. 50.

The superheater (fig. 50) is made either single-flow or double-flow, the latter type being adopted for higher degrees of superheat.

The single-flow type has headers of equal length, and the steam has only a single pass through the tubes.

The double-flow superheater is similar in construction, with the exception that one of the headers is divided in its length to form two separate headers.

The steam is passed from the short inlet header, by way of the first nest of tubes, into the long header, and then through the second nest of tubes into the short outlet header.

The Babcock & Wilcox Standard Integral Superheater.

(Babcock & Wilcox, Ltd.)

The Babcock & Wilcox Patent Steam Superheater (fig. 51) consists of solid-drawn steel tubes bent into **U** shape, and connected at both ends with boxes or manifolds (F and H), one of which (F) receives the natural steam from the boiler through the dry pipe (N) and inlet pipes (D). The other (H) receives the superheated steam after it has traversed the superheater tubes (G), delivering it through pipes (J) and cross-box (K) to the stop valve (L) placed above the cross-box. Handholes are placed in the manifolds opposite the ends of the superheater tubes to facilitate inspection.

The superheater is placed in a position where there is practically no deteriorating condensation of the gases, and where the temperature is sufficiently high to ensure the steam receiving from 100° to 300°F. of superheat, or more if desired. It is not subject to the immediate action of the fire, as the furnace gases must first pass through the front part of the boiler, which comprises a considerable heating surface. Assuming the boiler to be in regular work, and the firing even, no

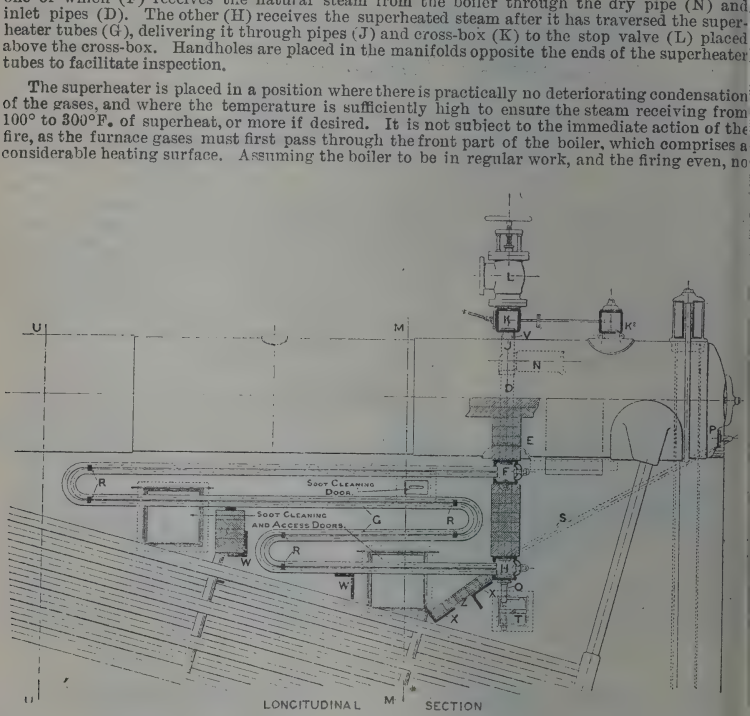


Fig. 51.

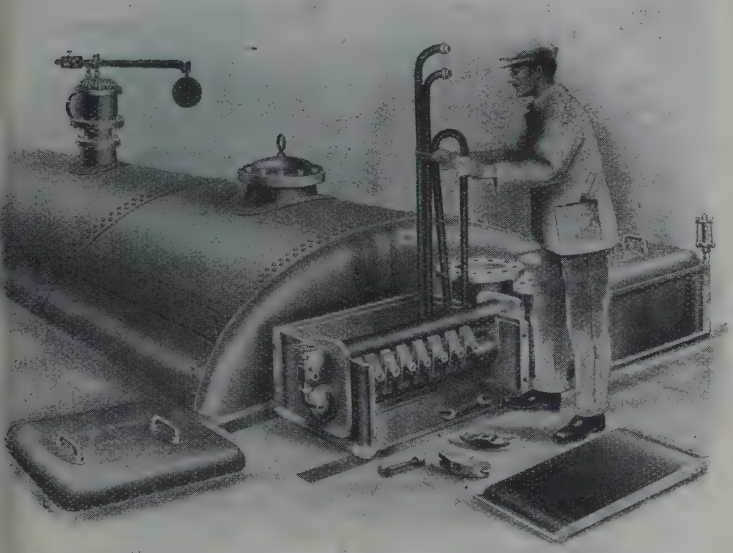
great fluctuations in temperature can take place where the superheater is fixed. It is readily accessible for examination, and for the renewal of tubes. There are no flanged joints, all the tube joints are expanded. Expansion is provided for by the tubes being free at one end, and by the manifolds not being rigidly connected with each other. Prevention against over-heating during steam raising from cold water after cleaning, etc., is ensured by the arrangement for flooding with boiling water, and using the superheater as part of the boiler-heating surface.

The flooding arrangement consists in a connection with the water space of the boiler drum; by means of the larger of two cocks (B) and connecting pipe (S) water can enter the lower manifold (H) and fill the superheater to the water level of the boiler. Any steam formed in the superheater tubes is returned into the boiler drum, through the collecting pipes (D), which, when the superheater is at work, convey saturated or natural steam into the upper manifold (F). Prior to opening the stop valve (L), when a superheater has been flooded, the water is drained away from the manifolds by the pipe (O) and the smaller cock (C). A sight glass (A) is attached to the outlet of the small cock to show when all the water has been blown out.

Very considerable economy is obtained by the use of superheated steam, and present practice in Central Station work is to use steam of the high temperature of 700° F.

'UNIT' Superheaters

The most efficient and accessible Superheater on the market, and manufactured to suit every type of boiler.



Each Tube Element is detachable. All parts interchangeable.

Head Office:

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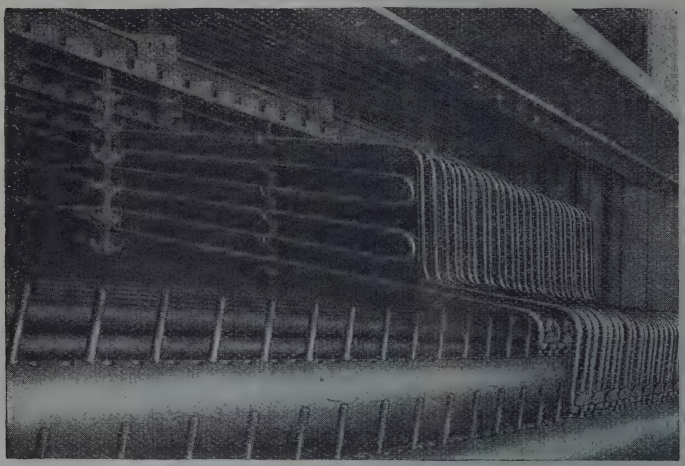
Also manufacturers of **Solid Drawn Steam Pipes**, in weldless steel, for High Pressure and Low Pressure mains. Enquiries solicited—prompt deliveries.



M.L.S.' HIGH DEGREE SUPERHEATER
(Inter Deck Design)

SPECIAL ADVANTAGES :

1. Fewer joints to be kept steam tight.
2. Type of joint proved most efficient for high pressures and temperatures.
3. Return Bend made by Patent 'M.L.S.' Integral Machine Forged Process.
4. Headers and joints are outside the boiler setting.
5. Uniform distribution of steam at all loads.
6. Highest heat transfer rate without objectionable cores.
7. Soot troubles and draught losses reduced to minimum.
8. Very little weight on boiler tubes.
9. Easy to install and inspect.
10. Placed in most favourable zone for high and uniform superheat.
11. Designed by superheater experts to meet specific requirements.
12. 'M.L.S.' denotes the standard of quality apparatus made by Europe's largest manufacturers of superheaters.

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Manchester

113

(*See Editorial pages* 1681 *and* 1683.)

The John Thompson Patent Sectional Superheater.

(*John Thompson (Wolverhampton) Ltd., Wolverhampton.*)

This superheater (fig. 52A, p. 1682) consists of a pair of mild steel cylindrical headers connected by two groups of U or W tubes. The tubes have tapered ends machined to gauge and fitted into milled holes in the headers, making a metal-to-metal joint, and are held in position by a right- and left-hand screw stud. The advantages of this method of fixing the tubes are, perfect interchangeability and speed and ease with which any tube can be removed or replaced for any purpose, as every tube can be taken out without disturbing the headers, pipe connections, or brickwork.

The steam passes through the hot gases four times, consequently the velocity of the steam is increased and great efficiency obtained.

This superheater is adaptable to all land boilers, and is suitable for the highest pressures.

The 'M.L.S.' Superheater.

(*The Superheater Company, Limited, London and Manchester; 'Schmidt' and 'Robinson' Superheater Patents.*)

The superheater, fig. 52, consists of solid drawn steel tubular headers, to which the elements are attached. These headers are reinforced internally with special strengthening bars into which the studs for the element connections are secured. The superheater elements are manufactured

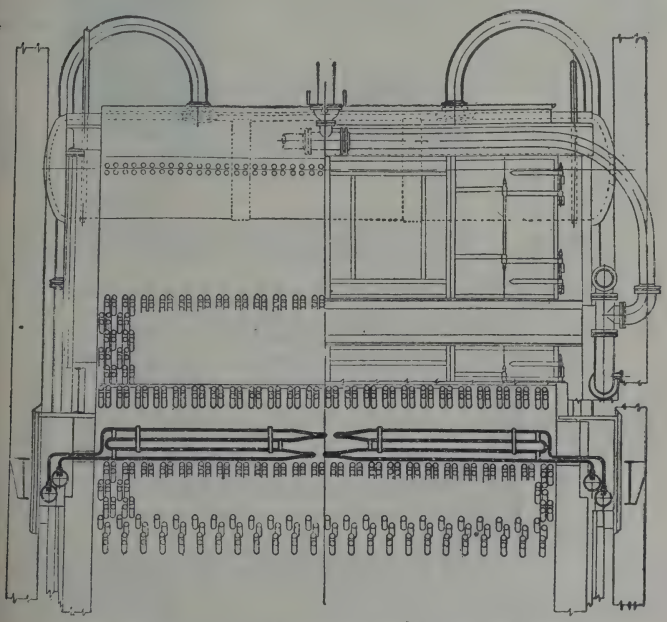


FIG. 52.—'M.L.S.' High Degree Superheater (*Inter-Deck Design*).

from high quality solid cold-drawn steel tubing, and they are connected to the headers by means of ball joint attachments, which latter have been adopted as standard by the manufacturers for their various types of superheaters. [*Continued on page* 1683.

THE 'JOHN THOMPSON' PATENT SECTIONAL SUPERHEATER.

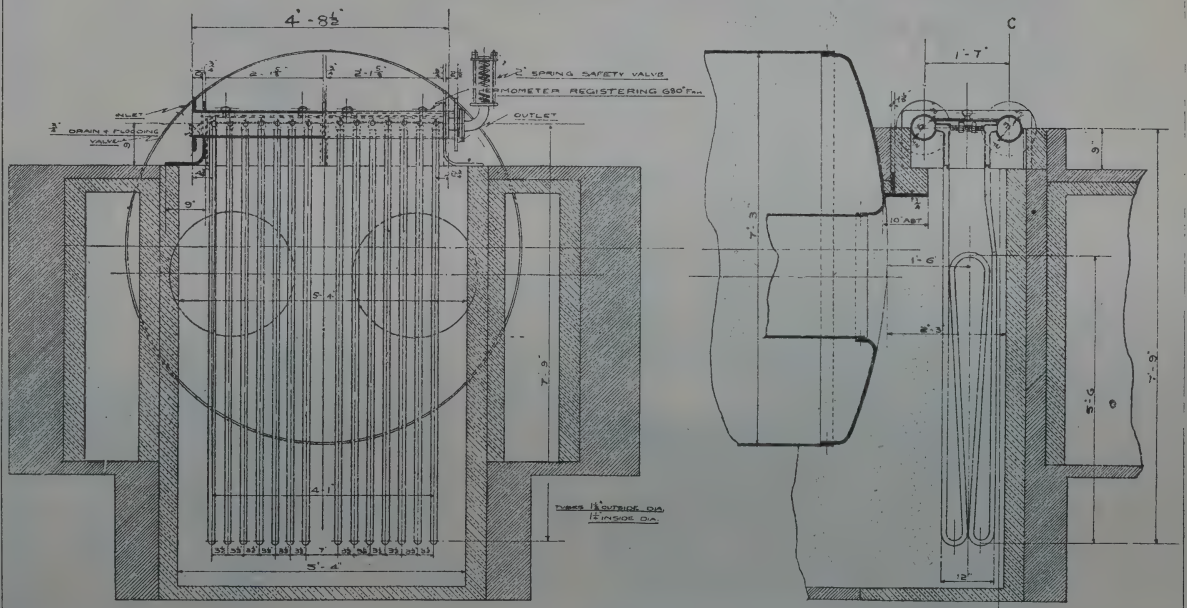
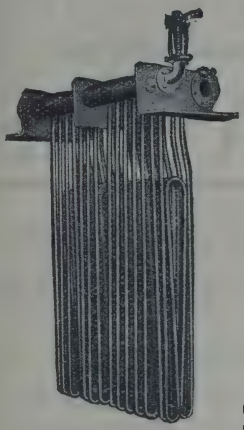


FIG. 52A.

STEAM PLANT ECONOMY

REDUCE YOUR COAL BILL



(Patent No. 1317 of 1914.)

Right and Left Hand Box Thread. By tightening or releasing this, the Tube is fixed or removed in less than a minute.

The 'JOHN THOMPSON' SUPERHEATER

Suitable for

LANCASHIRE, CORNISH, ECONOMIC (DRY BACK), OR WATER-TUBE BOILERS

All Tubes Interchangeable. Minimum Erection Costs. No Expanding Required

Write for Illustrated Catalogue or ask for one of our Engineers to Call and Advise you on the Economical Running of your Steam Plant.

JOHN THOMPSON

(Wolverhampton) LTD.

WOLVERHAMPTON, ENG.

F. 1682

McPHAIL & SIMPSON.

[Proprietors—John Thompson (Wolverhampton) Ltd.]

SPECIALITY:

PATENT DOUBLE HEADER WROUGHT STEEL

SUPERHEATERS

For Lancashire, Cornish, and all Types of Boilers.

Tubes Evenly Distributed.

More than 3,000 of these Superheaters now in Daily Use

NO LARGE JOINTS. NO STUDDED JOINTS.
EACH TUBE ACCESSIBLE WITHOUT DISTURBING INSTALLATION.
LEAKAGE IMPOSSIBLE.

THIS SUPERHEATER HAS STOOD THE TEST OF MANY YEARS, SUPERSEDING ALL OTHER DESIGNS.

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F. 1683

THE 'M.L.S.' SUPERHEATER—*cont.*

The balls formed on the element inlet and outlet ends are forged integrally with the tubing itself and seat in cone recesses in the headers, so that metal-to-metal joints are provided without any form of auxiliary packing. One of the particular features and advantages of these types of superheaters is in the construction of the return bend of the element tubing. These also are machine forged from the element tubing itself, so that the final result is a return bend occupying minimum space but absolutely integral with the element tubing, and no oxy-acetylene or other form of welding is employed. By this method of manufacture, instead of there being a stress or weakening of the metal at the bend, as must occur when the tubes are bent to a small radius, the material is actually reinforced and strengthened. An additional advantage of this type of construction is that it enables superheater elements to be manufactured with the necessary number of loops to give a large heating surface without occupying any more space than the ordinary type of 'U' loop tubes generally employed. This enables the superheater to be placed in the most advantageous position in the boiler to give a constant desired superheat under fluctuating loads.

De-Superheaters.

THE 'DRAYTON' DE-SUPERHEATER.

(The Drayton Regulator and Instrument Co. Ltd., West Drayton, Middlesex.

The body of this De-superheater consists of a vertical cylindrical shell, the size of which is determined by the amount of steam to be handled, its pressure, and the maximum temperature reduction required.

The superheated steam enters the shell towards the top of the body and passes down an annular space formed between the outside of the outlet pipe which extends downwards into the body from the centre of the top and the inside of the shell itself.

The de-superheating water, which should be supplied at least 15 lbs. per sq. in. in excess of the pressure of the superheated steam, passes through a fine strainer and two pressure-operated valves into the spray ring, which distributes it to the spray heads situated on the inside of the shell. A by-pass taken from between the two pressure operated valves enables the de-superheater to be placed under hand control.

Passing through the spray heads, the de-superheating water becomes a fine mist, travelling up the de-superheater body and meeting the superheated steam in contra-flow. The mist cools the incoming steam and itself becomes steam. The mixture then passes over baffles situated in the lower portion of the shell, when it is dried, and finds its way to the entrance of the outlet tube, Grit and other solid impurities are retained by the mud stool fixed to the bottom of the body and the clean, dried, de-superheated steam rises up the outlet tube, past the thermostat of the 'Drayton All-Metal Regulator' and into the service mains.

The pressure chamber of the first pressure-operated valve is connected to the inlet branch of the De-superheater. As the valve is opened by pressure, it is impossible for water to pass to the sprays unless steam is passing into the De-superheaters. On the other hand, the opening of the steam admission valve to the De-superheater automatically opens the water admission so that no superheated steam can pass out of the De-superheater. The second pressure-operated valve is under the control of the 'Drayton All-Metal Regulator' in the outflow from the De-superheater. The 'Drayton All-Metal Automatic Temperature Regulator' is of the relay type and operates as follows: Water or air at a pressure of 15–20 lbs. per sq. in. is brought to the thermostat head through a needle valve and strainer. This relay medium has free passage through the head to the pressure chamber of the controlled valve, where it compresses a metal bellows and holds the valve open. With increasing temperature the metal tube of which the thermostat consists expands, and at a predetermined point this expansion is caused to open a small relief valve to the passage through which the relay medium passes. The opening of the relief valve causes a dissipation of the pressure in the pressure chamber of the controlled valve, which moves towards a close position. By this means the amount of water passing to the spray heads is controlled by the temperature of the de-superheated steam passing into the service mains, and adjustments necessitated by fluctuation in load are made immediately.

By means of a simple device in the regulator head, it is possible to set the thermostat to operate at any desired temperature. When these fluctuations are very rapid and when the de-superheated steam is to be kept within fine limits, the 'Drayton All-Metal Regulator' is replaced by the 'Drayton Steady.' This Regulator operates on the relay principle and is fitted with a self-check action which positively prevents hunting.

An alarm signal is provided in case the temperature rises too high through failure of the water supply.

Every De-superheater is equipped with all necessary accessories such as safety valve, pressure gauge, dial thermometer, water level gauge and steam trap of latest and most suitable type.

SCALE IN BOILERS.

A coating of scale on boiler plates somewhat increases the resistance to heat transmission from flue gases to water. The resistance on the water side of plates, however, is only a small part of the total resistance, and even if it be multiplied several times by the presence of scale, the effect on the total resistance is small, and the efficiency of the boiler is only slightly reduced.

It is not its effect upon efficiency which renders scale objectionable, but its effect in altering the distribution of the temperature gradients from gas to water through the metal and the scale. It leads to an increase in the metal temperature which may reach a dangerous amount.

The oft-repeated statement that $\frac{1}{16}$ in. of scale requires the expenditure of 16 per cent. more fuel, and that greater thicknesses require enormously increased fuel expenditure, is quite wrong.

In regard to the increase in temperature of the plates as scale accumulates, all authorities are in agreement, and practical experience confirms the fact. Stromeyer states that with clean plates the plate temperature is only 400° F., with a water temperature of 380°, when the usual quantities of heat per sq. ft. of heating surfaces are being transmitted. With $\frac{1}{8}$ in. of scale he states that the temperature of the plate may go up to 700° F., which, of course, may result in strains being set up which are highly dangerous. Especially is this so if deposits of oil in addition to scale are allowed to accumulate on the water side of the tube, and even a very thin coating of grease may result in the boiler furnace being brought down.

Actual experience with Lancashire boilers in industrial concerns confirms the statement made by Stromeyer that, taking the boiler and economiser as a whole, the drop in efficiency will not be more than 5 per cent. with an average accumulation of $\frac{1}{8}$ in. thickness of scale. It will be found also that as the boiler becomes more scaled the outlet water from the economiser will increase in temperature, showing that this portion of the plant is absorbing the heat rejected by the unclean boiler surfaces.

The thickness to which scale may be allowed to form before being cleaned off depends on the rate of heat transmission. At higher rates cleaning must be more frequent for two reasons:

(1) Because with a given thickness of scale the temperature of the metal is higher, and hence safety is reduced;

(2) Because the scale forms more rapidly. Some engineers favour low rates of transmission in order to save the expense of frequent cleaning.

Scale is prevented by suitable treatment of the feed water. See p. 1685.

Preventives of Corrosion.

Internal corrosion is due to acids in the water, or acids formed from the salts in the water, or to electrolysis.

The methods used for prevention are suitable treatment of the feed water (see p. 1685), or means for ensuring that instead of the boiler plates being attacked the corrosion is limited to renewable zinc plates placed in the boiler for the purpose.

For boilers containing sea water, it is helpful to place rolled zinc plates in good metallic connection with the inside of boiler, under water, so that no part of the boiler is more than about 6 ft. from zinc, and renew them when wasted.

In the case of large boilers at high rates of evaporation, corrosion due to oxygen dissolved in the feed-water has become troublesome. To prevent corrosion due to this cause, appliances for 'de-gassing' or de-aerating the feed-water have been introduced. (See p. 1698.)

When the boiler is not at work, corrosion can be effectively prevented by filling quite full (to the top of a small filling pipe if necessary) with water in which soda (about 50 lbs. of common soda to 100 cu. ft. of water) has been dissolved. A bright nail should be placed in sample to note if it rusts. No more soda need be used than will make the water alkaline. (See p. 1687.)

In order to prevent external corrosion, the outsides of boilers should be well painted and lagged as a protection from moisture. Ashes should never be cooled in the ashpits.

The Cumberland Electrolytic Process for Preventing Scale and Corrosion.

In the process an electric current is passed from anodes placed in the boilers to the heating surfaces.

This process, whilst primarily intended for the prevention of corrosion, when applied to boilers not only arrests corrosion, but, owing to the mechanical action of the hydrogen given off from the negative surface, will loosen scale and precipitate it in the form of sludge, which is easily washed or blown out.

Where only the question of corrosion has to be dealt with in boilers, it is found that considerably ess current is required than 1 amp. per 300 sq. ft.

One of H.M. cruisers having twelve Yarrow water-tube boilers, with a total heating surface of 9,500 sq. ft., or 4,125 sq. ft. per boiler, was fitted with the process, and it was found in actual practice that all corrosion was arrested and heating surfaces kept clear of scale by using about 1 amp: for 800 sq. ft. of heating surface. The anodes in these boilers consisted of two 7-ft.

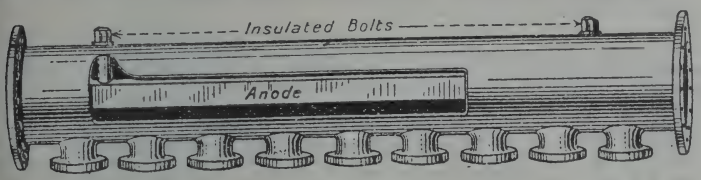

FIG. 53.

lengths of 3 in. × ⅝ in. bar iron, fitted in the steam drums of each slightly below the water level, and their life, it is estimated, will be considerably more than two years.

Fig. 53 shows the type of anode as fitted to economiser tubes. In economisers of the Green, Lowcock, or Clay Cross type it is necessary to replace the usual 4-in. pipes with others of 8 ins. diameter, otherwise the process cannot be installed.

TREATMENT OF FEED-WATER.

In steam plants using surface condensers the bulk of the water pumped into the boilers is condensed steam and is practically free from scale-forming salts—oil must, of course, be as far as possible removed. The condensed steam has always, however, to be supplemented by additional 'make-up' feed water, and as the effect of scale-forming matter in this water, even though it be a small proportion of the total feed, is cumulative, the use of most waters in the 'raw' state leads to serious scaling or to corrosion in the boilers.

Water intended for boiler feeding should be carefully sampled and analysed, and the treatment, if any, to be adopted decided upon only after careful consideration of the character of the water as revealed by the analysis.

The choice of a suitable process of treatment or softening depends on the nature and the amount of the salts found in the water.

The majority of waters available for use in industry contain salts of calcium, magnesium, and sodium, also silica in small quantities, and sometimes iron compounds. Moorland waters often contain organic acids; these must be neutralised in order that the water may be used with safety.

The salts which occur to the greatest extent are the bicarbonates of calcium (carbonate of lime) and of magnesium, and the sulphates, chlorides, and nitrates of calcium, magnesium, and sodium. These compounds are the causes of 'hardness' and of deposits of scale in boilers if used without suitable treatment.

If water containing bicarbonates of lime and/or of magnesia—$CaH_2(CO_3)_2$ and $MgH_2(CO_3)_2$ respectively—is boiled, CO_2 is driven off and the resulting carbonates $CaCO_3$, $MgCO_3$ are precipitated almost wholly in the case of the $CaCO_3$, which is nearly quite insoluble, but only partially in the case of $MgCO_3$, which is slightly soluble. Hardness due to those salts which can be removed by boiling is termed 'temporary hardness,' though it must be remembered that not *all* the hardness due to magnesium bicarbonate is temporary.

It is the driving off of CO_2 from 'temporarily hard' water as it becomes heated which cause such waters, if untreated, to deposit scale copiously in economisers, feed heaters, feed pipes, or round about the feed inlets to boilers.

'Permanent hardness' is not removed by boiling. It is due to sulphates, chlorides, and nitrates of calcium and magnesium. These salts are often more objectionable in boilers than the carbonates due to 'temporary' hardness.

The hardness of water is often expressed in 'degrees of hardness.' One degree of hardness is that due to the presence of one grain of calcium carbonate ($CaCO_3$) per gallon, hardness due to other salts being expressed as the equivalent of that due to $CaCO_3$. This is equivalent to 1 part of $CaCO_3$ in 70,000 parts of water by weight. Recently the system of expressing hardness in 'parts $CaCO_3$ per 100,000' has been advocated and is sometimes used. Care is therefore necessary in stating hardness, to make clear which system is used.

Hardness may be measured by finding the amount of a standard soap solution required in order to produce a permanent lather with a definite quantity of water. This method does not distinguish between the temporary and the permanent hardness, and is now being superseded by tests for alkalinity by means of a standard acid, the test being made in two stages giving the amounts of both kinds of hardness.

Analysis of the water by a chemist is always advisable, as it is only by ascertaining the particular salts causing hardness that the proper kind and proportions of reagents necessary for its treatment can be determined with accuracy.

Artesian waters from sand rocks are usually soft, those from limestone rocks or the red marls are hard. Superficial gravels often give hard waters, and the clay rocks, such as the lias, are often productive of hard water. Coal measures often give very bad water, even from sandy strata. Ancient rocks such as granite yield soft supplies, and the moorlands of the north country, being chiefly of millstone grit, yield remarkably soft water. Chalk yields hard water, but where covered with London clay the hardness is very much reduced, often falling to 6 degrees.

The reagent generally used for removing 'temporary' hardness is lime, in the forms of slaked lime, quicklime, or lime water. If the 'temporary' hardness is due to magnesium bicarbonate the amount of lime—i.e. hydrated lime, $Ca(OH)_2$—required is twice what would be necessary if the hardness were due to calcium bicarbonate.

Permanent hardness can be removed by the use of soda ash (carbonate of soda) for calcium salts, or by soda ash together with lime for magnesium salts.

Thus the lime-soda treatment serves to deal with waters containing a variety of salts, causing both kinds of hardness.

The proper quantities of the reagents to be used can only be correctly determined by reference to the results of the analysis of the raw water. The correctness of the treatment should be checked from time to time by applying simple tests to the treated water.

Caustic soda reacts with bicarbonate of lime, $CaCO_3$ being precipitated and sodium carbonate remaining in solution. If sulphate of lime is present, the sodium carbonate will react with it, calcium carbonate being precipitated and sodium sulphate then remaining in solution. Unless the two salts of lime are present in particular proportions the sodium carbonate formed in the first reaction will not be correct for the second, and as a rule additional sodium carbonate must be added. The caustic soda and the caustic soda and soda ash processes are based on these reactions. These processes are, as a rule, more expensive than the lime-soda treatment, and are, in any case, not so widely suitable; there are, however, certain waters for which these processes are suitable and efficient.

In general, it is better to treat the feed water before it enters the boilers rather than to use 'boiler compounds'; and, obviously, efficient filtering in order to remove the muddy deposit or substances precipitated in the feed tanks or softening plant, is essential.

Filters are charged variously with sponge, wood wool, cloths, crushed quartz, sand, broken coke, or sawdust, suitably packed.

With regard both to prevention of scale and prevention of corrosion, it is of great importance that an analysis be made and each case treated separately, so that the proper treatment may be determined.

Not only is mere analysis of the water required, but the treatment to be adopted should be decided upon with reference to the actual behaviour of similar waters under the conditions of steam generation.

Many of the substances used in boilers with the intention of preventing scale or of keeping scale in a loose, easily removed form are of little value, and occasionally, particularly if introduced in solid form, may themselves be a source of danger.

That in some cases a properly chosen compound for use in the boiler itself may be justified has been shown by E. M. Partridge (see *Power*, July 8, 1924). Scale formation depends on whether the insoluble matter formed in the boiler will attach itself to the plates, etc. Colloidal chemistry shows that the addition of certain colloidal substances to the water reduces the tendency of small suspended particles to coalesce, so that the insoluble matter forms a sludge rather than a scale. Partridge points out that the presence of this sludge in the boiler may be less objectionable than the increasing concentration of soluble sodium salts resulting from ordinary softening.

Boiler compounds, however, should not be used unless by the advice of a competent expert.

In connection with the application of colloidal chemistry to the treatment of feed water, it may be remarked that in a softening plant, the soda renders part of the chalk colloidal against which filtering is ineffective. The heat of the economisers or boilers changes the chalk from its colloidal form into an ordinary deposit, resulting in scale. 'By the use of suitable colloids, however, the insoluble matter resulting from lime and soda treatment is prevented from interlocking to form scale. Residual hardness, generally present to some extent in a water treated through a softener, also comes under the beneficial control of the colloids, because as this residual hardness is rendered insoluble by elevated temperatures, it is enveloped by the colloid, and so prevented from interlocking to form scale.' (*W. H. Bannister*, '*Institute of Mining Engineers*,' April 26, 1924.)

Aluminium sulphate or alumino-ferric may be used in small quantities to produce the colloid ffect, the precipitate being flocculent, so hastening settlement and facilitating removal.

It should be borne in mind that after treatment in a softener, water still contains salts, though hey are then soluble ones, and that undue concentration of these in a boiler is harmful, leading to oaming.

A. Winstanley (*Water and Water Engineering*, February 20, 1924) recommends that where eed water containing salts of sodium is used, samples be drawn from the boiler at intervals o determine the degree of concentration. From these samples the safe period of running so far as salts in solution are concerned) may be fixed. He suggests that 0·4 lb. per gallon e the maximum concentration allowed. He also recommends that the analysis of the feed vater be used to compute the amount of matter which will be precipitated in the boiler, and so .etermine the maximum period of continuous running so far as salts precipitated are concerned. As a fairly safe rule, he would fix a maximum of ½ lb. per sq. ft. of interior surface for adhesive alts, and double that amount for sludge or non-scale-forming material.

It is customary not to soften feed water completely, but to reduce the hardness to three or our degrees. With certain waters, however, containing acid-forming salts, such as magnesium hloride, it is advisable to use sufficient reagent to soften completely and to leave a small surplus, o that the treated water is slightly alkaline; otherwise corrosion occurs.

Dr. Joseph G. Rogers has proposed two methods of preventing boiler incrustation. One consists of introducing into the boiler a sufficient quantity of *sodium oxalate*, which converts the calc-forming impurities of the feed-water into insoluble oxalates as soon as they enter the boiler. These oxalates are precipitated as a mushy sediment, which has no tendency to form scale, and which may be blown out from the mud drum from time to time. The other consists in the use of *sodium tannate*, which is kept constantly present in the boiler in solution. It decomposes the calcium and magnesium carbonates as they enter, tannates being precipitated in a light, flocculent, amorphous form, which gradually accumulate in the mud drum, from which they may be readily blown out from time to time. The sodium carbonate formed in the reaction remains in solution, becoming bicarbonate by appropriation of the free carbonic acid in the water. This reacts upon the calcium sulphate, forming sodium sulphate and calcium carbonate, which latter in turn is acted on as above by fresh portions of the sodium tannate. The constant presence of the alkali protects the iron from any injurious action of the tannic acid. A similar reaction will take place between the tannate and the already-formed scale, though the action will be a gradual one.

'Caustic Soda in Boilers.

Failures of boiler plates due to 'embrittlement' have recently been investigated, and it is stated that the evidence points to concentration of caustic soda or of carbonate of soda in minute cracks on the surface of the plates in the vicinity of rivets as being the source of the trouble. It is the association of the soda compound and stress that appears to lead to a dangerous condition.

The degree of concentration which may lead to 'embrittlement' is not yet established, and, indeed, whether the presence of the soda is the true explanation of embrittlement at all is controversial. In view of the possible risk, however, it is advisable that when caustic soda has been used to assist in the removal of scale or for the prevention of corrosion when a boiler is out of service, it should be thoroughly washed out before the boiler is again put to work; also the concentration of caustic soda or of carbonate of soda due to softening reagents should not be allowed to become sufficient to give pronounced alkalinity.

The 'Dionic' Method of Water Testing.

(Evershed & Vignoles, Ltd.)

This method (Digby & Bigg's patent) is based on the fact that the electrical conductivity of water varies with the degree of hardness, or impurity in solution.

The essential units of the apparatus are a glass tube containing the water under test, together with a hand-driven direct-current dynamo and a conductivity meter.

A current is passed between electrodes, which are sealed at a fixed distance apart in the tube, whilst automatic compensation for temperature is effected by an adjustable thermometer which varies the effective cross-sectional area of the liquid path.

A direct reading of the conductivity is obtained, which affords information as to :—

(*a*) Whether condensers are leaking, and the extent of the leakage.
(*b*) The presence and degree of priming, if any.
(*c*) The control of oil-eliminating and water-softening plants.
(*d*) Feed-water.

A recording instrument of this type is now available.

The Crockatt Simplex Patent Electric Salinometer.

(W. Crockatt & Sons, Ltd., Glasgow.)

This is a direct reading instrument showing the amount of salt or other impurity in water, in grains per gallon, or other convenient measurement. An instrument board (fig. 53A) is fitted on

the control platform, and has on it the indicating instrument, warning lamp and relay for each point to be tested, interlocking switches and a warning bell or buzzer.

The lighting supply is coupled to a master switch on the board, and leads are run to the compensator boxes (fig. 53B) which contains the detector cell and compensating thermometer. One of these boxes is fitted for each condenser or feed line in which it is desired to measure the impurity.

A continuous stream of water flows through the thermometer pocket and the cell, and automatic correction is made here for varying temperature of the water.

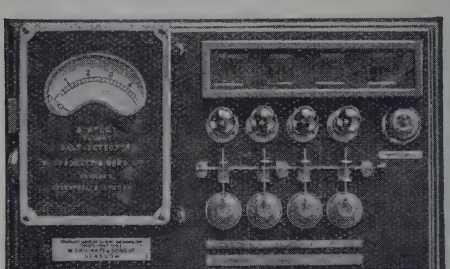

FIG. 53A.

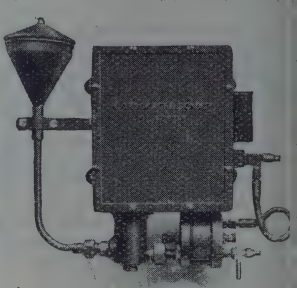

FIG. 53B.

The cells are, normally, all in circuit through the warning lamps, and the glow of any one of these indicates the presence of salt. This can immediately be measured by switching over that circuit to the indicating instrument. The switches for this purpose are all interlocked so that only one cell can be switched into circuit with the instrument at a time, the others being all in circuit through the lamps.

In the event of a large influx of salt or other impurity at any point, the corresponding relay closes, and a bell or buzzer gives audible warning to the engineer.

The Admiralty pattern instrument is entirely self-contained, the water being led directly to the thermometer pocket and cell, which are attached to the instrument case. This pattern indicates from zero (pure distilled water) to ·5 grains of chlorine per gallon, on a scale measuring over 4 ins. long, but the calibration and the range can be made to suit the special conditions of each case.

BOILERINE.

(*Boilerine Ltd.*, 885A-897 *Old Kent Road, London, S.E.* 15.)

This is a viscous fluid, consisting chiefly of a carbon compound which has no action upon iron, steel, or other metals, but which has the property of rendering all water impurities innocuous and incapable of forming scale, while it also works its way through the interstices of the scale, the rate of this percolation depending on the porosity and degree of compactness of the same, and when the preparation reaches the underlying plate of the boiler it there diffuses and insinuates itself behind the incrustation, causing it to crumble and flake, so that when the boiler is opened it can readily be removed. The preparation as a preventive of scale differs from the old style of boiler composition, inasmuch as it absorbs the gaseous carbonic anhydride from the water, forming an intermediate salt which throws the scale-forming salts out of solution, suspending them in the water in a non-crystallisable and powdery state. Incrustation is thus prevented. Steam generated from sea water containing 'Boilerine' is free from ammonia. Boilerine is not only a preventive, but also a disuniter of incrustation in boilers; it is absolutely non-volatile, and does not affect the purity of the steam produced from water treated with it; it does not discolour the water in the boiler, and it will not cause priming. It is guaranteed free from arsenic, acids, and poisonous substances, and is a neutraliser of grease and acids.

The boilers should be blown down and treated with Boilerine *daily*, as by this system greater efficiency is obtained. With average feed-waters the cleaning out should be done at intervals not exceeding 150 to 300 hours for vertical and locotype boilers; 500 hours for water-tube and marine dry-back boilers; 300 hours for the two bottom rows of tubes of Babcock boilers; 1,000 hours for Lancashire, Galloway, and Cornish boilers.

'FOLIAC' BOILER GRAPHITE.

(*Graphite Products Ltd.*)

The use of this material enables scale in a boiler to be easily and safely removed, a wire brush being used for the purpose. The graphite does not attack the metal of the boiler, nor, it is claimed, does it cause the metal to be attacked; it is not affected by any acid in the water or by the heat generated in the boiler. Particles of the graphite work through the minute fissures existing

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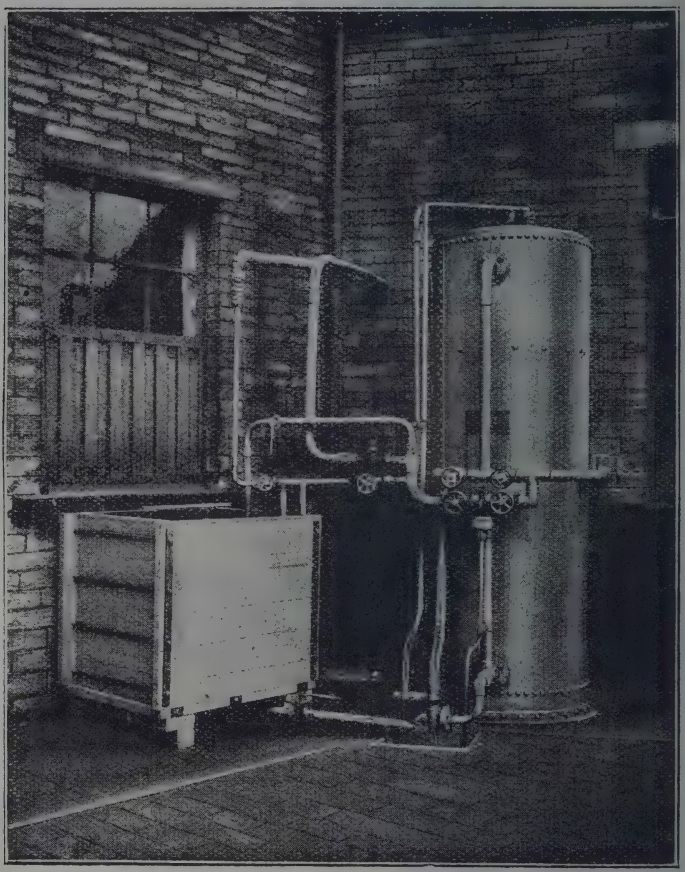
'PERMUTIT' Zeolite Pressure Softeners.



'Permutit' quick regeneration pressure plant. Instantaneous reaction Zero Water. Lowest Salt consumption.

UNITED WATER SOFTENERS LTD.

ALDWYCH HOUSE, LONDON, W.C. 2.

F. 1689

in the old scale and gradually penetrate between the scale and the metal. The scale thus loosened may be rapped off or removed with regular cleaning tools with little trouble. If the scale is very hard and thick it may require as long as three or four months for graphite to loosen it, but once removed the scale can never again adhere firmly to the metal as long as the graphite treatment is continued. The graphite also becomes thoroughly intermixed with new scale as it forms, rendering it soft and friable.

The graphite is introduced in the form of fine powder with the boiler feed, about half a pound being used per day for a 250-h.p. boiler.

Feed-Water Softening.

The two principal methods of feed-water treatment are (1) by lime and soda ash (see p. 1686) and (2) by zeolite, or base exchange materials.

The zeolite method consists in the use of special sodium aluminium silicates placed so as to form a bed three or four feet deep in a cylinder, and passing the hard water through this bed, when it runs out with absolutely zero hardness.

The soluble calcium and magnesium salts of every description interchange with the sodium of the zeolite, the calcium and magnesium salts remain in the tank and their equivalent in sodium sulphate and sodium bicarbonate is in the softened water.

The zeolite is 'revived' by blowing strong salt solution through the bed. The sodium zeolite is re-formed and the calcium and magnesium chlorides are run to waste. The plant will run for about eight hours, and then is 'revived' for half an hour.

The ideal method of softening is to reduce to 6 or 7 degrees of hardness by the lime-soda process and then to finish by zeolite, obtaining absolutely soft water with only a small amount of sodium bicarbonate. (Brownlie, in *World Power*, May 1927.)

Water Softening Plant.

WATER SOFTENING BY MEANS OF ZEOLYTIC EXCHANGE PROCESS.

(*'Permutit' Process—United Water Softeners, Ltd.*)

The Permutit system comprises filtration through a bed of the granular base-exchange material termed 'Permutit,' which has the property of giving up its sodium base to any water which is passed through it in exchange for any calcium or magnesium contained in the water.

This action takes place irrespective of whether the calcium or magnesium in the water is in the form of carbonate or sulphate, i.e. quite independent of whether the hardness is temporary or permanent.

There are two varieties of Permutit, the synthetic or artificial (Permutit A) and the treated and standardised natural product (Permutit B). Both are rapid in softening and regeneration, but Permutit B is more rapid in its action in either direction than any other base exchange material, either natural or artificial.

Such a method affords a means of presenting to the hard water a large supply of the softening element in readiness to be drawn upon by the water itself in exact proportion to its quantity and hardness; in other words, Permutit contains, in large excess, the active softening element, which, however, is effective in precisely the degree required to completely effect the softening of the water, and no more.

This action continues for so long as there remains in the Permutit active material (sodium) available for exchange; the total softening capacity of Permutit being represented by the multiple of the hardness and the quantity of any water, so soon as this quantity of water of the specified hardness has passed through the bed of Permutit, the sodium will become replaced by calcium or magnesium (or both), extracted from the water; thereafter, no further effect takes place either in respect of the Permutit, or of any further water passed through it. A fresh charge of the sodium is then transferred to the Permutit by flowing through it a weak solution of common salt (NaCl), when a similar exchange action takes place.

In this stage revivifying, or in its technical term 'regeneration,' takes place, by an exactly similar process. The bases of the hard salts (calcium or magnesium) are replaced in the Permutit by the sodium contained in the salt solution; and the calcium and magnesium combine with the chlorine of the salt forming the chlorides of these bases, which as a clear liquor may be run into any drain. Any slight excess of salt solution remaining amongst the granular particles of the Permutit after complete regeneration has been effected is washed out by a short rinse with clean water.

Permutit A can be regenerated in about one hour, while Permutit B is capable of being completely regenerated in 15 minutes. This rapidity of regeneration makes it practicable to use one unit practically continuously throughout the twenty-four hours.

A complete cycle of operations has then been completed, when hard water can again be passed through the filter, softening being complete as before, and continuing until the maximum quantity for which the filter is designed has again been treated.

During this to-and-fro softening action, the Permutit itself suffers no damage or wastage, it being merely a vehicle for the zeolytic exchange action which is the peculiar property of the substance. There is, therefore, afforded an extremely simple, though entirely scientific means for completely softening water of any hardness without any deposit of solid matter; any necessity for settlement and subsequent sludging away of precipitates, as was the case in the previous lime and soda systems, is thus completely obviated.

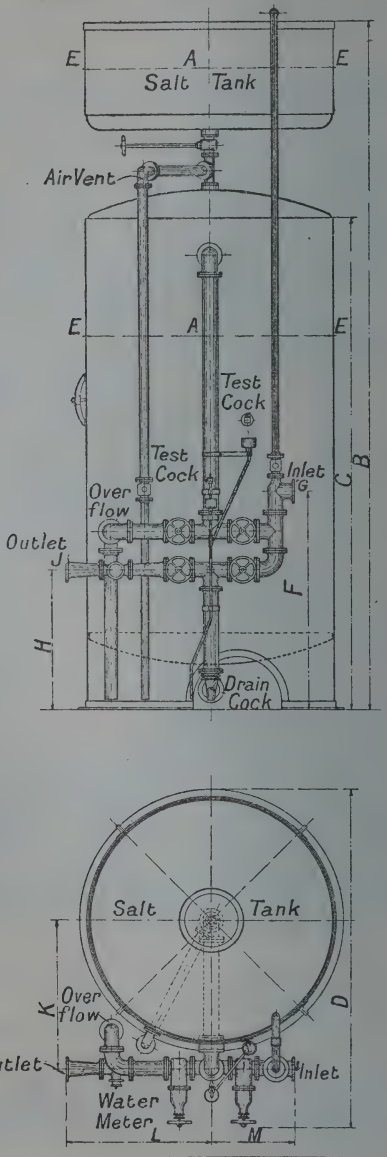
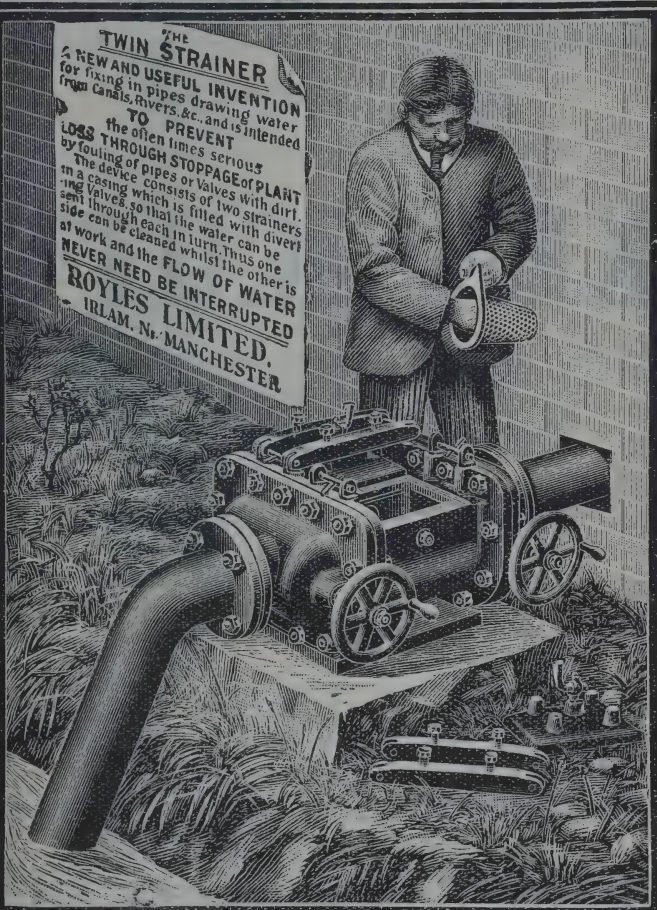


FIG. 54. PERMUTIT WATER SOFTENER.

ROYLES LIMITED



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KENNICOTT TYPE 'K' (Lime and Soda) WATER SOFTENER. Hot or cold process. Will reduce the hardness of water to 3°.

KENNICOTT TYPE 'P' (Zeolite) SOFTENER. Longest life Zeolite, lowest salt consumption. Will reduce the hardness of any water to Zero. No sludge. No trouble. No mess.

KENNICOTT SAND FILTERS remove all suspended matter from water.

Also manufacturers of Chlorinators, Baths Water Purification Plant, Town Supply Water Filtration Plant, De-aerators, etc., etc.

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IMPERIAL HOUSE, KINGSWAY——LONDON, W.C. 2.

LARGEST MANUFACTURERS OF WATER SOFTENING PLANT IN THE WORLD.

Another important feature attaching to the 'Permutit' system is the valuable means which it affords for treating water as it passes through the mains under pressure; and it has thereby become possible to treat any supply for industrial or domestic purposes as it enters the building in which it will be used, and to deliver the same in a completely softened condition to storage tanks in the top of the building, without any break in the pressure or consequent necessity for repumping.

Absolute uniformity in the final water, as well as elimination of any necessity for skilled control of the treatment by a chemist, are also features of importance attaching to the Permutit system.

In cases where temporary hardness preponderates heavily, and the difference in cost of lime and salt is also in favour of the lime treatment, a Permutit filter may with advantage be arranged to supplement a preliminary lime treatment.

Elimination of Iron and Manganese from Water Supplies.

By means of a special type of Permutit, prepared and oxidised by the use of manganese salts and permanganate, all traces of iron and manganese can be eradicated from a water supply, the treatment being effected under pressure and without calling for any extra pumping.

Large installations for some of the leading public water supplies throughout Europe have been laid down with conspicuous success for this purpose, as well as for the softening of the water as above described

The Permutit system constitutes practically the only one of certainty and success for the removal of manganese.

General Design of Permutit Plant.

The type of plant utilised for effecting Permutit treatment of water is of a standard design and is shown by fig. 54.

A mild steel cylinder of such proportions as are requisite, accommodates the proper quantity of Permutit.

Provision is made by means of suitable pipe connections and valves for agitating the Permutit bed by means of a flow in the opposite direction to that of filtration. By this means any uneven action due to air pockets or channels in the bed of the Permutit is prevented.

In the case of single units, the filter carries above it a shallow tank for dissolving the salt for regeneration—which is usually arranged to be effected once in each day.

In the case, however, of multiple-unit plants, these overhead salt tanks are dispensed with; and a common tank in steel or ferro-concrete provided, in which the salt solution is made up for the entire battery of the filters.

A complete plant of this description is in operation for both iron removal and softening at the Hooton Pumping Station of the West Cheshire Water Company.

Plants upon similar lines have been installed by a very large number of the leading industrial concerns both in England and on the Continent, as also by the Municipalities of Breslau, Dresden, and other leading cities.

The Kennicott Type 'K' Water Softener.

(*Kennicott Water Softener Co., Ltd., Imperial House, Kingsway, London, W.C.* 2.)

The Kennicott Type 'K' Plant is so designed as to be very simple to operate, and at the same time extremely accurate. The plant is absolutely positive in its action, and there are no oscillating parts to get out of order, and no valves or cups to get made up with lime. Fig. 55 (p. 1692) shows the general construction of the plant, the action of which is as follows:—

The calculated quantity of chemicals required for a day's supply are run into the chemical tank B, which is filled to a definite level. The hard water enters the plant by way of the pipe E into the hard-water box F, whence it flows through an adjustable slot over the water wheel D and out of the chute G at the bottom of the water wheel casing into the top of the downtake H. The incoming water, passing over a water wheel, provides all the power required for operating the plant. It drives the main shaft, and this shaft drives two vertical shafts, one in the downtake and the other in the chemical tank B. The shaft in the chemical tank B has a 4-bladed agitator at the bottom, and this keeps the chemicals constantly and homogeneously mixed. The shaft in the downtake has an agitator fixed to it, and this ensures that the chemicals added are thoroughly mixed with the water, a most essential feature. In order to proportion the chemicals, a small quantity of hard water from the hard-water box F is by-passed to the dividing box I, where the small quantity of by-passed water is divided, a portion running into the regulating tank K, and the rest down the drain. The dividing box is set so that the amount of water run into the tank K fills up this tank in a definite number of hours, generally sufficient for a day's run, and as this tank fills, the float riding on the water in this tank gradually rises and at the same time lowers the weir L in the chemical tank B, the float in the tank K being connected with the weir in the tank B by means of a flexible cable passing over two pulleys. It will thus be seen that the chemicals are added in an absolutely definite proportion to the quantity of water entering the plant. Immediately the chemicals come into contact with the water, the whole is thoroughly mixed by means of the mechanical agitator in the downtake, and the water passes down to the bottom of the downtake H, and finally flows upwards in the direction of the arrows, at a very slow rate, and is finally filtered at the top of the plant.

KENNICOTT TYPE 'K' WATER SOFTENER.

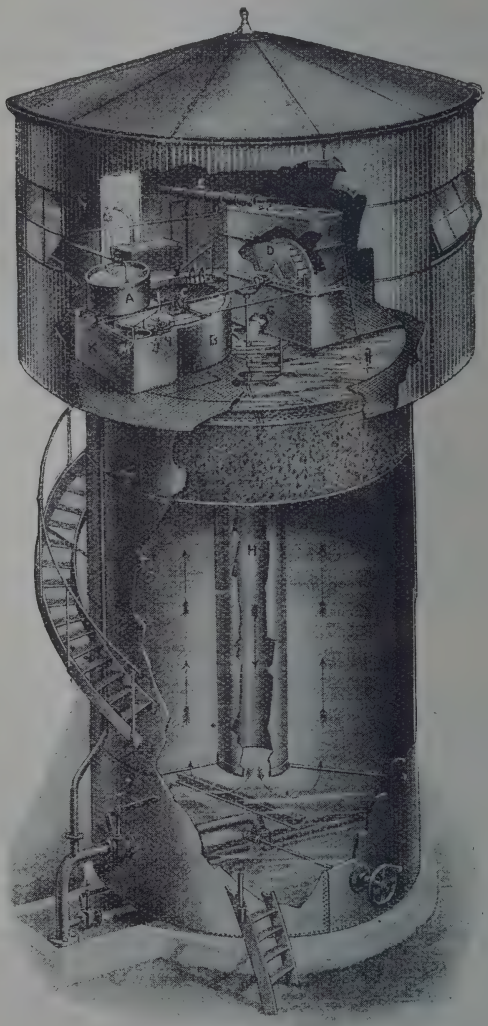

FIG. 55.

Any mud contained in the water, and the bulk of the precipitated hardening salts, settle on the bottom, and it is very necessary that this sludge should not be allowed to accumulate, otherwise the moving water will very quickly wash it up into the filter. By means of the *Kennicott Patent Revolving Sludging Gear*, however, the whole of the sludge settled on the bottom can be removed, the action of the sludging gear being very similar to a vacuum cleaner.

No Kennicott plant is made with less than three hours' settling, this being the minimum time that should be allowed for the complete precipitation of the hardening salts. With all Kennicott plants the mixing tank A is supplied. This tank is sufficiently large to hold a full day's supply of chemicals, so there is always a charge in readiness when the proportioning tank B is empty.

As the main tank always stands full of water, the clear soft treated water discharges from the overflow at the side of the main tank at a point above the filter as fast as the water to be treated enters the top of the downtake 'H.'

The machine is continuous and wholly automatic in its operation. The flow of the water furnishes all the power necessary for mixing the chemical reagents with the water and for operating the mechanism.

Every installation is designed for the work it has to perform, and to suit the site it must occupy. The chamber can be made either cylindrical or rectangular in shape. When a supply of exhaust steam is available, great economy can be obtained by installing a Kennicott Patent Type 'K' combined Heater and Softener.

The operation of this type of plant is exactly similar to the Kennicott Cold Water Softener described above. In addition to the chemical proportioning gear, there is fitted a very substantial heater, fitted with removable trays, over which the water passes. Steam is admitted at the bottom of this heater after passing through an oil separator, and passes upwards through the water. This raises it to boiling point, a considerable proportion of the hardening salts being at the same time deposited in the trays, which are from time to time removed for cleaning purposes. Practically the whole of the hardness originally present in the water is by this system removed, and at the same time a soft feed water of high temperature is available for boiler purposes.

Plants of the latest Type 'K' design of all sizes from 500 to 150,000 gallons per hour capacity are actually in operation.

The Kennicott Water Softener Co. also manufacture a Zeolite Water Softener which will reduce water, irrespective of its initial hardness, to zero degrees. This softener works under pressure, and the zeolite employed is a natural mineral which has been used for over ten years without showing any appreciable sign of deterioration.

The Kennicott Water Softener Co. claim that this zeolite is the most efficient and most durable zeolite procurable.

The Royles Automatic Water Softener and Purifier.

(*Reisert System.*)

In this apparatus, fig. 56, p. 1694 (*Royles, Ltd., Irlam, near Manchester*), the bicarbonate of lime is precipitated by hydrate of lime (lime water), and the sulphate of lime by soda. The softened water is then filtered and discharged.

The apparatus, which acts entirely automatically, consists essentially of an automatic lime saturator and decanter B, a soda chamber D, a water-distributing tank E with a lime-slaking division A and soda-mixing division C, a reaction chamber F, and an automatic self-cleansing filter K.

The *Lime Saturator* B requires no stirring contrivance, and lixiviates the lime completely; and owing to its upward widening shape, it turns the saturated lime water into a clear fluid.

By a constantly uniform water supply through the micrometer valve 3 from the distributing tank E, which is conducted downwards through the central pipe O, the lime paste at the bottom is stirred up and thoroughly impregnated, and rises, at first partly with the water, until the rapidity of the rising water diminishes so much, owing to the upward widening shape of the saturator, that the undissolved lime particles are no longer able to follow, so that the saturated lime-water, clarified, then leaves the saturator B at the top, and is carried into the reaction chamber F by way of the mixing pipe E^1.

As lime possesses the property of dissolving in a definite proportion in water until the latter is saturated, it is possible to continually keep a uniform stream of saturated lime-water supplied as required, for the precipitation of bicarbonates of lime and magnesia. Upon this uniform addition of lime depends the degree of purification of the water.

In the *Soda Apparatus* D, a quantity of soda (which, unlike lime, is very soluble), one gallon of water at 60° F. dissolving up to 1¼ lb. of dry sodium carbonate that will suffice for one or more days, is dissolved in the chamber C and let down into D through cock Q.

The action of the soda apparatus is based on the fact of the soda solution having a greater specific gravity than water, and thus the water flowing from the distributing tank E through the small micrometer valve 1—which is adjusted in accordance with the amount of soda required—into the soda chamber D, remains always on the surface of the soda solution (no mixing taking place), and displaces the same, it being carried through the small pipe from the bottom upwards, and into the mixing pipe E^1, and finally into the reaction chamber F.

The water-distributing tank, E, is supplied with the hard water to be treated, by pipe and cock as shown; it is also provided with an overflow pipe.

It is further provided with three micrometer valves at an equal height, viz.—(1) for the supply to soda tank; (2) for the supply of untreated water to the reaction chamber; and (3) for the supply to the lime saturator B. By arranging these three valves at an equal height the quantities of water flowing from them are always proportionate in the event of less water being supplied to the apparatus than corresponds to the capacity; or in the event of the water supply ceasing altogether, they cease simultaneously.

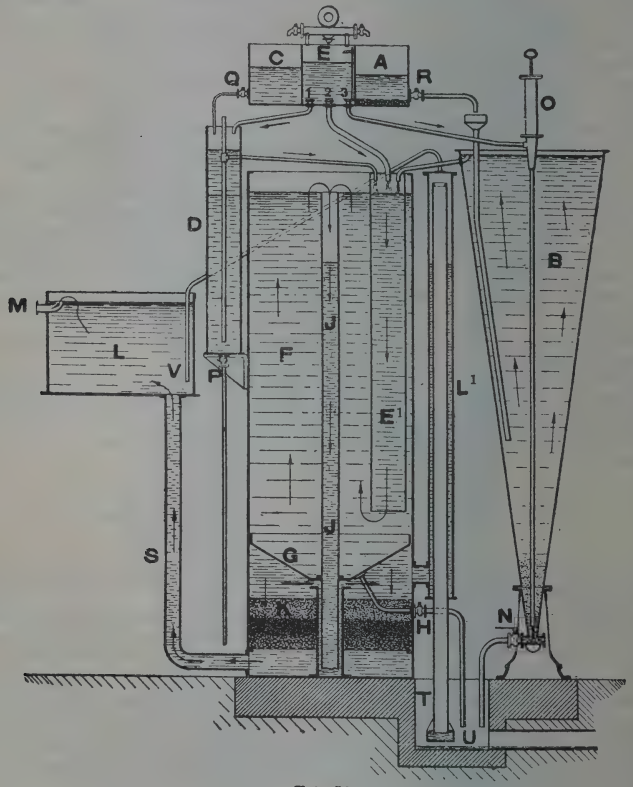

FIG. 56.

A *Lime-Slaking Division*, A, is arranged in the distributing tank. In it, once a day, the required quantity of lime is slaked by means of a supply of water obtained from the water inlet pipe. The lime paste is then conveyed in bulk to the bottom of the lime saturator, B, through the short depending pipe illustrated, by opening cock R. The *Reaction Chamber* F thus receives through the mixing pipe E¹, the untreated water, lime-water, and soda-water, which remain in this chamber until the chemical reactions have been accomplished.

The continuous inflow of the water and chemicals above described overflows *via* the pipe J into the filter chamber K, following the course of the arrows downward through the filter bed and upwards through pipe S into the tank L, the rest flowing away, at M, to reserve or for use. The height of the column of water in the pipe J will vary with the resistance of the filter bed, and as the latter fouls, the water will rise higher and higher in J.

Similarly it will rise to an equal and corresponding height in the Syphon pipe L¹, and as soon as the resistance through the filter bed reaches such a point as to cause the water to over-

flow this pipe, it forms a syphon and instantly reverses the current through the filter bed, drawing backwards the clear water held in the small tank L, thus thoroughly and automatically cleansing the filter, the sediment being discharged at T into the gully U. The small tank L is proportioned to hold sufficient water to thoroughly flush the filter K, and as soon as the tank is empty air enters *via* the pipe V, and destroys the syphonic action.

The filter then resumes its normal working, and so continues until the fouling is again such as to cause the pipe L to overflow, when the cleansing action is repeated. The loss of water in reflushing is very trivial. The filtering material rarely requires renewal.

The Lassen-Hjort Water Softening and Purifying Plant.

(United Water Softeners Ltd.)

The outstanding feature of the Lassen-Hjort patent automatic water softener, figs. 57 and 58 (p. 1696), is the device it embodies for the separate and exact measurement, in small, absolutely definite, and predetermined quantities, of both hard water and softening reagents. This device

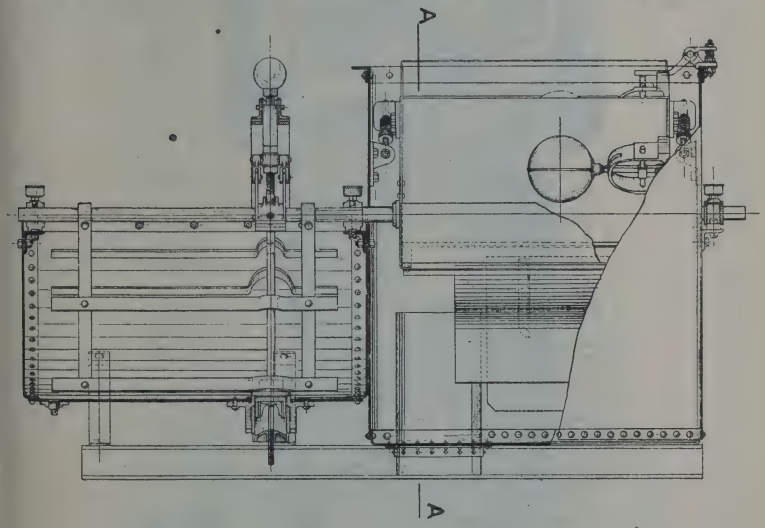

Fig. 57.

(termed the Lassen-Hjort Patent Measuring Apparatus) renders it possible to treat water or effluents of any character with any reagent or combination of reagents, in rigidly proportionate quantities, which can be varied at will and adjusted with the utmost precision.

The hard water to be softened is fed into the plant by a pipe which alternately fills each of the compartments of a two-chambered tipper oscillating on a shaft carried in bearings. When one of these compartments is full of water the disturbance of equilibrium causes the tipper to over-balance, and, by doing so, to discharge its contents of water into the tank in which it is suspended: at the same time the other compartment of the tipper is brought under the orifice of the inlet pipe and filled in its turn with hard water, to be discharged in the same manner when full. A counter affixed to the tipper shaft registers the number of oscillations, so that the quantity of hard water to be treated is thereby accurately measured.

An important feature of the apparatus is the recently introduced patent locking gear, by means of which the oscillating receiver is prevented from tipping until it contains a predetermined quantity of water. This ensures absolute precision in the measurement and delivery of the water to be softened.

The apparatus, fitted with this locking gear, has been tested as a water meter pure and simple, at the National Physical Laboratory, Teddington, and certified to be correct within 1 per cent.

At each discharge of water from the tipper into the tank in which it works, a corresponding amount of water is displaced from this tank through a standpipe and shoot into the reaction chamber of the softener, and here it receives at the same moment the requisite charge of chemical

LASSEN-HJORT WATER SOFTENER.

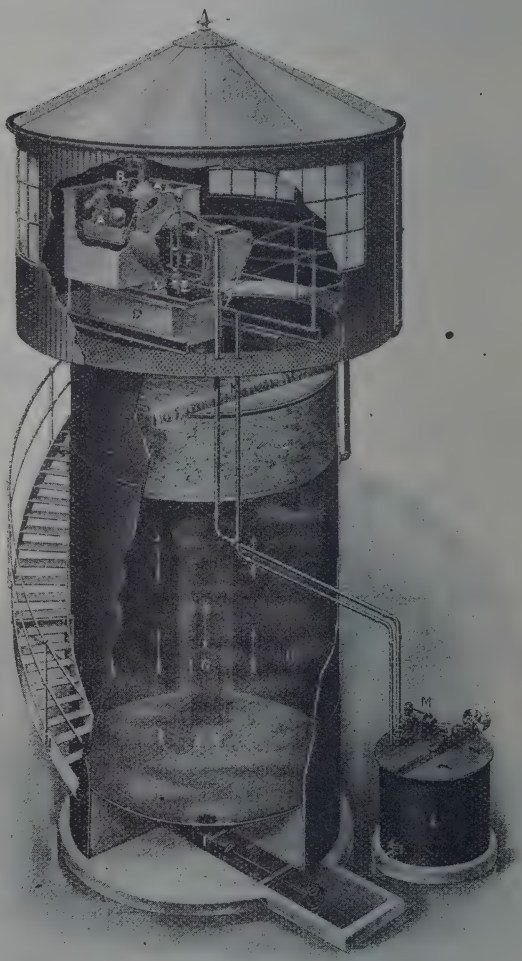

FIG. 58.

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The only softener which gives zero water continuously throughout the run.

Lowest salt consumption compatible with zero water throughout run.

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LASSEN-HJORT

WATER SOFTENERS

1. The Lassen-Hjort is the only plant possessing a positive adjustable device for measuring both hard water and reagents.
2. It operates automatically with unfailing precision, and requires only 15 minutes' daily attention.
3. It stops and starts itself in accordance with needs of soft water supply.
4. Every Lassen-Hjort plant is specially designed for the particular water it has to treat.
5. The design and workmanship of Lassen-Hjort plants are the best obtainable—the outcome of 25 years' unrivalled experience in water purification.

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F. 1697

solution from the semicircular chemical container affixed to the side of the tipper tank. This is effected by means of a ' positive discharge valve ' (patented) placed in the bottom of the chemical container, which is opened at each movement of the tipper, and caused to deliver into the reaction chamber the exact amount of softening reagent (in the majority of cases a mixture of lime and soda ash) required to soften it to the guaranteed figure.

The valve can be adjusted (with great ease and over a wide range) to discharge any specified quantity of reagent required by the volume of water in the tipper compartment, so that the plant can be easily regulated while working without any necessity for altering the strength of the chemicals or changing the solution in the container. The precision with which the chemicals and water are measured and mixed makes for speedy completion of the reaction.

A special feature of the tipper gear is the fact that all the working parts are in sight, whilst the whole gear is simpler (it is claimed) than that of any other water softener plant in use.

The average results obtained with the Lassen-Hjort plants show a hardness of the water after treatment, of 2° Clark, while the residual alkalinity (i.e. excess of lime and soda remaining in the water after the conclusion of the softening process) averages only 1·5 grain per gallon, or one and a half parts in 70,000 parts by weight, i.e. practically no excess of alkalinity.

The plant being primarily designed for adding lime automatically to water in exactly measured quantities, is very suitable for carrying out the Houston ' excess lime ' process of water sterilisation.

The Lassen-Hjort process has been adopted by Messrs. Babcock & Wilcox, who supply it throughout the world under license from the makers.

Many thousands of Lassen-Hjort plants are at present in use.

See also ' Purification of Boiler-Feed Water,' No. 4, 1921, *Proceedings Inst. Mech. Engrs.*

Filtrator Process for Prevention of Scale.

The use of ' colloidal ' substances to prevent scale formation has already been referred to (p. 1686).

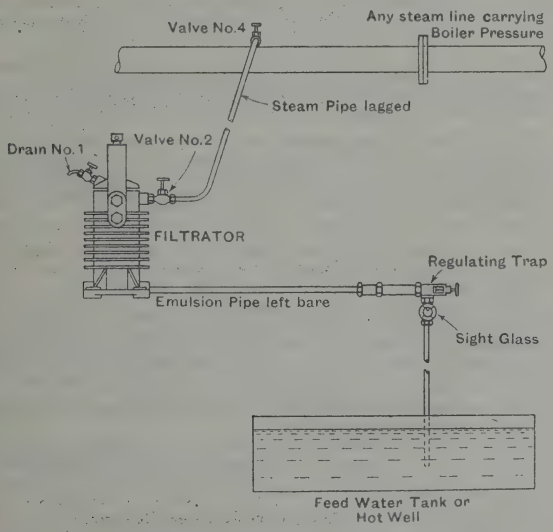

FIG. 58A.

A recently introduced patented system for carrying out such treatment is that of Messrs. Filtrators, Ltd.

The Filtrator is an apparatus having for its object the prevention of the formation of scale in steam boilers, economisers, and condensers, and the removal of scale existing previous to its application.

The apparatus (fig. 58A) is made both for air cooling and water cooling, and consists of an outer cast-iron cylinder with an inner perforated cylinder containing ordinary commercial linseed. Live steam entering the apparatus passes into the centre tube of the perforated cylinder and permeates the linseed, being induced to pass through the seed by the condensation taking place on the walls of the outer cylinder. By this means, a mucilage or emulsion possessing the properties of colloidal solutions is extracted from the linseed.

The steam is taken from any convenient steam line into the Filtrator, and the emulsion is led through a regulating trap of such a type that a constant flow of the linseed mucilage is maintained into the feed water. This mucilage, or emulsion, when leaving the Filtrator, is very little different in its consistency from ordinary water, and freely mixes with either cold or hot water in the feed tank so that the colloidal character of the solution is automatically maintained as long as the Filtrator is in operation.

A very important point about this method of installing the Filtrator is that it permits of the economisers being treated to keep them free of scale as well as any number of boilers being served from one central installation.

There are other methods of arranging the Filtrator, such as attaching direct to the boiler, but the arrangement suggested above is recommended.

It is well known that the cause of formation of scale in steam boilers consists mainly in the precipitation of different solid matters, when the water is heated to the temperatures characteristic of each, and also from the chemical reactions which take place in the water. When these matters are precipitated they adhere to the surface of the boiler and form scale, but when the mucilage from the linseed is introduced into the water in sufficient quantity it coats over all the scale-forming particles with a thin film, thereby preventing crystal growth (scale), and also preventing adhesion to the boiler shell. It must be obvious that if scale is not formed a sludge will be formed, and this requires periodically blowing down. The amount of blowing down does not exceed that required under ordinary working conditions.

Old scale will also be gradually removed. The emulsion penetrates the cracks which always exist on the surface of old scale; it thereby reaches the heated metal, when it expands, loosens the old scale, and this is gradually torn away by the circulating water.

The action of the mucilaginous emulsion is a physical one, no chemical reactions whatever taking place, so that this process is entirely harmless to the metal of the boiler and all fittings. By this physical method it is possible to treat any type of water, including sea water, and it is of great value where the water is of varying hardness or salinity.

Bare metal is not obtained with the Filtrator, but a protective scale coating which may reach, but will not exceed, 1-32 in. in thickness is formed in Lancashire or other fire tubular type boilers. In water tubular boilers, there is a maximum thickness of 1-64 in. of hard scale which forms a protective coating on the shell of the boiler, and over prolonged periods of steaming, scale is removed as soon as it reaches this maximum thickness. All scale which is formed is of a non-adhering character, and therefore the boiler metal surfaces are always open to water percolation.

One of the very interesting features of the treatment of the water in the boilers is that when marine boilers have been fitted with the apparatus, no corrosion or pitting has been found inside the boilers, notwithstanding that sea water only is used as 'make up.'

The lubricating oil that sometimes gets inside the boilers, owing to the impossibility of entirely eliminating it from the feed water by means of oil filters, has not been found in boilers fitted with Filtrator Apparatus. The most acceptable explanation is that the emulsion prevents the tiny globules of oil from agglomerating and forming film on the water's surface. It appears that the oil remains in this case in a finely divided state in suspension in the boiler water.

The Filtrator is applicable also to all types of condensers and water circulating systems generally.

As the husk of the seed remains intact throughout the process, and the condensed steam can extract only the matter soluble in water, no oil can possibly be extracted from the linseed.

Removal of Gases from Feed-Water.

The dissolved oxygen in feed-water may be reduced in amount in various ways. One method is to use a closed feed system, the condensate being kept from contact with the atmosphere, and the make-up feed-water being passed through the main condenser in which it is exposed to the vacuum and thus gives up part of its dissolved gases. Alternatively, a special de-aerating vessel may be included in the feed circuit. In the de-aerator the feed is finely divided or sprayed

by means of nozzles or by being made to fall in small streams over trays or through perforated plates. The de-aerator is either connected to the condenser or is provided with an air ejector so that the feed-water in its state of spray is exposed to a vacuum.

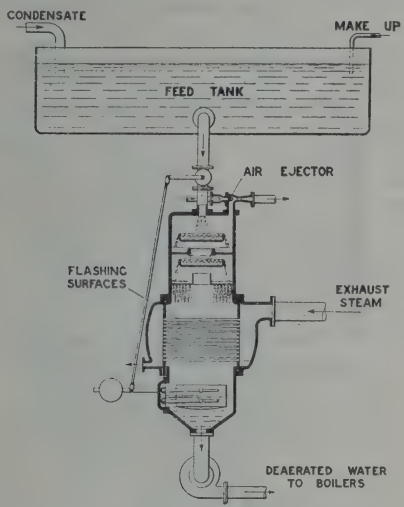

FIG. 59.

Fig. 59 shows one form of the 'Allen' de-aerator, in which the action of the vacuum in removing the dissolved gases is assisted by the spray falling upon steam-heated pipes placed across its path. The feed is thus heated as well as de-aerated in the same vessel.

A chemical method is exemplified by the Kestner De-gassing Plant.

THE KESTNER DE-GASSING PLANT.

(Kestner Evaporator and Engineering Co., Ltd.)

Fig. 60 shows diagrammatically one form of this plant.

The de-oxidising of the water is effected in the central portion of the vessel, which is filled with finely divided steel specially prepared both in respect to chemical composition and physical condition, so as to be readily oxidisable.

The apparatus is so proportioned that after passing through the de-gassing medium the water contains no oxygen capable of injuriously affecting the boiler, economiser, or pipe connections.

The water inlets (1) and outlets (2) are so arranged on the vessel that the flow of water may take place either upwards or downwards.

By arranging for a periodical reversal of the flow, portions of the material, which are most rapidly oxidised with the flow in one direction, are rested when the flow is reversed. During this period of rest a chemical change in the film of oxide takes place, the film being partially converted into a different form of oxide, which is easily detachable from the material.

A steam injector (6) is provided on the vessel through which steam is injected, causing sufficient turbulence to detach the oxide from the material. The flow of water carries the oxide through the filters (4), which retain the oxide, the cleansed water being returned to the feed reserve tanks. The operation of cleaning requires only a few minutes and involves no waste of water.

By changing the direction of flow every 24 hours, the de-gasser is kept in proper working condition, and will continue to function satisfactorily until the deoxidising material requires renewing.

For make-up water containing the usual proportion of dissolved oxygen, the makers state

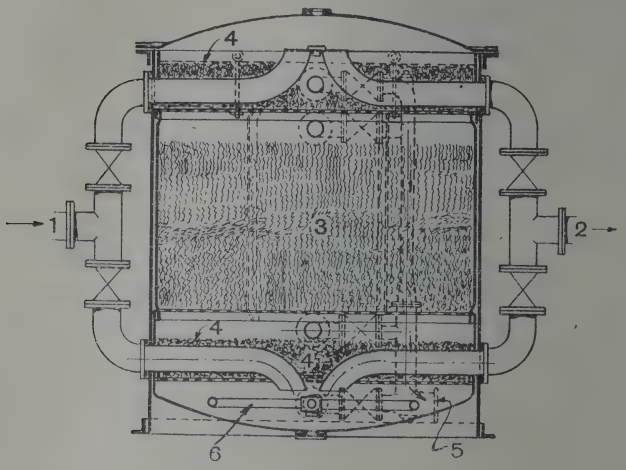

FIG. 60.

that the consumption of material amounts to about one ton for 100,000 tons of water. When the condensate is returned in a closed circuit, in which one of these de-gassers is included, a consumption as low as one ton of material for 1,000,000 tons of water may be obtained.

THE WEIR FEED-WATER DE-AERATOR.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

This de-aerator is designed on what is known as the 'flashing' principle—the water to be treated is heated and then passed into a vessel which is maintained at a vacuum higher than that corresponding to the temperature of the entering water. The energy liberated due to the fall in temperature causes the water to be disintegrated and the air liberated. The distinctive feature of the Weir de-aerator is that the flashing takes place in two stages, and is proportionally divided between each stage.

FEED-WATER HEATING

If heat which would otherwise be partially or wholly wasted be applied to heat the feed-water before it enters the boiler, an obvious saving is effected, since the amount of heat required to generate each pound of steam in the boiler is reduced. Even if the feed heating is carried out by means of steam withdrawn at low pressure from the engine or turbine, the gain by feed-heating may more than counterbalance the expenditure of steam.

The exhaust from auxiliaries is frequently used with advantage for feed heating.

Apart from questions of economy of fuel, feed heating is beneficial, as it reduces the temperature variations in the boiler, and thus also reduces the temperature strains. Also preheating the feed-water facilitates the removal of impurities and reduces the deposits in the boiler.

Assuming that heat which would otherwise be wasted, is used for feed heating, the saving may easily be calculated, as shown in the following example:—

Steam pressure 160 lbs. per sq. in.

Heat to generate 1 lb. steam from water at 60° F.
= 1203 — (60 – 32) B.Th.U. (see Steam Tables, p. 1593)
= 1175 B.Th.U.

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DISTILLING INSTALLATIONS (ALL SIZES)

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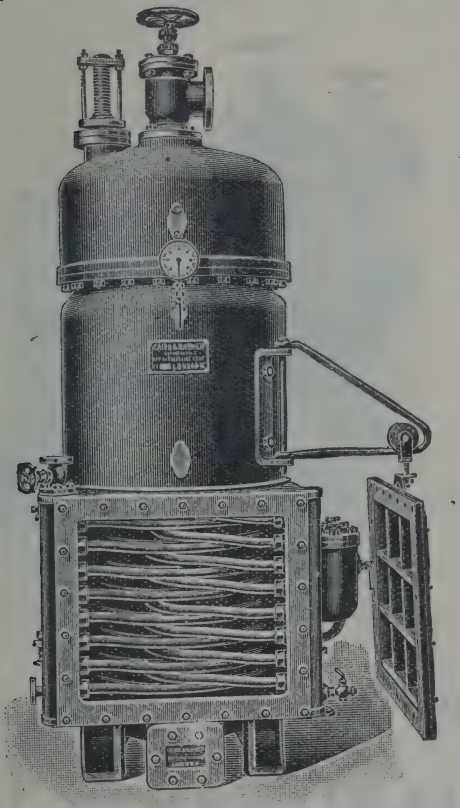

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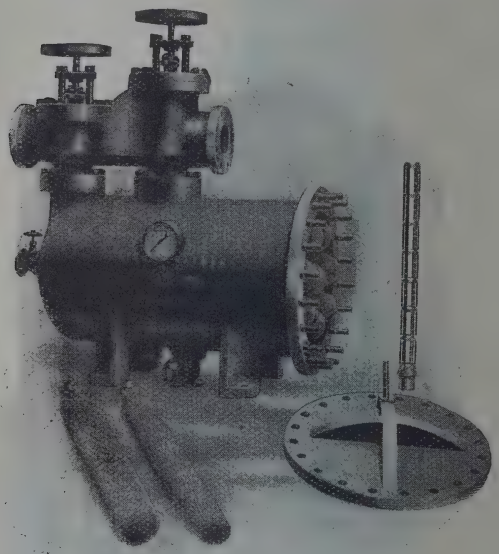

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If feed is heated to 200° F., the heat to convert 1 lb. of this hot feed into steam

$$= 1{,}203 - (200 - 32) \text{ B.Th.U.} = 1{,}035 \text{ B.Th.U.}$$

The saving is $\frac{1{,}175 - 1{,}035}{1{,}175} \times 100 = 11{\cdot}9$ per cent.

In general, if t_1, t_2 are the temperatures of the feed-water before and after heating, and H the total heat of the steam, whether saturated or superheated, the saving is

$$\frac{t_2 - t_1}{H - (t_1 - 32)} \times 100, \text{ per cent.}$$

The Row Feed-Water Heater

(Royles, Ltd., Irlam, near Manchester.)

In Row's Patent Feed-Water Heater, figs. 61 and 62, a peculiar form of indented tube is used, which it is claimed is *twice as efficient as an equal amount of plain tube surface*, giving great *compactness* and *efficiency*. The tube is also elastic in the direction of its length, thus avoiding liability of fracture or breakage when fixed between tube plates.

Fig. 61.

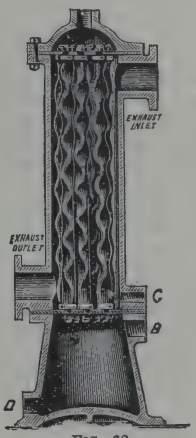


Fig. 62.

The Heater (fig. 61) shown is intended for good water—i.e. water not liable to scale—in which case the water is sent *through* the patent tubes. For bad water the order is reversed, i.e. the exhaust is sent through the tubes and the water circulates in the casing.

The Drayton Regulator and Instrument Co., Ltd., West Drayton, manufacture spirally corrugated tubes (fig. 63) fitted with plain copper ends for fastening to tube plates. These

Fig. 63.

tubes possess over 60 per cent. more surface than plain tubes of the same mean diameter, and are particularly useful where space for feed-water heaters is limited.

The 'Hudson' Economiser or Exhaust Steam Feed Heater.

This heater, which is also a steam condenser, is of simple construction, and, having no tubes, is claimed to cost nothing for renewal of parts.

The manufacturers state that the special features of this apparatus are :—

1. It extracts the grease from the exhaust steam *before* the latter comes in contact with the cold feed, and thus purified steam is obtained. This is important, as it is said to be impossible to perform the operation of separating the grease from the water afterwards without incurring considerable and constant expense.

2. The *purified steam* comes into direct contact with the *cold* feed (which enters the top chamber of the machine through a patent spray), the water being boiled, a large proportion of the carbonates and other impurities are thrown down, and these are easily removed through the manhole. Thus softened water may be obtained, *absolutely free from oil*, at a temperature of from 200° to 210° F. suitable for boiler feed, and, if required, a large surplus of hot softened water for washing and various other purposes may also be obtained by condensing the whole of the exhaust steam.

In many cases this softened water (free from oil) is being used for cask-washing in breweries, also in public baths, laundries, dye works, mineral-water factories, ice-making works, etc.

By use of this economiser, *incrustation* is entirely arrested before the feed-water enters the boiler, and generally the use of a metal brush may be substituted for the costly chipping of scale from the interior of the boiler shell. In this way a large saving is effected, and the apparatus by reason of this fact alone is of great value to steam users.

A report on *economy trials* by Professor T. H. Beare, M.I.C.E., showed an economy of fuel of 18·8 per cent. by the use of the economiser.

Automatic Temperature Regulation.

In heating feed-water it is essential to prevent the water being heated to boiling point, as at that point difficulties arise with feed pumps and injectors. By the use of automatic temperature regulators the predetermined feed-water temperature may be prevented from being exceeded. Automatic temperature regulators can be divided into two main groups: (1) Self-contained regulators producing their own operating energy for actuating valves, dampers, and such like; (2) indirect acting regulators in which the heat impulse merely brings into play an outside operating medium, which may be water under pressure, oil under pressure, compressed air, or electricity.

Self-contained regulators can work by vapour pressure obtained from a liquid with low boiling point, or by positive liquid pressure of an expanding liquid with a boiling point lying above the temperature for which the regulator is used. Vapour pressure regulators are limited to temperatures at which the vapour pressure is not too high, whilst liquid type regulators are limited to temperatures for which liquids with suitably high boiling point can be obtained. For temperatures above the limits of the vapour and liquid self-contained type, indirect regulation must be resorted to. In indirect regulators using air or liquid under pressure for the main regulation, a very small pilot valve only has to be actuated to control the main pressure, which can generally be effected with a very slight heat impulse, obtainable from a thermostat composed of two dissimilar metals. For temperatures which metals will not withstand without serious deterioration in a very short period the heat impulse must be obtained from electric pyrometers, which through at least two relays may operate either motors or powerful solenoids.

The 'Drayton' V.T. and M.S. Automatic Temperature Regulators.

(*The Drayton Regulator and Instrument Co., Ltd., West Drayton.*)

Fig. 64 shows the 'Drayton' V.T. Regulator, which is operated by the pressure of a volatile liquid in the bulb, acting through capillary tube on to a seamless metal bellows.

A spring opposing the action of the bellows determines the temperature at which the regulator will operate, and by varying the adjustment of the spring, a regulating range of 40° F. can be obtained.

Fig. 64A shows the 'Drayton' M.S. Air Operated Regulator, which is suitable where control within close limits is desired.

In this regulator the pressure of a volatile liquid or inert gas contained in the bulb acts on a diaphragm, which actuates a pilot valve controlling the supply of compressed air to the main diaphragm operated valve.

The principle of this regulator is shown by fig. 64B.

The Drayton Regulator and Instrument Co., Ltd., also manufacture regulators suitable for operation by water instead of compressed air, and time temperature regulators in which the temperature adjustment is operated by clockwork, so that any desired temperature curve may be reproduced.

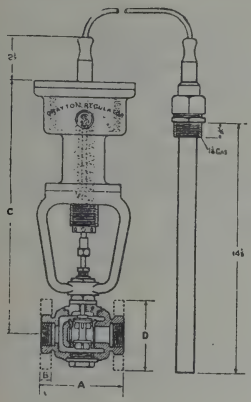


FIG. 64.—'Drayton' V.T. Automatic Temperature Regulator.

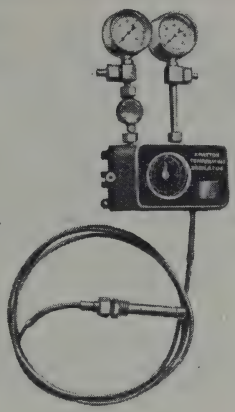


FIG. 64A. 'Drayton' M.S. Automatic Temperature Regulator.

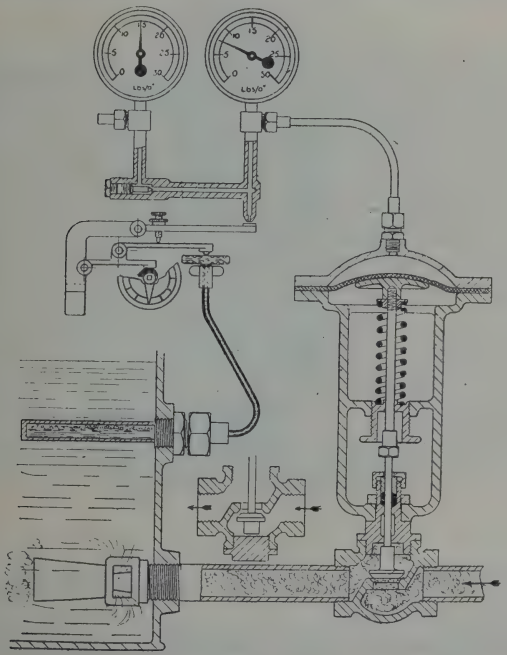


FIG. 64B.—'Drayton' operating principle of M.S. Regulator.

ECONOMISERS.

General Notes.

The term 'economiser' is usually applied only to those feed-water heaters in which the heat is obtained from the boiler flue gases before they pass to the chimney.

The standard pattern for pressures up to 250 pounds per square inch is represented by the Green and similar economisers.

For the latest turbine practice, with pressures of 350 to 450 pounds per square inch, steel pipes are used, and it is becoming usual to design the economiser as an integral portion of the boiler unit. In this sense there is no economiser, but only an equivalent addition to the boiler heating surface. An alternative method is to use cast-iron pipes of moderate surface, sufficient to heat the water to about 200° F. A rotary pump then delivers the water into the boiler proper. The aim of this arrangement is cheapness and the use of standard plant.

Economiser surface can decrease almost inversely as the gas and water velocities, and in fact follows very much the same laws as for boiler and superheater surface.

When using very cold feed, below 90° or 100° F., it should be preheated to 100° F. by live or other steam, before passing to the economiser, or the pipes will usually sweat, and serious external corrosion take place.

The 'Green' Economiser.

The 'Green' Fuel Economiser, fig. 65 (*E. Green & Son, Ltd.*), consists of a series of sections or rows of cast-iron tubes 4 ½ ins. in diameter and 9 ft long, placed in an enlarged part of the main flue, the tubes being fitted on their external surface with slow-moving scrapers. The sections are from 4 to 12 tubes in width, and the usual number of tubes is 96 per Lancashire

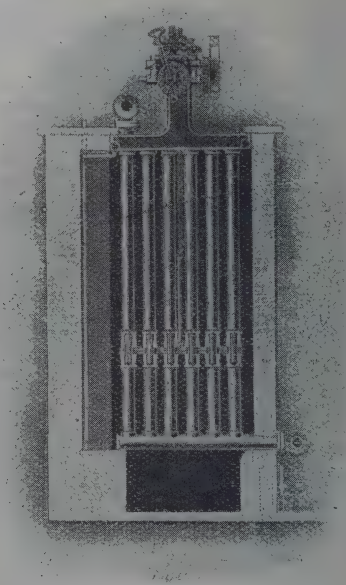


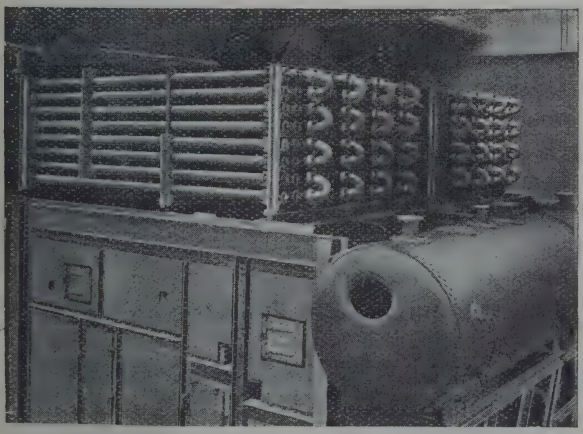
Fig. 65. The 'Green' Economiser.

boiler. When of large size the economisers are divided into a series of groups of 72 or 96 tubes each. The temperature of the waste gases may be reduced from 650° F. to 350° F., and the feed-water heated to a temperature of from 225° to 300° F. It is not advisable to feed an economiser with water at a lower temperature than 100° F. When the feed-water is colder than this, a small pipe should be led from the heated feed into the entering water, thus raising the temperature by mixture. This prevents external corrosion of the tubes, and improves the action of the scrapers.

GREEN'S

many designs of economisers meet every economiser requirement

Smooth Tubes and Gilled Tubes, Vertical, Horizontal and Inclined arrangements all have their specific value in modern power-station practice



Green's Tri-tube Economisers at a Power Station

Recommendations on receipt of details of boiler-plant

E. GREEN & SON LTD. WAKEFIELD ENGLAND

F. 1704

GREEN'S

manufactures include:—

STANDARD ECONOMISER
for all ordinary pressures.

RINGSTAY VERTICAL ECONOMISER
for present-day high pressures.

TRI-TUBE HORIZONTAL ECONOMISER
for Integral Boiler-Economiser Units.

GILLED TUBE ECONOMISERS

AIRHEATERS—for heating air for combustion or for industrial processes.

DAMPERS—wing, slide and swivel.

DOORS—for Economiser or other purposes.

VALVES—of cast-iron or steel.

ENGINES—for scraper-driving or other purposes.

LID and LID HOLE CLEANING MACHINES

PUMPS—for Anti-Incrustation Fluid.

STEEL-CASING—for enclosing Economiser or Airheater Sections.

WORM REDUCTION GEAR
for Motor Drive.

HIGH-SPEED SCALING MACHINES
for economiser tubes.

Booklets describing any or all of these may be had on application. Please mention this book.

E. GREEN & SON, LTD., WAKEFIELD
ENGLAND

F. 1705

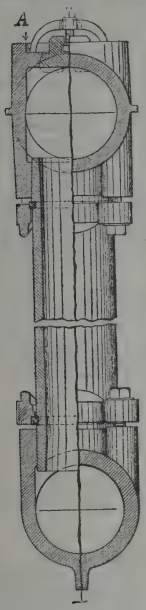
The weight of the economiser is about 1 ton for each eight tubes. Its water capacity is 6½ gallons per tube, and its heat-absorbing surface 10 sq. ft. per tube. The general rule is to provide 4 tubes per ton of coal per week (56 hours). Another rule is to provide 1 tube for each 3 indicated horse-power, but a more accurate standard by which to calculate the size of the economiser required for a given boiler plant is the evaporative capacity of the boilers.

This economiser is claimed to effect a saving in coal varying from 15 per cent. to 20 per cent. in ordinary practice.

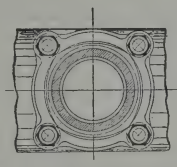
Green's Patent Ringstay Economiser

(for High Boiler Pressures).

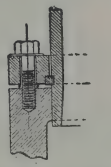
Extreme boiler pressures have made necessary certain alterations in the design of the standard economiser, which, although suitable in every way for normal pressures, does not provide for the higher pressures now met with. The chief alterations are: The staying of a certain number



Sectional View through Headers.



Plan of Ringstay Joint.



Details of Ringstay Joint showing Set-screw.

FIG. 66.

of socket joints in each section; a reduction in the diameter of the internal lid; a reversion to the circular type of top header, in place of the flat-topped rectangular design.

The Ringstay Joint, fig. 66, consists of an external ringplate and split ring threaded on to the end of the tube. The ring is held firmly to the shoulder of the tube by the ringplate, which is secured to the header by four set screws. Direct-pull tests have demonstrated that each of these joints is capable of sustaining a load of over twenty tons, irrespective of the friction of the tapered joint.

The lids are of the usual internal conical design, but of smaller diameter than the standard internal lid. The lid hole 'A' is stepped, so that if a tube requires replacing the metal can be more readily reamered out, the original lid being replaced by one of external type.

The lid holes are of sufficient diameter to enable the tubes to be cleaned, and as the headers are of the extended type, every tube can be inspected without breaking the top branch pipe joints.

One master lid is fitted into each top header.

The headers are of circular design, thereby ensuring a greater resistance to extreme internal pressures, and conforming in this respect to the best practice.

All the component parts are carefully examined, tested, and gauged before being used.

Green's Patent Tri-Tube Horizontal Economiser.

Green's Patent Tri-Tube Economiser was originally designed for erection in a horizontal position over modern types of water-tube boilers. In the space of a few years, however, it has become the standard type of economiser for modern high-duty, high-pressure boiler plants, and is installed either above or behind the boiler as necessary.

The economiser is constructed of cast iron of remarkably high tensile strength, while the patent Ringstay Joint increases by 100 per cent. the holding power between tubes and headers. The great resistance of cast iron to corrosive influences is well known and appreciated, and constitutes one of the chief reasons why Green's Tri-Tube Economisers are almost invariably specified for new installations. The success attained by this type of economiser is evident from the fact that it has been adopted at some of the largest electricity undertakings in the world. (List on application.)

Description.—The whole economiser, with standards and connecting bends, can be arranged to rest on the boiler supports, or, if desired, on independent joists, and can be fitted inside existing casing or provided with separate casing of Green's design. The sections are of such dimensions that they can be installed to suit almost any requirements and are interchangeable.

Sections.—Three tubes pressed into a front and back header constitute one section, and each is supported independently on vertical standards provided with projections on which the headers lie flat. There is ample room for expansion between adjacent headers and between the header ends and the standards.

Circulation of Water.—The number of sections in height or width of the economiser is decided by the dimensions of the boiler-casing. The water may pass through the bottom row of tubes, return along the next, and pass through each successive layer of tubes in series, or, on the other hand, it may enter the lowest two or three rows simultaneously, return along the next two or three in parallel, and so on throughout the remaining rows, thus putting the economiser partly in series and partly in parallel, as may be desired.

Each header is in itself horizontal and of small dimensions, consequently the temperature of the water from end to end is uniform and the expansion regular throughout the casting.

Baffling of Gases.—In modern high-efficiency boiler plants the economiser should be arranged to give as nearly perfect contra-flow conditions as possible, *e.g.* gases and water should flow in opposite directions. The special construction of Green's Tri-Tube Economiser readily permits of this.

Economiser Data.*

The present standard design of economiser has been practically the same since the first inception, and it would seem to be a very difficult matter to suggest any real improvement on the original design.

The economiser pipe is usually of a standard dimension of 9 ft. length and 4 $\frac{5}{16}$ ins. external diameter, being constructed to suit the boiler pressure and tested by hydraulic pressure to, say, 200 lbs. over working pressure. Each of these standard pipes has approximately 10 sq. ft. of heating surface, holds 6$\frac{1}{2}$ gallons of water and weighs $\frac{1}{3}$ ton. The power required to drive the scrapers is very small, being, for example, about $\frac{1}{2}$ h.p. for a set of 96 tubes. Cast iron is the most suitable material for the tubes, at any rate up to 300 lbs. steam pressure, as steel, wrought iron, copper, brass, etc., will not resist so well the corrosive action of the hot gases.

Makers recommend an installation large enough to hold one hour's supply of feed water in the pipes. Thus if a boiler is evaporating 650 gallons per hour, each tube holds 6$\frac{1}{2}$ gallons, and the number of economiser tubes would be then 104. When the evaporation is not known it is customary to allow 4 pipes for every ton of coal burnt per week of 54 hours, or one pipe for every 3 i.h.p. developed.

Out of 250 boiler plants (see page 1618) only 155 were fitted with economisers, the other 95 having no means of utilising the waste heat from the boiler flues. In these 155 plants, the exact average saving obtained was 11·4 per cent. of the coal bill. In actual practice, therefore, only about 17 per cent. of the plants fitted with economisers were saving 15 per cent. or over of the coal bill, whilst over 30 per cent. were saving less than 10 per cent., the true average for the whole 155 plants being 11·4 per cent. as stated.

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* Abstract from 'Exact Data on the running of Steam Boiler Plants.' (D. Brownlie, B.Sc. Hons. (Lond.), F.O.S., J. Compston, and H. W. Royse; *Engineering*, November 1, 1918.)

The average figures from the 155 plants added together showed a beneficial rise in temperature the feed-water of from 115 deg. F. before the economisers and 241 deg. F. after, *i.e.*, an average e of 126 deg. F., equivalent to 11·4 per cent. saving. The corresponding fall in the flue gas nperatures from the 155 plants were 581° F. before the economisers and 389° F. after.

The reason the average figures for the actual saving are only 11·4 per cent. is not the fault the economiser as an appliance, but is due to the fact that the economical generation of steam scientific lines is not understood, and economisers generally are not installed on correct lines. e economiser is an absolutely essential part of any up-to-date boiler plant, and the saving tained should be 17½ per cent. to 20 per cent. under average conditions.

Other advantages of the economiser are the reduction of the strain on the boilers by the ovision of a high-temperature feed water preventing unequal expansion and contraction, and o that there is always a large reserve of hot water at hand for any sudden demand for steam. rther, the evaporative capacity of the boilers is greatly increased.

The chimney, as a draught producer, is an unscientific and wasteful method of creating a aught, depending for its efficiency on a great waste of heat. If this waste is utilised to the l by the economiser then the draught is curtailed and it is impossible to burn the necessary nount of coal to maintain the evaporation, in spite of the assistance of the economiser. There e many boiler plants that are forced, for this reason, to open slightly the by-pass dampers d allow a portion of the hot gases to go straight up the chimney to waste, so as to maintain raught to burn the amount of coal required to keep up steam. The mere installing of economisers rule-of-thumb lines may therefore in some cases be of little real advantage. This difficulty however, of little or no importance in the case of mechanical draught.

The water delivered into the economisers should not be over, say, 5 deg. to 6 deg. hardness, nen all encrustation troubles will be at an end.

Thousands of economiser pipes have been rendered useless in a few years because of corrosive tion. One remedy is to ensure that the feed water does not enter the economiser at a tempera- re of less than 100 deg. F., by providing an automatic circulating arrangement to take con- nuously a small portion of the water from the hot end and mix it with water from the cold d.

TABLE SHOWING RESULTS OF WORKING WITH ECONOMISERS.

Division according to Saving Obtained.	No. of Plants.	Average Temperature of Feed-water.		Average Temperature of Flue Gases.		Draught in Inches. W.G.		Steam Press Gauge.	Total Evaporation on Plant per Hour.	No. of Tubes on Plant.
		Before.	After.	Before.	After.	Chimney Base.	Side Flue or Down-take of Boilers.			
		deg. F.	deg. F.	deg F.	deg. F.			lbs. per sq. in.	lbs.	
o economiser at all .	95	—	—	—	—	—	—	—	—	—
ess than 5 per cent. .	14	134	172	568	371	0·85	0·41	80·0	17,616·0	228
per cent. to 7½ per cent.	15	123	194	576	423	0·61	0·35	79·0	15,340·0	203
½ per cent. to 10 per cent. . . .	23	119	261	549	374	0·74	0·33	100·0	16,630·0	231
0 per cent. to 12½ per cent. . . .	33	118	243	583	403	0·88	0·39	106·0	29,723·0	401
2½ per cent. to 15 per cent. . . .	46	110	262	584	379	0·99	0·41	99·0	19,760·0	280
ver 15 per cent. . .	24	170	284	610	375	1·35	0·60	119·0	23,497·0	392
Total plants .	250									

Some large economisers are now made with tubes 11 ft. long.

For high-pressure plants two feed pumps may be used, one being interposed between the economiser and the boilers. Thus the economiser does not have to stand the full boiler pressure. By this means also an economiser weakened by corrosion may be retained in service where otherwise it would have to be scrapped.

For the pump between economiser and boilers a turbine pump driven by a steam turbine is suitable.

AIR HEATERS FOR BOILERS.

The preheating of the air supply to boiler furnaces has recently attracted attention, and the system has been applied in several power stations.

The air is heated by flue gases, but the recovery of heat from these gases is not the only gain, for in addition the effect of preheating the air is to increase the furnace temperature, increase the completeness of combustion of the fuel, and increase the efficiency of the boiler.

It is claimed that each 20° to 30° F. of increase of air temperature will result in at least 1 per cent. saving of coal, and that an efficient air heater is superior to an economiser and less expensive. Having regard to the desirable temperatures of feed-water and of air supply, it is possible that the best plan may be to recover part of the heat of the flue gases in an air heater and part in an economiser.

LJUNGSTRÖM AIR PREHEATER.

(J. Howden & Co., Ltd., Glasgow.)

A recent development in the application of heated air to land boilers is the Ljungström Air Preheater. It is possible with this arrangement to extract from 70 per cent. to 75 per cent. of the heat contained in the flue gases and to return it to the boiler furnace, reducing the temperature of the exit gases to the neighbourhood of 200° F., giving boiler efficiencies up to 86 per cent., according to circumstances. Such a result could not possibly be obtained by a water economiser without very heavy capital cost for the economiser itself and the brickwork.

The space occupied by the Ljungström Preheater is comparatively small, and considerable reduction in the cost of buildings may be obtained by installing the Ljungström Preheater instead of economisers; the total reduction in capital cost may thus be very great.

A description of the Ljungström Preheater will be found on p. 2384.

THE 'GREEN' RECTANGULAR TUBE AIR HEATER.

This Air Heater has been designed to meet a demand for a heater of *light construction, economical proportions, maximum efficiency*, and *long life*. It consists of a number of elements grouped together *end to end, side by side*, and *one above the other*, in such a manner as to provide for a maximum amount of heat transmission with a minimum loss of pressure and draught.

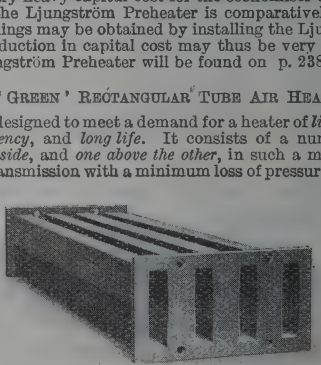


FIG. 67. One element: one-tenth full size.

Each element, fig. 67, comprises four rectangular tubes cast in one piece with a flange 10 in. × 5½ in. at each end. The tubes measure internally 2 ft. 6 ins. long, 4 ins. deep and 1 in. wide, and are 1½ in. apart, the complete element having 9·5 sq. ft. external and 8·33 sq. ft. internal heating surface. The flange faces of the elements are machined, and intermediate pairs of flanges are held together by bolts. The boundary flanges on the air inlet and outlet sides are bolted to suitable airtight sectional framework, with a converging mouthpiece opposite each tube in order to prevent undue eddying of the air (see fig. 68).

Each element weighs approximately 80 lbs; this is heavier than a heater of the same surface constructed of thin sheet-iron plates, but when it is remembered that the life of thin sheet-iron plates is only about one-tenth of the life of a cast-iron heater, a little extra weight is a decided advantage.

The space occupied by one element is slightly under 1 cu. ft.; consequently, a heater of sufficient capacity to supply the requisite quantity of air at a high temperature to the grate of a water tube boiler, need not take up more than 3 or 4 feet head-room, casing included, as the whole of the top of the boiler—being otherwise waste space—can be covered with these elements.

Accessible over the whole of the top surface of the boiler, a shallow heater can be inspected and cleaned with the greatest ease.

The elements are so arranged in the flue or uptake that the gases transversely sweep the flat surfaces of the tubes, which are arranged at 2½ ins. centres with, as already stated, 1½ in. spaces between adjacent tubes. The air, therefore, passes through the tubes in streams 4 ins. × 1 in. cross section, and the gases pass outside the tubes in streams 1½ in. in width.

The gases and the air to be heated can be made to pass either straight through the heater or through the several portions of it in series, according to the temperature and volume of air

required, and the weight of the gases at disposal. The design ensures, however, that both air and gases pass through the heater to the best advantage and with the least possible loss in pressure.

Fig. 68 shows a heater arranged immediately over a water tube boiler. Owing to the small amount of head-room taken up, it can be very easily cleaned, hand holes being arranged both in the top and sides of the casing.

The blowing off of the soot from a heater of this description is neither a lengthy nor a difficult process.

Cleaning doors in the side of the gas chamber admit hand lances for soot blowing by means of compressed air or steam.

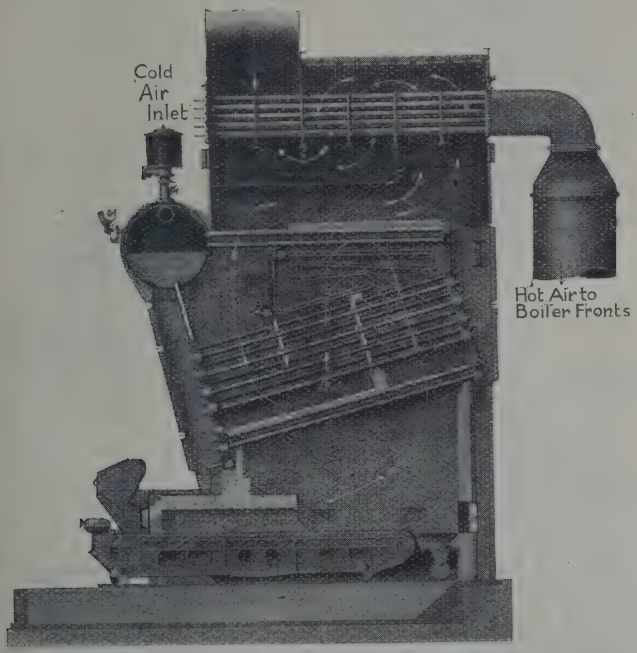


FIG. 68. 'Green' Rectangular Tube Air Heater over a Water Tube Boiler.

If desired, cleaning can be done from outside by means of fixed or revolving steam or compressed air pipes, so arranged that jets will play on or sweep practically the whole of the surface.

Hand cleaning holes can be provided in the top of the casing to give direct access to the upper part of the heater.

A large access door is recommended for entrance to the top of the heater should occasion necessitate.

The heater has no moving parts, and is therefore highly suitable for power stations where the number of necessary auxiliaries requiring close attention has become a serious problem.

THE GALLOWAY 'SUPERMISER.'

(Leek's Patents.) (*Galloways Ltd., Manchester.*)

The 'Supermiser' (figs. 69 and 70) is a combined air heater and economiser, that is, it serves to preheat the air for combustion and at the same time to heat the feed water, the heat for both these purposes being derived from the flue gases.

The apparatus contains a number of pairs of concentric tubes; the hot flue gases pass through

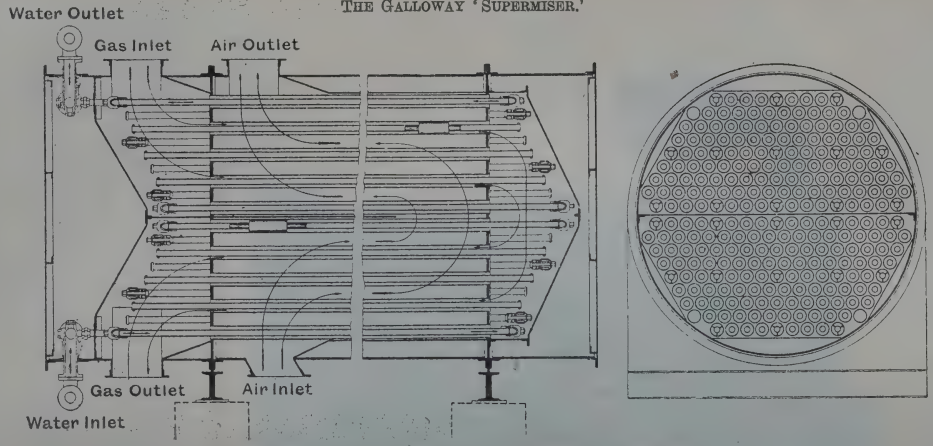


FIG. 69.—Section through 8 ft. 6 in. diameter 'Supermiser.'

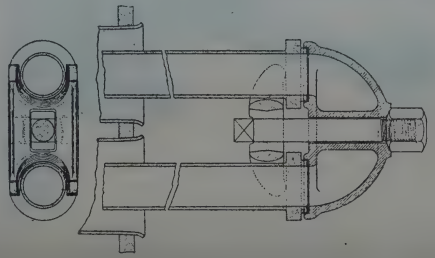


FIG. 70.—Section through header of 'Supermiser.'

the annular spaces between the inner and outer tubes, the air surrounds the outer tubes and the water flows through the inner tubes. The gas flows in the opposite direction to that of the air. The gases thus give up heat simultaneously to the water and to the air.

The rates of flow are intentionally high so that the rates of heat transmission are high, and thus the heating surfaces required are comparatively small, and the whole appliance is compact.

The tubes are carried between tube plates in a horizontal steel shell. The tubes are expanded into the tube plates at one end, but are merely a close fit at the other so that expansion and contraction due to temperature differences can take place freely.

The water tubes are supported inside the air tubes by thin radial fins parallel to the tubes, so designed as to offer minimum resistance to the gas stream, and are connected in series by headers of cast steel or of malleable cast iron.

The headers have removable caps and can themselves be quickly detached from the tubes. Ample opportunity for inspection and cleaning and, if required, removal of the tubes is thus provided.

There is a horizontal division plate about the centre of the Supermiser, which extends from the tube plate at the front end (the end at which are the gas and air branches), but which at the other end leaves sufficient passage-way for the air to pass from the lower to the upper half. The courses of the air, gas, and water are clearly indicated in the illustration.

The details of construction are carefully thought out, particular care being given to the avoidance of sudden changes of section of the gas path. This ensures that there shall be no ' dead pockets ' where dust and soot can be deposited. At the end inspection doors give ample access to the end boxes ; the headers and tubes can be fully exposed for inspection and cleaning.

The high speed of the gas through the tubes not only gives high rates of heat transmission, but prevents the deposition of the solid particles contained in the gas.

In large Supermisers the water divides into two or more circuits, in each of which the tubes are connected in series.

The high gas and air speeds involve considerable resistance in the gas and air passages and fans are provided to suit ; mechanical draught would in any case be necessary on account of the low temperature at the chimney. Results have proved, however, that the economies due to the Supermiser amply repay for the power and cost of the fans.

The gas fan is placed near the gas outlet, producing a suction and delivering the gas to the main flue through which it passes to the chimney.

The air fan takes air from the atmosphere, and delivers it under pressure to the Supermiser. The heated air, still at an inch or so of water gauge, is led through a sheet metal duct, properly heat insulated, to the front of the boilers, and enters the furnaces below the grates, still at slight pressure. The pressure is regulated by dampers at the boiler fronts, so that above the grates it is slightly below atmosphere, and thus the firedoors can be opened without risk for purposes of inspection or for hand firing.

No brickwork setting for the Supermiser is required. It may be placed over the flues or carried on a light steel staging.

The results obtained in practice have been very striking, the gas being cooled to a temperature below 250° and the overall efficiency of the boiler plant with an ordinary Lancashire boiler raised to over 80 per cent., which the makers are prepared to guarantee in all ordinary cases.

The possibility of corrosion of the tubes due to deposition of moisture has been considered. It must be borne in mind that owing to the uniform distribution of the gas streams, pockets of low velocity and low temperature are avoided, and hence the *average* temperature of the gas at exit, namely, say 250° F., is the lowest temperature of the gas at any part of the apparatus. Thus deposit of moisture is unlikely, and as a matter of fact has not been found in practice.

The high efficiency of the plant is accompanied by increased capacity. In cases where a boiler battery is overloaded, the installation of a Supermiser may relieve the situation and save the provision of an extra boiler.

Life of Boilers.

Lancashire and Cornish boilers last about 30 years, although there are cases in which Lancashire and Galloway boilers (with dirty, but not very scaly, water) have lasted for 50 years. Water-tube boilers (subject to a good deal of re-tubing) may be taken to last 20–25 years. Marine boilers, if properly treated and taken care of, should last at least 20 years under forced draught, and 25 years under natural draught.

The life of any boiler depends, naturally, upon the degree of care with which it is handled.

BOILER INSPECTION.

Boilers must be inspected once in every fourteen months. The owner or user may be made responsible for the effects of an explosion.

To prepare a boiler for inspection the manhole and mudhole doors should be removed, the blow-off cock closed, the steam valve locked to prevent tampering and danger to cleaners and inspectors, the hot feed valve locked, the bars and bridges removed from the furnace, and the flue doors removed and the hearth pit plates lifted away.

The flues and boiler plates in the flues should be swept clean of soot and dust.

The amount and nature of the internal scale should be observed, and the boiler thoroughly cleaned inside and scale removed.

The special points to be observed by the inspector are the condition of the plates along the seatings and all points of contact with bricks, the dryness of the flues, the absence of lime mortar nêar the plates, the dryness of the top covering, leakages at seams, circularity of furnaces, blisters, signs of overheating. Internally: grooving at plate junctions, around the angle irons of shell or furnace tube connection to end plates, at the root of angle irons or flanged seams or other points of stress or flexure, tautness of gusset stays, easy slackness of longitudinal stay bolts if present, condition of plates as to cleanliness, corrosion &c., condition of low-water appliances, scum troughs, feed pipes, gauge openings, and generally all points bearing on the safety of the boiler that may by some unlikely and hard to conceive contretemps lead to mishap of any sort.

In old boilers the openings in the shell should be looked to in order to ascertain the weakening due to removal of so much plate, and the degree of strength given back by added rings or other reinforcements. It is also desirable to note the quality of the attendance and workings of the boiler periodically, and to test the accuracy of the steam gauge and working of the safety valves.

The foregoing remarks apply more particularly to shell boilers. For water-tube boilers, the caps of the water tubes must all be removed, and each tube examined and seen through for scale deposit, and as far as possible externally for blisters. Locomotive-type boilers are not easy to inspect, should never have riveted shell seams below water line, and must be largely judged by the appearance of such parts as are visible. Every few years the shell should be examined internally, the fire tubes being removed for the purpose. The accessibility of a boiler for complete inspection ought to be a considerable factor in determining the choice of a boiler, and more particularly so when the water is dirty or corrosive in quality.

Experience is necessary to make a good inspector. He must possess judgment and sense of proportion, and be able to order a boiler not to be worked until further notice, without it being possible for further enquiry to show that there were not good grounds for his fears.

BOILER EXPLOSIONS.

The following table gives the description of the boilers which have exploded or collapsed during the thirty-nine and a half years from June 1882, when the first Boiler Explosion Act came into operation, to December 1921, and the causes of the explosions and collapses.

Type of Boiler.	Land Boilers.		Boilers Afloat.		Cause of Explosion or Collapse.	Land Boilers.		Boilers Afloat.	
	No. of Explosions.	No. of Collapses.	No. of Explosions.	No. of Collapses.		No. of Explosions.	No. of Collapses.	No. of Explosions.	No. of Collapses.
Plain cylindrical	71	0	0	0	Corrosion	124	116	15	18
Locomotive and portable	47	43	0	2	Grooving	29	5	0	0
Cornish	43	69	0	0	Excessive pressure	48	33	4	9
Vertical, with internal firebox	28	172	9	37	Outlets frozen	83	4	0	0
Lancashire	27	39	0	0	Failure of stays	15	15	0	4
Galloway	0	10	0	0	Deficiency of water	31	75	0	71
Chimney	1	6	0	0	Structural weakness	23	31	1	4
Marine	1	0	7	97	Fractures	18	2	0	0
Return flue	3	1	7	10	General deterioration	8	2	4	0
Water tube	52	0	4	0	Steam rips	11	0	0	0
Multitubular, externally fired	1	0	0	0	Deposit	28	12	1	39
Miscellaneous	34	5	0	3	Not ascertained	2	4	2	4
Hot water	112	4	0	0					
	420	349	27	149		420	349	27	149

(The British Engine, Boiler, and Electrical Insurance Co., Ltd.).

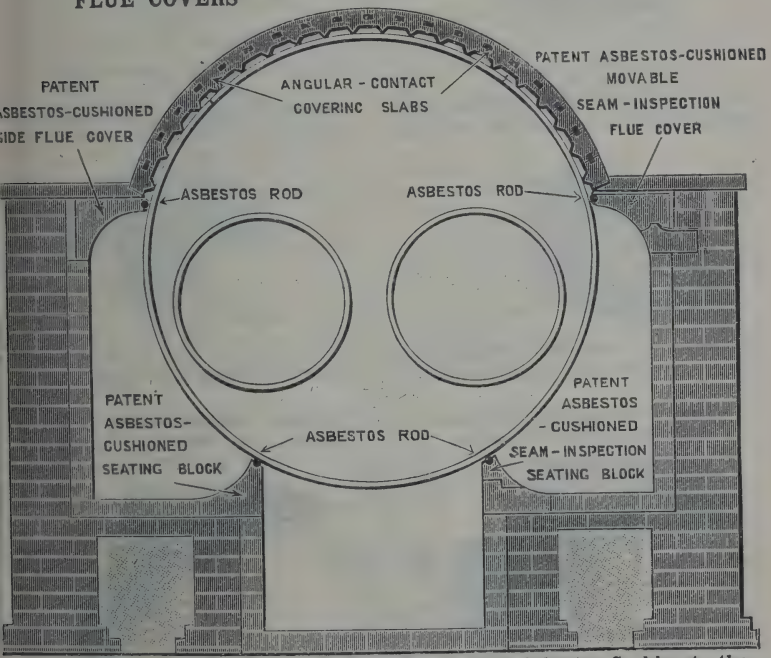
'MODERN METHODS OF SETTING STEAM BOILERS'

BASED ON

EFFICIENCY.

We are the only Boiler Setters who are the Actual Makers of the goods we supply

A BOILER SET WITH PATENT ASBESTOS CUSHIONED BOILER SEATING BLOCKS AND SQUARE ASBESTOS CUSHIONED FLUE COVERS



The above illustration shows the application of the Asbestos Cushion to the Seating Blocks and Side Flue Covers.

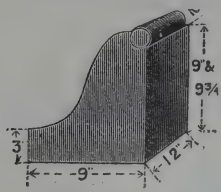
PREVENTS SHORT-CIRCUIT OF HEAT TO STACK.

E. J. & J. PEARSON, Ltd.,
Firebrick Makers,
STOURBRIDGE.

F. 1712

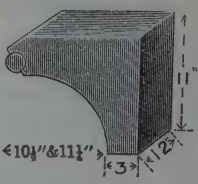
MODERN METHODS OF SETTING STEAM BOILERS BASED ON EFFICIENCY.

PATENT ASBESTOS CUSHIONED SEATING BLOCKS.



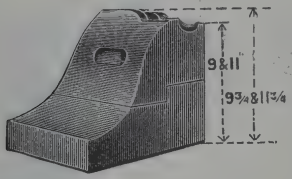
No. 1. Short 9"; Long 9¾"

PATENT ASBESTOS CUSHIONED FLUE COVERS.



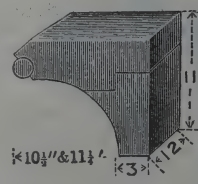
No. 11. Short 10½"; Long 11¼"
With or without Pyrometer hole.

PATENT ASBESTOS CUSHIONED SEAM INSPECTION SEATING BLOCKS



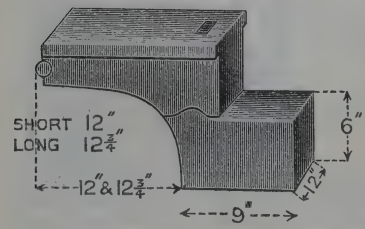
No. 3. For 9" & 9¾" Seating Block, Right hand. Made also Left hand to match.

PATENT ASBESTOS CUSHIONED SEAM INSPECTION FLUE COVERS



No 11. Short 10½"; Long 11¼"

PATENT ASBESTOS CUSHIONED REMOVABLE FLUE COVER



Alternative top portions of cover are spigoted and rebated.

Also made for Side Flues 9" wide
Short 9" Long 9¾"

PATENT INTERLOCKING ARCH BRICKS AND MANHOLE BLOCKS FOR DOWNTAKES.

N.B.—All the above can be obtained from stock. We also supply all types and patterns.

E. J. & J. PEARSON, Ltd., STOURBRIDGE.

F. 1713

BOILER LEGISLATION.

The Boiler Explosions Acts, 1882 (45 & 46 Vic. ch. 22) and 1890 (53 & 54 Vic. ch. 35) provide for inquiry into boiler explosions. The Acts extend to the whole of the United Kingdom. The term 'boiler' means any closed vessel used for generating steam, heating any liquid, or receiving steam for heating, steaming or boiling, excepting boilers used exclusively for domestic purposes or in the service of his Majesty. On the occurrence of a boiler explosion, notice must be sent within 24 hours to the Board of Trade by the owner, user, or person acting for him. This notice to state the name of premises or works, postal address, day and hour of explosion, number of persons killed and injured, description of boiler, purpose used for, particulars of failure, working pressure, by whom last inspected, and by whom insured.

The Act of 1890 makes the Act of 1882 applicable to sea and mine boilers.

The judgment of the court of enquiry into the Greenwich explosion of Christmas 1906 has made it a serious matter for engineers who have not acquired the necessary experience by training to assume responsibility for steam boilers. Steam engineers should be in charge of steam plant and machinery, is the lesson of the verdict in that case.

BOILER FITTINGS.

Injectors.

To Compute the Diameter of Throat and Volume of Discharge.

d=diameter of throat in millimetres; V=volume of water required per hour in gallons
P=pressure of steam in pounds per sq. in.

$$d = \cdot 709 \sqrt{\frac{V}{\sqrt{P}}} \qquad V = 1 \cdot 985\ d^2 \sqrt{P}.$$

Example.—The pressure of steam is 200 lbs., and the volume of water required to be delivered per hour is 1,010 gallons.

Then $\cdot 709 \sqrt{\frac{V}{\sqrt{P}}} = \cdot 709 \times 8 \cdot 45 = 6$ mms.; and $1 \cdot 985\ d^2 \sqrt{P} = 1 \cdot 985 \times 36 \times 14 \cdot 142 = 1{,}010$ gals.

The above particulars apply to all properly proportioned live steam injectors.

The Penberthy Patent Injector.

The 'Penberthy' Injector (fig. 71) is a perfectly automatic arrangement; by this is meant that when the injector is working and forcing water to the boiler, if the current of water be suddenly broken by any cause, such as a sudden jar or jolt in the case of a traction engine or road roller,

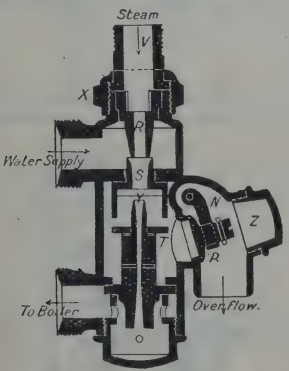


Fig. 71.

R, steam jet; O, plug; N, overflow hinge; S, suction jet; V, tail pipe; P, overflow valve; Y, delivery jet; X, coupling nut; Z, overflow cap.

or in the case of a marine boiler by the rolling of the vessel throwing the sea-cock out of the water for a moment, the injector will pick up the water and again establish the current to the boiler automatically, *i.e.* without the manipulation of a single valve or the least attention from an attendant. It is this quality which has made the 'Penberthy' so popular among marine

engineers and which has led to its adoption by the great majority of the traction and threshing engine manufacturers.

The Penberthy delivers water to boiler at 160° to 212° Fahr., according to temperature and steam pressure; but 200° to 211° can always be delivered at nearly all pressures over 50 lbs. by throttling the suction valve and delivering the minimum capacity.

The injector is made in fifteen sizes, from ⅜ in. to 2½ ins., and it is also supplied in three distinct styles to suit various positions. The maximum quantity delivered is from 80 to 4,200 gallons per hour according to size, and it is applicable to boilers up to 600 h.p. Sizes AA to CC are especially supplied for traction, portable, and ploughing engines. It is most efficient at the pressures of 50 to 80 lbs. (when with the valve wide open it will lift 20 ft.), although it will work at a lower pressure and also up to as high as 180 lbs. under favourable conditions. It is suitable for all classes of boilers. A *low-pressure* non-lifting pattern is supplied for steam pressures below about 20 lbs.; these injectors will start at from 1 to 3 lbs. steam pressure where water is taken from a barrel or tank at, or just above, the level of the injector. With water pressure of 20 lbs. they will start at from 10 to 12 lbs. low steam, but with two globe valves in water-supply pipe the pressure can be reduced and injectors started at correspondingly lower pressures.

A special pattern (Nos. 328, 332) also is being made in ½ in., ¾ in., and 1 in. sizes, for very high pressures—namely, up to 200 lbs. No. 328 AA. is used extensively for steam wagons and tractors.

For pressures to 240 lbs., and for hot-feeds, the Auto-positive type is supplied. This type has fine working parts, and combines the features of both the positive and the automatic injector.

Over one million of the Penberthy Injectors are in use.

POWER AND CAPACITY OF PENBERTHY INJECTORS.

Size.	Horse-power.	Pipe Connections.	Capacity per Hour. 1 to 3 ft. lift, 60 to 110 lbs. Steam Pressure.	
			Maximum.	Minimum.
O O.	4 to 8	⅜ inch	80 gallons	45 gallons.
A.	8 „ 16	½ „	135 „	70 „
A A.	12 „ 22	½ „	180 „	100 „
B.	17 „ 32	¾ „	260 „	140 „
B B.	20 „ 45	¾ „	360 „	180 „
C.	40 „ 65	1 „	475 „	300 „
C C.	45 „ 80	1 „	600 „	350 „
D.	50 „ 100	1¼ „	800 „	425 „
D D.	75 „ 135	1¼ „	1,000 „	525 „
E.	100 „ 180	1½ „	1,400 „	800 „
E E.	115 „ 255	1½ „	1,900 „	900 „
F.	160 „ 320	2 „	2,400 „	1,300 „
F F.	200 „ 400	2 „	3,000 „	1,600 „
G.	300 „ 500	2½ „	3,600 „	2,000 „
G G.	375 „ 600	2½ „	4,200 „	2,500 „

(W. H. Willcox & Co. Ltd.)

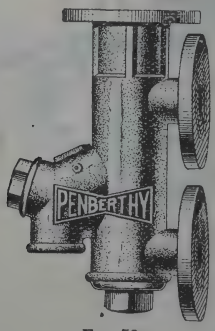


FIG. 72.

Owing to the increasing use of flange connections in this country, especially on fine works, the Penberthy Injector is now made up with flanges as shown in fig. 72. The working qualities

of the flanged injector are only slightly different from those of the screw-nipple machine, except that by the different construction of the body the high working pressure is brought up to 180 to 185 lbs. The injector with flanges is connected and operated in precisely the same manner as the injector with screw nipples. It is made in all sizes except ¼ and ⅜ in.

TABLE OF FLANGED PENBERTHY INJECTORS.

Size No.	Pipe Connections.	Diam. of Flanges.	Thickness of Flanges.	* Gallons of Water delivered to Boiler per Hour on 100 to 120 lbs. Steam Pressure, 3 ft. lift.	Horse-power.
	Ins.	Ins.	Ins.		
228	½	2 9/16	⅜	180	12 to 22
230	¾	3 5/16	7/16	355	20 „ 45
232	1	4 5/16	½	600	45 „ 80
234	1¼	5 ½	½	1000	75 „ 135
236	1½	5 ½	9/16	1900	115 „ 255
238	2	6 13/16	9/16	3000	200 „ 400
240	2½	7 13/16	11/16	4200	375 „ 600

(*W. H. Willcox & Co. Ltd.*)

* These capacities can be reduced 40 per cent. by regulating water supply valve.

WILLCOX'S EJECTOR STEAM-JET PUMP OR WATER RAISER.

This ejector, fig. 73 (*W. H. Willcox & Co. Ltd.*), will lift water 20 ft. with any steam pressure above 25 lbs., and 25 ft. with pressure at 40 lbs. or over. On pressures above 80 lbs.

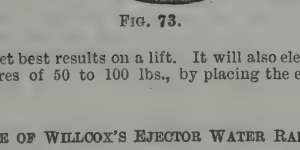


FIG. 73.

steam must be throttled to get best results on a lift. It will also elevate 50 ft. at 60 lbs. pressure, and 65 to 100 ft. on pressures of 50 to 100 lbs., by placing the ejector within 12 to 18 ins. of water supply.

TABLE OF WILLCOX'S EJECTOR WATER RAISERS.

Size Nos.	1	2	3	4	5	6	7	8	9	10
Pipe connection, steam . ins.	⅜	½	¾	1	1	1¼	1½	2	2	2½
„ suction and delivery „	½	¾	1	1¼	1½	2	2½	3	3½	4
CAPACITY PER HOUR.										
40 to 65 lbs. Steam, 3 ft. lift, gall.	240	500	840	1,350	1,950	3,500	5,700	9,500	13,600	18,400
20 „ 40 „ or 65 to 100 lbs. „	235	450	700	1,300	1,850	3,000	4,350	8,160	12,400	17,100
40 „ 65 „ 50 ft. elevation „	120	250	420	650	975	1,750	2,500	4,750	6,800	9,200
40 „ 65 „ 25 ft. „ „	180	375	625	950	1,450	2,600	3,750	7,200	10,200	13,800
VERTICAL LIFT.										
40 to 75 lbs. Steam . . ft.	23	25	25	25	25	25	25	25	25	25
25 „ 40 „ or 75 to 100 lbs. „	20	22	22	22	22	22	22	22	22	22
Horse-power of Boiler . .	2 to 6			8 to 12			15 to 20		25 to 30	

The ejectors are also suitable for exhausting air from pumps to create vacuum, and are largely used for this purpose.

Notes on Injectors.

A very frequent cause of trouble is that by one means or another the injector becomes overheated and refuses to lift its water. This may be due to steam leaking past the check valve into the body of the injector, and then passing to the suction pipe, so that the latter becomes too hot. Under these conditions it is impossible to make the injector work. Another cause of overheating is sometimes to be traced to the proximity of the fitting to the hot boiler shell, which allows heat from the latter to pass to it by conduction and radiation. In the first case the remedy is to fit a well-made check valve, combined with a plug cock, between the injector and the boiler. This should be done, even if the former is designed with a self-contained back-pressure valve. Further, the plug cock should be shut off when the injector is not in use. In the second instance, it sometimes happens that an injector is employed which is fitted with its own back-pressure valve, and it is then bolted directly to the boiler. This is very bad practice, as a single valve is not dependable in the first place, and a further point is, that the injector is much too close to the hot boiler. This is a fruitful cause of trouble. Also, should anything go wrong with the injector, it is necessary to blow down the boiler before it can be put in order; whereas, with a combined check valve and plug cock, the latter can be closed, and the injector removed under steam.

An injector will not work satisfactorily if supplied with wet steam; therefore, in order to ensure that this is as dry as possible, it should be taken from the highest available point in the boiler.

Another defect sometimes arises through the check valve not having sufficient lift, or on account of some sort of obstruction in the delivery pipe. The effect of this is that the injector will lift the water, but on account of the greater pressure due to the obstruction against which it has to work, it will be unable to force the water into the boiler, which will consequently find an escape through the overflow instead.

In some cases the water supply to the injector is taken from a tank placed beside the boiler, on the boiler-house floor, the supply to the tank being from an external source, and controlled by a ball cock with a float attached, so that the level of the water in the supply tank is constant. This is a very satisfactory arrangement. In other instances the source of supply may be some little distance away, and connected to the injector by means of pipes. Further, if the water is taken from a well the level may vary between considerable limits. Hence, when purchasing an injector, it is of the utmost importance that the manufacturer should be given all possible data, such as the greatest static head and the length of pipe with the number of bends, so that he can obtain the total suction lift and supply an injector to suit the conditions.

Much trouble will be experienced if the feed-water is allowed to become hot. The lower the temperature the better. There are many so-called hot-water injectors, but even these will not prove very satisfactory if the temperature of the feed-water is allowed to rise too near to the maximum temperature specified by the makers. In order to prevent as much as possible any rise in temperature, it is of the greatest importance that the overflow from the injector should not be allowed to drain back into the feed-tank. An overflow pipe should be fitted that will lead this hot water clear of the feed supply. Such a pipe should not be closed, but should enter an open cup, similar to the overflow of the circulating water in a gas-engine jacket. It is then under constant observation of the man in charge, and if any irregularity occurs it is quickly detected.

Occasionally an injector will refuse to work, due to a leak in the suction pipe. If this defect is present it may be located by fixing a plug in the suction pipe and opening the steam supply to the injector, when the position of the leak will be easily detected.

Lastly, dirt and grit are a source of trouble at times. To prevent this as far as possible, a straining rose should be fitted to the suction pipe. This will not exclude all grit, and occasionally small grains of solid matter suspended in the feed-water will find their way through and lodge on the internal surface of the injector. Also if the water contains soluble salts of magnesium and calcium, it becomes heated on passing through the injector, and some of these salts are deposited, forming incrustations which may cause the injector to refuse to work, either because it has become totally choked up, or else small particles of the incrustations may break away and become lodged under the back-pressure valve or check valve and prevent its closing, when the injector will refuse through overheating.

It is always advisable to keep a spare injector in stock, and if the water contains a considerable amount of impurity, instructions should be given to change the injector at regular periods. The length of time that one should be allowed in continual service must be governed by experience with the particular conditions under consideration. In order to loosen the deposit the injector may be left to soak in diluted hydrochloric acid.

If the above very easily followed points are given attention, injectors will be found most reliable, and few complaints will be heard.

(*'Mechanical World.'*)

SAFETY VALVES.

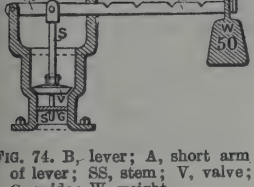


FIG. 74. B, lever; A, short arm of lever; SS, stem; V, valve; G, guide; W, weight.

WEIGHT ON SAFETY VALVES.

If A = area of valve in sq. ins., P = pressure in lbs. per sq. in., l_1 = distance of valve from fulcrum, l_2 = length of lever, w_1 = weight of lever in lbs., l_3 = distance of centre of gravity of lever from fulcrum, w_2 = weight of valve and stem in lbs.

Then W, the weight required at the end of the lever,

$$= \frac{P \times A \times l_1 - w_1 \times l_3 - w_2 \times l_1}{l_2}.$$

SAFETY VALVE AREAS.

Since the steam production of a boiler is sensibly the same at all pressures, and since the density of steam increases very nearly as the pressure, and since steam escapes at an outlet at practically constant volume, it appears that safety valves, like boiler stop valves, may be reduced in size as pressure increases. Ordinary valves have a very small lift. Special valves in which the steam reaction is utilised to increase the lift will give a much greater opening. If a valve lift a height equal to a fourth of its diameter the area of opening is equal to the valve area, and no greater lift would give greater output.

It is not sufficiently well known that boilers working at a low pressure require larger safety-valves than boilers at a high pressure. Thus, for example, a boiler working at 15 lbs. by the steam gauge requires three times the area of safety valve opening that is required by a boiler at 75 lbs. This is the more important when it is remembered that in a boiler which is safe only at low pressure, an additional 15 lbs. pressure doubles the strain, whilst in the boiler at 75 lbs. a rise of 15 lbs. adds but a fifth to the stress on the plates. This point as to the safety-valves on old low-pressure boilers is too little known or recognised.

Safety-valve areas should be inversely as the absolute pressure.

In well-proportioned dead-weight safety valves it is usually expected that if a pressure of 60 lbs. per sq. in. opens the valve, a pressure of 70 lbs. will keep it sufficiently open for the escape of all the steam produced.

The former Board of Trade rules are largely followed, and as they are more detailed, bringing out many points of importance, extracts are given below, also extracts from the rules of Lloyd's and Bureau Veritas.

BOARD OF TRADE RULES FOR SAFETY VALVES.

The area per square foot of fire-grate surface of the locked-up safety valves for boilers with natural draught should not be less than that given in the table (page 1719) opposite the boiler pressure intended, but in no case should the valves be less than 2 ins. in diameter.

When ascertaining the fire-grate area, the length of the grate should be measured from the inner edge of the dead plate to the front of the bridge, and the width from side to side of the furnace on the top of the bars at the middle of their length.

[*Note.*—The table corresponds to the formula $A = \frac{37 \cdot 5}{P + 15}$, where A = safety-valve area in sq. ins. per sq. ft. of grate, and P = pressure in lbs. per sq. in.]

Where forced draught is used, the area should not be less than $\frac{A}{20} \times$ estimated coal consumption in lbs. per hour per sq. ft. of grate.

The safety valves should be fitted with lifting gear, so arranged that the two or more valves on any one boiler can at all times be eased together, without interfering with the valves on any other boiler. The lifting gear should in all cases be arranged so that it can be worked by hand either from the engine-room or stoke-hole.

Care should be taken that the safety valves have a lift equal to one-fourth their diameter; that the openings for the passage of steam to and from the valves, including the waste-steam pipe, have each an area not less than the area according to the table; and that each valve box has a drain pipe fitted at its lowest part.

In the case of lever valves, if the holes in the lever are not bushed with brass, the pins must be of brass; iron and iron working together must not be used.

Too much care cannot be devoted to seeing that there is proper lift, also that free means of escape for the waste steam are provided, as it is obvious that unless the means for escape of the waste steam are ample, the effect is the same as reducing the area of the valves or putting an extra load upon them. The valve seats should be secured by studs and nuts.

At least two valves should be fitted to each boiler.

The springs and valves must be so cased in that they cannot be tampered with.

Provision must be made to prevent the valves flying off in case of the springs breaking.

The requisite safety-valve area must be cased in and locked up in the usual manner of the Government valves.

The size of the steel of which the springs are made must be in accordance with that found by the following formula.

$$d = \sqrt[3]{\frac{L \times D}{C}};$$

where,

L = load on the spring, in pounds;
D = diameter of the spring—from centre to centre of wire—in inches;
d = diameter, or side of square, of the wire in inches:
C = a constant, being 8,000 for round and 11,000 for square steel.

The springs must be protected from the steam and impurities issuing from the valves.

When valves are loaded by direct springs, the compressing screws must abut against metal stops or washers, when the loads sanctioned by the surveyor are on the valves.

The springs must have a sufficient number of coils to allow a compression under the working load of at least one quarter the diameter of the valve.

Spring-loaded valves are tested under full steam and full firing for at least twenty minutes with the feed-water shut off and stop-valve closed.

When the valves are of novel design, and the accumulation of pressure exceeds 10 per cent. of the loaded pressure, the case has to be specially reported upon by the surveyor.

Lloyd's Rules for Safety Valves.

(Abridged.)

At least two safety valves are to be fitted to each boiler, arranged so that springs and valves are cased in, that valves cannot be overloaded while steam is up, that the valves can be lifted by easing gear and turned round on their seats, and that valves cannot lift out of their seats if the springs break.

Vertical boilers with 100 square feet or more of heating surface to have two safety valves each not less than 1·5 in. diameter; those with less than 100 square feet heating surface one valve not less than 2 ins. diameter.

All safety valves of one boiler may be fitted in one chest connected direct to boiler by passage having cross-sectional area not less than half the aggregate area of the valves. Valve chest to be drained. The minimum aggregate area of safety valves of a boiler, coal- or oil-fired, in square inches

$$= \text{total heating surface of boiler in square feet} \times \frac{C}{p + 15},$$

where

p = pressure in lbs. per square inch;
C = 1·25 for boilers using coal;
C = 1·5 for boilers using oil and for those with closed stokehold forced draught.

Waste-steam pipe to have area not less than 1·1 times area given by above formula.

Safety valves to be set under steam. During test of fifteen minutes with stop valve closed and full firing conditions accumulation of pressure is not to exceed 10 lbs. per square inch.

Bureau Veritas Rules and Regulations for Safety Valves.

At least two spring safety valves of an approved design must be fitted to each main boiler.

The total area of the safety valves is given by the formula

$$A = \frac{8{\cdot}7}{\sqrt[4]{(P - 18)^3}},$$

where

A = sectional area of safety valve in sq. ins. per sq. ft. of grate surface; P = working pressure in lbs. per sq. in. No safety valve to be less in diameter than 1¼ in.

When forced draught or oil fuel is provided for, the area is to be increased in proportion to the increased evaporative power of the boilers.

Suitable arrangements and gear to be fitted in connection with the safety valves, whereby they may be lifted from the deck as well as from the stoke-hole floor.

BOARD OF TRADE RULES AND REGULATIONS FOR STEAMSHIPS.

SAFETY-VALVE AREAS. (*Abridged Table.*)

Boiler Pressure.	Area of Valve per Square Foot of Fire-grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire-grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire-grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire-grate.
Lbs.	Sq. Ins.	Lbs.	Sq. Ins.	Lbs.	Sq. Ins.	Lbs.	Sq. Ins.
15	1·250	62	·487	109	·302	156	·219
16	1·209	63	·480	110	·300	157	·218
17	1·171	64	·474	111	·297	158	·216
18	1·136	65	·468	112	·295	159	·215
19	1·102	66	·462	113	·292	160	·214
20	1·071	67	·457	114	·290	161	·213
21	1·041	68	·451	115	·288	162	·211
22	1·013	69	·446	116	·286	163	·210
23	·986	70	·441	117	·284	164	·209
24	·961	71	·436	118	·281	165	·208
25	·937	72	·431	119	·279	166	·207
26	·914	73	·426	120	·277	167	·206
27	·892	74	·421	121	·275	168	·204
28	·872	75	·416	122	·273	169	·203
29	·852	76	·412	123	·271	170	·202
30	·833	77	·407	124	·269	171	·201
31	·815	78	·403	125	·267	172	·200
32	·797	79	·398	126	·265	173	·199
33	·781	80	·394	127	·264	174	·198
34	·765	81	·390	128	·262	175	·197
35	·750	82	·386	129	·260	176	·196
36	·735	83	·382	130	·258	177	·195
37	·721	84	·378	131	·256	178	·194
38	·707	85	·375	132	·255	179	·193
39	·694	86	·371	133	·253	180	·192
40	·681	87	·367	134	·251	181	·191
41	·669	88	·364	135	·250	182	·190
42	·657	89	·360	136	·248	183	·189
43	·646	90	·357	137	·246	184	·188
44	·635	91	·353	138	·245	185	·187
45	·625	92	·350	139	·243	186	·186
46	·614	93	·347	140	·241	187	·185
47	·604	94	·344	141	·240	188	·184
48	·595	95	·340	142	·238	189	·183
49	·585	96	·337	143	·237	190	·182
50	·576	97	·334	144	·235	191	·181
51	·568	98	·331	145	·234	192	·181
52	·559	99	·328	146	·232	193	·180
53	·551	100	·326	147	·231	194	·179
54	·543	101	·323	148	·230	195	·178
55	·535	102	·320	149	·228	196	·177
56	·528	103	·317	150	·227	197	·176
57	·520	104	·315	151	·225	198	·176
58	·513	105	·312	152	·224	199	·175
59	·506	106	·309	153	·223	200	·174
60	·500	107	·307	154	·221		
61	·493	108	·304	155	·220		

WATER GAUGES.

The breakage of a water-gauge glass in high-pressure steam boilers is fraught with danger, especially in places where the attendants are working in confined places from which it is difficult for them to escape, and any appliance which prevents the serious consequences arising from this cause is one of the most important and desirable safety fittings that can be attached to a steam boiler.

The Klinger High Pressure Water Gauge

(Richard Klinger, Ltd., 120 Southwark Street, London, S.E. 1.)

The latest type of this well-known gauge (fig. 75) is suitable for working pressures up to 1,000 lbs. per square inch, the great advantage of which is that it can be entirely dismantled whilst the boiler is under steam. This is made possible by the inclusion of an auxiliary plug, which can be screwed right home, thus shutting off the water and steam.

It is impossible to make a mistake in reading the gauge, as the water shows black and the steam silver.

These gauges can be supplied tipped forward at an angle of 30° for Babcock & Wilcox, Stirling, Vickers, and Thompson water-tube boilers.

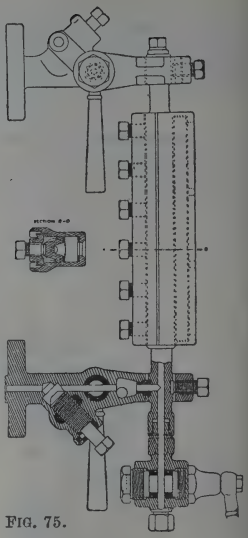


Fig. 75.

Fig. 76.

Hulburd's Cartridge Sight Glasses.

(Patent.)

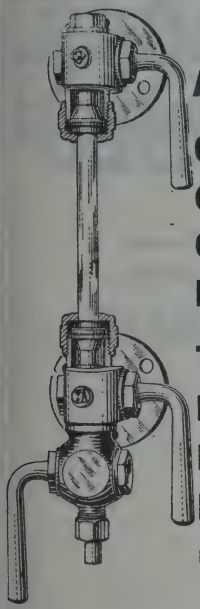
This (fig. 76) is a neat and efficient device for protecting and rapidly removing and replacing sight glasses in water gauges and sight-feed lubricators. In Hulburd's make of gauge frames and lubricators the glasses are packed at leisure in metallic guards or sheaths, each thus forming a self-contained 'cartridge' from which the system derives its name. In the event of breakage of a glass the complete cartridge, containing the broken fragments, is easily withdrawn while under steam, and a new one readily inserted in its place. The metallic guard or cartridge case enables all splinters of glass to be removed without danger to attendants, and permits the immediate screwing up of the gland nuts without the possibility of fracture, the metallic cartridge case receiving the gland pressure and completely protecting the glass tube within it. Suitable windows are provided in the cartridge case of ample size to afford an unobstructed view of the glass tube and contents, and in the case of gauges the back is arranged as a water level indicator of special design, which shows with peculiar distinctness the height of the water column and makes it impossible to mistake an empty glass for a full one.

'Woodite' Packing.

The material known as 'Woodite' (*The Woodite Co.*) is of a special secret composition to resist the action of high or low pressures, whether of steam or water, and is impervious to acidulated or other chemically impure fluids. 'Woodite' is made to any shape or size and of a quality or flexibility to suit the service to which it is to be applied. It has been extensively employed for conical gauge-glass rings, packing rings, pump valves, hydraulic packings, gaskets, etc., with most satisfactory results. The chief advantages of the Woodite conical gauge-glass and packing rings for steam users are their ease of application or renewal, the maintenance of a perfectly tight joint, the entire avoidance of unnecessary pressures on the glasses or rods, which causes breakages in the former and excessive friction in the latter, and the elimination of the dangers incident to steam or water passages becoming choked in the case of gauge glasses. On large slow-moving boiler feed-pumps these conical packing rings have shown excellent results and economy, working at 185 lbs. steam pressure with superheat, the piston rods being $3\frac{3}{8}$ ins. diameter.

Ordinary valve spindles packed with these packings will always be found free to move, no matter how long the valve has been idle.

WOODITE GAUGE GLASS RINGS.



Absolutely reliable for water and steam pressures.

Greatly prolong life of Gauge Glasses.

Overcome breakages due to excessive pressure.

Only require a few moments to install or renew.

Do away with all digging out of old packings.

The glass is only subjected to boiler pressures.

Hindrances to free passage of water or steam avoided

Impossible to overpack as with other packings.

Never adhere to nor corrode the glass.

Give ideal results under all conditions.

Data required—Internal and external (bottom of thread) diameter and depth of stuffing boxes, also outside diameter of gauge glass.

Adopted by H.M. Navy, War Dept., Foreign Navies, and most of the leading Steamships and Railway Companies in all countries as well as by Manufacturers and Steam Users generally.

THE WOODITE COMPANY, LTD.,

MITCHAM COMMON,

SURREY, ENGLAND.

Also Woodite for Pump Cups, Hydraulic 'U' Rings, Pump Valves Gaskets and Joints of all kinds, Sheeting, Hose, Belting, etc.

F. 1720

"EUREKA"
GAUGE GLASSES

ESTABLISHED 1853.

Makers of the New "HERCULES" High-Pressure
Gauge Glass for Special High-Pressure Boilers.

MAKERS OF STEAM GAUGES.

PRESSURE AND INDICATING
GAUGES OF ALL DESCRIPTIONS

JOSEPH TOMEY & SONS, Ltd.,
Aston, BIRMINGHAM.

F. 1721

Defects in Water Gauges.

As ordinarily fitted, the gauge is usually attached directly to the boiler and provided with three taps, one connecting to the steam space, the second to the water space, and the third controlling the discharge to atmosphere. The latter should always discharge inside the boiler-house, where the effluent can be seen, and not be as it sometimes is, with a mistaken idea of cleanliness, coupled to a waste pipe, led outside, where the evidence of its action is not visible when the attendant opens the tap. It is of value to have duplicate gauges, as the cost is comparatively trifling, and one gauge serves as a check on the other. All three taps should be tested independently, that is to say, the bottom tap should be shut while the top one is opened and *vice versâ*, the top one shut while the bottom is opened, so as to give a thorough 'blow through' of the steam and water connections to the boiler. Unless this is done there is no certainty of the gauge being in working order, while there is risk of the top and bottom connections becoming choked and causing a false reading. More than one serious accident has been traced to defects in the taps themselves, owing to the holes in the plugs of the taps not coinciding with the thoroughfare of the fitting, so that when the position of the handle suggests the tap is open it is in reality nearly closed. Another cause of false readings is the blocking of the passage in the glass tube through the indiarubber packing ring working over the ends of the glass, owing to the glass being cut too short and the gauge not being provided with a nipple in the bottom of the gland to protect the glass against this risk. Having regard to the serious results which may attend overheating from shortness of water, it is advisable whenever possible to supplement the water gauge with a fusible plug, and if the boiler is a large one, with a low-water safety-valve as well. (*Mechanical World.*)

Gauge Glasses.

It is important to have the fittings exactly in line with each other, and to have them large enough so as not to cause the glass to bind or to be cramped in the least. When the fittings are not in line the glass is apt to be cramped either when putting it into the sockets in the fittings or when tightening the packing nuts. Wrenches should not be used for tightening the packing nuts around the gauge glass. When a glass is packed with the proper kind of packing and the nuts have been screwed up just tight enough to prevent leakage when both the glass and the packing have been warmed, the glass may readily be turned around in the fittings with merely the thumb and forefinger.

After putting in a new glass turn on a very little steam, leaving the drip at the bottom of the glass open so that the steam will gradually fill the glass and escape through the drip-cock. The glass is thus warmed thoroughly before the water is let into it and before it is subjected to pressure. When the glass has become thoroughly hot, open the steam valve wider, then open the water valve a like amount, and continuing to open both valves alike until fully open, then slowly close the drip at the bottom. This method not only allows the fittings to be thoroughly blown out, but enables the operator to increase the pressure on a new glass and new packing more gradually. It is best to anneal all the glasses before using them. This is generally accomplished by means of a water and steam bath, the water and the glasses being heated by steam. It is cheaper in the long run to cut glasses with a gauge-glass cutter than to attempt to cut or break them off with a broken file, or by similar means, because a slight nick in the glass at the wrong place may mean the early destruction of the glass when subjected to pressure and varying temperature. Some engineers fit a thin brass or copper thimble into the upper end of the tube, as shown in fig. 77, which prevents scale and water

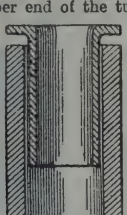


Fig 77.

Fig. 78.

from coming in contact with the glass when blowing out the latter, and hence it reduces the eroded and pitted appearance commonly seen at the upper end of unprotected glasses. Tubes made of aluminium may be obtained of dealers in engineers' supplies which accomplish the same result.

These tubes and thimbles, it will be seen, protect the inner surfaces of the glass only, and as the glass is liable to be crowded to one side or the other in the packing nut as well as in the fitting itself, it is a good plan to also protect the glass on the outside.

A simple means of protecting the glass on the outside is also obtained from dealers in gauge glasses. The arrangement consists of a rubber sleeve adapted to slide over the end of the glass, as shown in fig. 78. The glass cannot come in contact with the socket in the fitting, neither can the packing nut touch the glass when the packing is screwed up. The combination

the thimble and the latter device prevents the rapid wear of the glass at the top, and also retains the glass clear of all metallic contacts, which has been found to be very desirable where glasses are subjected to high pressure and temperature and sudden changes in the latter.

When the rubber protector is employed, separate packing rings are not needed, because the packing forms a part of the sleeve, as shown. Annealed gauge glasses protected inside and out by this or similar means will last as long under any circumstances as it is possible to make them by any means thus far made known.

If packing 'rings' are used, then in order to secure a tight joint with the least possible pressure, thus avoiding any tendency to break or to cramp the glass due to the packing, it is necessary to obtain a form of packing that will fit snugly in the space in the nut.

(*H. E. Waverly, 'Mechanical World.'*)

Superheated water acts on most varieties of glass as a violently corrosive agent, and for gauge glasses ordinary glass cannot be used. A special glass, under the brand 'Hercules,' to resist high pressure steam, is made by Joseph Tomey & Sons, Ltd., Birmingham. It is specially constructed of boro-silicate, and is made after the 'Jena' formula. The glass is practically white in colour and has withstood the following remarkable tests:—

After the glass had been submerged in iced water for five minutes it was plunged into molten lead, and showed no signs of fracture. It has withstood 4000 lbs. hydraulic pressure, and 750 lbs. steam pressure.

Although the glass was specially manufactured to meet the requirements of high-pressure and superheated boilers, it has been used for a great number of low-pressure boilers, because at low pressure the material is practically unbreakable and is considerably cheaper in the long run than the ordinary quality gauge glass.

Unbreakable Water Gauge.

A simple and effective form of water-level indicator which has all the advantages of the test cocks in checking the water level, but does not suffer from their disadvantages, has been patented by Messrs. Cammell Laird & Co., Ltd., and is being manufactured by Messrs. W. Crockatt and Sons, Ltd., of 64 Darnley Street, Glasgow. It consists of a perforated metal tube, and replaces the $\frac{3}{4}$-in. glass tube in an ordinary water-gauge mounting. The diameter of the holes is $\frac{1}{32}$ in. On the gauge cocks being opened, water issues from the hole below the water line in the form of a rapidly diverging white cloudy spray, well defined and readily distinguished. Steam, on the other hand, which issues from the holes above the water line, is only faintly visible and is hardly discernible. The steam jet is almost parallel and quite distinct in character from that of the water; a definite indication is therefore assured. The character of the water jet bears a distinct relation to the thickness of the wall of the tube; by reducing the thickness of the tube, the jet can be made to assume wider proportions. Good results are obtained by thinning the tube down to $\frac{1}{32}$ in. round a $\frac{1}{32}$ in. diameter hole. Much smaller holes than these, however, will give a perfectly visible jet.

PRESSURE GAUGES.

Apparatus for Testing Pressure and Vacuum Gauges.

(*Brotherhood's Patent.*)

This apparatus will test the accuracy of gauges at all steps on the scale instantaneously, independent of temperature variation, and does not rely on springs. A permanent accuracy

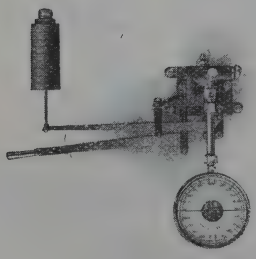


Fig. 79.

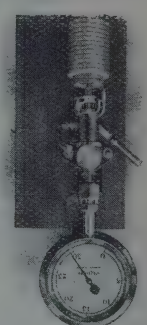


Fig. 80.

within $\frac{1}{2}$ per cent. is proved by official tests. In the pressure-gauge testing-machine a hand-operated oil pump supplies pressure below a ram which, while being entirely oil-tight under the highest pressure, will fall freely by its own weight when the pressure is released. For moderate

slowly, surely and silently the efficiency of your plant, robbing it of just that necessary power that makes THE DIFFERENCE BETWEEN PROFIT AND LOSS, and you have only yourself to blame. You can STOP THIS LOSS AT ONCE AND FOR ALL BY USING "KLINGERIT," the only jointing that has been proved under the most exacting tests to withstand high pressure, super-heat, hot oils, alkalis, acids and ammonia.

Forty years of rapid advancement in steam engineering still finds "KLINGERIT" far ahead of any other jointing for reliability and long life, a unique position that can only be maintained by rigid adherence to that quality which has made it the standard by which all other jointings are judged.

Somewhere in your plant there is need for "KLINGERIT."

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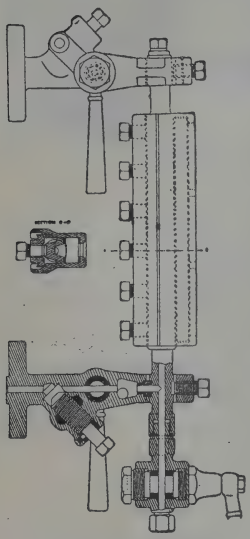
THE STANDARD "Klingerit" JOINTING OF THE WORLD

F. 1722

KLINGER

Gauges for Water, Oil, Spirit, etc.

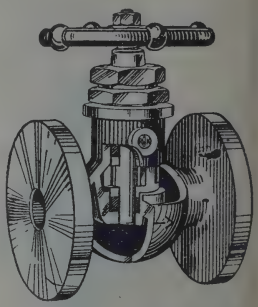


THE LATEST HIGH PRESSURE GAUGE

THE latest type is suitable for working pressures up to 1,000 lbs. per sq. inch, the great advantage of which is that it can be entirely dismantled whilst the boiler is under steam. This is made possible by the inclusion of an auxiliary plug, which can be screwed right home, thus shutting off the water and steam.

These gauges can be supplied tipped forward at an angle of 30 deg. for Babcock and Wilcox, Stirling, Vickers and Thompson water-tube boilers.

THE KLINGER "NO TROUBLE" VALVE



TESTED for over two years under the hardest working conditions met with in Power House, Factory and Engineering Works all over the country and proved to be a "no trouble" valve. *Some of the chief features:-*

NO SEAT
NO REGRINDING
NO SPINDLE STUFFING BOX

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F. 1723

pressures the ram lifts graduated weights direct, and for higher pressures, up to 6,000 lbs. per sq. in., weights are applied through a lever carried on hardened steel knife edges. This is shown in fig. 79.

In the vacuum-gauge testing-machine, shown in fig. 80, an oil-sealed pump exhausts the air in the space above the plunger and below the gauge. The readings being controlled by the absolute difference of pressure within and without the gauge, no correction for barometric or temperature conditions is needed. In this respect the machine possesses great advantages compared with the mercury column often employed.

The machines can be made for fixing to the wall or to stand on a shelf or table, and are enclosed in dust-proof boxes.

A certificate of the National Physical Laboratory can be supplied with each machine.

THERMOMETERS

Negretti & Zambra's Distance Thermometer.

(Patent.)

In all superheaters and boiler work, the registration of temperature is very important, and not only should the thermometer be accurate, but it should be legible and easy to read. The instrument, fig. 81 (*Negretti & Zambra*, 38 *Holborn Viaduct*, *London*, *E.C.* 1), which is claimed to effect the desired result, is actuated by distilled and purified mercury contained in a steel bulb connected by means of steel capillary tubing to a Bourdon tube to which is attached a pointer spindle. The special feature in the apparatus is the compensation of the capillary tubing, whereby any changes of temperature of the tubing itself do not affect the accuracy of the reading; an invar wire is run down the centre of the bore of the tubing so as to make the amount of mercury in the tube to be in the same proportion to the size of the steel tube as the expansion of mercury is to the expansion of steel: thus the tubing can be made red hot and any expansion of mercury will be taken up by the tube itself. Another important feature is the construction of the Bourdon tube which enables the pointer to be attached direct to the tube itself, thus eliminating all gears, hair-springs, levers, etc.

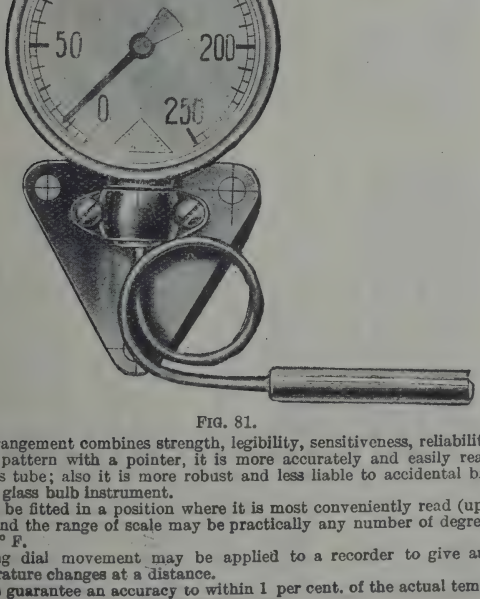


Fig. 81.

The whole arrangement combines strength, legibility, sensitiveness, reliability, and accuracy.

Being a dial pattern with a pointer, it is more accurately and easily read than a liquid column in a glass tube; also it is more robust and less liable to accidental breakages such as might occur in a glass bulb instrument.

The dial may be fitted in a position where it is most conveniently read (up to 100 ft. away from the bulb), and the range of scale may be practically any number of degrees on the dial or chart up to 1,000° F.

A transmitting dial movement may be applied to a recorder to give automatic written records of temperature changes at a distance.

The patentees guarantee an accuracy to within 1 per cent. of the actual temperature.

HOPKINSON'S STANDARD SPECIFICATIONS OF BOILER MOUNTINGS.

Fitting.	Description. Specification 'A—1928.' For Lancashire Boilers up to 120 lbs. Working Pressure and 8 ft. 6 ins. Diameter.	Description. Specification 'B—1928.' For Lancashire Boilers up to 160 lbs. Working Pressure and 8 ft. 6 ins. Diameter.	Description. Specification 'C—1928.' For Lancashire Boilers up to 200 lbs. Working Pressure and 8 ft. 6 ins. Diameter.
Safety Valves:	One Hopkinson's 'Duad' Safety Valve, fig. 7, for High Steam and Low Water, fitted with C.I. Valve Box, 'Platnam' Valves and Seats and C.I. Plate-Weights complete One 3-in. Hopkinson's Patent 'Ipsed' Safety Valve, fig. 10, for High Steam only, with parts subject to pressure in cast iron	One Hopkinson's 'Duad' Safety Valve, fig. 7, for High Steam and Low Water, fitted with C.I. Valve Box, 'Platnam' Valves and Seats and C.I. Plate-Weights complete One 2½-in. Hopkinson's Patent 'Ipsed' Safety Valve, 'Platnam' Valve and Seat, with Controlled Flow and Lock-up Weights, fig. 10, for High Steam only	One Hopkinson's 'Duad' Safety Valve, fig. 24, for High Steam only, with Cast-steel Valve Box, fitted with 'Platnam' Valve and Seat, and C.I. Plate-Weights complete One Hopkinson's Patent 'Sprised' Safety Valve, with Cast-steel Valve Box and Y Pipe and 'Platnam' Seats, Controlled Flow and Lock-up Weights, fig. 24, for High Steam only
Steam Valve:	One 7-in. Hopkinson's Patent 'Triad' Junction Valve, fig. 1000, with C.I. Body and Cover, 'Platnam' Valve and Seat	One 7-in. Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Hopkinson's 'Hipress' Cast-steel Body and Cover, fitted with 'Platnam' Valve and Seat	One 7-in. Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Hopkinson's 'Hipress' Cast-steel Body and Cover, fitted with 'Platnam' Valve and Seat
Feed Valve:	One 2½-in. Hopkinson's 'Accessible' Check Feed-Valve, fig. 1320, with C.I. Body and Cover, 'Platnam' Valves and Seats	One 2½-in. Hopkinson's 'Accessible' Check Feed Valve, fig. 1322, with Hopkinson's 'Hipress' Cast-steel Body and Cover, 'Platnam' Valves and Seats	One 2½-in. Hopkinson's 'Accessible' Check Feed Valve, fig. 1322, Hopkinson's 'Hipress' Cast-steel Body and Cover, 'Platnam' Valves and Seats
Blow-off Valve:	One 2½-in. Hopkinson's Parallel Slide Blow-off Valve, fig. 2540, bronze, with 'Platnam' Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion One 2½-in. Wrought-iron Box Key, fig. 6223, for ditto	One 2½-in. Hopkinson's Blow-off Valve, fig. 2540, bronze, 'Platnam' Metal Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion One 2½-in. Wrought-iron Box Key, fig. 6223, for ditto	One 2½-in. Hopkinson's Blow-off Valve, fig. 2540, bronze, 'Platnam' Metal Seats and Discs, Improved Locking Gland and Patent 'Oplok' Pinion One 2½-in. Wrought-iron Box Key, fig. 6223, for ditto
Water Gauges:	Two ¾-in. Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Hopkinson's Patent Safety Plugs and Shields (Class B) to 18-in. centres One Water-Level Pointer, fig. 6250, bronze	Two ¾-in Hopkinson's 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Hopkinson's Patent Safety Plugs and Shields (Class B) to 18-in. centres One Water-Level Pointer, fig. 6250, bronze	Two ¾-in. Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Hopkinson's Patent Safety Plugs and Shields (Class B) to 18-in. centres One Water-Level Pointer, fig. 6250, bronze
Steam Gauge:	One 10-in. Hopkinson's Steam Gauge, fig. 4000, graduated to 240 lbs., red mark at 120 lbs., with flanged asbestos-packed bronze cock and syphon, and Inspector's Gauge connection, fig. 4180	One 10-in. Hopkinson's Steam Gauge, fig. 4000, graduated to 320 lbs., red mark at 160 lbs., with flanged asbestos-packed bronze cock and syphon, and Inspector's Gauge connection, fig. 4180	One 10-in. Hopkinson's Steam Gauge, fig. 4000, graduated to 400 lbs., red mark at 200 lbs., with flanged asbestos-packed bronze cock and syphon, and Inspector's Gauge connection, fig. 4180

Fitting.	Description. Specification 'D—1928.' For a Cornish or Small Lancashire Boiler up to 120 lbs. Working Pressure.	Description. Specification 'W—1928.' For a 'Babcock & Wilcox' Water-Tube Boiler up to 200 lbs. Working Pressure.	Description. Specification 'S—1928.' For a 'Stirling' Water-Tube Boiler up to 200 lbs. Working Pressure.
Safety Valves:	One Hopkinson's 'Duad' Safety Valve, fig. 7, for High Steam and Low Water, fitted with C.I. Valve Box, 'Platnam' Valves and Seats, and Plate-Weights complete	One Hopkinson's Patent 'Ipsed' Valve, fig. 10, on each Boiler Drum	One Hopkinson's Patent 'Ipsed' Valve, fig. 10, on each Boiler Drum
(Alternative)	—	Hopkinson's Patent 'Dused' Valve, fig. 12, or the 'Sprised' Valve, fig. 24 High and Low Water Whistle Alarm, fig. 340, can be supplied if required	Hopkinson's Patent 'Dused' Valve, fig. 12, or the 'Sprised' Valve, fig. 24 High and Low Water Whistle Alarm, fig. 340, can be supplied if required
Steam Valve:	One 5-in. Hopkinson's Patent 'Triad' Junction Valve, fig. 1000, C.I. Body and Cover, with 'Platnam' Valve and Seat	One Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Body and Cover of Hopkinson's 'Hipress' Cast-steel and 'Platnam' Valve and Seat	One Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Body and Cover of Hopkinson's 'Hipress' Cast-steel and 'Platnam' Metal Valve and Seat
Feed Valve:	One 2-in. Hopkinson's 'Accessible' Check Feed Valve, fig. 1320, C.I. Body and Cover, with 'Platnam' Valves and Seats	'Accessible' Check Feed Valves, fig. 1377, with Body and Cover of Hopkinson's 'Hipress' Cast-steel and 'Platnam' Valves and Seats	2-in. Hopkinson's 'Accessible' Check Feed Valves, fig. 1322, with Body and Cover of Hopkinson's 'Hipress' Cast-steel and 'Platnam' Valves and Seats
Blow-off Valve:	One 2-in. Hopkinson's Blow-off Valve, fig. 2540, bronze, with 'Platnam' Seats and Discs, Improved Locking Gland and Patent 'Oplok' Pinion	2-in. Hopkinson's Blow-off Valves, bronze, fig. 2540, 'Platnam' Metal Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion	2-in. Hopkinson's Blow-off Valves, bronze, fig. 2540, 'Platnam' Metal Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion
	One 2-in. Wrought-iron Box Key, fig. 6223, for ditto	One 2-in. Wrought-iron Box Key, fig. 6223, for above	One 2-in. Wrought-iron Box Key, fig. 6223, for above
Water Gauges:	Two ¾-in. Hopkinson's Patent 'Equilibrium' Water Gauges, fig. 6540, bronze, which automatically shut off water when the glass breaks, fitted with Patent Safety Plugs and Shields (Class B) to 18-in. centres	Two sets ¾-in. Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Patent Safety Plugs and Shields to 19½-in. centres	Two sets ¾-in. Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Patent Safety Plugs and Shields to 18-in. centres
(Alternative)	One Water-Level Pointer, fig. 6250, bronze		
Steam Gauge:	One 10-in. Hopkinson's Steam Gauge, fig. 4000, and flanged asbestos-packed bronze cock and syphon, and Inspector's Gauge connection, fig. 4180	One 12-in. Hopkinson's Steam Pressure Gauge, fig. 4000, complete with massive bronze syphon and cock, fig. 4196	One 10-in. Hopkinson's Steam Pressure Gauge, fig. 4000, complete with bronze control cock, fig. 4242, and bronze angle control cock on drum, fig. 6621

HOPKINSON'S STANDARD SPECIFICATIONS OF BOILER MOUNTINGS—*continued*.

Fitting.	Description. Specification 'P—1928.' For a Dry-Back or Marine Type Boiler.	Description. Specification 'G—1928.' For a Clarke-Chapman Water-Tube Boiler up to 200 lbs. Working Pressure.
Safety Valves:	One Hopkinson's Patent 'Dused' Valve, fig. 12, for High Steam only, with parts subject to pressure in Cast-steel, 'Platnam' Valves and Seats	One Hopkinson's Patent 'Ipsed' Dead-weight Valve, fig. 10, for high steam only, on each boiler drum, with parts subject to pressure in Cast steel, 'Platnam' Valve and Seat
Alternative)	Hopkinson's Double Marine Spring Safety Valve, fig. 64, for high steam only	Hopkinson's Patent 'Dused' Valve, fig. 12, or the 'Sorised' Valve, fig. 24. High and Low Water Whistle Alarm can be supplied if required
Steam Valve:	One Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Hopkinson's 'Hipress' Cast-steel Body and Cover, 'Platnam' Valve and Seat	One Hopkinson's Patent 'Triad' Junction Valve, fig. 1004, with Hopkinson's 'Hipress' Cast-steel Body and Cover, 'Platnam' Valve and Seat
Feed Valve:	One 2½-in. Hopkinson's 'Accessible' Check Feed Valve, fig. 1374, with Hopkinson's 'Hipress' Cast-steel Body and Tee-piece, 'Platnam' Valves and Seats	One Hopkinson's 'Accessible' Check Feed Valve, fig. 1375, with Hopkinson's 'Hipress' Cast-steel Body and Cover, 'Platnam' Valves and Seats
Blow-off Valve:	One 2½-in. Hopkinson's Blow-off Valve, fig. 2540, bronze, with 'Platnam' Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion One 2½-in. wrought-iron Box Key, fig. 6223, for above	Three Hopkinson's Blow-off Valves, fig. 2540, bronze, with 'Platnam' Seats and Discs, Improved Locking Gland, and Patent 'Oplok' Pinion One wrought-iron Box Key, fig. 6223, for above
Water Gauges:	One Polished Bronze Pillar, Pattern B, fig. 6476, fitted with two sets Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, and Patent Safety Plugs and Shields also	Two sets ¾-in. Hopkinson's Patent 'Absolute' Water Gauges, fig. 6440, bronze, which automatically shut off both steam and water when the glass breaks, fitted with Patent Safety Plugs and Shields
Steam Gauge:	One 10-in. or 12-in. Steam Pressure Gauge, fig. 4000, with Pillar Syphon and Tester Bend for Inspector's Gauge, fig. 4197	One Hopkinson's Steam Pressure Gauge, fig. 4000, complete with bronze control cock, fig. 4242, and bronze angle control cock on drum, fig. 6621

NOTES.—When several boilers are connected in parallel, it is most important that Hopkinson's Patent Isolating Valves, figs. 6000 and 6005, should be used.

The Steam and Feed Valve sizes are to be chosen in accordance with the evaporation and steam pressure of the boiler.

Cast-steel Junction and Feed Valves can be supplied at an extra cost if preferred, in those cases where Cast-iron Valves are specified.

Safety Valves can similarly be supplied with the parts subject to pressure in cast steel, if preferred, at an extra cost.

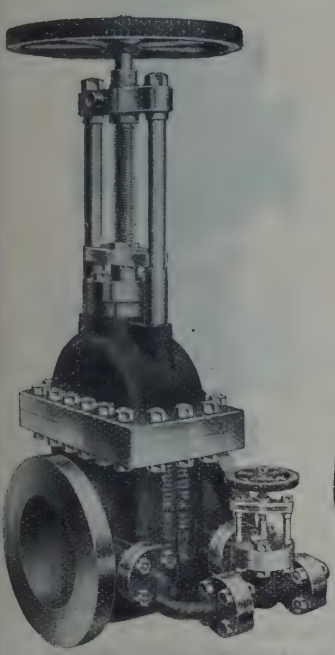
VALVES.

The large valves on the steam mains should each be provided with a small by-pass valve to enable a length of cold steam pipe to be warmed up, and the pressure balanced before the main valve is opened. This will prevent the straining of the joints caused by sudden expansion, and likewise accidents due to water hammer.

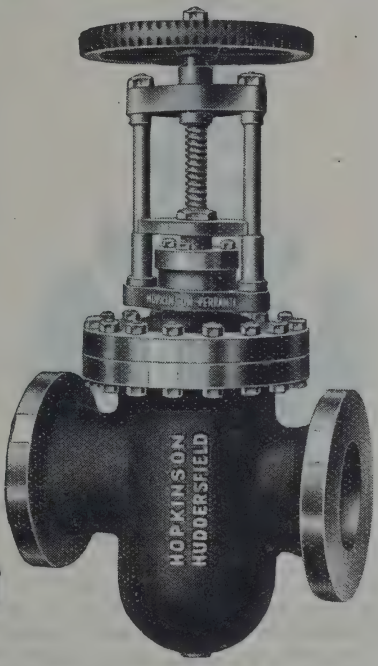
The outlet valve from the boiler should be at the highest point possible, so that there may be a fall from the valve towards the engine. There should not be a vertical pipe rising from the valve since this affords a pocket for water which will be dangerous should the drainage fail.

It has been suggested by W. H. Booth that since the loss of pressure in steam pipes is due to friction, there would be no very serious loss caused by a short length of less diameter placed in the course of a long pipe, and he suggests that the valves might be much smaller than the pipes, being connected to them by conical ajutages. These cones should not be isoceles but scalene, so that the floor of the valve should be in one level with the lower side of the pipe, thus allowing free flow of water. These small valves would greatly reduce the cost of the valve installation, especially where valves are numerous, as in the needlessly complicated pipe systems so much in vogue.

HOPKINSON'S
PATENT VALVES
FOR HIGHEST PRESSURES AND SUPERHEAT



HOPKINSON'S
Patent Fullbore Parallel Slide Valve
(with bye-pass Valve.)



HOPKINSON-FERRANTI
Patent Steam Stop Valve

FITTED WITH "PLATNAM" VALVES AND SEATS

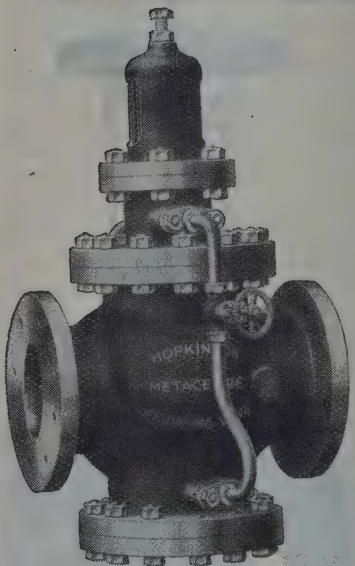
HOPKINSONS
LIMITED, HUDDERSFIELD.

TELEGRAMS "HOPKINSON HUDDERSFIELD"

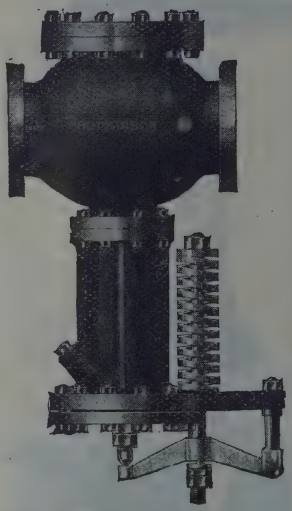
TELEPHONE HUDDERSFIELD 1269 (3 LINES)

Codes: A B C 5th Edition, Liebers, Western Union
LONDON: IMPERIAL HOUSE, KINGSWAY, W.C.2.

HOPKINSON'S
REDUCING VALVES
FOR ALL SERVICES



HOPKINSON'S
"Metacentre" Reducing Valve.



HOPKINSON'S
"Springus" Reducing Valve

Fitted with valves and seats of "PLATNAM" which is non-corrodible and practically indestructible.

"PLATNAM" is an exceptionally hard-wearing, heat-resisting alloy, retaining its special properties under the most severe working conditions.

HOPKINSONS
LIMITED,
HUDDERSFIELD.

TELEGRAMS "HOPKINSON - HUDDERSFIELD"

TELEPHONE HUDDERSFIELD 1269 (3 LINES)

Codes: A B C 5th Edition, Liebers, Western Union
LONDON: IMPERIAL HOUSE, KINGSWAY, W.C.2

Stop-Valves.

The Hopkinson-Ferranti Patent Stop Valve.

This valve (fig. 82) is designed to pass an amount of steam equal to the full carrying capacity of the pipe. The working parts of the valve are similar to those of the Patent Parallel Slide Valve, and are placed in the throat of a converging-diverging nozzle. The construction allows a large reduction in size, weight, and first cost, as compared with ordinary full-way valves.

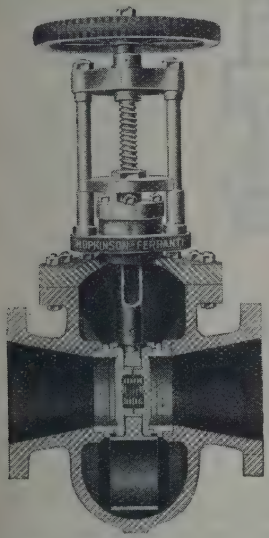


Fig. 82.

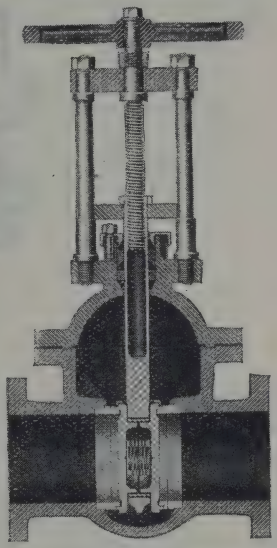


Fig. 83.

The design is such that a part of the pressure energy of the steam is converted into kinetic energy in the converging nozzle, the steam increasing in velocity and dropping in temperature and pressure. With the high velocity thus acquired the steam passes through the valve proper and enteres a diverging nozzle in which the kinetic energy is reconverted with an increase of pressure and temperature. The steam thus leaves the valve at the pressure, temperature, and velocity with which it entered the converging cone on the inlet side, the loss of pressure under normal conditions being negligible.

Hopkinson's Patent Fullbore Parallel Slide Valve.

This valve (fig. 83) is fitted with ' Platnam ' seats and discs which do not corrode or soften under high temperature of superheated or high-pressure steam.

There is no wedging action to cause unnecessary or dangerous strains or to make it difficult to open and close.

The valve when closed is held to its seat by fluid pressure and in opening and closing slides upon the seats with an equally uniform flexible pressure. The discs rotate on their axes, ensuring even wear and perfect condition of the valve faces. This valve is free from the mechanical strains usual in mushroom or wedge valves, being also fluid tight and easy to operate under varying pressures. It is fitted with Hopkinson's composite gland, which eliminates spindle gland leakage.

The Hopkinson-Ferranti Valve for steam is made in all the standard sizes from 4 inches to 24 inches diameter, with cast-iron or cast-steel body and cover in accordance with the pressure and temperature, and with ' Platnam ' disc and seats in all cases. Steam can be passed in either direction as required, the old pattern with unequal nozzles having been superseded. The principle is also applied to valves for water and air, and a number of special patterns are manufactured.

The 'Vee-Reg' Valve.

(*Engineering Specialists, Ltd., Craven House*, 121, *Kingsway, London, W.C.* 2.)

This valve, fig. 84, has a cylindrical sliding guide part (containing specially arranged triangula openings) that fits into the seat, the face of which is protected. As the valve is raised, there is no appreciable passage of steam or fluid until the faces are well apart, so when steam does pas

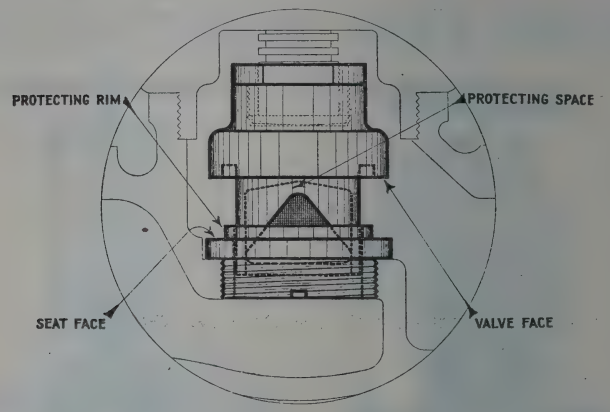


Fig. 84.

it is deflected from the faces. Thus the possibility of 'scoring' taking place is reduced to a infinitesimal degree. In addition, the triangular openings ensure a very fine control—a distinc advantage. The combination of the prevention of 'scoring' and the fine control ensures a very efficient and, incidentally, economical valve service. There are grades of these valves for al pressures from the lowest to the highest.

The Klinger Valve.

(*Richard Klinger, Ltd.*, 120, *Southwark Street, London, S.E.* 1.)

This valve (which is of quite novel design), fig. 85, consists of a piston sliding through tw flexible rings, generally of asbestos. A close contact on the piston is maintained when the ring wear, by tightening a form of gland in which the rings are held, but the rings are constructe so that no amount of pressure from this direction can displace them.

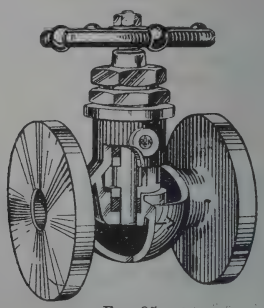


Fig. 85.

The permanent contact provided by the upper ring cuts off the working parts from the valv chest, avoids the necessity for the ordinary type of spindle stuffing box, and provides a perfectl steam-tight joint with very much less friction.

VEE-REG VALVES

THE VALVES THAT DO KEEP TIGHT

Specifically designed to eliminate valve troubles.

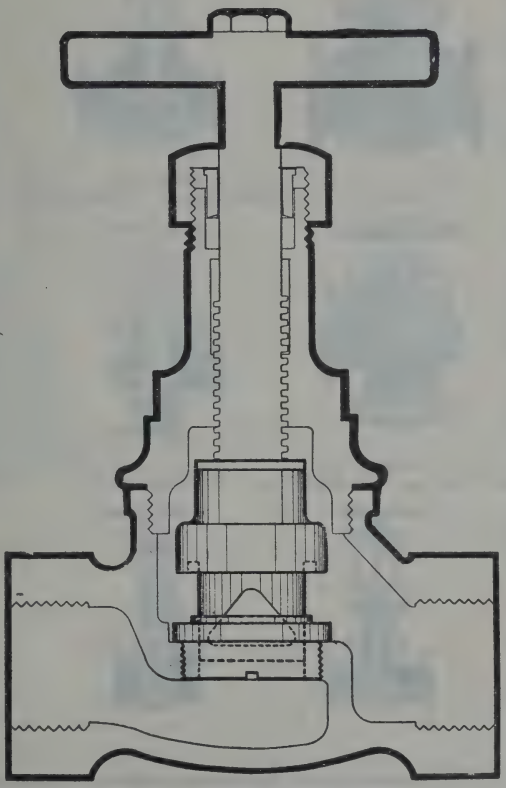
Protected Faces prevent "Scoring"

Regulating Action ensures Fine Control.

Stainless Steel Clacks and Seats.

Good Spindle Thread Engagement.

The valves that give you the service you often have wished to have.



ENGINEERING SPECIALISTS, LTD.

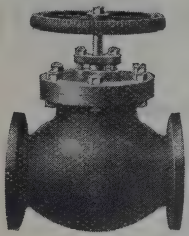
Craven House, 121 Kingsway, London, W.C.2.

HOLBORN 4210. FORWARDLY WESTCENT LONDON

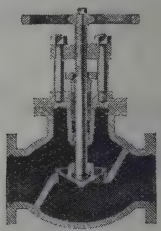
F. 1728

"Sentinel" Valves.

L.P. Stop Valve No. 200.
125 lbs. Working Pressure.



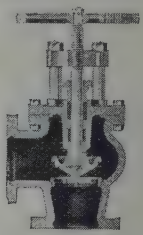
H.P. Stop Valve.
No. 206 Cast Iron. 200 lbs. Working Pressure.
No. 208 Cast Steel. 300 lbs. Working Pressure.



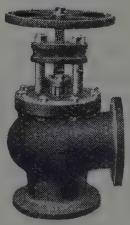
L.P. Stop Valve No. 201.
125 lbs. Working Pressure.

L.P Stop Valve No. 202.
125 lbs. Working Pressure

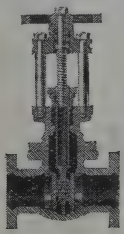
H.P. Stop Valve.
No. 207 Cast Iron. 200 lbs. Working Pressure.
No. 209 Cast Steel. 300 lbs. Working Pressure.



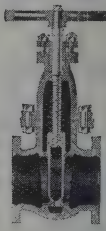
L.P. Stop Valve No. 203.
125 lbs. Working Pressure



H.P. Parallel Slide Valve
No. 260 Cast Iron. 200 lbs. Working Pressure.
No. 261 Cast Steel 100 lbs. Working Pressure



L.P. Sluice Valve No. 270.
125 lbs. Working Pressure.



L.P. Sluice Valve No. 275.
125 lbs Working Pressure.

258 Catalogue, giving dimensions, weights, prices, and other particulars of many types of "Sentinel" Valves, free on application.

Alley & MacLellan, Ltd.
Sentinel Valve Works. WORCESTER.

The piston when lowered into and through the bottom ring closes the valve, and is of such a length that wear due to wire-drawing action takes place on the portion that protrudes, while the closing surfaces are always kept out of the steam area.

The rings have been found in actual practice to last much longer than nickel or other seatings and, of course, they are very much cheaper.

The valves are used with superheated and saturated steam, hot oils, motor spirit, water, air, gas, and chemicals, and have been found in the various materials in which they are made to be very suitable for these duties.

The principal points in favour of the valve are: extremely low maintenance costs, simplicity of adjustment, and absolute tightness under the hardest conditions.

Valve Refacers.

The Brooke Valve Refacer.

(*Patent.*)

The trouble caused by leaky valves, owing to wear or bad cutting of the surfaces, is often a source of great annoyance, and the possibility of refacing the same without removal of the valve is a very important point. This refacing can effectively be carried out by the Brooke valve seat refacer. This device (fig. 86) is very simple in all its parts, and is capable of standing a fair amount of rough usage without getting out of order, and should last the life-time of any steamer, with ordinary care.

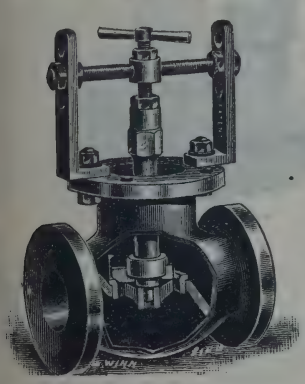


Fig. 86.

In the arrangement, the legs are reversible on the crosshead, the feet being turned inwards for small flanges, and outwards for large, also, whether fastened one way or the other, there is no part that prevents the operator from seeing the cutter. When once the machine is set in position, it need not be disturbed to change the cutter, as the mandril (which may be of any desired length) can be unscrewed from the box nut and taken out, while any extra cutters are easily made by the engineers, if required.

Disc steadies are provided for plain bore seats, and leg steadies for star-ribbed seats, which not only centre the end of the mandril at once, but obviate any tendency to vibrate—so that the machine will reface a valve-seating true, and leave it without jars or riffles.

The refacer is operated with an ordinary spanner and is made complete with five cutters and necessary guides for dealing with all sizes of valves from 1¼ in. to 4½ ins. Larger sizes are made for valves up to 10 ins. diameter.

The Simplex Patent Valve Reseating and Facing Machine.

(*W. Crockatt & Sons, Ltd., Glasgow.*)

(1)

This tool, fig. 87, has been designed to avoid the necessity of using the studs in the valve chest as a means of steadying. At the same time it is simpler and stronger than the machines which are secured and centred by means of a chuck operated by a scroll.

The tool is fixed in the valve chest (which may be either plain or screwed) by means of three stepped arms, pivoted at their upper ends. These arms are expanded by a cone which is depressed downwards by means of the hand nut. The action of expanding these arms both centres the tool in the valve and fixes it securely in position. This is ensured by the manufacture of the tool, the arms being turned up truly central with the spindle, after assembling. The cutters used are made of flat steel, and one end is arranged for flat and the other for bevelled seats. The simplicity of this type of cutter is found to counterbalance any slight advantage the milled type of cutter may have. Also a very much smaller number of cutters can be employed to deal with a large range of valves, as each cutter is adjustable. In order to prevent chattering of the tool, the feed is against the action of a strong spring, which keeps an upward pressure on the tool, so that feeding only takes place when the cutter is forced down by the action of the nut. This prevents the cutter following any irregularities in the face of the seat.

A simple attachment is provided when desired for trueing up the valves themselves. The valves are centred in this part of the tool and faced up by a movable tool, which can deal with either flat or bevelled valves. The arms and lower part of the body of the tool are made of cast steel, so that the machine will stand hard wear. Ball-bearings are fitted throughout, to ensure smooth working and to avoid jarring.

The machine is made in three standard sizes to deal with valves from $\frac{3}{4}$ in. to 8 ins. diameter, but has been supplied and can be easily adapted to do valves up to 12 ins. or more.

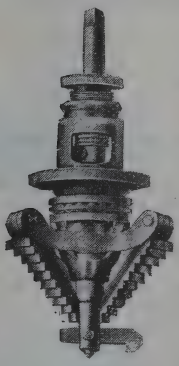


FIG. 87.

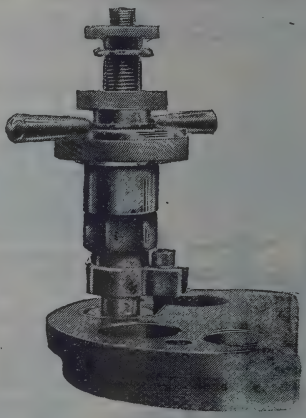


FIG. 88.

(2)

In order to meet the demand for a tool which will face up the seats of the group valves in Weir's and similar feed pumps, the Simplex No. 3 machine has been introduced. This tool, fig. 88, is secured in position by the expansion of three segments, which are turned concentric with the central spindle, and which are expanded hard against the inside of the bore of the valve seat by the action of the tapered end of the spindle. It can easily be adapted to flat or bevelled seats by simply changing the cutter used.

If it is desired to face up the valves in the bottom seat of the pump without drawing the complete seat, a special tool with an extended body can be supplied.

Besides being suitable for the type of valve mentioned, the tool is equally adaptable to dead weight safety valves, or indeed, to any design of valve in which the inside of the bore is a plain cylindrical surface. Ball bearings are fitted to ensure smooth and easy working.

REDUCING VALVES.

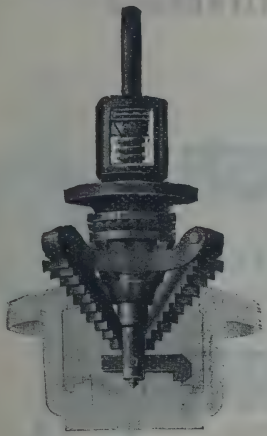
These are very needful fittings in connection with steam appliances when steam has to be reduced from a high to a uniform low pressure. It is a common mistake to order reducing valves too large, which leads to their excessive wear. No reducing valve should be implicitly trusted; but wherever a rise in steam-reduced pressure is liable to bring about serious results a relief valve should follow the reducing valve.

Reducing valves which are too large for the amount of steam they are to pass are usually unsatisfactory; either they will open and close continually and chatter violently, or will stand in a position nearly closed and become steam-cut and leaky. It is more satisfactory to use two small valves in parallel, one set slightly heavier than the other, so that one will supply steam up to its maximum capacity before the other opens. Another way is to use one reducing valve equal to about one-half the maximum demand, and a by-pass of about the same capacity with a hand-operated valve in it, so that when the reducing valve reaches its capacity the by-pass valve may be opened wide and the reducing valve be closed down and make up the shortage. This, of course, requires that an attendant shall observe the pressure gauge occasionally.

(*'Power.'*)

CROCKATT SIMPLEX

PATENT
VALVE RESEATER



Reduces repair costs and saves time. Enables your engineering staff to keep Steam and Check Valves tight without recourse to a lathe.

This tool has been supplied to hundreds of ships, factories, repair shops, power stations, etc., and a large proportion of our orders are repeats.

MADE IN FOUR SIZES FOR VALVES FROM ⅜" TO 12".

CROCKATT SIMPLEX TUBE BRUSHES
are made in a variety of designs for tubes from ⅜" to 27" diameter.

Among our other manufactures are
Tube Expanders, Turbine-driven Tube Cleaners, Feed Water Filters, Electric Salt Detectors, Terrazzo Floor Polishers, Machine Cut Gearing.

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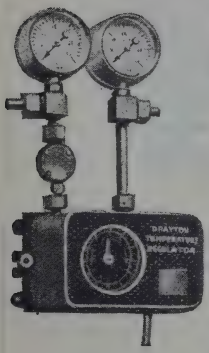

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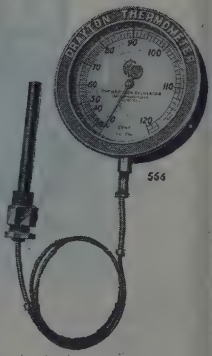
RECORDERS

for Temperature Pressure, Vacuum, Humidity, and Liquid Level.

DRAYTON

AUTOMATIC REGULATORS

for Temperature Pressure, Vacuum, Humidity, and Liquid Level.



DRAYTON TRANSMITTING THERMOMETER.

The DRAYTON REGULATOR & INSTRUMENT CO., LTD.,

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F. 1731

FEED-WATER REGULATORS.

The Crosby Patent Feed-Water Regulator.

The action of this regulator (*The Crosby Valve and Engineering Co. Ltd.*, 41–42 *Foley Street*, *London*, *W.*1) is in no way dependent upon the rising and falling of a float, and there are very few parts which are liable to give trouble and so to cause the apparatus to work in an erratic manner.

In fig. 89, A is a chamber which is put into communication with the steam space of the boiler, the steam being led in through the pipe H. A pipe L also puts the chamber in connection with the boiler, but in this case with the water space. If, for example, the apparatus is fitted to a Babcock boiler it might be placed at the side of the drum, so that the top of the chamber A is in line with the required water level. If the pipe L be then connected to the drum G, about

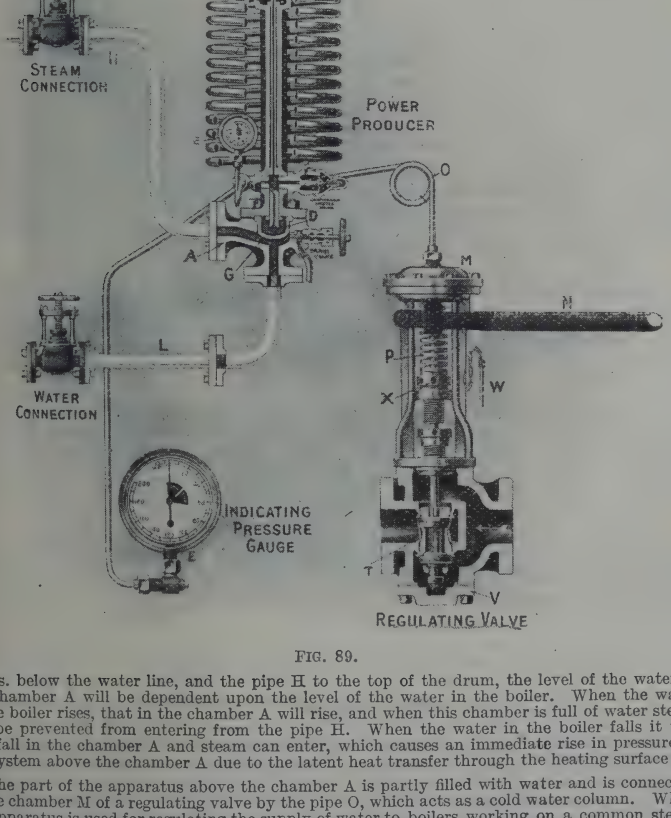

Fig. 89.

12 ins. below the water line, and the pipe H to the top of the drum, the level of the water in the chamber A will be dependent upon the level of the water in the boiler. When the water in the boiler rises, that in the chamber A will rise, and when this chamber is full of water steam will be prevented from entering from the pipe H. When the water in the boiler falls it will also fall in the chamber A and steam can enter, which causes an immediate rise in pressure in the system above the chamber A due to the latent heat transfer through the heating surface G.

The part of the apparatus above the chamber A is partly filled with water and is connected to the chamber M of a regulating valve by the pipe O, which acts as a cold water column. When the apparatus is used for regulating the supply of water to boilers working on a common steam main, the double-beat balanced valve T is connected in circuit with the feed pipe, each boiler being provided with one of these regulating valves.

There is a diaphragm in the chamber M, this being connected to the double-beat balanced valve by means of a spindle. When the water level in the boiler falls, the pressure formed in the apparatus as described below is exerted on the diaphragm, causing the valve to open against the action of the spring. When, however, the water rises, this pressure falls and the spring causes the valve to close, thus shutting off the supply of water to the boiler.

When the apparatus is first put into use, both the cocks on the boiler are closed, so that neither steam nor water can enter the chamber A. The air valve B is removed, and water is poured in. At the same time the union, or plug, on the diaphragm chamber is loosened, in order to enable the water to drive out the air in the pipe connecting the two pieces of apparatus. This having been done, the union on the chamber M is again tightened up, and more water is poured into the chamber at B when the air valve is closed. Steam from the boiler is then admitted under the partition G and the water in the system above is boiled up, the air valve B being loosened to let the air escape. This process is repeated several times, and on each occasion the apparatus is allowed to cool. In this way a vacuum is created in the apparatus above the partition G, and when a gauge to the left of the upper chamber registers a vacuum of at least 10 ins. the device is ready for use. The gauge serves for registering both pressure and vacuum, the latter being to the left of the zero mark and the former to the right of it.

The vacuum having been obtained, the two cocks on the boiler are opened, and the device commences to work. When the water in the boiler falls and steam is admitted to the chamber A through the pipe H, the heat of the steam is transmitted through the plate G. This heat boils the water in the chamber D. The pressure of the steam so generated, acting on the surface of the water in the top chamber, gives rise to a pressure above the diaphragm in the chamber M. This diaphragm is depressed, and the valve (which in a battery of boilers is arranged in the feed-pipe to each boiler) is opened, a supply of feed-water is admitted to the boiler, and in this way the water level is raised. As the water rises in the drum of the boiler, it also rises in the chamber A, and when the proper level in the boiler has been reached, steam ceases to enter from H. The chamber A then contains nothing but water. Under these conditions the water in the chamber D is no longer evaporated, and the steam condenses, the pressure in the top chamber consequently falls, and the valve closes. The supply to this particular boiler then ceases for the time being. The pressure gauge indicates whether the apparatus is working properly, and in this way the stoker is provided with a means of guarding against low water even should the device get out of order, which, however, is not at all likely to occur.

When the apparatus is working properly the pressure rises and falls slightly in accordance with the fluctuations in level in the boiler, opening the regulating valve wider or allowing it to close, thus increasing or reducing the feed supply to the boiler. It does not constantly open and shut, but regulates the feed so as to keep the water level constant within close limits. A lever is provided on the regulating valve for testing its operation or to keep the valve open if desired, and an adjustable device is provided to keep the valve always open a limited amount if required.

The principal advantages claimed for the apparatus are the following:—(1) It enables a lower water level to be maintained with perfect safety, thus increasing the steam space in the boiler and ensuring a supply of dry steam; (2) it reduces coal consumption by reason of maintaining a regular feed proportionate to the evaporation of the boiler; and (3) it ensures a greater regularity in the steam-raising, and so tends to prevent fluctuations in the pressure; (4) it will work continuously without requiring attention or repair.

A desirable adjunct to the Boiler Feed Regulator is the Crosby Automatic Feed Pump Control. This regulates the speed of the Boiler Feed Pump in accordance with the demands of the feed line to the boilers; and consists of a balanced valve in the steam supply pipe to the pump, controlled by means of a device which maintains the pressure in the feed line a constant amount above the boiler pressure irrespective of the demand. The magnitude of this excess pressure is adjustable at will.

The 'Drayton' Feed-Water Regulator.

(The Drayton Regulator & Instrument Co., Ltd., West Drayton.)

This regulator, fig. 90, is of the 'delayed action' thermostatic type, the lag of the thermostat allowing the stoker to adapt the firing to altered conditions of steam consumption. The all-metal thermostat is contained in a steel tube which lies at an angle outside the boiler across the normal water-level line; the highest point of the tube corresponding to the highest, the lowest point to the lowest permissible water level. The upper end of the thermostat container is connected to the steam space, the lower end to the water space of the boiler. The thermostat actuates through a magnifying lever a small relief valve, which latter is connected to the

pressure chamber of the feed valve, into which water enters at 15 lbs. per square inch pressure through a strainer and a needle valve. With rising water level the thermostat contracts, closes the relief valve, and allows the feed valve to close; with falling water the tube fills

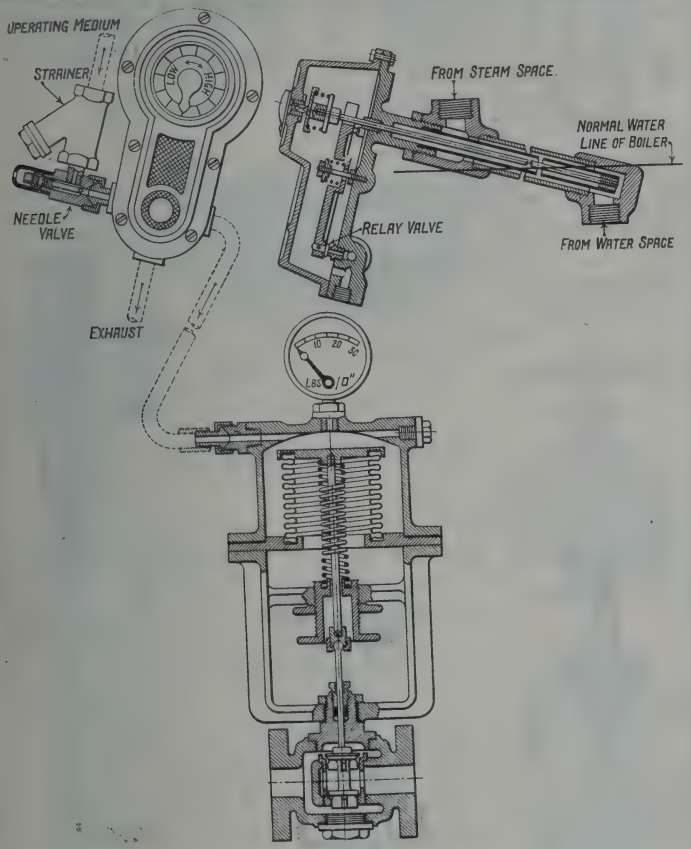

FIG. 90.

with steam, the thermostat expands, opens the relief valve, and causes the feed valve to open gradually.

THE 'THERMOFEED' FEED-WATER REGULATOR.
(Patent.)

This regulator consists of a float chamber and an automatic regulating valve.

Fig. 91 shows how the appliances should be fitted to the boiler front. This can be effected either in the way shown, or connection may be made behind the gauge glass, using the suitable pieces. The chief point is to provide steam and water connections from the boiler to the float chamber.

In the float chamber is a float made of special material, and guaranteed non-collapsible under any reasonable pressures. By a system of toggles the motion of the float is transmitted to a

small valve, which will either stop or allow steam to pass through a three-way valve to the large automatic regulating feed valve fitted into the feed supply pipe of the boilers. As long as sufficient water is in the boiler—*i.e.* the float being at a certain height—no steam is allowed to pass to the regulating valve; but if the ball rises to a certain point, steam connection is made, the steam condenses and reaches the piston on the top of the regulating valve, so that a certain

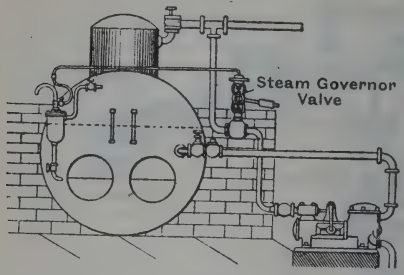

FIG. 91.

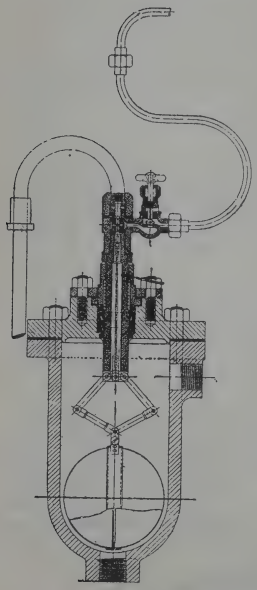

FIG. 92.

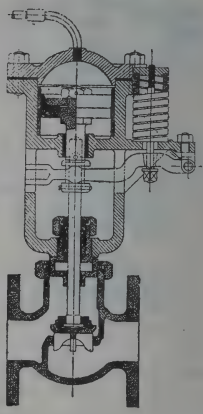

FIG. 93.

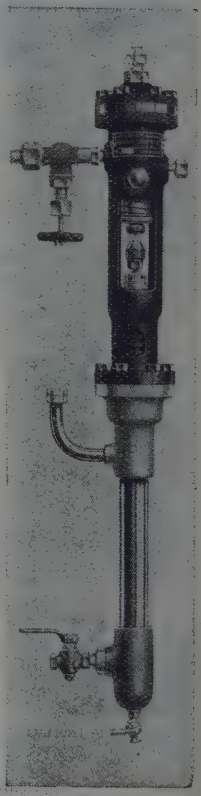

FIG. 94.

head of water is resting upon it; this will cause the feed valve to close and will prevent any more water from entering the boiler. If the water becomes lower, the float drops; the steam then passes through to the exhaust tube (shown as a slight bend in the fig.), and the automatic regulating valve opens again to admit water.

A special and distinctive feature of the Thermofeed is that by closing the three-way valve on the float chamber the regulating valve is always full open; hand feeding may therefore be resorted to at any time if constant heavy alterations in the load occur.

ROYLES LIMITED,

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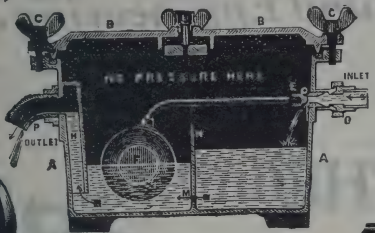

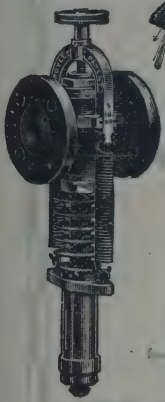

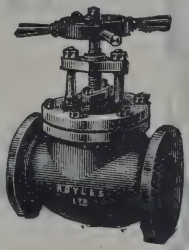

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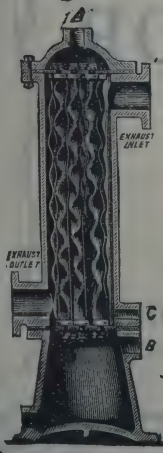
STEAM TRAPS.
OVER 215,000 SOLD.

Reducing Valves, Stop Valves, Wedge Valves, Steam and Hydraulic.

ROYLE'S Patent AUTO THERMAL FEED
For Returning Condensation to Boilers.



Row's Patent
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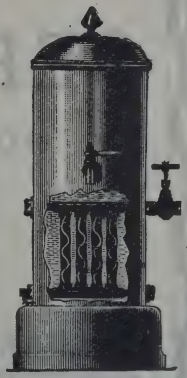
AIR HEATERS.
CALORIFIERS.

Steam and Gas Kettles.

BOILING BATTERIES,
Twice as efficient as Coils.



Row's Patent
STEAM KETTLES
Copper Bodies, all water surfaces tinned.

We Catch Units of Heat.
If you have any waste heat we shall be pleased to advise.

F. 1734

A Sound Engineering Job

THE

"BAKER"

OIL

SEPARATOR

FOR EXHAUST STEAM

(*See Editorial Notice p.1736*)

Sole Makers

The BAKER OIL SEPARATOR Co.

MELROSE STREET WORKS - - - SCARBOROUGH

The same principle of feed-water regulation is also used for marine purposes, but certain modifications have been made. The float is guided in such a manner that the rolling of the ship is unable to influence this unit, and the design is modified in order to meet general marine conditions.

In a single boiler installation the Thermofeed regulator may be used to start and stop the pump automatically. As will be seen from figs. 92, 93, this is possible by providing a special type of governor valve in the steam supply pipe to the pump, this governor valve being connected to the float chamber as shown. It will be understood that the admission or cut-off of the steam results in the pump being started or stopped.

The arrangement will maintain the water-level within a variation of $\frac{1}{8}$ in. (water-tube $\frac{1}{4}$ in.), acting independently of the pressure of the steam or the temperature of the feed.

By the use of the regulator a saving of 8 per cent. in coal bills is stated to be not unusual.

The manufacturers also supply a Differential Governor (fig. 94) for use in conjunction with the Regulator or independently on any self-starting steam pump. The pump governor automatically starts the pump and stops it if excess pressure is created in the feed supply pipe. The waste of bye-passing the not required water is, therefore, obviated, and the governor is a power saver of the first order.

The pump governor consists of a cylinder which is connected to the water and steam supply as indicated above. The water presses on a glass ram which acts on a small controlling valve. This small controlling valve acts in its turn on a stop valve built into the steam supp y of the pump. It is obvious, therefore, that at a pre-determined pressure the pump is stopped or started again as soon as the pressure in the water line falls. The 'Thermofeed' pump governor can be adjusted for any desired ranges of pressure.

The 'Arca' Compact Valve.

This valve (fig. 95) is used for small steam, air, or water regulating valves where the hydraulic

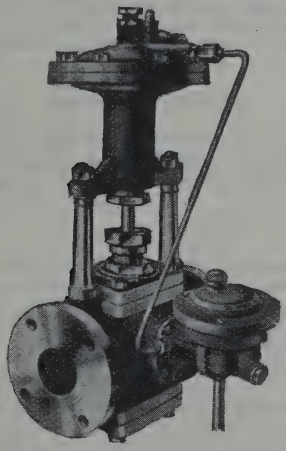


Fig. 95.

cylinder is unnecessary and where only comparatively small power is required to operate the valve; it is operated by a diaphragm in precisely the same manner as the pilot valve is operated where a hydraulic cylinder is used. Great care has been taken in the design to ensure the same accuracy and reliability as with the cylinder type. The cost of the combined unit embodying relay and compact valve, is of course considerably less than the cylinder type, though possessing the same sensitiveness and accuracy. It is particularly suitable for use with steam for heating purposes.

OIL SEPARATORS.

Lubricating oil, if allowed to pass into boiler feed-water, constitutes a danger to boilers so serious that means for its separation and removal are now invariably insisted upon by insurance companies. The method generally employed is that of the mechanical separation and extraction of oil and grease from the exhaust steam before it enters the condenser.

The fitting of high-pressure boilers with superheaters has increased the difficulty of the removal of the oil, while rendering the necessity of the complete separation all the more imperative.

For *small* quantities of greasy water, finely-broken coke placed in a perforated-bottom pail and hung below the greasy drip of an exhaust pipe has been found efficient in separating oil.

The 'Baker' Patent Oil Separator for Exhaust Steam.

(The Baker Oil Separator Co., Scarborough.)

This separator is designed to eliminate lubricating oil from the exhaust steam of all classes of reciprocating engines and under all working conditions, varying between 29 inches of vacuum and 75 lbs. per square inch back pressure. The sizes made have pipe connections ranging from 2-in. bore to 60-in. bore. Separation is effected by mechanical means only, the apparatus being fitted into the exhaust steam pipe between the cylinder of the engine and the condenser or other receptacle in which the cleansed steam is to be used. The makers give a definite guarantee as to the results obtained, which in actual practice means that all condensed steam can be used for boiler feeding, or any manufacturing purpose, without fear of oil contamination. The apparatus is extensively used for colliery winding, rolling mill, and central exhaust engines, special attention being given to the strength and rigidity of all internal parts, to ensure their withstanding the heavy pulsations from these types of engines. In every instance, each Baker Patent Oil Separator is designed and manufactured to suit the particular working conditions specified at time of ordering, and is guaranteed accordingly. It should be noted that the makers' claim is to cleanse the exhaust steam, not to recover the lubricating oil, although in many of the larger installations as much as from 50 per cent. to 75 per cent. of the oil is recoverable for use again.

There are no maintenance costs in running the apparatus.

The 'Drayton' Oil Separator.

(The Drayton Regulator & Instrument Co., Ltd., West Drayton.)

This separator differs from other types by the absence of rigid baffles. The eliminators consist of vibrating elements which shake off the oil into an inverted cone-shaped bottom, from where it is removed in the usual way by grease trap or vacuum trap of the makers' own design.

It is claimed that one-tenth of a grain of oil per gallon of condense can be guaranteed without time limit.

BOILER CLEANERS.

The Hulburd Mechanical Boiler Cleaner.

Excellent results have been obtained with the Hulburd mechanical boiler cleaners, apparatus which, although suitable for all classes of boilers, are especially recommended for locomotives, in

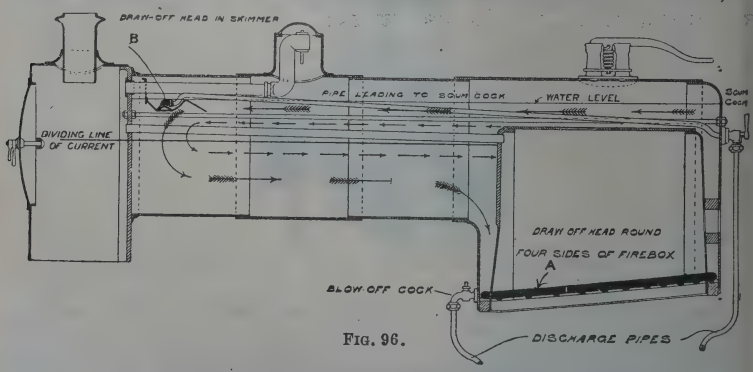


FIG. 96.

which reduced efficiency of the heating surfaces, due to formation of scale and obstruction of the water spaces by accumulations of deposit, are above all things to be prevented if possible.

As almost invariably fitted, the cleaners, fig. 96, consist essentially of two portions; one in

the boiler barrel, placed in such a position near the forward end as to collect all scum-forming matter in a kind of skimmer-trough, or basin, to which it is brought by the natural circulation of the water and from which it is discharged, while running, by a suitable cock worked from the cab ; the other in the water spaces surrounding the firebox, immediately above the foundation ring, to evacuate by means of blow-off cocks the sediment which otherwise inevitably accumulates there. Both front and back portions are in the form of draw-off heads having openings or suckers on their undersides spaced so as effectively to scour the whole of the surfaces with which they have to deal, and their efficacy is such that an engine fitted with the apparatus, working on water which may previously have necessitated opening up the boiler and washing out every four or five *days*, can with the Hulburd cleaners be run 5, 6, or even 8 *weeks* without being laid off a single day for cleaning in the ordinary sense.

Among the advantages obtained by the use of the cleaners are :—

1. The immediate stopping of priming by the use of the scum cock in connection with the forward fitting.

2. The preservation of the boiler tubes, firebox sheets, stays, etc., in a clean condition through the removal of all scale-forming matter as soon as it is deposited. The cleaners' action may be advantageously assisted in some cases by the use of a suitable boiler composition, which together with other resultant solid matter is evacuated as soon as it becomes inert.

3. Immunity from leaky tubes, stays, and strained tube plates, owing to the less frequent necessity for cooling down and washing out boilers.

4. Saving in washers' wages, cost of repairs, and depreciation of boiler fabric.

5. More efficient steaming, owing to the entire boiler being kept clean, and a consequent saving of fuel.

Soot Removers.

It has been shown that the presence of scale on the water side of boiler heating surfaces does not affect the efficiency very much. The presence of ' soot ' on the gas side, however, is more serious in this respect. The provision of efficient soot removers is therefore of importance.

Some modern installations are provided with permanent pipe connections, valves, and nozzles, so that jets of steam may be directed on the boiler tubes in order to remove the soot by merely operating the valves.

The Willcox-Ramoneur Boiler-Tube Soot Remover.

This apparatus, fig. 97 (*W. H. Willcox & Co. Ltd.*), consists of a 10-foot length of specially-constructed flexible Trellis Metal tubing, attached to the following parts :—*For Smoke Tubes*: a specially-designed, cone-shaped head, made in either of three sizes, viz. :—*large*—to suit tubes above 2¾-in. bore ; *small*—to suit tubes up to 2¾-in. bore; *extra small*—for loco. tubes ; this cone head is provided with an internal interchangeable nozzle, spiral partitions or webs, and a disc throttle for regulating the admission of air. Steam lance of finest quality steel tube. A sliding hand-hold, also protector on handling end of tubing. Lever regulating valve. Steam valve for fixing to steam pipe on boiler.

A special type is made for locomotives fitted with superheaters. This superheater type is arranged for cleaning both the fire tubes and the superheater tubes from the fire-box end, and is supplied with various cranked lances to reach the nest of tubes. For water tubes a slightly different pattern (for blowing around the outside of the tubes) is supplied.

The boiler being cleaned utilises its own steam—it does not have to be shut down.

The action of the apparatus is as follows :—On the steam valve being opened the steam passes through the flexible tube into the nozzle. This nozzle is made in various styles to suit the type of boiler and the existing steam pressure. Passing from the end of this nozzle, the steam meets with ten times its own volume of hot air drawn in from the surrounding flues of the boiler, and is thoroughly mixed with same. The combined hot air and steam strike against spiral-shaped partition webs inside the cone head, and, by the united action of the nozzle and the partitions, emerge at an increased velocity through the mouth of the cone into the boiler tubes in spiral form. The steam at this point has become completely dried by the admixture of hot air, and, further, it is now joined by an additional current of warm air from the exterior of the cone ; the whole ærated mass then assumes what is best described as a ' whirlwind ' movement, which sweeps with great force through the boiler tube, and drives all deposits out at the opposite end, in a similar manner to that of a projectile from a gun. As the steam is thoroughly dried in the process, there is no coagulation, and formation of sooty incrustations is avoided.

In the water-tube pattern the apparatus is fitted with a tubular end-piece, joined at its base to the form of cone head shown. The opening at the tubular end is provided with a spreader which creates a fan-shaped spray, which is directed upon the outside of the water-tubes. With

this arrangement it is possible to sweep away thoroughly, and with equal velocity, the soot and ash dust which collect on the surfaces of these tubes.

For works using both types of boilers the *'Combined Ramoneur'* is supplied. This is arranged with interchangeable heads, so that either the smoke or water-tube pattern may be utilised as required.

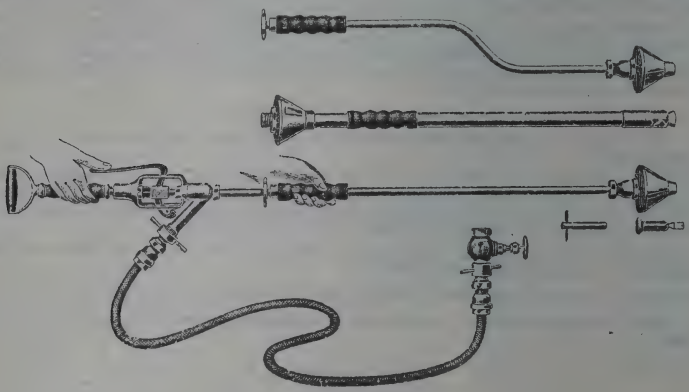


FIG. 97.

TUBE CLEANERS.

SIMPLEX PATENT BOILER TUBE BRUSHES AND SCRAPERS.

(W. Crockatt & Sons, Ltd., Glasgow.)

The 'Simplex Boiler Tube Brushes' are made with short hardened steel wires which, being comparatively unyielding, are capable of removing deposits which softer brushes will not readily attack. The necessary spring of the brushes is obtained through the action of the arms, which are made of spring steel of sufficient strength to put a reasonable pressure on the tubes being cleaned. The filling of the brush plates is done in a special machine, and in such a way that it is impossible for the bristles to come out, unless they are worn quite away.

Two designs of brush are made, the 'Self-Adjusting Brush,' which depends for its action entirely on the spring of the arms, and the 'Adjustable Brush,' which also has a certain amount of spring in the arms, but which has also a central spindle with a wing nut at each end, by which the diameter of the brush can be increased within a limited range.

The 'Simplex Patent Tube Scraper' is made of drop forgings and will remove harder deposits than will the brushes. It is arranged to scrape only on withdrawal from the tubes, so that the soot, etc., is brought to the front of the boiler, and not shoved into the back ends. This tool also is adjustable by means of a nut which is easily operated as required.

The 'Simplex Condenser Brushes and Scrapers' are for use in marine work as well as on shore.

THE CROCKATT SIMPLEX TURBINE TUBE CLEANER.

(W. Crockatt & Sons, Ltd., Glasgow.)

This appliance (fig. 98) is made in sizes from 1⅜ ins. upwards, and is driven by a turbine suitable for either air, steam, or water, at about 100 lbs. pressure. The cleaning head is detach-

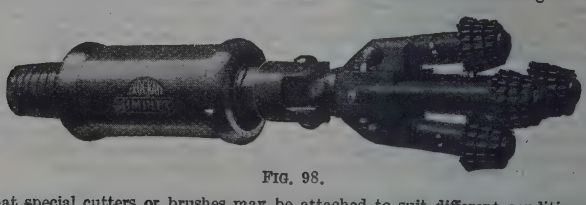


FIG. 98.

able, so that special cutters or brushes may be attached to suit different conditions, and the universal joint enables the tool to be used in curved tubes, such as in Stirling boilers. It is suitable also for Babcock tubes, economiser tubes, and any other kind of pipes having hard scale.

STEAM PIPES.

It is essential in steam pipe arrangements to make adequate provision for (*a*) drainage, and (*b*) expansion.

The pipes if possible should not rise from the valve on the boiler to the main steam pipe, as this causes a dangerous water pocket and, if suitably drained, only automatic steam traps should be used; these should be tested by blowing to atmosphere at least twice a day.

The best steam pipe arrangement between engine and boiler is that the boiler stop valve should stand at the top of a vertical pipe on the boiler and there should be a steady, if small, slope from that valve to the engine separator. Rupture from water-hammer occurs from failure of pipe drains, and if possible all drains should be unnecessary by design. The closing of no valve should be able to cause water to accumulate against it. Where it is impossible to avoid drainage points, these should be carefully arranged, and unduly small drain pipes must be avoided lest they choke with rust or dirt. New pipes and drains especially should be well blown through before fixing traps.

Long lengths of drain piping, from steam mains to traps, should be avoided; they are a continual source of waste, and with superheated steam the water they drain away has largely been formed by condensation in the drain piping itself. Therefore the pipes from steam main to traps should be as efficiently lagged as the main steam line.

Idle parts of the steam range should be isolated when not in use, and carefully drained, as valves often leak when shut, through scoring of faces and grit wedging in, preventing tight closing.

All live steam drains should be returned to the feed tanks.

(See also Manchester Steam Users Association Reports 1907, 1908.)

The connecting pipes from the boilers to the main steam pipe, and from the main steam pipe to the engines, should be preferably of steel, with half (not 'full,' which would form a 'water pocket') swan-neck bends, to allow for expansion.

Steam pipes between 32° and 212° F. expand by heat 0·0000111 per degree C. = 0·00000618 per degree F., if of cast iron. For wrought iron these figures become 0·0000118 and 0·00000656. Between 60° F. and a pressure of 190 lbs. or a temperature of 383° F. the expansion is about 4½ ins. per 100 ft. The coefficient for steel is 0·000006 per degree F.

With superheated steam, pipes may expand nearly 6½ ins. per 100 ft. of their length. At higher temperatures the coefficient of expansion is considerably larger.

In fixing pipes the expected movement when hot should, if possible, be half provided for in the opposite direction, in order to minimise stresses.

Expansion bends are best arranged to project horizontally from the line of pipe, in order to allow a free passage for water. If they stand vertically upwards they prevent water flowing, and if hung downwards they form water pockets. In both cases they necessitate careful drainage.

Pipes often vibrate under the pulsating demand of steam by an engine. This requires that they should be anchored at one or more points.

The pipes should be marked when cold opposite marks on the walls, and again when hot. Anchors should be at the points where least movement is shown. Pipes are best carried on brackets. Where they rest they should have rubbing pieces firmly attached, and they should not rest on rollers as the friction helps to check vibration.

The centre of a main steam pipe should be anchored, to divide the longitudinal expansion. Where engine and boiler room are in line and steam mains are of considerable length, a ∩ or Ω-shaped bend should be inserted between the engine and boiler-room. Anchor-plates should then be fixed in the centre of the engine-room main and in centre of boiler-room main.

When erecting new steam pipes, attention should be given to the thorough cleaning of the pipes, as otherwise fine particles of grit, driven by the steam into the faces of the valves, cut into the seats, causing considerable trouble and expense.

Riveted pipes and flanges may be used from 6 ins. diameter upwards.

If the pipes are of riveted steel the necessary thickness must be secured for caulking. It is not the practice to make these plates less than ¼-inch; it is better to use $\frac{5}{16}$ plates. To avoid risk of rivet-heads springing off during caulking, rivets should not be less than $\frac{5}{8}$ in. in diameter.

Serviceable and reliable steam pipes may be made up of lap-welded mild steel with heavy wrought-iron flanges, the flanges being screwed on hot and the ends brazed. The flanges must be faced up to enable good joints to be made.

The radius of curvature measured to the centre of pipes should not be less in solid drawn pipes than three times the diameter of pipe; even this radius of curvature causes a reduction in thickness of 20 to 25 per cent. on the outside of the bend, and a corresponding increase in thickness on the inside. Sharper bends can, if necessary, be made by working the pipes out of two plates with a brazed joint along each side. The latter construction is more expensive than the former.

STANDARD RADIUS OF STEEL AND WROUGHT-IRON STEAM PIPE BENDS.

Bore .	Ins. 1½	Ins. 2	Ins. 3	Ins. 4	Ins. 5	Ins. 6	Ins. 7	Ins. 8	Ins. 9	Ins. 10	Ins. 11	Ins. 12
Radius	Ins. 6	Ins. 9	Ft. 1	Ft. Ins. 1 3	Ft. Ins. 1 6	Ft. Ins. 1 9	Ft. 2	Ft. Ins. 2 6	Ft. 3	Ft. Ins. 3 6	Ft. 4	Ft. Ins. 4 6

Radius may be slightly less, but this is not advisable.

Pipes may be best bent by filling with thoroughly dry sand and plugging the ends. They will then bend without buckling.

Copper pipes are bent by being filled with melted resin, or with solder, the pipe bent cold, and the filling then melted out.

Copper pipes (although not advisable), if used for steam, should be solid drawn, and not brazed. Flanges to be screwed and brazed should be of brass in all cases. On no account should copper or brass be used for superheated steam, owing to loss of strength at these high temperatures, which to obtain the full benefit of superheat is raised to 650° or 700° F. (*Horobin.*)

Brazed copper is apt to be unreliable, and copper steam pipes ought to be wound with steel wire.

Corrugated Steel Steam Pipe Bends.*

These bends, which are adapted for resisting steam at a pressure of 400 lbs. per sq. in. superheated to a temperature of 750° F., have a series of corrugations (fig. 98A) which in themselves strengthen the tube, especially as the process of manufacture thickens the wall of the tube. The corrugated pipe is formed into a bend in the usual way, and there can be no thinning of the wall in bending as all that happens is that the corrugations are somewhat opened out on the outside of the bend and are closed up on the inside.

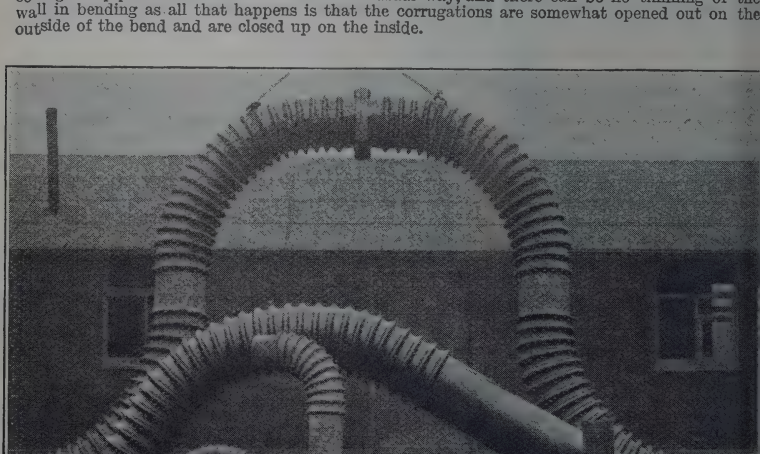


Fig. 98A.

These corrugated pipes can be bent to a much smaller radius than plain pipe—in extreme cases they can be bent to the same radius as an elbow. In all cases, to stand corrugating, the tubes must be of a good soft quality of steel and must be well made, free from variations of thickness; they are usually solid drawn tubes, hot finish, 24 tons to 28 tons tensile, 25 per cent. elongation in 8 ins.

Bends made from corrugated tube are five times as flexible as similar bends made from plain tube—that is to say, if the same thrust is applied to both bends the corrugated one will move five times as far as the plain one.

An expansion bend of the lyre type made from plain tube 10 ins. bore and 138 ins. high from the centre of the main to the centre of the pipe at the crown of the bend, allows for a movement

* 'Steam Pipes for Extra High Pressure and Temperature,' paper by J. A. Aiton, C.B.E. (*Transactions of the Institute of Marine Engineers*, Oct. 1926).

of 2½ ins. out or in; a bend made from corrugated pipe of the same bore can be made 55 ins. high, and gives 2½ ins. out or in, and a similar bend 72 ins. high gives 3⅜ ins. out or in, or 50 per cent. more than the much larger plain bend.

The severest test of the behaviour of the bends under heavy vibration has been on steam hammers. A 5-ton hammer when first started to work had connected to it a plain 5-in. steel bend and subsequently a copper bend, but this did not last more than a month, and the steam joints had to be remade, on an average, once a day. A 5-in. corrugated bend 24 ins. × 20 ins. made from stock solid-drawn hot-finish tube, $\frac{7}{32}$ in. thick, was fitted, and after working for two years was microscopically examined and showed no signs of deterioration.

Roughly speaking, the pitch of the corrugations is 2½ ins. and each curve of the corrugation 1¼ ins. The steam friction is about double that of a plain bend.

There are no records of a corrugated pipe ever having failed in service.

Pipe Thickness.

If t = thickness in inches; p = pressure in lbs. per sq. in.; d = internal diameter in inches.

$= \frac{pd}{6000}$, for lap-welded iron or lap-welded or solid-drawn steel, provided the thickness is not less than ¼ in.; $t = \frac{pd}{3500} + \frac{1}{4}''$, for cast iron;

$t = \frac{pd}{6000} + \frac{1}{16}''$, for brazed copper; $t = \frac{pd}{6000} + \frac{1}{32}''$, for solid drawn copper

Thickness of Copper Main Steam Pipes.

Internal Diameter of Pipe in Inches.	Working Press of Steam in Boiler in Lbs. per Sq. In.				
	100 lbs.	125 lbs.	150 lbs.	180 lbs.	200 lbs.
	Thickness of Pipe in Inches.				
1½	·140	·143	·147	·152	·155
2	·145	·150	·155	·161	·165
2½	·150	·156	·162	·170	·175
3	·155	·162	·170	·179	·185
3½	·160	·168	·177	·188	·195
4	·165	·175	·185	·197	·205
4½	·170	·181	·192	·206	·215
5	·175	·187	·200	·215	·225
5½	·180	·193	·207	·224	·235
6	·185	·200	·215	·233	·245
6½	·190	·206	·222	·242	·255
7	·195	·212	·230	·251	·265
7½	·200	·218	·237	·260	·275
8	·205	·225	·245	·269	·285
8½	·210	·231	·252	·278	·295
9	·215	·237	·260	·287	·305
9½	·220	·243	·267	·296	·315
10	·225	·250	·275	·305	·325
10½	·230	·256	·282	·314	·335
11	·235	·202	·290	·323	·345
11½	·240	·268	·297	·332	·355
12	·245	·275	·305	·341	·366

(*Philip Dawson.*)

Lloyd's Rules for Steam Pipes.

The following is abstracted and abridged from Lloyd's Rules:

Pipes made from electro-deposition of copper on a mandril are not to be used for steam.

Copper pipes are to be properly annealed.

Copper pipes for pressures over 75 lbs. per square inch are to be solid drawn.

Pipes for pressures above 180 lbs. per square inch are not to be of copper if the diameter exceeds 5 ins.

Copper pipes are not to be used for superheated steam.
Permissible working pressures (W.P.) are as follows:

where,

t = thickness in hundredths of an inch; d = diameter of pipe in inches.

For brazed copper . . . . . W.P. $= \frac{45\,(t-3)}{d}$

For solid-drawn copper . . . . . W.P. $= \frac{60\,(t-3)}{d}$

For solid-drawn cold-finished steel . . . W.P. $= \frac{120\,(t-10)}{d}$

For solid-drawn hot-finished steel . . . W.P. $= \frac{120\,(t-12)}{d}$

For lap-welded iron or steel with or without covering straps . . . . . W.P. $= \frac{90\,(t-12)}{d}$

Pipe Hangers.

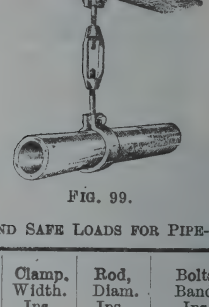


FIG. 99.

DIMENSIONS AND SAFE LOADS FOR PIPE-HANGER PARTS.

Pipe, Size. Ins.	Pipe, Thick. Ins.	Band, Width. Ins.	Clamp, Thick. Ins.	Clamp, Width. Ins.	Rod, Diam. Ins.	Bolts, Band. Ins.	Bolts, Clamp. Ins.	Safe Load. Lbs.	Length ½ Band. Ins.
2	¼	1½	⅜	1½	½	½ × 2	½ × 2¼	1,160	6
2½	¼	1½	⅜	1½	½	½ × 2	½ × 2¼	1,160	7
3	¼	1½	⅜	1½	½	½ × 2	½ × 2¼	1,160	8
3½	¼	1½	⅜	1½	½	½ × 2	½ × 2¼	1,160	9
4	¼	1½	⅜	1½	⅝	½ × 2	⅝ × 2¼	1,870	10½
4½	¼	1½	⅜	1½	⅝	½ × 2	⅝ × 2¼	1,870	11
5	¼	2	⅜	2	⅝	½ × 2	⅝ × 2¼	1,870	13
6	¼	2	½	2	⅝	⅝ × 2¼	¾ × 2¼	1,870	14
7	⅜	2	½	2	¾	⅝ × 2½	¾ × 3	2,830	16
8	⅜	2	½	2¼	¾	¾ × 2¾	⅞ × 3½	2,830	18
9	⅜	2	½	2½	⅞	¾ × 2¾	⅞ × 3½	3,940	20
10	½	2	½	2½	⅞	¾ × 3	⅞ × 3½	3,940	22
12	½	2½	½	2½	1	⅞ × 3½	1 × 3½	5,180	25
14	½	2½	½	2½	1⅛	1 × 3½	1⅛ × 3¾	6,510	27
15	½	2½	½	2½	1⅛	1 × 3½	1⅛ × 3¾	6,510	30
16	½	3	⅝	3	1⅛	1⅛ × 3¾	1¼ × 4	6,510	33
18	⅝	3	⅝	3	1¼	1⅛ × 4	1¼ × 4	8,410	35
20	⅝	3	¾	3	1¼	1¼ × 4	1¼ × 4½	8,410	37
22	¾	3	¾	3	1½	1¼ × 4½	1¼ × 4½	8,410	39
24	¾	3	¾	3	1¼	1¼ × 4½	1¼ × 4½	8,410	42

Exhaust Pipes.

These may be of cast iron and should be free from blow holes. The flanges should be faced and jointed with soft rubber rings. Exhaust pipes should be painted while under vacuum, preferably with several coats of red lead paint well brushed in until all the pores are filled. It has been suggested that exhaust pipes, especially if long, might be laid in a concrete trench under water so as effectually to prevent air leakage.

Flanges and Joints for Steam Pipes.

Pipes for steam and hot water should not be jointed with socket and spigot; this is a dangerous type of joint.

Steam pipes may be screwed into sleeves or branch pieces, but the screws should be tapered. This method is quite good for small-bore pipes which do not have to stand up to a very high steam pressure, and seems to have been adopted generally by American engineers for marine work. It makes a very neat job and is easy to cover.

Flanges should have the number of bolts increasing in multiples of 2. In marine work the usual method for spacing the bolts with regard to position of flange is as follows: For vertical and inclined flanges there should be one bolt hole spaced on either side of vertical centre line, and for horizontal flanges one bolt hole spaced on either side of fore and aft centre line of flange. The thickness of flanges for different materials to some extent should vary with the modulus of elasticity of the material, and consideration given as to shock and vibration which may take place.

The following formula gives thickness of flange with the constants as now generally adopted by the British Engineering Standards Association for marine flanges:—

$$\sqrt{\frac{4P \times l^4}{t^3}} = \text{constant } (C).$$

C for cast iron = 11; for brass or steel = 12·5 to 13·5,

where,

P = working pressure in lbs. per sq. in.; t = thickness of flange in ins.; l = pitch between bolts or studs.

For the attachment of flanges to pipes up to 8-in. bore, the usual practice is to screw on the flanges with a vanishing thread, which should be about 11 threads per inch. These screwed-on flanges require to have collars in order to obtain a suitable depth of screw, which varies from $1\frac{1}{8}$ in. to $1\frac{1}{2}$ in. For pipes above 8-in. bore, the flanges are riveted on.

For steam pressures up to about 180 lbs. per sq. in., machine-faced flanges may be jointed simply with a ring of copper, preferably corrugated, or jointed with some form of asbestos, such as Kymbala or Tauril jointing.

In large-sized steam pipes, also small pipes for high-pressure and superheated steam, it will be found that the best joints are made by forming a channel recess round face of flange $\frac{1}{16}$ in. deep and $\frac{1}{4}$ in. wider than the diameter of bolt holes. The face of the flange projecting above this recess is scraped up by hand to suit a small hand surface plate. The channel is then filled with red lead paint or some type of soft asbestos packing, when making up joint. This form of joint is adopted universally for high-pressure steam from about 200 lbs. per sq. in. and upwards.

A cement for pipe joints that is said to be as good as red lead putty in a faced or rough flange joint, but at one-tenth the cost, consists of a mixture of ordinary pine tar and dry oxide of iron. It is stated that it does not harden so soon as red lead, and is very adhesive under pressure.

A thin gasket has less edge surface exposed to the pressure, and is therefore less likely to blow out than a thick one.

The Use of Metallic Gaskets.

The ordinary corrugated copper gaskets are approximately $\frac{1}{64}$ in. thick, and are generally used as a ring inside the bolt circle.

Some engineers recommend the use of two gaskets in order to allow for the spring of the pipe flanges when bolted up. Flanges, however, should be stiff enough not to spring sufficiently to touch at the edges when one gasket is used. The second gasket should then be omitted. The gaskets should be dipped in jointing red lead (red lead mixed with boiled oil). Metal gaskets should be coated with pipe cement, graphite and oil, or lead and oil, and bolted up before the coating has dried, so that each corrugation flattening under the pressure forces a ring of this filler concentrically around the flange, and the copper gasket practically acts as a binder. Copper gaskets should be annealed soft and pliable after corrugating.

The ideal gasket is one that covers the pipe ends as well as the flange if the pipes are faced off flush with the flange, because such a gasket will save thread leaks. If, however, the pipe does not come out flush with the flange, this cannot be accomplished with any gasket.

For jointing purposes the corrugated copper gaskets in common use have not been very successful with superheated steam. The reason lies in the fact that the annealing temperature of copper lies in the neighbourhood of 600° F., corresponding with a boiler pressure of 180 lbs. to a superheat of 220°. Corrugated gaskets, moreover, used by careless pipe fitters are always likely to give trouble owing to the danger of the bolts and flanges being overstrained. Joints of asbestos and of rubber preparations have often been used, but they last but a short time. It is fairly certain that the high temperature of superheated steam at the usual boiler pressure prohibits the use of organic material for jointing purposes if results of any permanence are desired. A satisfactory joint has been found to be one in which a gasket of thin steel of a radial width not exceeding $\frac{5}{8}$ in. has been used, the steel being soft annealed. The comparatively small area of the gasket enables great pressure to be brought to bear by bolts of ordinary size, with the result that the soft steel is thoroughly pressed into the rough surface of the flange. Such a joint will, although simple and cheap, give all the permanence that could be desired.

(*Times Engineering Supplement.*)

'Dexine.'

This material (*Dexine, Ltd.*) is a very suitable substance for making joints. It does not stick to the flanges, nor does it press out, blow out, or burn out; and it can be used over and over again. It is made in sheets from $\frac{1}{64}$th inch upwards.

Beldam's Pilot Jointing.

(*The Beldam Packing & Rubber Co., Ltd.*, 16 *Gracechurch Street, London, E.C.*3.)

This is a compressed asbestos fibre jointing for all steam or water pressures, ammonia, acids, oils, etc. It will stand temperatures (up to 750° F.), and will not burn, blow, or squeeze out. Its tensile strength is over 3 tons per sq. in.

Joints made of this material can be opened up as often as desired, and it does not lose its elasticity.

To facilitate quick measuring when cutting, the sheets are marked in 1-in. squares.

Leaks in Steam Pipes.

Leaks in steam pipes that cannot be stopped by caulking or plugging may be stopped with a cement made by mixing black oxide of manganese with enough raw linseed oil to form a thick paste. The steam pressure should be relieved in the pipe, but the pipe should be kept warm enough to dry the oil.

Size of Steam Pipes.

The diameter of a steam pipe is usually in practice chosen to give a certain steam velocity in the pipe, 100 feet per sec. being a customary velocity for steam at ordinary pressures.

Many engineers use this speed for both saturated and superheated steam. Others vary the velocity as in the following table:

Diameter of Pipe.	Velocity. Feet per sec. Saturated.	Superheated.
Up to 3 ins.	75	100
3½ ins. to 9 ins.	90	120
10 ins. and over	90	140

For superheated steam in long, straight pipe lines 180 ft. per sec. may be used.

For steam at high pressures, 300 to 500 lbs. per square inch, useful information is given by Broido (*Amer. Soc. Mech. Engineers*, 1922, page 1199), who concludes that for steady flow in pipes over 5 ins. diameter 10,000 to 12,000 feet per min. is advisable, and states that velocities up to 15,000 ft. per min. have been used in larger pipes without undesirable effects.

It should be remembered that the higher the velocity the smaller is the pipe diameter, and hence the external radiating surface is less.

Pressure Drop in Pipe Lines.

The formula (known as the Babcock formula) usually employed to relate the flow, pressure drop, and pipe diameter is

$$W = 87{\cdot}5\sqrt{\frac{D\,(p_1 - p_2)\,d^5}{L\left(1 + \frac{3{\cdot}6}{d}\right)}},$$

where W = weight in pounds; d = diameter in inches; D = density or weight per cubic foot; p_1 = initial pressure; p_2 = pressure at end of pipe; L = length in feet.

This formula corresponds to $p_1 - p_2 = 0{\cdot}0001306\,\frac{W^2 L\left(1 + \frac{3{\cdot}6}{d}\right)}{D d^5}$ and also to $h = f\,\frac{v^2}{2g}\cdot\frac{4L}{d_1}$, where h = loss of head in feet, d_1 = diameter in feet, f = coefficient of friction of the steam in the pipe, f being equal to $0{\cdot}0027\left(1 + \frac{3}{10 d_1}\right)$; this coefficient is due to R. C. Carpenter, and is accepted by Unwin.

The following table gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure, through straight, smooth pipes, each having a length of 240 times its own diameter. The table is calculated from the above formula.

TABLE OF FLOW OF STEAM THROUGH PIPES.

Initial Pressure by Gauge.	Internal Diameter of Pipe in Inches. Length = 240 diameters.													
	¾	1	1¼	2	2½	3	4	5	6	8	10	12	15	18
Lbs. per Sq. In.	Weight of Steam per Minute in Pounds, with One Pound Loss of Pressure.													
1	0·92	1·79	4·80	9·4	15·6	23·8	45·5	75·0	112	209	337	497	799	1160
10	1·14	2·20	5·90	11·5	19·2	29·4	56·0	92·2	137	258	415	611	982	1430
20	1·33	2·58	6·91	13·5	22·7	34·4	65·6	108	161	302	486	716	1150	1680
30	1·49	2 89	7·75	15·2	25·3	39·5	73·5	122	180	338	545	803	1290	1880
40	1·64	3·18	8·54	16·7	27·8	42·5	81·0	133	198	372	600	885	1420	2070
50	1·77	3·44	9·23	18·1	30·1	46·0	87·6	144	215	403	650	956	1540	2240
60	1·89	3·67	9·85	19·3	32·1	49·0	93·5	154	229	429	694	1020	1640	2390
70	2·01	3·91	10·45	20·5	34·1	52·1	99·5	164	244	457	736	1080	1740	2540
80	2·12	4·11	11·0	21·6	35·9	54·9	105	172	266	480	775	1140	1830	2670
90	2·22	4·31	11·6	22·6	37·7	57·6	110	181	269	504	813	1200	1930	2810
100	2·32	4·50	12·1	23·6	39·3	60·0	114	188	281	526	850	1250	2010	2920
120	2·50	4·85	13·0	25·4	42·4	64·6	123	203	302	567	914	1340	2160	3150
150	2·74	5·33	14·3	28·0	46·5	71·0	136	223	332	623	1004	1480	2380	3480
200	3·11	6·04	16·2	31·7	52·8	80·5	154	253	377	705	1140	1679	2700	3940

(*Morley.*)

The foregoing table is based on saturated steam. For any other loss of pressure multiply by the square root of the given loss. For any other length of pipe *divide* 240 *by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient*, which will give the flow for 1 lb. loss of pressure. Conversely, dividing the given length in diameters by 240 will give the loss of pressure for the flow given in the table.

For superheated steam multiply the values in the table by $\sqrt{\frac{\text{density of superheated steam}}{\text{density of saturated steam}}}$ —or *approximately* $\frac{1}{\sqrt{1 + {\cdot}0015\,t_s}}$, where t_s = degrees of superheat.

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe, and passing elbows and valves, will reduce the flow given in the table. The resistance at the opening, and that at a globe valve, are each about the same as that for a length of pipe

equal to 114 diameters divided by a number represented by $1 + (3{\cdot}6 \div \text{diameter})$. For the sizes of pipes given in the table these corresponding lengths are, approximately :—

$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to two-thirds that of a globe valve. These equivalents—for opening, for elbows, and for valves—must be added in each instance to the actual length of pipe. Thus a 4-in. pipe, 120 diameters (40 ft.) long, with a globe valve and three elbows, would be equivalent to $120 + 60 + 60 + (3 \times 40) = 360$ diameters long; and $360 \div 240 = 1\frac{1}{2}$. It would therefore have $1\frac{1}{2}$ lbs. loss of pressure at the flow given in the table, or deliver $(1 \div \sqrt{1\frac{1}{2}}$ ·816), 81·6 per cent. of the steam with the same (1 lb.) loss of pressure.

In place of the calculations on the table given in the preceding paragraphs, the following nomographic chart (based on the formula, p. 1745) may be used, and provides a very convenient and sufficiently accurate method of determining pipe sizes, pressure drops, etc.

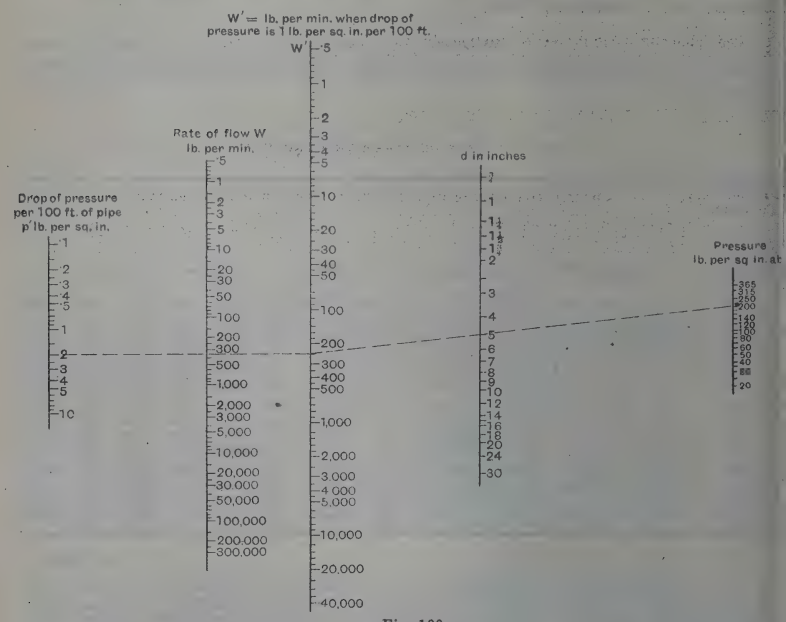


Fig. 100

Method of use of chart :

(*a*) To find diameter for given quantity and pressure drop, join W and p' and produce to cut scale of W′, join point so found to pressure scale at right, read required diameter at intersection with scale of d.

(*b*) To find quantity for given pipe and pressure drop, reverse above process, finding first W′ and then W.

(*c*) To find pressure drop for given pipe and flow, join points on scales of pressure and d, produce to find W′, join W′ to W and produce to cut scale of p' at required value.

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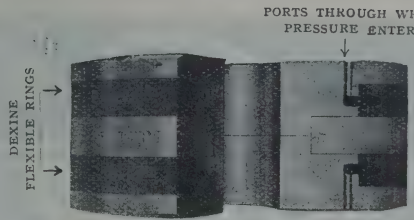

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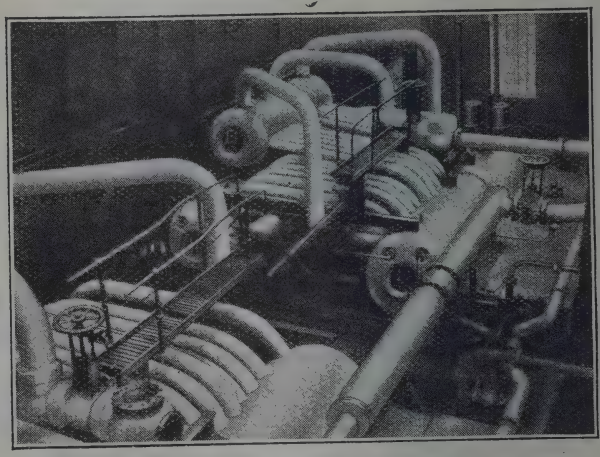

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F. 1747

Flow of Air and Steam in Pipes.

The Babcock and other formulæ for the flow of steam have recently been reviewed and compared with the results obtained by improved experimental methods.

The conclusions of the investigation made by McAdams and Sherwood (Amer. Soc. Mech. Eng., October 1926) are that for air the best formula is:

$$P_1 - P_2 = \frac{0{\cdot}13 f L Q^2 P^2}{P_a D^5 T}$$

$$\text{or } Q_1 = 2{\cdot}77 \sqrt{\frac{D^5 (P_1 - P_2)\, T}{f L P_1^2}}$$

and for steam:

$$P_1 - P_2 = 0{\cdot}0184 \frac{f L G^2}{D^5 w_a}$$

$$\text{or } G = 4{\cdot}51 \sqrt{\frac{D^5 w_a (P_1 - P_2)}{f L}}$$

where

P_1, P_2 are initial and final pressures in lbs. per sq. in.;
P_a = average pressure, lbs. per sq. in. abs.;
Q_1, Q = cub. ft. air per minute at P_1, P, respectively;
D = inside diameter of pipe in inches;
L = equivalent frictional length of pipe in feet;
= length of straight pipe + 2·5 D × number of elbows;
T = air temperature, ° Fah., abs.;
G = lbs. steam per minute;
w_a = lbs. per cub. ft. of fluid at average temperature and pressure;
f = friction coefficient.

f is given by charts from which the values in the following table are extracted:

Values of $\frac{G}{D}$ for Steam, or $\frac{QP}{DT}$ for Air.	Steam.	Air.			
		Iron and Steel Pipes.		Copper and Brass Pipes.	
		300°	70°	300°	70°
0·10	—	0·0113	0·0104	0·0094	0·0088
0·20	—	0·0098	0·0090	0·0080	0·0074
0·40	0·0097	0·0085	0·0079	0·0067	0·0062
0·60	0·0086	0·0078	0·0072	0·0061	0·0056
0·80	0·0081	0·0074	0·0068	0·0056	0·0052
1·00	0·0077	0·0070	0·0065	0·0053	0·0049
1·50	0·0076	0·0065	0·0060	0·0048	0·0045
2·00	0·0066	0·0062	0·0059	0·0045	0·0043
4·00	0·0060	0·0059	0·0058	0·0041	0·0038
10·00	0·0059	0·0058	0·0058	—	—
20	0·0056	0·0058	0·0058	—	—
30	0·0056	0·0058	0·0058	—	—
40	0·0055	—	—	—	—

Loss of Heat from Uncovered Steam Pipes.

The large amount of heat lost from bare steam pipes, and the consequent waste of coal, is frequently not fully appreciated. One square foot of uncovered pipe surface, the pipe containing steam at 100 lbs. per sq. in., will dissipate about 3 B.Th.U. per hour per degree of temperature difference between the steam and the atmosphere, or about 850 B.Th.U. per hour at ordinary

atmospheric temperatures. The steam condensed per hour due to this square foot of bare pipe will be 0·96 lb. In a year of 3,000 working hours the steam wasted will amount to 2,880 lbs., corresponding to a coal consumption of about 410 lbs.

A single 9-ft. length of 6-in. pipe, if uncovered, will waste by heat loss about 2·5 tons of coal per year.

80 to 90 per cent. of this loss may be avoided by the use of suitable coverings, the expense of which is amply counterbalanced by the saving in coal.

It is important that flanges, valves, etc., as well as the body of the pipe lengths, should be covered.

The loss of heat per hour per sq. ft. of surface, in the case of bare pipes, depends principally upon the difference of temperature between the pipe—*i.e.* practically, that of the steam in the pipe—and the surrounding atmosphere, but also is influenced to some extent by the diameter of the pipe, its position—whether horizontal or vertical—the presence of air currents about the pipe, the nature of the pipe surface, and the velocity of the steam in the pipe.

Complete data on all these factors are lacking.

It is usually assumed that the loss is proportional to the difference of temperature, but careful experiments show that the rate of loss, B.Th.U. per sq. ft. per degree F., increases at the higher temperature differences. Thus from 1·95 at 50° difference, it becomes 2·4 at 150°, 3·26 at 300°, 4 at 400°, and 5·26 at 460°. (*McMillan.*)

There is little experimental data on the effect of pipe diameter, but it appears that the loss per sq. ft. decreases as the diameter increases, and this is in accordance with theory.

The following table shows the heat loss from pipes covered with various thicknesses of 85 per cent. magnesia composition, and the approximate loss from uncovered pipes is given for comparison.

LOSS OF HEAT FROM STEAM PIPES, WITH STEAM 300° F. ABOVE ATMOSPHERIC TEMPERATURE. LOSS IN B.TH.U. PER HOUR PER SQUARE FOOT OF PIPE SURFACE.

	Pipe Diameter.					
	1 in.	2 ins.	4 ins.	6 ins.	8 ins.	12 ins.
Bare pipe	1100	1070	1010	945	920	880
Magnesia covering 0·5 in. thick	340	280	250	240	235	230
,, 1·0 in. ,,	260	200	170	155	148	140
,, 1·5 ins. ,,	220	165	145	120	115	105
,, 2·0 ,, ,,	195	140	110	100	92	87
,, 3·0 ,, ,,	170	120	89	75	71	66
,, 4·0 ,, ,,	—	110	75	65	59	52
,, 5·0 ,, ,,	—	—	66	58	52	46

(*Based on tests by McMillan, 'Trans. Am. Soc. M.E.'* 1915.)

The 'efficiency' of the covering in preventing loss of heat is taken as the ratio (heat loss from bare pipe — loss from covered pipe) ÷ heat loss from bare pipe. The table shows that this 'efficiency' varies with the thickness and the pipe diameter, hence to compare different covering materials, the comparison must be made under the same conditions of thickness, etc., if the comparison is to show the relative insulating properties.

The coverings may also be compared on the basis of cost per foot run—*i.e.* taking a greater thickness in the case of the cheaper materials.

The relative properties of various pipe coverings are shown in the following table, the thickness being about 1·4 ins., diameter of test pipe 1 in., steam pressures in pipe 50, 100, and 200 lbs. per sq. in.

Relative Value of Pipe Coverings.

Material.	Weigh per foot run, lbs.	Insulating Efficiency per cent.		
		At 50 lbs. per sq. in.	At 100 lbs. per sq. in.	At 200 lbs. per sq. in.
Sectional cork	1·0	85	86	87
Slag wool	2·6	83	84	—
Cellular asbestos	2·4	81	82	83
Silk waste	2·3	85	85·5	86
Hair felt and asbestos	2·7	83	84	85
Sectional magnesia	1·6	79	79	—
Plastic magnesia	2·2	77	77	—
Diatomite (plastic)	2·2	79	79	—
Kisol and magnesia (plastic)	2·9	77	78	79
Kisol and hair felt (plastic)	3·0	75	77	78
Slag wool and composition (plastic)	1·5	75	76	—
Mica (plastic)	2·6	73	75	—
Asbestos composition (plastic)	3·9	69	71	72
Thinner Coverings.				
Hair felt 0·5 in. thick	—	79	—	—
Magnesia-filled rope 0·7 in. thick	0·8	61	64	—
Asbestos rope 0·7 in. thick	1·2	47	53	—

(*Bradley.*)

Boxes for Pipe Flanges.

In estimating the loss of heat from covered pipe lines, the effect of the boxes covering the flanges in adding to the total area of radiating surface must be allowed for.

For typical flange boxes, assuming one box at each 10 feet of pipe line, the additional area may be taken as about 7 per cent. *i.e.* to find the heat radiated, calculate the pipe surface in square feet, as if there were no flanges, add 7 per cent., and multiply by the appropriate figure from the table on page 1745.

Notes on Coverings for Pipes and Boilers.

As well as having good heat insulating properties, it is important that pipe coverings be durable. A material which easily disintegrates under vibration will not long remain an efficient insulator, nor will a material which cannot stand high temperature. For example, hair felt is a good insulator, but will not stand contact with pipes carrying high pressure or superheated steam.

Tests with locomotive-type boilers, first uncovered and then covered with 2 ins. of 85 per cent. magnesia, showed in the second case 2·5 per cent. additional evaporation for 13·8 per cent. less coal, or a total coal saving of 16 per cent.

(*'Chem. and Met. Eng.,' Feb.* 16, 1921.)

Recent tests at the National Physical Laboratory have shown that 85 per cent. magnesia (that is, 85 per cent. hydrated magnesium carbonate and 15 per cent. asbestos) begins to calcine at 450° F., and that at 600° F. the decomposition is considerable. At the high steam temperatures now coming into use in large power stations (pressures up to 375 lbs. per sq. in. and temperatures up to 700° F.) it is necessary to place next the pipe a material unaffected by heat. About ½ in. of slag wool or of special composition may be used, then a layer of 85 per cent. magnesia or other good non-conductor, and then an outer layer, ½ in. thick, of hard-setting composition to bind the whole together.

Notes on Lagging.

The surface temperature of a lagging, when in use, is commonly supposed by engineers to furnish a clue to its efficiency, and conclusions are often formed from the sensation of heat experienced when the hand is placed on the surface. Another test, frequently employed, is to make

a small hole in the lagging into which the bulb of a thermometer is inserted ; and it is then assumed that the material in which the lowest reading is obtained possesses a superiority in respect to insulating power. Whilst a correct measurement of the temperature of the surface is of value in conjunction with other tests, if taken alone an entirely erroneous opinion of the merit of the material may be formed.

The important factor which is not taken into account in the above rough-and-ready test is the nature of the surface in respect to its radiating power. A lagging with a rough exterior radiates heat with much greater freedom than one which is finished smooth, and the latter which is superior as an insulator, owing to retention of heat by the surface, will feel hotter than the former when touched by the hand. Hence it follows that a given non-conducting coating, if improved by painting and varnishing the surface, would appear to have suffered in insulating power if judged by its surface temperature only. To avoid such a fallacious conclusion, it is evident that the radiating power must also be taken into account, and only when this is done can a correct inference be drawn.

When the radiating surfaces are identical, the surface temperature furnishes a reliable and delicate guide to the insulating powers of different materials. A smooth metallic surface, such as aluminium paint, may be hotter than an unprepared surface, and yet radiate less.

On reference to a test in which a thermometer bulb is placed in a hole made for the purpose in the outer part of the lagging, into which it is customary to pour mercury to secure a good contact between the material and the bulb of the thermometer, it is difficult to say what the reading indicates, as the temperature recorded will be the mean of that existing between the end of the bulb and the surface ; and, moreover, the normal condition of the lagging at this part is entirely changed by the introduction of the mercury and thermometer bulb. One thing is certain : that the reading affords no clue to the surface temperature it is supposed to measure ; and in this respect the test is inferior to the application of the hand. The thermal-junction method is undoubtedly the best for obtaining a definite reading of the surface temperature : and as it is now possible to obtain cheap portable indicators for use with a junction, other so-called measurements should be definitely abandoned.

The relations between surface temperature and efficiency may be summarised as follows :—

1. When the surface of a given insulating material is treated so as to reduce its radiating power, the temperature is higher, although the heat escaping is less.

2. If two different materials possess identical surfaces, that which has the higher surface temperature, under given conditions, is the worse insulator.

A recognition of these two points will prevent engineers from being led astray by the extravagant claims frequently put forward for compositions, based entirely on imperfect surface temperature measurements. The advantage of finishing the surface with aluminium paint instead of ordinary paint and varnish, should be recognised, as not only is the insulating power improved, but the finished work has a better appearance. The fact that such a surface feels warmer to the touch is in this instance not a proof of inferiority, but of the contrary.

(*C. R. Darling*, '*Engineering*,' *Sept.* 22, 1911.)

The holding of slag wool to pipes or boilers (to which asbestos composition has been applied) is best effected by means of wire-bound split laths, so spaced that the finishing overlay of cement may not only be keyed in between them but may also afford a means of locating any leakages, in addition to preserving a favourable density estimated at from 10 to 12 lbs. per cubic. foot.

A cheaper but decidedly less effective way of holding slag wool together is by means of wire netting in the meshes of which an overlay of plastic cement is impacted. When, therefore, disintegration takes place and the wool settles down by its own gravity, the upper surface is reduced to a mere shell of wire and cement by which the bulk is held in suspension.

Silk waste, although almost equal in efficiency to slag wool, is wanting in durability.

Hair-felt is one of the finest non-conductors known, but is quickly consumed by direct contact with heated surfaces. See also pp. 1751, 1752. (*E. Kenyon.*)

Normal Pipe Size.	Thickness. STD.	Thickness. Double Layer Double Standard.		Temperature of the Fluid in the Pipe. 650° F. to 800° F. Thickness of Fire Backing.	650° F. to 800° F. Thickness of 85 per cent. Magnesia.	500° F. to 650° F. Thickness of Fire Backing.	500° F. to 650° F. Thickness of 85 per Cent. Magnesia.
1	$\frac{7}{8}$	$1\frac{3}{4}$	Straight pipe and bends	2″ sectional 6 oz. sheeting covered	None	2″ sectional sheeting covered	None
			Fittings, flanges, etc.	2″ sectional 6 oz. sheeting covered	None	2″ sectional sheeting covered	None
$1\frac{1}{4}$	$\frac{7}{8}$	$1\frac{3}{4}$	Straight pipe and bends	2″ sectional sheeting covered	None	2″ sectional sheeting covered	None
			Fittings, flanges, etc.	2″ sectional sheeting covered	None	2″ sectional sheeting covered	None
$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{3}{4}$	Straight pipe and bends	2″ sectional sheeting covered	None	2″ sectional sheeting covered	None
			Fittings, flanges, etc.	1″ × 3″ × 36″ block	1″ × 3″ × 36″ block	1″ × 3″ × 36″ block	1″ × 3″ × 36″ block
2	$1\frac{1}{32}$	$2\frac{1}{16}$	Straight pipe and bends	$1\frac{1}{32}$″ sectional	4″ sectional covering $1\frac{1}{2}$″ thick	$1\frac{1}{32}$″ sectional	4″ sectional covering $1\frac{1}{2}$″ thick
			Fittings, flanges, etc.	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block
3	$1\frac{1}{32}$	$2\frac{1}{16}$	Straight pipe and bends	$1\frac{1}{32}$″ sectional	5″ sectional covering $1\frac{1}{2}$″ thick	$1\frac{1}{32}$″ sectional	5″ sectional covering $1\frac{1}{2}$″ thick
			Fittings, flanges, etc.	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block
4	$1\frac{1}{8}$	$2\frac{1}{4}$	Straight pipe and bends	$1\frac{1}{8}$″ sectional	6″ sectional covering $1\frac{1}{2}$″ thick	$1\frac{1}{8}$″ sectional	6″ sectional covering $1\frac{1}{2}$″ thick
			Fittings, flanges, etc.	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	1″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block
6	$1\frac{1}{8}$	$2\frac{1}{4}$	Straight pipe and bends	$1\frac{1}{2}$″ sectional	$1\frac{1}{2}$″ segmental block to cover $1\frac{1}{2}$″ covering on 6″ pipe	$1\frac{1}{2}$″ sectional	$1\frac{1}{2}$″ segmental block to cover $1\frac{1}{2}$″ covering on 6″ pipe
			Fittings, flanges, etc.	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block
8	$1\frac{1}{4}$	$2\frac{1}{2}$	Straight pipe and bends	$1\frac{1}{4}$″ sectional	2″ segmental block to cover $1\frac{1}{4}$″ covering on 8″ pipe	$1\frac{1}{2}$″ sectional	$1\frac{1}{2}$″ segmental block to cover $1\frac{1}{2}$″ covering on 8″ pipe
			Fittings, flanges, etc.	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block	$1\frac{1}{2}$″ × 3″ × 36″ block

PIPE COVERING STANDARDS FOR VARIOUS SERVICES—(*cont.*)

Normal Pipe Size.	Thickness. STD.	Thickness. Double Layer Double Standard.		Temperature of the Fluid in the Pipe. 650° F. to 800° F. Thickness of Fire Backing.	650° F. to 800° F. Thickness of 85 per cent. Magnesia.	500° F. to 650° F. Thickness of Fire Backing.	500° F. to 650° F. Thickness of 85 per cent. Magnesia.
10	1¼	2½	Straight pipe	1½″ segmental	2″ segmental block to cover 1½″ covering on 10″ pipe	1½″ segmental	1½″ segmental block to cover 1½″ covering on 10″ pipe
			Bends, fittings, flanges, etc.	1½″ × 3″ × 36″ block	2″ × 3″ × 36″ block	1½″ × 3″ × 36″ block	1½″ × 3″ × 36″ block
12	1½	3	Straight pipe	1½″ segmental	2″ segmental block to cover 1½″ covering on 12″ pipe	1½″ segmental	1½″ segmental block to cover 1½″ covering on 12″ pipe
			Bends, fittings, flanges, etc.	1½″ × 3″ × 36″ block	2″ × 3″ × 36″ block	1½″ × 3″ × 36″ block	1½″ × 3″ × 36″ block
14	1½	3	Straight pipe	2″ segmental	1½″ segmental block to cover 2″ covering on 14″ pipe	1½″ segmental	1½″ segmental block to cover 1½″ covering on 14″ pipe
			Bends, fittings, flanges, etc.	1½″ × 3″ × 36″ block	2″ × 3″ × 36″ block	1½″ × 3″ × 36″ block	1½″ × 3″ × 36″ block
16	1½	3	Straight pipe	2″ segmental	2″ segmental block to cover 2″ covering on 16″ pipe	1½″ segmental	1½″ segmental block to cover 1½″ covering on 16″ pipe
			Bends, fittings, flanges, etc.	2″ × 3″ × 36″ block	2″ × 3″ × 36″ block	1½″ × 3″ × 36″ block	1½″ × 3″ × 36″ block

Double layer double standard 85 per cent. magnesia sectional covering (pipes and bends) up to and including 8″ pipe. Segmental block 10″ pipe and larger. — 300° F. to 500° F.

Standard thickness 85 per cent. magnesia sectional covering (pipe and bends) up to and including 8″ pipe. Segmental block on pipe 10″ and larger. — 100° F. to 300° F.

Single ply tar paper. Two 1-in. layers hair felt fastened with 4-ply jute twine. Tar-paper 6 oz. sheeting sewed on, and painted, out-doors. Barrets 'ever jet' water pp. — Anti-Freeze. — General Service and City Water.

1-in. tar-lined wool felt covering. 6-oz. sheeting pasted on and fastened with ¾″ × 1″ staples painted outside. Hair felt and 6-oz. sheeting for fittings, etc. — Anti-Sweat. — Drinking Water.

1½″ sectional cork covering. #16 galvanised soft steel wire. 6-oz. sheeting and glue comes with covering.

Note A.—Each layer of all two-layer block coverings is to be tied on with galvanised wire, 16 gauge on pipes over 10 ins., 18 gauge on 10 ins. and under.

Note B.—The outside layer on pipe 6 ins. and larger is to be covered with ¼ in. of S.B. Conklins #00 asbestos cement finished smooth and wrapped 6-oz. sheeting, pasted on.

Note C.—All covering to be wrapped with 6-oz. sheeting, pasted on, except as noted.

Note D.—Flat blocks are known as 'John Manville fire backing,' sectional form as 'John Manville high temperature Insulation.'

(*Power, Sept. 28, 1926.*)

CARRYING water in a sieve is like conveying heat energy through uninsulated or semi-insulated pipes.

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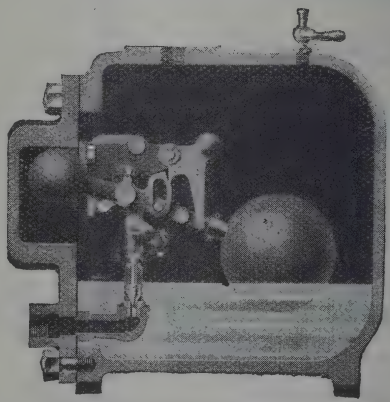
F. 1752

STEAM TRAPS

The BRADFORD Steam Trap.



WEIGHT-OPERATED TYPE

(*See article, page 1753, 1754.*)

Greater Capacity than any other.

Instantaneous Opening and Closing.

No Wire Drawing.

Discharge Full Open or Dead Closed.

Will Deal with Flooding or Priming.

Piston or Weight-Operated Discharge.

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116 Fenchurch St., London; 632 Royal Liver Bldg., Liverpool; Palatine Bldg., Bolton; Pembroke Bldgs., Swansea; 52 St. Enoch Sq., Glasgow; 2 Collingwood St., Newcastle-on-Tyne, &c., &c.

STEAM DRYERS AND WATER SEPARATORS.

STEAM TRAPS

Dry steam plays a far more important part in the efficiency of engines and boilers than is generally recognised, the economical efficiency of an otherwise high-class plant being frequently marred by the waste, condensation, broken joints, etc., due to wet steam.

Water carried forward from the boiler by priming, although it does no work whatever, is nevertheless heated up to the same temperature as the steam itself, and therefore represents a loss in coal proportionate to its weight. All boilers prime more or less, but priming is invariably heavy in boilers that are worked to their limit, or in any way hard pushed.

An engine may give a satisfactory diagram and yet be anything but economical if regard is had to the quantity of water contained in the steam, or to the amount of condensation in the cylinder, which the presence of water greatly increases. In the same way a boiler may appear to have a high evaporative efficiency, judged by the quantity of water it disposes of, whereas its efficiency would frequently appear in quite a different light if judged only by the amount of water it evaporated, *i.e.*, gave off as dry steam.

Dry steam itself is not a good conductor of heat, but water is, and therefore its presence in steam pipes and cylinders should never be permitted, as by acting as a conductor between the steam and the metal it sets up active condensation and absolutely prevents economical results being obtained, even in engines of the best design.

Wet steam is very deleterious in steam turbines, causing erosion and abrasion of the blading and deposition of solid matter on the blades and passages.

In addition to the above considerations, there is also the fact that water in steam pipes invariably causes leaky joints and other annoyances of a nature only too well known.

A separator should be fitted near the engine, unless the steam is superheated, in which case the separator is of questionable service, any water drained from it being probably due to the large surface of the separator itself offers for cooling by radiation.

Separators as a rule act by causing change of direction of the steam, either giving it a definite whirling path, or by causing it to pass down one side and up the other side of a vessel having in it a plain vertical baffle.

STEAM TRAPS.

Steam traps are indispensable adjuncts to steam apparatus in which water of condensation must be drained off with regularity and certainty, and without loss of steam.

A steam trap should work reliably and economically and without adjustment with considerable fluctuations of steam pressure, and working parts should be readily accessible without having to disconnect pipes.

All steam traps are either of the expansion (thermostatic) or float (bucket) type. The three main groups of expansion traps work (*a*) on expansion and contraction of metal tubes, (*b*) on expansion and contraction of either a liquid enclosed in a tube actuating a valve attached to a piston (cartridge type), or expansion and contraction of a rod other than metal, to which the valve is attached, and (*c*) on expansion and contraction of volatile liquid enclosed in a capsule or bellows (vapour type).

Float traps are made either with closed (ball) float or with open floats operating valves either directly, or through levers, or operating pilot valve only, the main valve being operated by the steam pressure.

Expansion traps on account of their small dimensions are generally preferred for draining individual steam-heated appliances (radiators, calorifiers, evaporators, etc.). When cold they are always wide open and therefore do not require venting devices.

Float traps are desirable for draining collecting drain pipes, steam mains, oil separators, and generally where sudden variations in water quantity are likely.

'THE BRADFORD' STEAM TRAP.

(*United States Metallic Packing Co., Ltd., Soho Works, Allerton Road, Bradford.*)

'The Bradford' Steam Trap embodies a new principle in this class of device. It is a float trap, but with an important difference. The float does not open or close the discharge valve. It simply releases or engages a weighted lever, which is so arranged that the outlet is instantaneously opened or instantaneously closed. There is no middle position. This effectually prevents the wire-drawing of the discharge, which cuts the valve and seat and so destroys the efficiency of those traps where the opening and closing take place gradually.

The method of operation is as follows (fig. 101). The water accumulates in the collecting chamber and gradually raises the float until the latter reaches the desired point, when it trips the weighted lever, which immediately opens the discharge to its fullest extent. The water is

then forced out under full pressure until it reaches the bottom level, when the lever is again tripped and the discharge is at once closed. The outlet is always submerged, so that there can be no escape of steam.

The apparatus is made in two classes, viz. the piston-operated trap and the direct-operated trap. Fig. 101 represents the piston-operated trap, in which the discharge valve is operated by the steam acting on a piston working in a cylinder. By this method the maximum diameter of outlet opening is obtained without reference to the steam pressure. This is a most important feature, as in consequence of the unusually large outlet the trap will deal equally well with flooding and priming as with ordinary condensation. In the direct-operated trap the action is simpler, the discharge being opened and closed directly from the trip lever, but the area of the outlet is smaller.

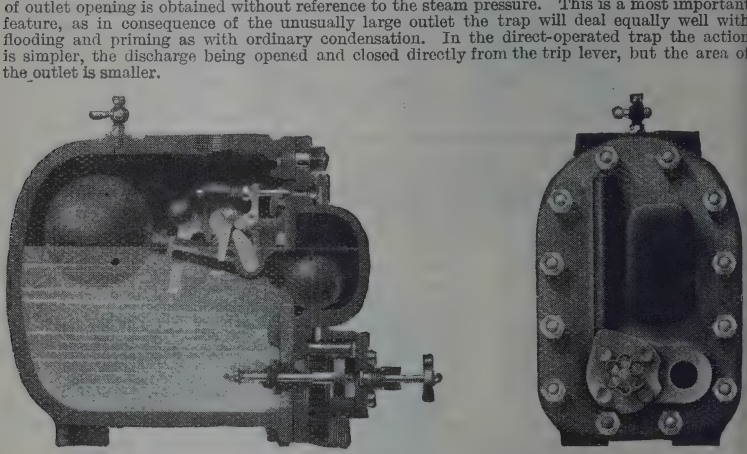

FIG. 101.—Piston-Operated Trap.

The traps will work at any pressure from 250 lbs. downwards, and are made in several sizes. The piston-operated traps will discharge from 10,000 to 160,000 gallons per hour when working at 100 lbs. pressure. In the direct-operated traps the discharge capacities range from 325 to 1,800 gallons per hour at 100 lbs. pressure. Both traps will force the discharge water 1 foot high for every pound of steam pressure.

An *eliminator*, which combines the above trap with a convenient form of separator, is also prepared, the manufacturers being The United States Metallic Packing Co., Ltd., of Soho Works, Allerton Road, Bradford.

THE 'DRAYTON' DIFFERENTIAL STEAM TRAP.

(The Drayton Regulator and Instrument Co., Ltd., West Drayton.)

This arrangement, fig. 102, consists of two sections: (1) the 'Drayton Capacity Multiplier,' (2) the 'Euston' all-metal thermostatic steam trap.

The 'Drayton Capacity Multiplier' is a pear-shaped vessel having a central tube to the outlet and a nozzle situated at the highest point thereof. The entrance to the nozzle is controlled by a throttling screw with outside adjustment.

The 'Euston' steam trap contains an inner tube which forms an expanding element and carries a valve seat at its higher end. The valve is supported by a spindle passing through the trap cover and held by a thread in an exterior bridge.

Condensate and steam pass freely into the body of the Capacity Multiplier. The condensate rises evenly inside and outside the central tube by virtue of the steam pressure being transmitted to the central tube through the nozzle. The steam, having free access to the trap, expands the inner tube and the valve is held closed.

When the condensate rises sufficiently high in the capacity multiplier to seal the lower end of the nozzle, the steam is shut off from the trap; condensation causes a rapid fall of pressure in the trap and the central tube of the capacity multiplier, which permits the pressure in the main body of the capacity multiplier to lift the condensate into the trap.

The condensate which has been longest in the capacity multiplier is the first to enter the trap, and the considerable difference in temperature between this and the steam causes immediate

contraction of the inner tube of the trap and opening of the trap valve ; the condensate, therefore, is expelled through the valve, and passes to the outlet down the annular space between the inner and the outer tubes, thereby expediting the opening of the valve to its fullest extent.

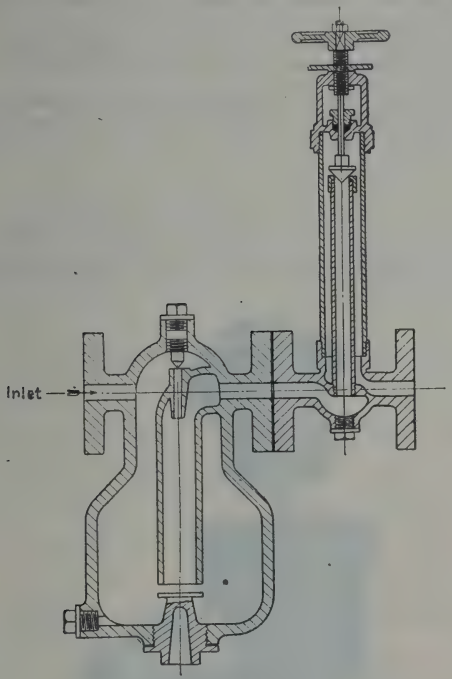

FIG. 102.

The nature of the discharge depends entirely on the amount of condensate handled. When the rate at which condensate accumulates in the capacity multiplier is slower than the rate at which it can be discharged through the trap valve, the action is intermittent ; under these conditions it will be found that the trap opens and closes sharply ; there is little or no live steam lost after the

Size	A	B	C	D	E	F
ins.	ins.	ins.	ins.	ins.	ins.	ins.
$\frac{1}{2}$	$2\frac{5}{8}$	$8\frac{3}{4}$	$5\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{3}{8}$	$10\frac{3}{8}$
$\frac{3}{4}$	$2\frac{5}{8}$	$8\frac{3}{4}$	$5\frac{3}{4}$	4	4	$10\frac{1}{2}$
1	$2\frac{5}{8}$	$8\frac{3}{4}$	$5\frac{3}{4}$	$4\frac{3}{4}$	$4\frac{1}{2}$	11
$1\frac{1}{4}$	3	13	8	$5\frac{1}{2}$	$5\frac{1}{2}$	$12\frac{3}{4}$
$1\frac{1}{2}$	$3\frac{1}{4}$	13	9	$5\frac{1}{2}$	6	14
2	4	18	10	$6\frac{1}{2}$	$7\frac{1}{8}$	$15\frac{1}{8}$

trap has finished discharging. On the other hand, if the rate at which the condensate accumulates in the capacity multiplier approaches or equals the rate at which the trap valve permits discharge, the action is continuous.

When the level of the condensate in the capacity multiplier sinks to the lower end of the central tube, steam passes into the trap, closes the valve, by expanding the inner tube, and the cycle commences again. As condensate is continuously trickling into the trap, the level in the

capacity multiplier will commence to rise as soon as the flow up the central tube is broken by the unsealing of the lower end of the nozzle.

All grit, dirt, and other impurities which may come through with the steam and condensate, are retained in the base of the capacity multiplier by the mud stool. A plug is provided for draining out periodically.

To adjust for any working pressure, the valve should be advanced towards or withdrawn from the valve seat. This can easily be done by means of the hand wheel provided.

Condensate can be lifted 2 ft. for every pound of steam over 5 lb. per sq. in., if a check valve is fitted on the outlet.

The 'Drayton Differential' is made in materials suitable for any pressure of saturated or superheated steam. When used for pressures under 40 lbs. per sq. in. the 'Euston' is made with longer internal and external tubes.

Sizes up to 1¼ in. are fitted with cone metal-to-metal valves; 1½ in. and 2 in. traps are fitted with flat metal-to-metal valves.

'Drayton' Balanced Pressure Trap.

(The Drayton Regulator and Instrument Co., Ltd., West Drayton.)

Fig. 103 shows the 'Drayton' Balanced Pressure Trap with cover and thermostatic element removed. This trap is of the thermostatic type and utilises the difference in temperature between steam and water.

Fig. 103.

The particular feature of the 'Drayton' Balanced Pressure Trap is that the thermostatic element is so filled that the difference in pressure inside and outside the bellow chamber remains constant, no matter what the actual pressure outside the thermostatic element may be.

In place of the usual diaphragm, a bellows of large diameter is employed, and the length of the bellows is such that the valve has a lift of $\frac{3}{16}$ in.

This trap requires no adjustment for varying steam pressures, and opens and closes sharply

General Notes on Steam Trap Practice.

Steam traps when cold should be wide open, or air vents should be provided so that at starting all air and water are expelled from the pipes when steam commences to pass. The traps close automatically, so that there is no possible chance of water hammer and rents occurring in pipes through an accumulation of cold water suddenly receiving the impact of live steam, the cause of many accidents.

The traps should always be fixed at a point where a droop or bend in the pipe is situated, and at the lowest possible point.

In the event of the drain pipe being screwed into a cylinder or pipe, great care should be taken that the drain does not rise above the inside of the vessel or pipe, otherwise perfect drainage is not possible.

It will be found that if a length of pipe is fitted between traps and vessels to be drained, so as to form a reservoir for the water, it will greatly facilitate the easy working of the trap, as the discharge water is much cooler, and enables the trap to do a larger amount of work than it would do under ordinary conditions.

Every lb. per sq. in. pressure balances a column of water 2¼ ft. high, so that in arranging for tanks, if 2 ft. of water for every 1 lb. of steam pressure is allowed for, the allowable height for placing the tank can be ascertained. In this case a non-return valve, similar to a boiler feed check valve, should be placed on the outlet side when the trap is used for lifting water, to prevent the water returning into the pipes when main steam is shut off.

When discharging into a sealed drain it is advisable to fit a three-way cock to the outlet, so that the trap can be adjusted with the cock opened to the atmosphere. There is an additional advantage in having a three-way cock fitted, as the working of the trap can be inspected at all times by simply opening the cock to the atmosphere.

By blowing the pipes through with live steam before fixing the trap, the dirt will be cleaned out, and much trouble saved in the after working of same.

The greatest precaution taken cannot always prevent grit getting into the pipes, and if same is not blown out at starting it is likely to get into the trap and become fixed in the seat or valve face. The consequence is, the trap is likely to let steam pass. Steam at high pressure cuts almost as badly as compressed air, and the longer the steam is allowed to blow through, the worse the valve is cut; when this takes place the valve should be examined, and, if cut, it should be trued up in a lathe, or if badly cut it should be renewed.

Steam issuing from the discharge of a high-pressure trap is not a proof of steam leakage, Wherever water under pressure and at a temperature above 212° is released to the atmosphere, about 1 per cent. will flash into steam for each 10° by which the original water temperature exceeds 212°.

Selection, Installation, and Upkeep of Steam Traps.*

(Abstract.)

The two main factors to be considered in selecting traps are (1) the steam pressure at the trap, and (2) the amount of condensation to be handled. It should be carefully noted that the steam pressure desired is that at the trap, not the boiler pressure or the pressure at some

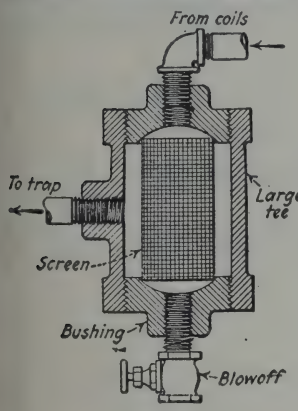

FIG. 104.

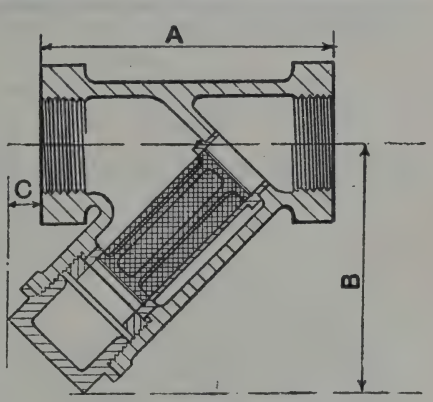

FIG. 105.

point near the trap. Where the pressure varies, the trap should have the correct opening for the higher pressure, yet it should have ample capacity to operate on the lower pressure.

The best practice is to put a separate trap on each steam coil, drying cylinder, steam main, steam separator, etc.,

When a trap is attached to a piece of apparatus using superheated steam, care must be taken that the steam is not superheated when it reaches the trap, otherwise the latter will not operate.

* E. Smiley, *Power*, July 11, 1922.

Drips on superheated lines are necessary to handle such conditions as the priming of the boilers In such cases the connection to the trap must have enough radiating surface to ensure condensa tion for the trap to work on. Traps of the continuous-discharge type and many of the bucke traps require a certain amount of water in the body. If superheated steam gets into the trap it re-evaporates the water and causes leakage and wiredrawing. On account of the tendency to wiredrawing with superheated steam and with apparatus operating at high pressure with but little condensation, a special metal should be provided in the valve and seat.

The best way to avoid trouble from dirt, scale, or sediment is to use a 'strainer' like that shown in fig. 104, which is easily made up from pipe fittings and a strip of heavy brass or copper wire screen made in the form of a cylinder, so that it will fit in the recesses of the bushing. Another convenient type of strainer is that shown by fig. 105, and made by *The Drayton Regulator and Instrument Company, Ltd., West Drayton*, which can be inserted into pipe line at the trap inlet side and can be cleaned without breaking the pipe line.

A strainer requires occasional cleaning, but that is a simple matter compared to cleaning the trap.

Many traps are provided with blow-off pet-cocks or valves, so that the traps can be blown down and cleaned out periodically. A simpler but less efficient remedy is a dirt leg in the piping in front of the trap. This can be made up with a tee, long nipple and cap. Excessive oil in the line can usually be traced to a faulty oil separator in the system.

The only way to be absolutely sure that a trap is clean is by an examination of the interior. In fact, it is good practice to inspect traps at least once or twice a year.

Although 1 lb. pressure at the trap will support 2·4 ft. of water at 212 deg., it is well to figure back pressure at the rate of about one pound for every two feet of head. This makes a reasonable allowance for friction in the pipe and fittings.

High-pressure traps should not in general discharge into sealed return pipes under a low pressure, as the breaking into steam (or flashing, as it is called) of the high-temperature water upon release will cause snapping and water hammer in the pipes. It is usually best for all traps, when the condensation is to be saved, to discharge into a vented receiver above the water line. This prevents any backing up or water hammer, and also gives an opportunity to detect severe steam leakage by an inspection of the outlet to the vent pipe leading from the trap.

A general rule on the location of a trap is to keep it below the lowest water level in the unit it is draining. This keeps the discharge line free of condensation when the pipes get cold on intermittent service, and thereby decreases the possibility of water hammer.

Traps that are outside and likely to be injured by freezing should be insulated and located as near the heating unit as possible. Their discharge lines should also be automatically drained in case they rise above the lowest water level of the trap. This prevents the condensation from flowing back into the traps when the pressure is taken off. It is of primary importance that they be accessible for periodic inspection.

SECTION XXX

PART III

RECIPROCATING STEAM ENGINES

EXPANSION OF STEAM — HORSE-POWER—STEAM CONSUMPTION—INDICATOR AND INDICATOR DIAGRAMS — ENGINE TYPES FOR VARIOUS DUTIES — WEIGHTS OF ENGINES — ENGINE DESIGN — FRAMES — CYLINDERS — BEARINGS — FLYWHEELS — GOVERNORS — PACKINGS — PISTONS — SLIDE VALVE GEARS—LINK MOTIONS

(Revised by T. B. Morley, D.Sc., M.I.Mech.E.)

Expansion of Steam.

It is found in practice that in engines using saturated steam the expansion line follows closely the hyperbolic law :—

absolute pressure × volume = a constant.

Hence it is usual to compute indicator diagrams on the assumption that the expansion is hyperbolic. With highly superheated steam the pressure falls more rapidly than the hyperbolic curve indicates.

Referring to fig. 1, the theoretical indicator diagram is A B C D O, there being no clearance and a perfect vacuum. Steam is cut off at B and exhausted at C.

FIG. 1.

p = absolute pressure in lbs. per sq. in.;

u = volume in cubic feet;

R = ratio of expansion = $\frac{OD}{AB}$;

W = area of diagram;

P = mean effective pressure in lbs. per sq. in. (M.E.P.);

pu = a constant.

then $W = ABCE + ECDO$

$= p_2u_2 \text{ hyp. log } R + p_2u_2$.

$$P = p_1\left(\frac{\text{hyp. log } R + 1}{R}\right) = p\ K.$$

TABLE OF MEAN PRESSURE CONSTANTS K.

The table also gives the points of cut-off (nominal), based on assumed cylinder ratios, L.P. to H.P., in the case of multiple-expansion engines.

R.	K.	Nominal Cut-off (clearance neglected) as proportion of Stroke.			
		Single Cylinder, including Uniflow.	In H.P. Cylinder of Multiple-Expansion Engine.		
			Compound. Cylinder ratio = 4.	Triple. Cylinder ratio = 6.	Quadruple. Cylinder ratio = 8.
1·25	0·979	0·8			
1·4	0·955	0·72			
1·6	0·919	0·62			
1·8	0·882	0·55			
2·0	0·847	0·50			
2·5	0·767	0·40			
3·0	0·700	0·33			
3·5	0·644	0·29			
4·0	0·597	0·25			
4·5	0·556	0·22			
5·0	0·522	0·20			
6·0	0·465	0·17	0·67		
7·0	0·421	0·14	0·57		
8·0	0·385	0·12	0·50		
9·0	0·355	0·11	0·44		
10·0	0·330	0·10	0·40	0·60	
11·0	0·309	0·091	0·36	0·55	
12·0	0·290	0·083	0·33	0·50	
14·0	0·260	0·072	0·29	0·43	0·57
16·0	0·236	0·062	0·25	0·38	0·50
18·0	0·216	0·055	0·22	0·33	0·44
20·0	0·200	...	0·20	0·30	0·40
25·0	0·169	...	0·16	0·24	0·32
30·0	0·147	...	...	0·20	0·27
35·0	0·130	...	...	0·17	0·23
40·0	0·117	...	...	...	0·20

(*Morley.*)

The referred M.E.P. of compound engines is the equivalent M.E.P. if the entire expansion were to take place in the low-pressure cylinder.

The nominal ratio of expansion is the stroke volume of the L.P. cylinder ÷ volume swept by H.P. piston up to point of cut-off, or

$$R = \frac{V_L}{a\ V_H} = \frac{\text{cylinder ratio}}{a}$$

where V_H, V_L are stroke volumes of H.P. and L.P. cylinders, and a is proportion of stroke at which cut-off takes place in the H.P. cylinder.

If C_H and C_L are the clearance volumes at each end of the H.P. and L.P. cylinders, the real ratio of expansion is

$$\frac{V_L + C_L}{a\ (V_H + C_H)}$$

To determine the probable actual mean pressure (referred to the low-pressure cylinder in the case of a multiple-expansion engine) multiply the initial pressure (absolute) by K, deduct the back pressure, and multiply by a suitable 'diagram factor.'

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Diesel Engines, Land and Marine;

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Centrifugal Pumps, Fans and Blowers of all kinds;

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"Sulzer Dry System" of Coke Cooling;

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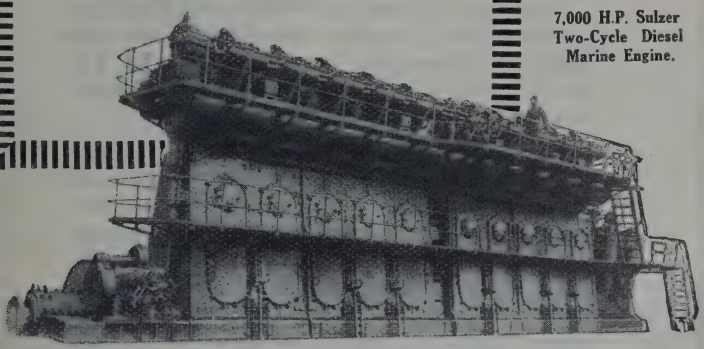
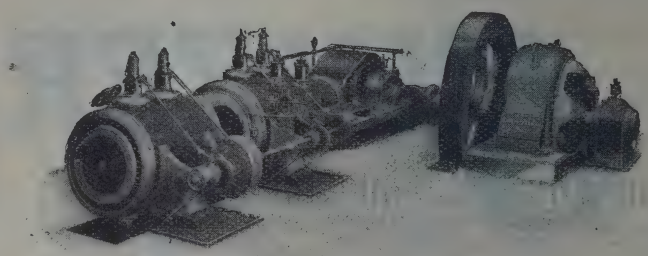


7,000 H.P. Sulzer Two-Cycle Diesel Marine Engine.

SULZER BROS. 31 Bedford Square, LONDON, W.C.



THE PAXMAN Positive Valve Gear engines are suitable for boiler pressures up to 200 lb. per square inch, with a total steam temperature up to 600 degrees Fahr.

The economy of the steam consumption of these engines is remarkable, it being possible to obtain one-horse power for every $9\frac{1}{2}$ to $10\frac{1}{2}$ lb. of superheated steam.

With an installation comprising our 'Economic' type of boiler and Positive Valve Gear engine combined, we are able to guarantee consumptions of 1·1 to 1·2 lb. of coal per I.H.P. per hour under suitable conditions.

The PAXMAN Positive Valve Gear lends itself to the easy conversion of existing engines to Paxman-Lentz type. Under actual practice, improvements and economies in steam consumption up to 26% have been obtained with a great reduction in maintenance costs.

Steam Engines and Boilers of all types. Superheaters, Gas Engines and Producers.

DAVEY, PAXMAN & CO. Ltd.,
Colchester, and Aldwych House, Aldwych, W.C.2.

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F. 1761

Diagram factors depend on the type of engine, type of valves and valve gear, jacketing, superheating, speed, etc. Approximate typical values are as follows:—

TABLE OF DIAGRAM FACTORS.

Triple-expansion	·65–·75
Compound condensing, superheated	·65–·75
„ „ saturated	·7– ·8
„ non-condensing	·8–·85
Simple condensing, trip gears	·9–·95
„ „ slide valves	·85– ·9
„ non-condensing	·9–·95

Note.—In calculating the M.E.P. the clearance is ignored. If the clearance is allowed for, the ratio of expansion for a given cut-off is lower and the theoretical M.E.P. higher, necessitating a lower diagram factor, particularly for simple and compound engines. Thus, some authorities give from 0·7 to 0·9 for simple engines.

Low revolutions, large clearance, jackets, reheaters, and low compression increase the diagram factor. These special conditions must be allowed for, as in slow-speed pumping engines.

Usual Expansions in Various Types of Engines.

Single Condensing Engines	from 2 to 5 times
Two-cylinder Compound Engines	„ 10 „ 20 „
Triple-expansion Engines	„ 12 „ 25 „
Quadruple-expansion Engines	„ 16 „ 30 „
Uniflow Engines	„ 7 „ 12 „

INDICATED HORSE-POWER OF STEAM ENGINES.

P = Mean effective pressure, in pounds per square inch;
A = Area of cylinder in square inches;
L = Stroke in feet;
N = Revolutions per minute;

then

$$\text{I.H.P. (for a double-acting engine)} = \frac{2\ PLAN}{33{,}000}$$

(See also p. 1773.)

The I.H.P. of a compound or multiple expansion engine is the sum of the powers of the individual cylinders, each calculated as above. For such engines, the 'referred M.E.P.' or 'M.E.P. referred to the L.P. cylinder' is frequently spoken of and used in designing. It means that M.E.P. which, if it acted in a single cylinder of the same dimensions as the L.P. cylinder of the compound engine and working at the same speed, would produce the same power.

The '*referred M.E.P.*' is thus equal to M.E.P. of H.P. cylinder $\times \frac{\text{H.P. cylinder area}}{\text{L.P. cylinder area}}$

$+$ M.E.P. of I.P. cylinder $\times \frac{\text{I.P. cylinder area}}{\text{L.P. cylinder area}} +$ M.E.P. of L.P.

For a two-cylinder compound engine the middle term disappears.

Brake Horse-Power (B.H.P.).

'Brake' or 'Effective' or 'Actual' horse-power is the horse-power delivered by the engine to whatever it is driving. If the engine shaft is coupled to the driven machine—such as a generator for electric power, or a rolling mill, or whatever it may be—the B.H.P. is the power transmitted at the coupling. For a rope drive it is the power at the engine rope pulley. In all cases the B.H.P. is the indicated H.P. less the power absorbed in the running of the engine itself. This latter power—the frictional H.P.—is about 10 per cent. in good modern engines, 8 per cent. in those of the highest class, but may be as much as 20 per cent. in small engines of crude design.

Mechanical Efficiency.

The 'mechanical efficiency' is the ratio of B.H.P. to I.H.P. For high-class engines of, say, 100 H.P. and upwards, typical values of the mechanical efficiency at various loads are as follows:—

Load	Full	¾	½	¼
Mechanical efficiency, per cent.	92	90·5	88	80·5

TABLE OF STANDARD HORSE-POWER FOR DIFFERENT NATIONS.

Country.	Kilogrammètres per Second.	Baden Foot-pounds per Second.	Saxon Foot-pounds per Second.	Wurtemberg Foot-pounds per Second.	Prussian Foot-pounds per Second.	Hanoverian Foot-pounds per Second.	English Foot-pounds per Second.	Austrian Foot-pounds per Second.
France and Baden . .	**75**	**500**	529·68	521·58	477·93	513·53	542·47	423·68
Saxony	75·045	500·30	**530**	523·89	478·22	513·84	542·80	423·93
Wurtemberg	75·240	501·36	531·12	**525**	479·23	514·92	543·95	424·83
Prussia	75·325	502·17	531·97	525·85	**480**	515·75	544·82	425·51
Hanover	75·361	502·41	532·23	526·10	480·23	**516**	545·08	425·72
England	76·041	506·94	537·03	530·84	484·56	520·65	**550**	429·56
Austria	76·119	507·46	437·58	531·39	485·06	521·19	550·57	**430**

STEAM CONSUMPTION.

The ideal steam-engine cycle, adopted as a standard of comparison, is the Rankine cycle. In it the steam is fully expanded adiabatically, and there are no losses due to throttling, clearance, leakage, condensation, etc.

The following tables show the work done (in B.Th.U.) per lb. of steam, and the steam consumption per i.h.p. hour in the case of ideal engines:—

(1) when the expansion is incomplete;
(2) when the expansion is complete—*i.e.* the Rankine cycle.

TABLE OF STEAM CONSUMPTION AND WORK DONE BY STEAM.

(1)

Theoretical lbs. of steam per i.h.p. hour and work done in B.Th.U. per lb. of steam, assuming adiabatic expansion from dry steam and no compression or clearance losses, to:—

(1) 25 lbs. release pressure with 16 lbs. back pressure.
(2) 10 lbs. release pressure with 2 lbs. back pressure.

All pressures are in lbs. per square inch absolute except the approximate gauge boiler pressure corresponding to the absolute initial pressure at the engine. A pressure drop of 5 lbs. between boiler and engine is assumed.

The correction given in the table is the change in theoretical steam consumption for one pound change in the back pressure, other conditions remaining unaltered.

Boiler Pressure lbs. gauge.	Initial Pressure absolute.	Back Pressure, 16 lbs. absolute.			Back Pressure, 2 lbs. absolute.		
		Lbs.	B.Th.U.	Correction per lb.	Lbs.	B.Th.U.	Correction per lb.
210	220	13·5	188	0·2	9·4	270	0·2
200	210	13·8	185	0·2	9·6	266	0·2
190	200	14·1	181	0·2	9·7	262	0·2
180	190	14·4	177	0·2	9·8	259	0·2
170	180	14·7	173	0·3	10·0	255	0·2
160	170	15·1	169	0·3	10·1	252	0·2
150	160	15·5	164	0·3	10·3	248	0·2
140	150	15·9	160	0·3	10·5	243	0·3
130	140	16·4	155	0·3	10·7	238	0·3
120	130	17·1	149	0·3	10·9	233	0·3
110	120	17·8	143	0·3	11·2	227	0·3
100	110	18·6	137	0·4	11·5	222	0·3
90	100	19·6	130	0·4	11·9	214	0·4
80	90	20·9	122	0·4	12·3	207	0·4
70	80	22·5	113	0·5	12·7	200	0·4

(*Morley.*)

Table of Steam Consumption and Work done by Steam.

(2)

Theoretical steam consumption in lbs. per i.h.p. and work done per lb. of steam in B.Th.U., assuming adiabatic expansion from dry saturated steam with complete expansion. Rankine cycle.

Absolute Initial Pressure, Lbs.	Lbs. per i.h.p. hour. Back pressure, lbs. abs.				B.Th.U. per lb. of Steam. Back pressure, lbs. abs.			
	14·7	2	1·5	1	14·7	2	1·5	1
220	12·9	8·2	7·85	7·4	198	310	324	344
210	13·0	8·3	7·9	7·45	195	307	321	341
200	13·2	8·4	8·0	7·5	192	303	318	338
190	13·5	8·5	8·1	7·5	188	300	315	334
180	13·8	8·6	8·2	7·6	184	297	311	331
170	14·1	8·7	8·3	7·7	180	293	308	328
160	14·5	8·8	8·4	7·75	175	289	304	324
150	14·9	8·9	8·5	7·95	170	285	300	320
140	15·3	9·1	8·6	8·1	166	280	295	315
130	15·9	9·25	8·75	8·2	160	275	290	310
120	16·5	9·4	8·9	8·35	154	270	285	305
110	17·2	9·65	9·1	8·5	148	264	279	300
100	18·0	9·9	9·3	8·65	141	257	273	294
90	19·1	10·2	9·55	8·85	133	250	266	287
80	20·5	10·5	9·8	9·1	124	243	259	279
70	22·1	10·9	10·2	9·4	115	234	250	271
60	24·7	11·4	10·6	9·75	103	223	241	261
50	28·6	12·0	11·2	10·2	89	211	227	249

(*Morley.*)

The steam consumption, lbs. per i.h.p. hour = 2545 ÷ work done, B.Th.U. per lb.

For pressures of 100 to 200 lbs. per sq. in. and back pressures 1 to 2 lbs. per sq. in., the steam consumption of the ideal (Rankine) engine decreases about 6 per cent. for each 100° F. of superheat.

EFFICIENCY OF ENGINES.

The thermal efficiency—of the engine alone, exclusive of boiler plant—is the ratio of the work done per lb. of steam (in B.Th.U.) to the heat required to generate 1 lb. of steam, at the pressure and temperature, at the engine stop valve from feed water at the temperature of the engine exhaust.

$$\text{Thermal efficiency } e = \frac{\text{I.H.P.} \times 42{\cdot}42}{w\,(H_1 - h_2)} = \frac{\text{I.H.P.} \times 2545}{W\,(H_1 - h_2)}$$

where,

w = steam used, lbs. per minute; W = do., lbs. per hour;
H = total heat at pressure and temperature at boiler side of engine stop valve;
h_2 = water heat at temperature of exhaust.

It is customary to express the performance of engines in steam consumption per h.p. hour, but since the heat required to generate the steam increases with pressure and temperature, the steam-consumption figure alone is not a complete criterion of the merit of the engine.

It has been proposed to state the performance of engines in B.Th.U. per minute per i.h.p $= \frac{w\,(H_1 - h_2)}{\text{I.H.P.}} = \frac{42{\cdot}42}{e}$, or in 'equivalent feed,' which is the weight of steam which would be required per i.h.p. hour if $H_1 - h_2$ were 1100, thus equivalent feed $= \frac{W}{\text{I.H.P.}} \times \frac{H_1 - h_2}{1100}$.

Neither of these proposals has been widely adopted.

EFFICIENCY RATIO.

The ratio of the thermal efficiency of the actual engine to that of the Rankine cycle—or of the steam consumption of the Rankine cycle to the actual steam consumption (both having the same pressure, superheat, and vacuum (or back pressure))—is the 'efficiency ratio.'

The efficiency ratio varies with the pressure, superheat, and vacuum, as well as with the merit of the engine as regards freedom from condensation, leakage, and other losses.

Nevertheless the 'efficiency ratio' is useful in comparing engine test results and in predicting steam consumptions.

Economy of High-pressure Working.

The consumption of steam in pounds per horse-power per hour decreases as the pressure rises. The actual steam consumptions vary according to the size and type of engine.

It is estimated that the saving resulting from pressure increase from 200 lbs. to 500 lbs., keeping steam temperature constant at 600° F. and vacuum at 28 ins., would be $1,400 per annum per 1,000 kw. (assuming boiler efficiency 70 per cent., load factor 60 per cent., and cost of 14,000 B.Th.U. coal $5 per ton). Capitalised at 17 per cent., this corresponds to a saving of $8·25 per kw. compared with a probable cost of $3·50 per kw. to work at the higher pressure.

(*J. T. Foster, in 'Electrical World,' May* 11, 1918.)

Steam Saving by Superheating.

Superheating improves the efficiency ratio, so that in practice the saving due to superheating is much greater than that calculated for the Rankine cycle.

Superheating reduces the steam consumption approximately at the rate of 1 per cent. for each 10° F. of superheat, but the rate is rather greater for the lower grades of superheat and less for higher grades.

The practical steam and fuel economy due to the use of superheated steam are about as follows, all superheats being measured at the engine stop valves :—

Approximate Percentage Reduction in Steam Consumption by Superheating, for Compound and Uniflow Engines.

Superheat, deg. Fahr.	50	100	150	200
Common Steam and Exhaust Ports . . .	12	20	26	30
Separate " " " . . .	10	16	21	25
Uniflow, about	8	12	17	21

(*Foster.*)

Superheat reduces the steam consumption most in simple engines.

For superheat in steam turbines see Part IV, page 1833.

The advantages of superheating in general are chiefly :—

1. Greater thermal efficiency of the engine, due to reduced condensation loss.
2. If the boiler plant is not provided with very ample heating surface the addition of a superheater increases the boiler plant efficiency and capacity apart from the engine effect.
3. As compared with saturated steam, higher steam velocities in the pipes may be used with superheated steam, and consequently the pipes may be smaller. For this reason, the percentage loss of heat in the pipe system is lower, in spite of the higher temperature.
4. Reduction in size of auxiliary plant owing to smaller weight of feed water and coal.

Degree of Superheat.

In modern practice the following are usual :—

1. General engine practice : superheat at boilers 150° F., or, say, 120° to 130° at engine. Up to 650° F. total temperature, say 260° F. of superheat at 200 lbs. pressure, can be used if the engine is designed for it.

2. General turbine practice: superheat at turbine 200°–250° F., say up to 650° F. total temperature.

3. Latest turbine practice: superheat at turbine of 250° to 300° F., say up to 750° F. total temperature, at about 350 lbs. sq. in. pressure.

In general, with flat slide or Corliss valves on the high-pressure cylinder, the lower temperatures (about 550° F. total temperature) must not be exceeded.

Characteristics of Superheat.

Condensed steam is a slight lubricant. The absence of this must be met by adequate lubrication when using superheated steam. The high temperature requires a special oil of high flashpoint. Pipe friction losses are reduced by superheating.

In reciprocating engines a later cut-off is required to develop the same horse-power. Hence the maximum power which can be developed is slightly reduced by superheating.

Very high superheats lead to growth and distortion of cast-iron turbine cylinders. Steel should be used at the high-pressure end.

Moderate superheat, about 50° or 100° F., is desirable for evaporating and similar heating purposes, especially with long pipe mains, but very high superheats are undesirable, as the steam should have little, if any, superheat by the time it reaches the heating surfaces of the evaporators.

Throttling slightly raises the superheat in steam; expansion, as in a turbine nozzle, very greatly reduces it.

Except for very moderate superheat, cast-iron and copper must not be used for pipes and valves in contact with the steam.

STEAM JACKETS.

Steam jackets are rarely adopted to-day except for slow-running engines. There is no doubt that a well-arranged jacket leads to considerable economy when the engine is supplied with saturated steam. The economy is much less marked with superheated steam, especially as jackets are usually arranged. Having regard to the extra first cost and complication, jackets are not to be recommended with superheated steam unless the conditions are exceptional.

The usual arrangement of steam supply is defective; the steam is supplied to the jacket and a trap fitted to drain away the condensed steam, but there is no through flow. Usually, on intermediate and low-pressure cylinders the jacket steam pressure is reduced to a few pounds above the steam chest pressure; except to relieve the cylinder barrels and liners of mechanical stress, there is no justification for such an arrangement; from the point of view of steam economy it is ridiculous and largely nullifies the value of the jackets. Wherever possible, the jacket steam should have a through flow. With saturated steam the engine steam should pass through the jackets and then through a water separator before entering the cylinders.

When jackets are used with steam superheated 100° F. or more, they are unnecessary on the high-pressure cylinder.

Small and slow-running engines benefit most from jackets.

Reheaters, *i.e.* appliances for heating the steam in the receivers between the cylinders, do not appear to be useful with saturated steam.

With good initial superheat, say over 150° F., reheaters give good results.

Steam Consumption.

Typical steam consumptions, with the corresponding efficiency ratios, are shown in the following table:—

TYPICAL STEAM CONSUMPTIONS AND EFFICIENCY RATIOS.

Type of Engine.	Pressure at Stop Valve. Lbs. per Sq. In. (Gauge.)	Superheat °F.	Condensing.		Non-Condensing.	
			Steam. Lbs. per I.H.P. Hour.	Efficiency Ratio.	Steam, Lbs. per I.H.P. Hour.	Efficiency Ratio.
Simple	160	—	17 to 17·5	51 to 49	21 to 22	67 to 64
	160	150	12 to 13	65 to 61	16 to 17	78 to 74
	120	—	18·5 to 19·5	49 to 47	24 to 25	65 to 62
	120	150	14·5 to 15	57 to 55	19 to 20	73 to 70
	80	—	22 to 23	45 to 43	30 to 33	62 to 56
	80	150	16 to 17	56 to 53	24 to 26	69 to 64
Compound	200	—	12·5 to 13	66 to 64	—	—
	200	150	10 to 10·5	74 to 71	—	—
	160	—	13 to 13·5	66 to 64	17·5 to 18·5	80 to 75
	160	150	10·5 to 11	74 to 71	14·5 to 15	86 to 83
	120	—	14 to 15	65 to 61	19·5 to 20·5	79 to 75
	120	150	11·5 to 12·5	72 to 67	16 to 17	86 to 83
	80	—	—	—	25 to 26	74 to 71
	80	150	—	—	20·5 to 21·5	81 to 77
Triple	200	—	11·5 to 12	72 to 69	—	—
	200	150	10 to 10·5	75 to 71	—	—
	180	—	12 to 12·5	70 to 67	—	—
	180	150	10·2 to 11	75 to 70	—	—
Uniflow	200	—	11·8 to 12·3	70 to 67	—	—
	200	150	10 to 10·5	75 to 71	—	—
	160	—	12·5 to 13	69 to 66	19 to 20	74 to 70
	160	150	10·5 to 11	75 to 71	16 to 17	78 to 74
	120	—	13·5 to 14·5	68 to 63	21·5 to 22·5	73 to 69
	120	150	11·5 to 12·5	72 to 67	18 to 19	78 to 73

The particulars in the table refer to high-class modern engines with Corliss or drop valves, and of about 600 i.h.p. or upwards working at normal full load.

In the case of condensing engines, the vacuum has been taken as 26 ins.

The non-condensing uniflow values are subject to considerable variations.

The figures given being for engines of the highest class, for good average practice add from 5 to 10 per cent. For badly clothed or defective engines add 20 per cent. or more. For small engines add from 5 per cent. upwards according to size. The superheat is measured at the engine stop valve. The loss of temperature between superheater and engine may be from 20 to 100 degrees, according to steam-pipe conditions. Simple (alternating-flow single-cylinder) engines vary a good deal according to the cut-off. In general, a uniflow has a rather lower steam consumption than a good compound engine.

TYPICAL ENGINE TESTS.

REFERENCE No.	1	2	3	4	5	6
Type	H.T.C.C.	V.C.C.C.	—	H.T.C.C.	V.T.C.	Uniflow
Cylinder Diameter, inches	15·94 × 31·94	28 × 57	Same as No 2	26·65 × 45·3	13·7–24·4–39	30·5
" Stroke, "	48	48		47·24	72	39·0
R.P.M.	75·37	80·35	80·5	100·5	50·59	120
Stop Valve Pressure Gauge	124	170	169	146·5	175·7	116·5
Superheat, deg. Fahr.	0	117	110	171	0	142
Vacuum	27·2	25·5	25·6	27·0	27·25	27
H.P. Valves	Corliss	Corliss	—	D.B. Drop	Corliss	D.B. Drop
L.P. Valves	Corliss	Corliss	—	D.B. Drop	Corliss	—
Steam Jackets	No	No	No	L.P.	H.P., L.P., L.P.	Cyl. ends
Reheater	No	Not used	In use	No	Yes	—
Clearance Volume %, H.P.	8·5	6·65	—	5·0	—	(2)
" " %, L.P.	5·6	6·4	—	5·0	—	—
" Surface %, H.P.	310	320	—	206	—	(150)
" " %, L.P.	185	215	—	161	—	—
Nominal Cylinder Ratio	4·01	4·15	—	2·9	3·17—8·1	—
Total I.H.P.	394	1,401	1,405	1,234	576	570
I.H.P. in H.P. Cylinder %	53·2	55·7	50·0	62·0	26·2	100
" I.P. " %	—	—	—	—	32·3	—
" L.P. " %	46·8	44·3	50·0	38·0	41·5	—
Receiver Pressure Gauge	11·0	18·9	20·8	25	46·5—2·4	—
Total Piston load about H.P. lbs.	22,500	92,000	89,000	76,000	18,500	80,000
" " I.P. lbs.	—	—	—	—	19,500	—
" " L.P. lbs.	18,500	69,000	74,000	32,000	17,500	—
Cut-off in H.P. Cylinder, %	32	31	30	24	38·4	—
" I.P. " %	—	—	—	—	34·5	—
" L.P. " %	45	35	35	42	48·0	—
Dryness H.P. Cut-off %	86	103	97	114·3	—	—
" H.P. Release %	90	95	94	101·2	—	—
" I.P. Cut-off %	—	—	—	—	—	—
" I.P. Release %	—	—	—	—	—	—
" L.P. Cut-off %	71	82	90	85	—	—
" L.P. Release %	74	86	89	89	—	—
M.E.P. referred to L.P. Cyl.	27·24	28·44	28·41	32·5	26·3	33·2
" in H.P. Cylinder	58·2	67·0	60·1	58·3	57·0	33·2
" in I.P. "	—	—	—	—	22·1	—
" in L.P. "	12·75	12·53	14·2	12·36	10·9	—
Total Expansions, apparent	12·5	13·4	13·8	12·1	21·1	—
Piston Speed, ft. min.	602	642·8	644	791·2	607	780
Steam per I.H.P. hour lbs.	13·89	11·74	11·67	10·75	11·22	11·86
B.Th.U. per I.H.P. per min.*	259	226	224	218	211	236
Efficiency Ratio* %	61	69	69	70	70	68
Drive	Mill	Mill	Mill	Mill	Pumps	—
Date	1896	1907	1907	1909	1895	—
Builders	British	British	British	Belgian	U.S.A.	British
Authority	Longridge	Longridge	Longridge	Longridge	Miller	Stumpf

(*Foster.*)

* Recalculated on basis of Callendar's steam tables.—*T. B. M.*

Duty of Engines.

The duty of an engine is rarely spoken of except for pumping engines, and is then expressed in terms of the work done in lifting the water per 1,120 lbs. of steam used, or some other basis. Sometimes 1,000 lbs. of steam is used, especially in America; and sometimes coal or heat units is the basis.

Example.—Pumping engine consumes 14 lbs. of steam and 1·8 lbs of coal per water, or pump h.p. hour. The total heat added per lb. of steam is 1,125 B.Th.U.

Duty per 1,120 lbs. steam is $\frac{1,120}{14} \times 33,000 \times 60$ . . . . = 158,400,000 ft. lbs.

Duty per 112 lbs. coal is $\frac{112}{1·8} \times 33,000 \times 60$ . . . . . = 123,200,000 "

Duty per 1,000,000 B.Th.U. in steam is $\frac{1,000,000}{1,125} \times \frac{158,400,000}{1,120} = 125,700,000$ "

The steam consumption of high-class slow-speed triple-expansion pumping engines is very low.

TRIPLE PUMPING ENGINE PERFORMANCE.

	(1)	(2)	(3)
Cylinder diameters, ins.	23, 43, 64	16, 30, 44	20, 36, 33
Stroke, ins.	36	36	48
R.P.M.	41·25	29·3	25·7
Pressure at stop valve, lbs. per sq. in. (gauge)	183·6	148·5	161·5
Superheat, ° F.	119	nil	34
Vacuum (corrected to 30 ins. barometer)	27·3	29·92	Not stated
I.h.p. (total)	562·5	—	267
Water h.p. (neglecting slip)	537·1	—	242·7
W.h.p. (actual)	523·9	162	—
Steam per i.h.p. hour	10·04	—	10·3
Steam per w.h.p. hour	10·78	—	11·32
Efficiency ratio, per cent.	72·9	—	—
Overall mechanical efficiency, per cent.	95·5	—	90·9
Duty in millions of ft. lbs. per 1,000 lbs. steam	183·6	163·4	192

Remarks :—(1) From official tests in 1907–8 of engine at Johannesburg waterworks. (2) Tests in 1910 at Toronto waterworks. (3) Margate waterworks. See *Engineer*, June 3, 1921. Slip neglected.

The duty of Winding Engines is rarely measured, but is sometimes stated in terms of steam used per shaft h.p. hour, or per h.p. hour in the coal hoisted. This steam consumption increases greatly when the cages are not fully loaded and the number of winds is below maximum. Under favourable conditions compound non-condensing engines use from 30 to 50 lbs. of steam per shaft h.p. (in the coal raised) per hour. For high-pressure engines and unfavourable conditions the consumption increases to about 100 or 120 lbs., and occasionally more.

TABLE SHOWING STEAM CONSUMPTION OF WINDING ENGINES.

Colliery.	Cylinders, ins. diam. × stroke.	Boiler Pressure.	Lbs. per Shaft H.P. Hour.
Bolsover	32 × 72	—	129
Denaby and Cadeby	45 × 84	80	83
Tredegar Coal Company	18 & 28 × 48	140	177
A Lancashire Colliery	36½ × 78	60	114
Richard Evans	36 × 78	180	95
Silkstone	32 × 72	120	70
Rotherham	40 × 78	105	48
Hulton	32 × 72	80	102
Hulton	36 × 72	80	129
Atherton	22 × 52	100	58
Hickleton Main	40 × 78	100	88
Sherwood	26 × 54	127	43
Cowper	60 × 84	20	178

(*W. C. Mountain.*)

Tests of a cross-compound non-condensing engine at Sherwood colliery gave a steam consumption of 40 lbs. per S.H.P. hour. The engine cylinders were 32 ins. and 53 ins., stroke 66 ins., pressure 125 lbs. per sq. in., superheat 65° F.

For the steam consumption of turbines *see* Part IV. Steam Turbines, page 1832.

The Indicator.

The function of the engine indicator fig. 6, p. 1770, is to produce a diagram which shall show with reasonable accuracy the pressure in the cylinder in relation to the position of the piston in its stroke. Usually the diagram is drawn on a paper wrapped round a drum, which is reciprocated by means of a cord attached to a reducing mechanism driven by the engine, so that the motion of the paper is a copy on a reduced scale of the piston motion. The pencil which draws the diagram must move parallel to the axis of the drum, so that its distance from a datum line represents the pressure in the cylinder.

For very high speeds, special forms of indicator, in which the diagram is traced out by a spot of light, and recorded photographically, are used.

The Crosby Indicator.

This indicator (sold by *Crosby Valve and Engineering Co., Ltd.*, 11–12 Foley Street, London, W. 1) has been designed for use with engines, either steam, gas, or oil. Fig. 2 shows the Crosby

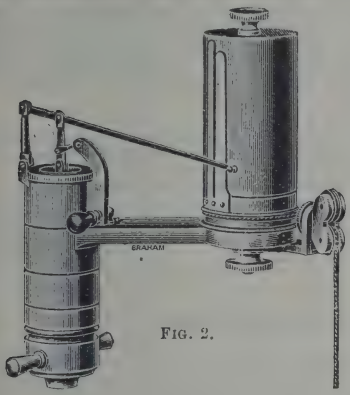


Fig. 2.

Fig. 3.

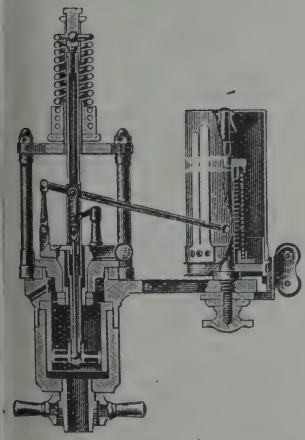


Fig. 4.

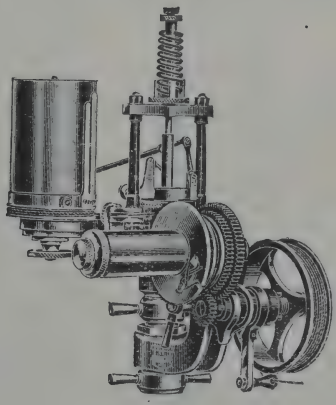


Fig. 5.

Indicator as ordinarily made, having a drum 1½ ins. in diameter, this being the correct size for high-speed work, and answering equally well for low speeds.

The special feature in the indicator is the use of a double-coil spiral spring, very carefully calibrated; this form of spring, which is shown in fig. 3, enables the strains to which it is subjected to be transmitted from the centre of the piston through a ball-and-socket joint. Each spring is made of a single piece of wire wound from the middle into a double coil, the ends of which are screwed into a head with four wings having spirally drilled holes to receive and hold them securely in place. Adjustment is made by screwing the spring in or out of this head until it is exactly of the right strength, when it is firmly brazed.

Fig. 4 shows a sectional view of the Crosby New No. 2 Indicator. This has the spring mounted outside the cylinder, where it is easily detached and replaced, and where it is removed from any effect of heat—a very necessary precaution when the indicator is used with superheated steam, or on gas engines. Another novel feature in this indicator is the shape of the piston. It is in form the central zone of a sphere, an arrangement which practically eliminates cylinder friction. The piston is connected to the pencil mechanism by a rod terminating in a ball-and-socket joint in the centre of the piston. The position of the pencil lever on the drum can be altered by screwing the spring up or down and locking it in place.

For the purpose of making the indicator of the utmost value to engineers, the Crosby New 'Continuous Drum' has been designed, and this apparatus makes it possible to obtain a series of diagrams on a roll of paper. The latest form has a novel arrangement, allowing the period between each diagram to be altered at will; the diagrams can be taken close together or farther apart as desired, and the roll supplied is 12 ft. long. Such an apparatus is of great value in ascertaining variations of load in electrical tests, and in connection with rolling and winding engines.

Another useful device, which saves having a reducing apparatus added to an engine, is the Crosby 'Reducing Wheel.' This gives a perfectly correct reduction of the stroke of any engine to the stroke of the indicator drum, and it is connected directly to the indicator and mounted on the indicator cock. The arrangement is portable and can be used on any engine.

The latest pattern includes a detent device which enables the indicator to be stopped to put on a fresh card without disconnecting the reducing wheel from the engine crosshead. See fig. 5.

To take an Indicator Card.

See that the indicator is in good order, the piston clean and free in the cylinder, all joints in the pencil gear free yet without slack. The pencil should fall by its own weight when the indicator is assembled without a spring. The spring should be chosen with reference to the pressure range, so as to give a diagram about 1¼ ins. high, or less still if the speed is high. (At very low speeds a lighter spring may be used and a larger diagram obtained.) Assemble the indicator, and see that the spring is properly secured at both ends without any slack. Couple the indicator to the cock F. Adjust the length of cord connecting the indicator drum to the reducing gear, so that there is no knock or slack at either end of the motion of the drum. At high speeds the tension of the drum spring should be considerable, so as to minimise variations in the tension of the driving cord.

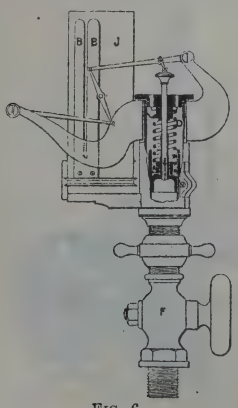


FIG. 6.

Fasten the paper on the drum J by means of the clips BB. Draw the atmospheric line by pressing the pencil lightly on the paper and pulling the drum round by the cord.

Adjust the pencil stop so that the pencil cannot be pressed too hard on the paper. The pencil point must be kept smooth and fine. A clear, fine line will thus be drawn without excessive friction between pencil and paper.

Connect the driving cord to the reducing gear, open the indicator cock, and after allowing steam to blow through for a few seconds, apply the pencil to the paper and allow it to remain in contact for a few revolutions and then withdraw it.

Shut the cock, disconnect the cord and remove the paper with the indicator diagram.

Mark the card with a reference number and write on it the particulars of speed, pressure etc., unless these are separately logged.

Indicator Piston.

In any indicator the piston should always fit the cylinder loosely enough to allow the steam to blow by it. This is very important, whether the instrument is used at high or low speeds. In regard to any errors that may result from leakage by the piston, it should be distinctly understood that leakage, unless it be sufficient to add to the atmospheric pressure above the piston, cannot affect the accuracy of the indications. Absurd devices have been even patented for keeping the piston tight, while the one thing needful is absolute freedom of motion.

In order that leakage past the piston may not accumulate pressure above the piston, the space above the piston must be in free communication with the atmosphere.

Indicator Connecting Pipes.

In general, short direct connections are preferable.

The use of a long connecting pipe may cause quite an appreciable addition to the clearance volume of a cylinder, especially in the case of small engines. Where, however, the connecting pipe has a bore of $\frac{5}{16}$ in. or $\frac{1}{2}$ in., as is usual, and suffers no contraction up to the indicator tap, and the speed is moderate, there is no appreciable error in the diagrams due to the connecting pipe being even 4 feet long, provided the bore of the two-way cock is quite $\frac{3}{8}$ in.; a bore of $\frac{3}{16}$ in. only may introduce serious error.

(*T. B. Morley*, '*Trans. Inst. E. and S.*,' 1914–15.)

THE INDICATOR DIAGRAM.

General Definitions.

The Atmospheric Line, AB, fig. 7, is a line drawn by the pencil of the indicator when the connections with the engine are closed and both sides of the piston are open to the atmosphere. This line represents on the card the pressure of the atmosphere, or zero gauge pressure.

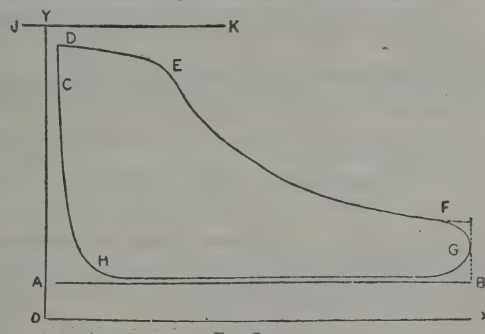


FIG. 7.

The Line of Absolute Zero Pressure, OX, is a reference line usually drawn about 14·7 lbs. by scale below the atmospheric line. It represents a perfect vacuum, or absence of all pressure.

At any considerable height above sea level the line OX becomes nearer the line AB.

The Clearance Line, OY, is another reference line drawn at a distance from the end of the diagram equal to the same percentage of its length as the clearance volume is of the piston displacement. The distance between the clearance line and the end of the diagram represents the volume of the clearance and of the ports and passages at the end of the cylinder.

The Line of Boiler Pressure, JK, is drawn parallel to the atmospheric line, and at a distance from it by scale equal to the boiler pressure shown by the gauge. The difference in pounds between it and DE shows the loss of pressure due to the steam pipe and the ports and passages in the engine.

The Admission Line is in two parts, CD, which show the rise of pressure due to the admission of steam to the cylinder by opening the steam valve (if the steam is admitted quickly when the engine is about on the dead centre this line will be nearly vertical), and

DE, which is drawn when the steam valve is open and steam is being admitted to the cylinder.

The Point of Cut-off, E, is the point where the admission of steam is stopped by the closing of the valve. It is difficult to determine the exact point at which the cut-off takes place. It is usually located where the outline of the diagram changes its curvature from convex to concave.

The Expansion Curve, EF, shows the fall in pressure as the steam in the cylinder expands and does work.

The Point of Release, F, shows when the exhaust valve opens.

FG represents the change in pressure that takes place when the exhaust valve opens; exhaust continues to the point H.

The Back Pressure Line, GH, shows the pressure against which the piston acts during its return stroke. On diagrams taken from non-condensing engines it is either coincident with or above the atmospheric line, as in fig. 7. On cards taken from a condensing engine, however, it is found below the atmospheric line, and at a distance greater or less according to the vacuum obtained in the cylinder.

The Point of Compression, H, is the point where the exhaust valve closes. It cannot be located very definitely, as the change in pressure is at first due to the gradual closing of the valve.

The Compression Curve, HC, shows the rise in pressure due to the compression of the steam remaining in the cylinder after the exhaust valve has closed.

The Mean Effective Pressure (M.E.P.) is the mean net pressure urging the piston forward.

The Initial Pressure is the pressure acting on the piston at the beginning of the stroke.

The Terminal Pressure is the pressure above the line of perfect vacuum that would exist at the end of the stroke if the steam had not been released earlier. It is found by continuing the expansion curve to the end of the diagram, as in fig. 7.

Defects in Diagrams.

A very common and serious defect in diagrams arises from the stretching of the indicator cord. If two diagrams taken from the same engine at the same time show noticeably unequal lengths the cords are probably inaccurate. As a rule the stretch is greatest when the drum is pulled open. Thus one end of the diagram is widened and the other narrowed, giving incorrect M.E.P. and points of valve action.

The cord used should be as short and as inextensible as possible.

The reducing gear should give an accurate copy of the motion of the engine crosshead, and the cord from the reducing gear should run in a direction parallel to the line of motion of the crosshead.

If the diagram is very much to one side of the card, and if the near end is quite straight and vertical, the drum is probably hitting its stop at one end of its travel. Alter the length of the indicator cord.

If the expansion line is stepped in rough terraces the indicator piston is probably sticking and the M.E.P. is too high.

If the expansion is wavy the spring is too light and should be replaced by a stiffer one.

Mean Effective Pressure.

This is best determined by finding the area of the indicator diagram; dividing this by the length, so obtaining the mean height; then, multiplying the mean height by the pressure scale the mean effective pressure is the result.

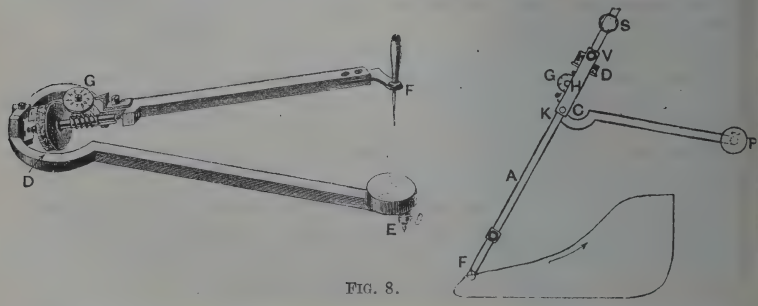


FIG. 8.

The best method of measuring the area of the diagram is to use a planimeter, which if carefully handled gives results accurate to hundredths of a square inch.

The most commonly used planimeter is of the Amsler type, and is shown by fig. 8.

It consists of two arms hinged together; one is constrained to swing round a fixed pivot, the other carries a tracing point which is made to follow the outline of the diagram. This arm also carries a roller, with its axis in the centre line of the arm, and provided with a scale and vernier by which its rotary movements can be accurately measured. As the tracing point moves round the diagram the roller partly slides and partly rolls over the paper or board on which the diagram is drawn or to which it is pinned. The readings of the scale before and after each exact circuit of the diagram are noted; their difference measures the area of the diagram on a scale determined by the proportions of the instrument.

The roller should be pivoted so as to rotate freely, but without endshake, and the surface on which it moves should be flat and unglazed. The position of the pivot point should be chosen so that the tracing point can reach freely all parts of the outline. The pivot point has a needle which can then be pressed into the paper or board.

It is advisable to check the planimeter occasionally by running it round a simple figure, such as a square or circle, the area of which can be easily calculated independently.

To Calculate the Horse-Power of an Engine.

P = M.E.P. (mean effective pressure) on piston, in lbs. per sq. in.;

A = net piston area in sq. inches. (The net area at the crank end of the cylinder = area of cylinder less area of rod. If there is a tail rod at the end remote from the crank, A = cylinder area less area of tail rod.);

L = length of stroke in feet;

N = revs. per minute.

Then the I.H.P. developed on *one side* of the steam-engine piston $= \frac{\text{PLAN}}{33{,}000}$

For a double-acting steam-engine, the I.H.P. developed in the cylinder $= \frac{2\ \text{PLAN}}{33{,}000}$, where P, A, are the mean M.E.P., and mean area for the two cylinder ends.

More exactly I.H.P. $= \frac{(P_1A_1 \times P_2A_2)\ LN}{33{,}000}$,

where P_1, P_2, A_1, A_2, are the pressures and areas for the two sides respectively.

For a gas engine (single acting, single cylinder) the I.H.P. $= \frac{\text{PLAE}}{33{,}000}$, where E = explosions or impulses per minute, and depends on the cycle and governing system as well as on the revs. per minute.

For a double-acting steam-engine cylinder

$$\text{I.H.P.} = \frac{\text{PAS}}{33{,}000}, \text{ where S = piston speed in ft. per minute, since S = 2 LN.}$$

Approximate Steam Consumption, from the Indicator Diagram.

Draw a horizontal (constant pressure) line on the diagram so as to cut the expansion line and compression line (or compression line produced, if necessary) at a pressure just above release (exhaust opening).

If

u = volume in cu. ft. of one lb. dry steam at the pressure of this horizontal line;

a = length of horizontal line between expansion and compression lines;

b = length of stroke of diagram;

then

$$\text{Lbs. dry steam on diagram per i.h.p. hour} = \frac{13{,}750\ a}{\text{M.E.P.}\ b\ u}.$$

This is often referred to as the theoretical or 'indicated' steam, the actual being less or greater according to the degree of superheat, jacketing, leakage, etc. Hence the theoretical consumption must be *divided* by a factor (which is approximately the dryness fraction at exhaust opening).

For a compound engine first find the 'indicated' steam consumption for either cylinder as above; then for the whole engine, multiply by the i.h.p. of that cylinder and divide by the i.h.p. of the engine. This result divided by the steam consumption factor gives the probable actual steam consumption of the engine.

STEAM CONSUMPTION FACTORS.

Cylinder.	H.P.	L.P.
High superheat	1·0 –1·1	0·8 –1·0
Moderate superheat	0·9 –1·0	0·75–0·95
Saturated steam	0·8 –0·85	0·7 –0·75
Badly clothed, saturated steam	0·65–0·75	0·6 –0·7

To Interpret the Indicator Diagram.

Besides the calculation of horse-power and the rough estimate of steam consumption, from the diagram, other important information can be learned from a study of the diagram, as follows :—

The diagram will show the opening and closing of the valves, as explained on p. 1771, fig. 7. If the point of cut-off is fixed, as with most slide and piston valve engines, the depth of the steam admission line DE below the boiler pressure line YK is a measure of the loss by throttling. If this is invariably considerable, it may pay to shift the eccentric so as to give an earlier cut off. With a simple slide or piston valve this would make the exhaust open earlier and the compression commence earlier. These, and particularly the latter, must be watched, as too early compression sends the compression pressure above the steam chest pressure. This is not good; although the compression line should rise nearly to the admission pressure. In the case of a reversing engine having a Stephenson, Joy, or similar link motion, the point of cut-off is varied by shifting the equivalent eccentric; and thus at early cut-off the exhaust and compression are both early, but at late cut-off the exhaust and compression both become late. Hence when studying such diagrams these changes of exhaust and compression with cut-off must always be kept in mind. The points of valve action can also be altered by changing the lap. Thus if the exhaust edge of the valve is chipped the exhaust takes place earlier and the compression later. Similarly chipping some of the lap off the steam edge of the valve makes the cut-off later and lead earlier.

If the admission line DE falls rapidly, the valve is too small or the valve travel too small.

In a multiple-cylinder engine the diagrams give the distribution of power and forces among the several cylinders. As a rule these should be roughly equal for the several cranks, but need not be equal for the two cylinders of a tandem engine. Indeed, in the latter case, the h.p. cylinder may with advantage take rather more than half the load if the steam is superheated.

Valve setting should always be checked by actual indicator cards after an engine is first started to work.

It is found in practice that the expansion line (fig. 7, p. 1771) is closely hyperbolic when using saturated steam, the two axes of the hyperbola being the absolute zero line OX and a vertical touching the diagram at CD. Hyperbolic curves can be purchased printed on transparent paper for placing over indicator diagrams. If the expansion line rises above the hyperbola as the pressure falls it indicates leakage past the steam valve into the cylinder. Similarly, if the expansion line falls more rapidly than the hyperbola it indicates either leakage past the exhaust valve out of the cylinder, excessive condensation of steam in the cylinder, or the use of initially superheated steam. If superheated steam is used, the vertical axis of the hyperbola should be about the clearance line OY in fig. 7; but the exact position depends on the degree of superheat.

The hyperbola is easily drawn more or less completely as desired when it is remembered that the absolute pressure multiplied by the volume has the same value at all points on the same hyperbolic curve.

ENGINE TYPES FOR VARIOUS DUTIES.

Each type of engine has a field, not sharply defined, in which it shows to best advantage.

Elaborate and expensive types are least desirable when coal is very cheap, the working hours few, labour unskilled, or the working conditions very rough.

Non-condensing engines consume from 20 to 50 per cent. more steam and coal than condensing engines.

Unless floor space is limited or very high speeds are desired, a horizontal engine is generally more satisfactory than a vertical. It is cheaper to install and more accessible for running and overhauling.

Steam turbines are relatively uneconomical in very small units. In the neighbourhood of 1,000 to 1,500 horse-power they surpass the best reciprocating engines, and for very large units—unless for some special purpose, as driving a reversing rolling-mill—are without serious rival. To show to advantage a turbine must be run condensing, with a good vacuum.

Where economy is at all important the ordinary simple (single-expansion) engine is at a marked disadvantage, which, however, is least with steam superheated 120° or 150°F. For most purposes the compound is the standard type, although the uniflow (a special form of single-expansion engine) is widely adopted. Triple and quadruple expansion engines are more economical than compound, but are more costly and complex. They are therefore chiefly employed on ships, for towns pumping, flour mills, and other situations where coal consumption is specially important. Their superiority over the compound engine is reduced if the steam is superheated.

The class of engine is frequently designated by the valve gear. Thus the plain slide valve gives the cheapest engine and also, other things being equal, the least economical.

The piston valve is really a circular slide valve, and gives an engine of similar characteristics. For the highest economy and class of engine Corliss or drop valves are desirable. The Corliss valve is really a circular slide valve of small diameter which rotates to and fro through a small angle in its valve chamber. The drop valve may be of the double-beat seating type or of the double-beat piston type. As a rule Corliss and drop valves are operated by a trip valve gear or other form of valve mechanism enabling the cut-off to be automatically varied to suit the load. Slide and piston valves, on the other hand, are not so suitable for cut-off governing and are not usually so arranged, but rely on throttling the steam to meet changes of load. High-speed engines almost invariably have piston or slide valves, because trip and other cut-off gears are unsuitable at high speeds of revolution.

Cut-off, or expansion, governing gives the best economy for variable loads, except at very light loads, when throttling is superior. The difference is least with highly superheated steam, which tends to equalise the steam consumptions at different loads (measured per horse-power, of course).

The superior economy of Corliss and drop valve engines is often believed to be due to the superior qualities of trip valve gears. Actually this is a very minor factor. The chief gain arises from the fact that the inlet and exhaust ports and valves are usually quite separate.

The following list shows the engine types frequently adopted for various duties :—

Duty.	*Type of Engine.*
Agriculture, occasional service	Simple, slide or piston, N.C.
„ regular service	Compound, slide or uniflow, N.C.
Cement works	Compound, Corliss or drop, uniflow, turbine, S.
Electric generating, small	Compound, high-speed vertical, Corliss, or drop, S.
„ „ medium	Compound, Corliss or drop; uniflow; or turbine, S.
„ „ large	Turbine, S.

Duty.	*Type of Engine.*
Factories, cotton mills, etc.	Compound, Corliss or drop, uniflow, geared turbine, S.
Flour mills	Compound or triple, Corliss or drop, uniflow, S.
Paper mills	Compound, Corliss or drop; uniflow, turbine, also with steam extraction, S.
Portable	Same as agriculture.
Pumping, centrifugal	Compound, usually high-speed vertical, also uniflow if at moderate speed, S.
,, hydraulic and town water	Triple three-crank vertical, slow-speed, Corliss or drop, S.
,, well pumps	Compound or triple, Corliss or drop, S.
Rolling mills, not reversing	Horizontal compound, Corliss or drop, uniflow, S.
,, ,, reversing	Two- or three-crank, piston valves, simple or tandem compound, often N.C., S.
Winding	Two-crank simple or compound (tandem usually), N.C., S.

Note.—N.C. indicates non-condensing. S. indicates superheated steam.

Engine Types, General.

As coal increases in price the general tendency must be towards the more efficient engines. Thus, for agricultural, portable, and other 'occasonial' engines, superheated steam is highly desirable. Condensation is often difficult to arrange, and this makes the merit of the uniflow engine less pronounced. Compounding does not add very much to the cost and justifies itself where the total hours worked in the year reaches a reasonable figure.

For factory working, a high-class compound or uniflow engine or turbine is essential and the steam should be superheated 100 to 150° F.; similarly for electric generation, other than occasional or intermittent use.

For large electric generating sets the steam turbine alone need by considered, and should use high pressure and high superheat.

For rolling mills and winding engines a fairly high degree of superheat, 100 to 150° F., is advisable. If non-condensing the exhaust steam should be utilised in a low-pressure turbine. If this is not convenient, condensation should be employed, although it is not yet usual. In that case compounding should be adopted.

The Uniflow Engine.

The special characteristic of the uniflow engine is that the steam is exhausted through a central ring of ports; the piston has a length about 90 per cent. of the stroke, and uncovers the exhaust ports at about 90 per cent. of the working stroke (see fig. 9). The steam enters by inlet valves, usually of the double-beat seating type, placed at the cylinder ends, and, as it leaves at the middle, the inlet ends are never cooled by exhaust steam rushing over their surfaces, nor are the exhaust ports exposed to live steam. The clearance volume is 2 to 3 per cent. of the stroke volume, and compression normally begins when the piston covers the exhaust ports—*i.e.* at about 10 per cent. of the compression stroke.

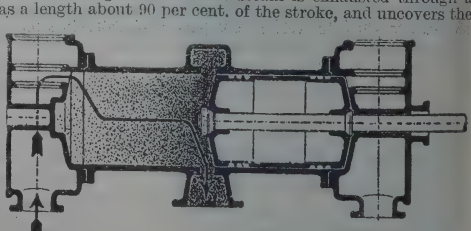


Fig. 9.

The high compression serves to heat not only the clearance surface, but the piston face, and condensation during admission is reduced to a minimum. Cyclic temperature changes in the cylinder walls are reduced, and the temperature falls gradually from the ends to the exhaust belt.

The entire expansion takes place in one cylinder, hence early cut-off is necessary.

The number of expansions is usually about 10; that is, about 10 per cent. cut-off. This is not quite so high a figure as for a typical compound engine, but owing to the absence of receiver losses and reduced initial condensation, a better economy by 5 to 10 per cent. is obtained with the uniflow, if condensing.

The full steam pipe pressure comes on the large piston, and the load on the line of parts is high in proportion to the M.E.P. This makes for weight and cost, but higher unit stresses, if based on steam pressure only, are permissible if due advantage is taken of the heavy reciprocating parts and high rotational speed to give a high inertia loading. The uniformity of turning is then equal to that of a good tandem compound engine, but is inferior at low rotational speeds.

Owing to the high compression ratio, if the vacuum falls below normal, the pressure at the end of compression would become excessive unless an efficient preventive device ('compression release gear') were provided.

The Galloway Uniflow Engine.

(Galloways, Ltd., Manchester.)

The steam valves are double-seated drop valves, and are placed in the cylinder covers, which form steam jackets for the valves and cylinder ends. In boring the cylinder, allowance is made for the higher temperature, and consequent greater expansion, at the ends when working. The cylinder is provided with an inspection door, by removing which the piston rings and cylinder bore may be inspected.

The novel features of the engine described are the patent shockless high-speed valve gear and the automatic compression release gear. In this valve gear (fig. 10A) oil under pressure is

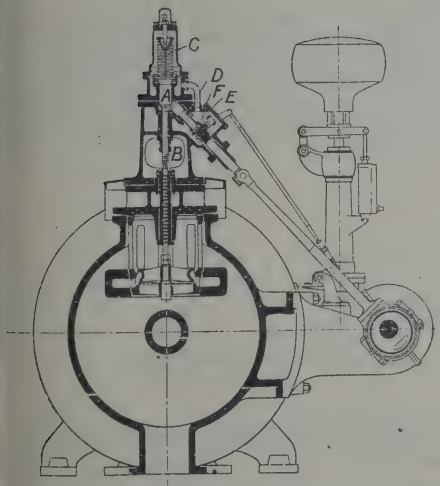


FIG. 10.—Cross Section of Cylinder.

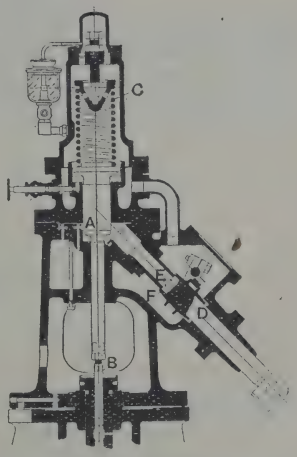


FIG. 10A.—Arrangement of Oil Valve Gear.

applied below the plunger A connected to the valve spindle B and lifts the valve. An eccentric on the lay shaft operates the ram D of an oil pump in the valve bonnet. The ram is hollow, and has a ring of slots or ports E, which at certain parts of the travel may be covered by a sleeve F, the position of which is controlled by the governor. On the upstroke of the pump oil is forced into the chamber below the plunger, thus raising the plunger and the steam valve. At a point determined by the position of the governor, the ports in the hollow ram are overrun by the sleeve and the oil escapes. The valve is then free to close under the combined

action of a spring and dashpot. The valve gear is silent, compact, and takes little power to operate it.

The automatic compression release gear is shown in fig. 11. Two supplementary exhaust valves G, H, are arranged on the side of the cylinder. They are normally kept closed by springs J, K. On the engine lay-shaft is a sleeve L carrying two cams of tapering form, which are capable of longitudinal movement. Their axial position is made to correspond automatically with the vacuum by means of the spring-controlled piston O of a small cylinder P at the end of the lay-shaft, one end of this cylinder being in communication with the condenser. The

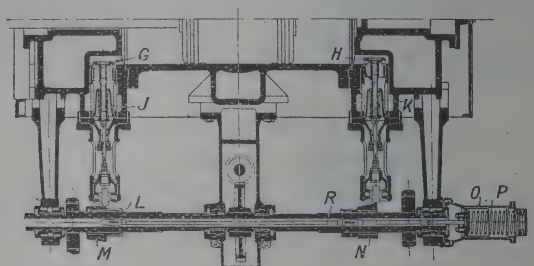


FIG. 11.—Arrangement of the Automatic Exhaust Gear.

piston operates the cams by the rod R. At normal vacuum the small end of each cam is just clear of the roller on the valve stem, and the valves are not opened. If the pressure in the condenser rises the cams move axially, so that each exhaust valve is opened during part of the compression stroke, the amount and duration of the opening depending on the cam position, and hence on the vacuum. This engine starts without vacuum, as it drives its own air pump, and the compression release gear gives full relief of compression until a vacuum is established, and then permits the compression to increase until at normal vacuum full compression is reached. Fig. 12 shows the operation of this gear.

FIG. 12.—Indicator Diagrams, showing Operation of Compression Release Gear.

THE PAXMAN POSITIVE VALVE GEAR ENGINE.

The Paxman type of engine is chiefly noticeable for its simple positive valve gear, its high rotational speed, massive construction, and silent running, its sensitive inertia governor, frictionless metallic packing, and also for its low steam consumption, a result of under 10 lbs. per i.h.p. hour being obtainable under favourable working conditions.

With the Paxman valve gear, fig. 13, no dashpot is used. The valve is raised by the cam lever A, acting upon the roller B, this lever being moved by the eccentric, and the whole movement is accomplished without noise or hammering. The roller B is always kept in close contact with the cam or lever A during the travel of the valve, by means of the spring shown in the

bonnet. The cam does not move clear of the roller until after the valve is seated, and consequently, even when the engine is running at the highest speeds, the gear is entirely silent. The friction to which the valve is exposed is practically nil.

There is no tripping movement with the valve gear, but the valve is lowered gently on to its seat by means of the cam (the profile of which is so shaped as to allow this to be done rapidly) and when the valve is seated, and not until then, the cam moves clear of the roller. The system renders quite permissible the employment of such high piston speeds and revolutions (even in the case of very large engines) as could not be possible with trip-gear.

The valves are free to lift easily in the case of any abnormal pressure arising within the cylinder, and they thus act as relief valves, avoiding all danger of water shock.

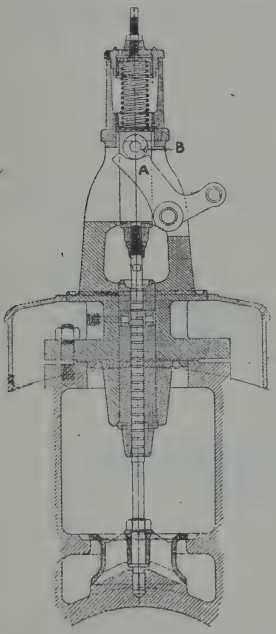


FIG. 13.

The valve spindles are grooved and work in cast-iron sleeves; by means of the Paxman system of draining, no stuffing boxes are required, which reduces the friction to a minimum, and allows the governor to be extremely sensitive while having great stability.

The governor is of the inertia type, and is placed on the side shaft: it is directly connected to the two high-pressure steam eccentrics, which eccentrics are movable on a slide block keyed to the shaft: thus the governor can alter the eccentricity, and consequently the cut-off. It regulates within an exceptionally short period, and the momentary change of speed due to the load being thrown on or off is only slightly in excess of the permanent change. Fig. 14 shows graphically the very slight alteration in speed occasioned by throwing the load suddenly off or on the engine, the resultant change of speed being hardly perceptible. The action of the Paxman governor is immediate, and it combines extreme sensibility with a perfect stability comparable with the best turbines.

Fig. 15 shows the piston-rod packing of the Paxman effective type. By eliminating springs, friction is reduced to a minimum, and as the packing is free from wear, perfect steam

tightness is assured. The packing consists of a series of cast-iron rings which fit over the rod, and are held in cast-iron boxes which allow them to oscillate sideways, thus avoiding friction between rod and rings. There is no gland bush, the steam having direct access to the packing, but it returns to the cylinder during the period of expansion, instead of leaking through the packing. The rings form a series of chambers which are efficiently drained, any steam escaping

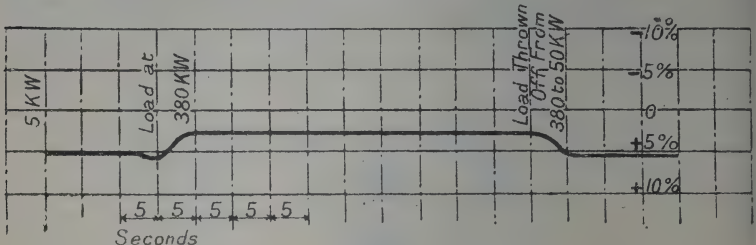


FIG. 14.

from the front chamber entering the second chamber, and there expanding. A small part of it may escape to the third chamber and undergo further expansion, and so on, but the last ring will never show the slightest leakage.

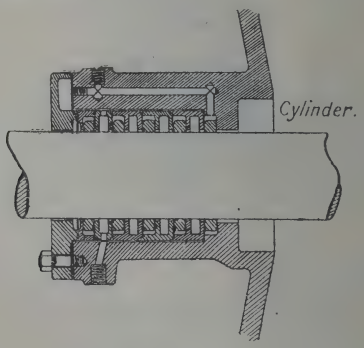


FIG. 15.

Paxman engines are made of the single-cylinder coupled compound, or tandem compound horizontal types, and for any steam pressure up to 190 lbs. at the engine stop valve.

The Paxman Positive Valve Gear lends itself to the easy conversion of existing engines to Paxman-Lentz type. In actual practice, improvements and economies in steam consumption up to 26% have been obtained with a great reduction in maintenance expenses.

ROBEY DROP-VALVE REVERSING AND OVERWINDING GEAR FOR WINDING ENGINES.

(Patent.)

The distinguishing feature of this gear, fig. 16, is its simplicity combined with absolute efficiency.

Both steam and exhaust valves are actuated by the one eccentric marked A. This is effected by the rod B actuating the rocking lever C, which is supported on a fixed bearing **D**, giving an up-and-down motion to the steam actuating lever E, and the exhaust lever F; the latter, by means of the bell crank lever G, opening the exhaust valve at the proper moment.

The steam admission rod E by means of the well-known Robey trip-motion opens the steam valve. The rods E and F have a constant movement, and the reversing is done by varying the

position of the rod B. This is effected by moving the eccentric A (the strap and connections are omitted in the figure). This eccentric is mounted on a square block H, which is driven from a fixed plate on the layshaft.

By means of the sliding sleeve on the layshaft, and two bell crank levers, the eccentric A can be moved to the position indicated by the dotted lines, and the engine will then run in the opposite

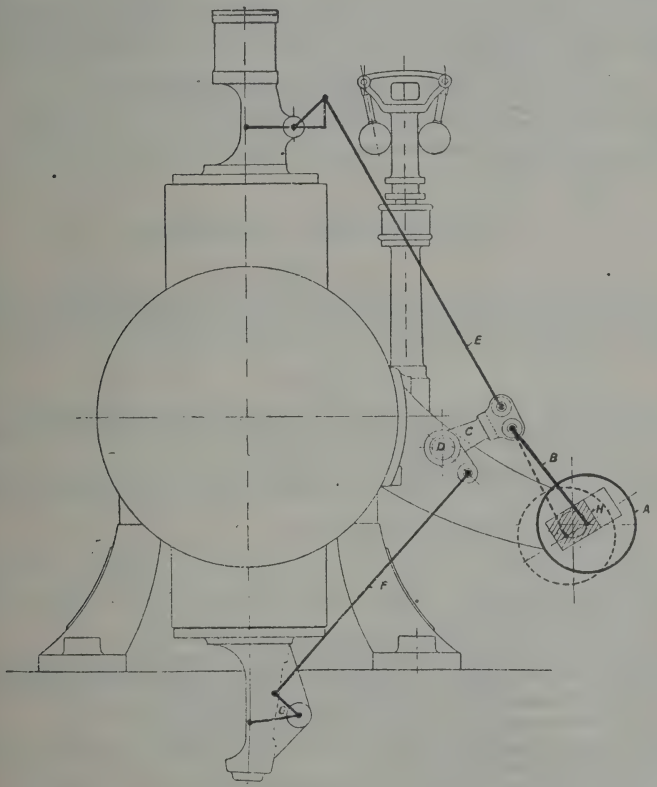


FIG. 16.—Robey Drop-Valve Reversing Gear.

direction. The sliding sleeve is connected by a simple fork connection to the reversing lever and the power necessary to move this eccentric A is very small indeed, and the lever can be worked by hand in engines up to the largest sizes.

Each end of the cylinder has an exactly similar arrangement of the gear, and the same sliding sleeve actuates both eccentrics.

When it is desired to have the gear under the control of the governor, and not by hand alone, it is necessary to have a small auxiliary eccentric on the layshaft, which is keyed on in a fixed

position, and does not vary with the direction of running of the engine. This auxiliary eccentric, in conjunction with the governor, regulates the exact cut-off in accordance with the speed of the engine.

When the governor is in the lowest position, the cut-off is at the maximum, and the driver has therefore only to turn full steam on at the commencement of the wind, as the governor will cut off the steam when maximum speed is obtained. The connection of the governor to the gear is automatically thrown out of action when the engine is reversed, thus enabling the driver to put full steam against the engine.

The steam admission valves are of the well-known Robey type, and there is no liability whatever for the valve to hold up. As a measure of precaution, however, an arrangement is fitted which closes the valve positively if it should by any means not fall, but this has never been known to come into action.

Indicator diagrams show that the lead at all points is practically constant.

In the patent overwinding gear the steam is shut off immediately at the cylinder instead of at the throttle; this renders the system particularly effective.

The overwinding gear is absolutely part of the valve gear, and has not to be driven by an independent chain or gearing of any description.

The Robey High-Speed Vertical Engine.

(Open Type.)

Figs. 17, 18 show the latest type of high-speed vertical engine with open front. It is fitted with the Robey improved crankshaft throttle governor driven direct from the crankshaft without either gearing or belt, thus ensuring absolute reliability. The flywheel can be supplied either suitable for belt driving or of the disc type suitable for direct coupling.

Specification.

Cylinder is made of the best cold-blast iron, free from all defects, fitted with bright covers secured by studs and nuts. All stuffing boxes have gunmetal neck bushes and gunmetal glands. Cylinder drain cocks are fitted with copper-pipe connections.

Governor is of the crankshaft throttle type, dispensing with either belts or gearing for actuating governor. The speed of the engine can be varied while running by means of the adjusting arrangement fitted on the governor.

Piston is of cast iron fitted with expanding rings.

Piston Rod is of steel, coned at top end, fastened to end of piston by nut and pin, and forged solid with crosshead.

Crosshead is of forged steel, fitted with cast-iron slipper, with ample bearing surface and suitable means of adjustment.

The gudgeon pin is of case-hardened tough mild steel ground up true.

Connecting Rod is of best mild steel finished bright all over, fitted with marine large end, and small end provided with adjustment. The top is fork ended and with gudgeon pin shrunk in.

Valve Rod is of best mild steel with case-hardened eye adjustable by a small cotter.

Crankshaft is of steel turned all over and of the balanced slab type.

Standard is of special design with open front, securely attached to baseplate and cylinder, and has a removable polished pillar in front.

Crosshead Guide is tooled out perfectly true, and well fitted with oiling arrangements.

Base Plate and Bearings.—The cast-iron base plate has two adjustable bearings, fitted metal to metal, resting in bored-out carriages formed in base plate and secured by cast-iron caps, with brass and glass needle or drop-feed lubricators.

Flywheel is provided of a heavy pattern, accurately balanced, and turned on face for driving belt, or of the disc pattern with facing for direct coupling to dynamo as required.

Oiling Arrangements.—A special oil reservoir is provided at the top of engine standard with connecting pipes to all working parts.

The crank chamber is formed to collect the oil after use, which may be drawn off by means of a small cock provided at the bottom of the engine bedplate. Suitable splash plates are provided.

Extended Bedplate.—This can be made of suitable design to suit any make of dynamo.

THE 'ROBEY' SINGLE-CYLINDER OPEN-TYPE HIGH SPEED VERTICAL ENGINE.

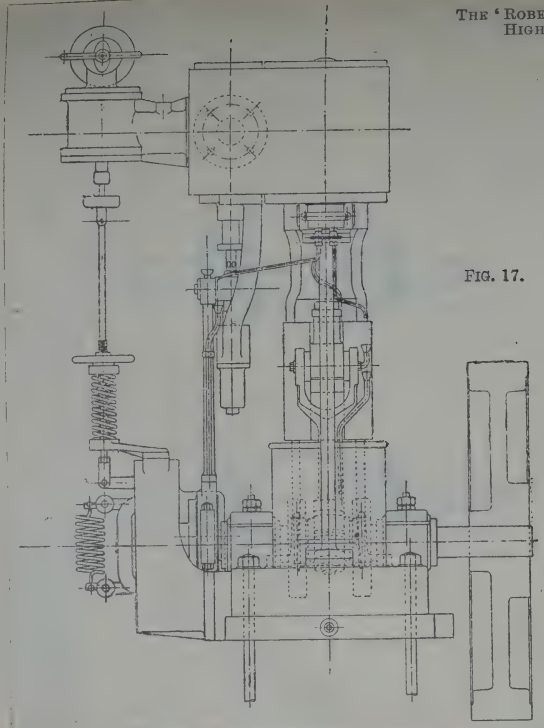


FIG. 17.

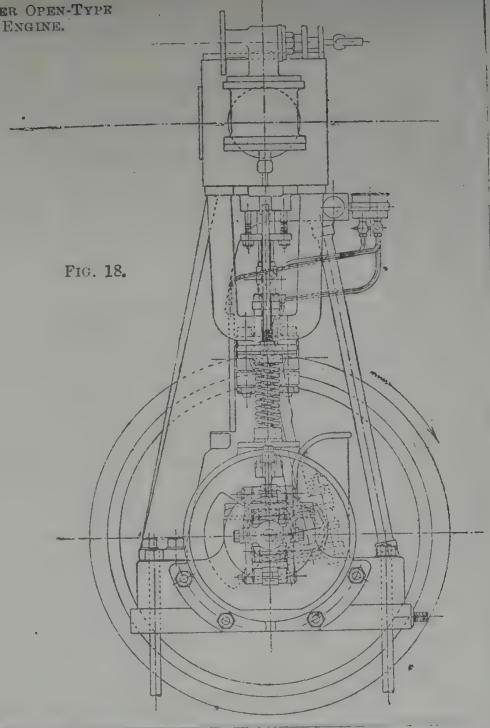


FIG. 18.

WEIGHTS AND MEASUREMENTS OF ROBEY HIGH-SPEED VERTICAL ENGINES (OPEN TYPE).

Cylinder.		Belt Fly-Wheel.		Space Required.		Approximate Weights.				Approximate Cubic Measurement, packed, both.
						With Pickering Governor.		With Shaft Governor.		
Diam.	Stroke.	Diam.	Width.	Length over Crank.	Width over Bed.	Unpacked.	Packed.	Unpacked.	Packed.	
Ins.	Ins.	Ft. Ins.	Ins.	Ft. Ins.	Ft. Ins.	Cwts.	Cwts.	Cwts.	Cwts.	Ft.
3½	3	1 9	3	2 0	1 4½	5	7	6	8	11
4½	4	3 0	3	2 5	1 8	6	8	6½	8½	12
5½	5	3 0	4½	2 9	1 10¾	7	9	8½	11	20
6½	6	3 6	5	3 2	2 0	12½	15	12½	15½	40
7½	7	4 0	6	3 7	2 5½	16	20	18	22	46
8½	8	4 0	6	3 8	2 8½	20	24	22	28	52
9½	9	4 6	8	4 3	3 7½	35	40	38½	46½	62
10½	10	4 6	9	4 6	3 6	42	50	43½	52	86
11½	11	4 6	10	5 5	4 2⅛	60	70	62	72	126
12½	12	5 0	12	5 10	4 5	91	101	96	108	190
13½	13	6 0	12	6 6	4 8	122	140	130	150	250
14½	14	7 0	15	7 0	5 3¾	150	170	160	180	300

THE GALLOWAY DROP PISTON VALVE ENGINE.

(*Patent.*)

The special features of this engine (*Galloways Ltd.*) lie in the steam valves, fig. 19, which are of the drop piston type working in a slotted seat, which in turn is carried by a short vertical cylinder standing in the inlet valve of the steam chest. This short cylinder is surrounded on all sides by steam at one temperature and pressure, and remains truly circular under all conditions however much the steam temperature and pressure may vary. This preserves the circularity of the valve liner and therefore its steam-tightness.

The piston valve itself is of the double-beat type fitted with 'Duplex' spring rings. The duplex rings are so arranged that they cannot fall out of the body of the valve in case of breakage.

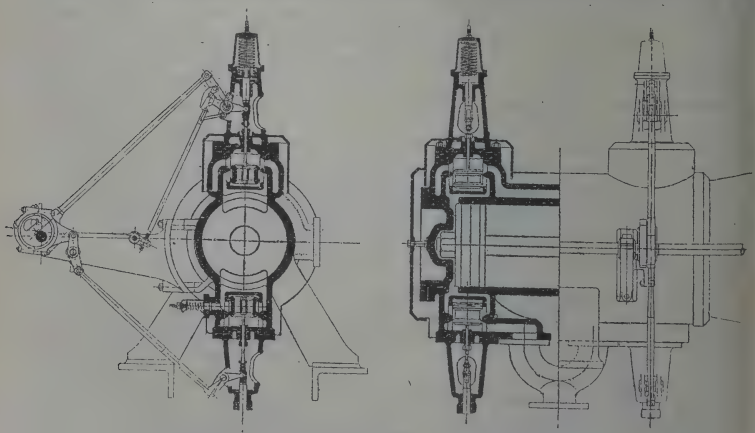


FIG. 19.—Sections through Cylinder, showing Drop Piston Valves.

There being two rings, one inside the other, bedded against each other over their whole circumference, the ring cannot be collapsed by the application of sudden pressure, as when the ring passes over a steam port. On test, the steam leakage in a 14-inch steam valve of this type proved to be a fraction of 1 per cent.

The Galloway Reversing Rolling Mill Engine.

In connection with the reversing rolling mill engines Messrs. Galloways fit a patent single lever expansion control gear. By the employment of one handling lever, both the throttle valve and the cut-off are suitably varied in a predetermined manner. This is so arranged that during the mean rolling period the engine works with variable cut-off and full steam pressure in the cylinders, thus securing maximum economy. When starting up, the gear partially closes the throttle and gives late cut-off so as to product an even steady turning at a slow speed. When the handling lever is brought to mid gear at the completion of a pass, the control valves are forcibly closed so that no steam leakage can take place. By means of this valve gear the steam consumption is claimed to have been reduced to one-half, or less, of that normally required, whilst the output of the rolling mill is increased, as the single lever expansion control gear gives very rapid action on the part of the engine.

Forced Lubrication.

Forced lubrication as a continuous or arterial system of conveying oil under pressure to all the working parts of an ordinary reciprocating engine was patented in 1890 (No. 7397) and introduced by Messrs. Belliss & Morcom Ltd. of Birmingham in their self-lubricating engine (*vide* sectional illustration, fig. 20, which shows their original design of compound engine 'O' type). The constant supply of oil under pressure prevents the working surfaces coming together, the film of oil taking an appreciable time to squeeze out, which is sufficient in a double-acting engine running at a high speed to last until the stress is reversed and the film on the other brass comes into operation; the bearing surfaces are thus prevented from coming into actual contact. In this system the engine is enclosed, and oil drawn from a reservoir in the bedplate by a pump is fed to circumferential grooves in each of the main bearings. The crankshaft is drilled, so that oil drawn from the circumferential grooves in the main bearings is conducted to similar circumferential grooves in the crankpins and thence to the crosshead pins and guides. The valve motion is lubricated in the same way, also the working joints in the governor. The oil escaping from the journals returns to the oil-well in the bed for re-use. The pump, which is of the oscillating type without loose valves or packings, is operated from the eccentric and draws its supply through a gauze strainer. The pressure of oil generally used may be anything between 10 and 25 lbs. per sq. inch.

The Belliss and Morcom 'O' Type High-Speed Engine.

The special feature of this engine, fig. 20, is the arrangement of the slide valves, requiring one eccentric and rod only. The low-pressure valve is superimposed above the high-pressure, working in the same valve chamber, the high-pressure valve taking steam on the inside and exhaustion direct to the low-pressure, which cuts off on the outside edge. The cranks are necessarily set opposite to each other, the steam being admitted simultaneously to the top of one cylinder and the bottom of the other, by which arrangement the reciprocating parts are to a great extent balanced, the stress on the bearings much reduced, and a high speed of revolution made possible. A variation of speed not exceeding 3 per cent. between full and no load can be guaranteed. The governor gear is arranged so that the speed of the engine is capable of being adjusted whilst running.

A modification of this design of engine, more recently introduced, is the 'V' type (see fig. 21, p. 1786).

BACK PRESSURE AND EXTRACTION ENGINES.

Increasing attention is now being paid to the saving of fuel, which is rendered possible by the combination of power supply and heating services, the heating being effected by using exhaust steam or steam taken from the engine at an intermediate pressure. Factories using steam for heating in their own industrial processes offer special opportunities in this direction, though schemes have also been successfully carried out in which the heating of adjoining offices and houses has been effected in addition to the heating required in the factory processes.

For example, in a factory requiring 200 i.h.p. for driving machinery, and 3,200 lbs. of steam per hour at about 5 lbs. per sq. in. gauge pressure for heating purposes, the methods of independent and combined supply may be compared as follows. In the independent method an economical condensing engine would be used, taking, say, 11 lbs. steam per i.h.p. hour, or $11 \times 200 = 2{,}200$ lbs. steam per hour. The total steam is thus $2{,}200 + 3{,}400 = 5{,}600$ lbs. per hour.

In the combined system, a back pressure engine would be used, exhausting at the pressure required for the heating steam. It would require, say, 18 lbs. steam per i.h.p. hour, or 3,600 lbs. per hour. Allowing 10 per cent. for loss by condensation, 3,240 lbs. exhaust steam per hour are available for heating. Thus the steam to be generated for all purposes is 3,600 lbs., as

Continued on page 1788.

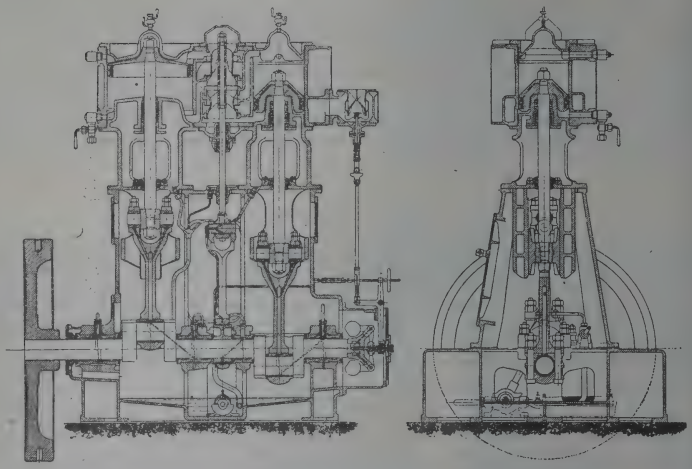


FIG. 20.—Belliss Patent Self-lubricating 'C' Type Compound Engine.

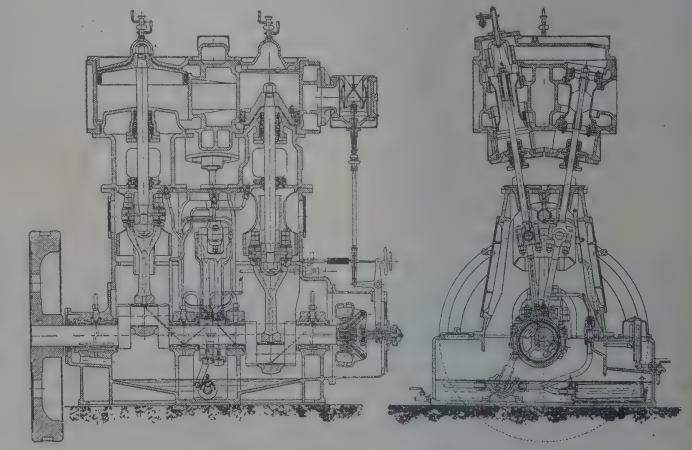


FIG. 21.—Belliss Patent Self-lubricating 'V' Type Compound Engine.

(Messrs. Davey, Paxman & Co. Ltd., Colchester.)

COMPOUND PORTABLE STEAM ENGINE ON ROLLED GIRDER FRAME (Working Pressure, 140 lbs.).

Nominal Horse-Power.	Brake Horse-Power.		Diameter of Cylinder.		Stroke. Both Cylinders.	Fly-Wheel.			Total Heating Surface.	Approximate Space required.			Approximate Weight.		Approximate Cubic Measurement Packed.
	Economical Load.	Maximum Load.	High Pressure.	Low Pressure.		Diameter.	Face.	Revolutions per Minute.		Length Overall.	Width over Wheel Caps.	Height to top of Fly-Wheel.	Unpacked.	Packed.	
	H.P.	H.P.	Ins.	Ins.	Ins.	Ft. Ins.	Ins.		Sq. Ft.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Cwt.	Cwt.	Cub. Ft.
8	19	23	5½	9	14	5 0	7	155	145·4	11 6	5 7	9 1	108	121	430
10	26	30	6½	10½	14	5 0	8	155	172·8	12 0	5 10	9 6	130	144	500
12	30	35	7	11¼	14	5 0	9	155	219·7	12 6	6 7	9 11	153	168	580
16	41	48	8	13	14	5 6	10	155	274·8	13 1	7 0	10 8	206	222	750
20	50	60	9	15	16	6 0	11	135	350·7	14 0	7 7	11 6	260	278	930
25	68	78	10	16	18	7 0	12	120	410·8	16 0	7 10	11 11	310	330	1,100
30	77	90	11	18	18	7 0	14	120	486·5	16 6	8 2	12 2	350	370	1,200

PORTABLE ENGINES. SINGLE CYLINDER. (Working Pressure, 140 lbs.)

Type.	Code Word.		Brake Horse-Power.		Cylinder.		Fly-Wheel.			Approximate Nett Weight in cwts.	
	Portable.	Semi-Portable.	Full Working Load.	Temporary Overload.	Diam. Ins.	Stroke. Ins.	Face Ins.	Diam. Ft. Ins	Speed. R.P.M.	Portable.	Semi-Portable.
L5	SPERNES	SPERRGLAS	13	16	5¼	10	7	3 7	210	75	67
L6	SPERNETIS	SPERRHORN	17	20	5⅝	10	7	3 7	210	94	82
L8	SPERNIMUS	SPERRSITZ	22	26	6¼	12	8	3 9	200	105	93
L10	SPERRERO	SPERRUNG	27	32	7	12	8	3 9	200	112	100
L12	SPERRFORT	SPERVER	34	40	7¾	13	10	4 2	180	135	120
L14	SPERRGELD	SPESACCIA	40	45	8½	13	12	4 2	180	150	135

PAXMAN PORTABLE ENGINES. DOUBLE CYLINDER. (Working Pressure, 120 lbs.)

Nominal Horse-Power.	Brake Horse-Power.		Cylinder.		Flywheel.			Approximate Space Required.			Approximate.		
	Economical Load.	Maximum Continuous Load.	Diam.	Stroke.	Diam.	Face.	Speed.	Length.	Width.	Height.	Measurement Packed.	Weight Unpacked.	Weight Packed.
			Ins.	Ins.	Ft. Ins.	Ins.	R.P.M.	Ft. ins.	Ft. Ins.	Ft. Ins.	Cub. Ft.	Cwt.	Cwt.
8	20	27	7	12	5 0	7½	140	11 11	6 3	9 0	510	110	125
10	26	34	7¾	12	5 0	8	140	12 8	6 3	9 6	585	128	143
12	32	40	8⅛	12	5 0	9	140	13 3	6 6	10 0	645	150	165
14	39	48	9¼	14	5 6	9	125	13 11	6 9	10 0	740	175	190
16	46	56	10	14	5 6	10	125	14 3	7 1	10 1	875	195	215
20	57	71	11	16	6 0	11	115	15 1	8 1	10 9	940	225	245
25	72	90	12	18	6 6	12	110	16 5	8 6	11 0	1,090	255	275
30	84	110	13	18	6 6	14	110	17 2	8 9	12 0	1,310	290	315

NOTE.—The Power given in Columns 2 and 3 is the Brake Horse-Power; the Indicated Horse-Power will be correspondingly higher.

against 5,600 lbs. in the former case, and even though the whole of this steam has to be generated at high pressure and (preferably) superheated, the fuel consumption at the boiler is reduced in nearly the same proportion. The saving in fuel is thus $\frac{5,600 - 3,600}{5,600} \times 100 = 35{\cdot}6$ per cent. approximately.

By means of such systems the large proportion of heat carried away and lost in the condensing water of even highly economical power plants is greatly reduced; cases are on record in which the heat utilised as work in the engine, together with heat made available for heating purposes, amounts to 77 per cent. of the heat in the steam delivered by the boiler.

In the 'intermediate steam extraction' system, which is adapted for fluctuating power and heating requirements, a compound engine is used, the heating steam is taken from the receiver between the cylinders, and only a part of the steam used in the h.p. cylinder passes to the l.p. cylinder, and thence to the condenser. By means of a pressure regulator, the intermediate pressure is allowed to vary only between fixed limits. With an increased demand for heating

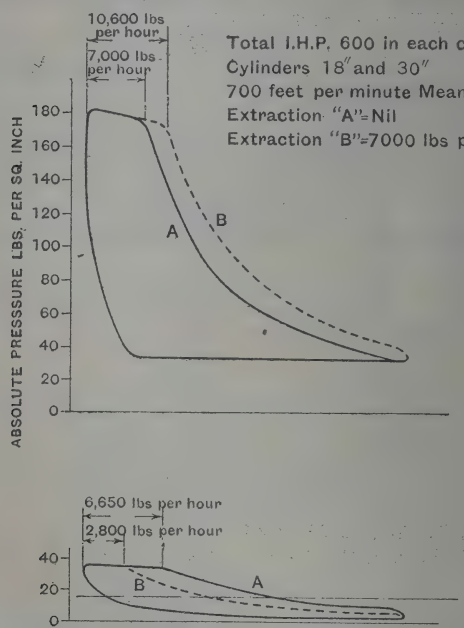


FIG. 21A.

steam, the pressure falls slightly, the pressure regulator makes the l.p. cut-off take place earlier, and, if the load on the engine remains unchanged, the speed governor makes the h.p. cut-off correspondingly later; thus more steam passes through the h.p. cylinder and less through the l.p. Provision is usually made for supplementing the 'extraction' steam, when necessary, by steam taken directly through a reducing valve from the live steam main; this additional supply is also controlled automatically. The l.p. cylinder may with advantage be of the 'uniflow' type (page 1776).

On account of the variations in the distribution of the power between the two cylinders with varying demands for extracting steam, the extraction engine usually has its cylinders arranged in tandem.

This is not, however, absolutely essential, and, particularly if the extraction steam is comparatively small in quantity, the engine may be of the cross compound arrangement.

Typical indicator diagrams for an extraction engine are shown in fig. 21A.

The steam quantities in each cylinder with and without extraction are marked on the diagrams, the total load being the same in both cases.

The Galloway Extraction Engine.

Fig. 21B shows a typical extraction engine as made by Messrs. Galloways Ltd., Manchester. It is of the tandem type, with a uniflow low pressure cylinder.

The inlet valves of both cylinders are of the double beat drop type and are operated by the firm's liquid valve gear (see p. 1777). The exhaust valves of the high pressure cylinder are piston valves, driven by eccentrics on the lay shaft through intermediate rocking levers.

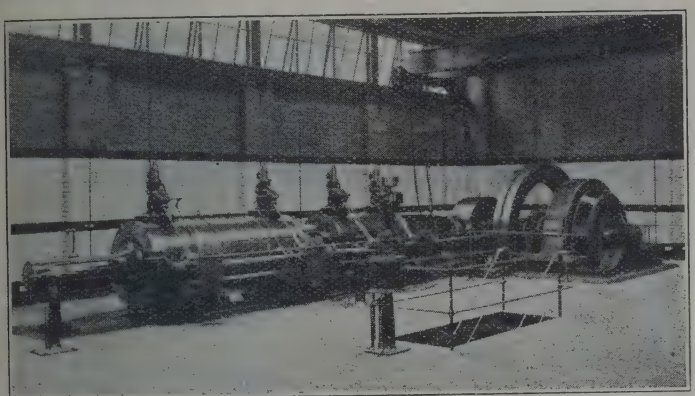


FIG. 21B.—The Galloway Extraction Engine.

The engine is totally enclosed, with forced lubrication to the cylinders and principa lparts and is in accordance with the best modern high-class practice.

The speed is controlled by a vertical spindle centrifugal governor, and the pressure of the extraction steam is adjusted and automatically maintained constant within fine limits by means of the pressure regulator which is seen in the foreground. The servo-motor which actuates the valve gear is in this instance below the floor; in other respects the pressure regulator is as described below.

The Galloway Steam Pressure Regulator.

(*Patent.*)

This Pressure Regulator, in the form suitable for use with an extraction engine, is shown in fig. 21C.

A pipe A conducts steam from the process-steam main through a strainer T and valve S to the interior of a closed cast-iron chamber C. The entrance of the steam to the chamber is controlled by a valve B, held closed by an adjustable spring D. The tension of the spring is so regulated that at the pressure desired in the main there is a slight escape of steam past the valve B, this steam emerging from the chamber C through an adjustable leak F to atmosphere.

The rod E controlling the valve B is of stainless steel, and, to avoid friction in operation, the right-hand end is finished to a thin strip, which is secured to a lug, and bends slightly as the rod moves. The end supporting the valve has a cup engaging the rounded end of the valve spindle. The whole mechanism is practically frictionless, and responds to the slightest variation in the pressure in the main.

The steam escaping from the valve B fills the chamber C at a pressure slightly above atmospheric owing to the throttling effect of the leak F. Any variation in pressure in the main will result in a corresponding change in the pressure inside the chamber. It is this latter variation which is made use of to operate the regulating mechanism.

In the chamber is a container H filled with mercury, which communicates through a hole K with a chamber J open to atmospheric pressure. In this chamber rides a cast-iron float L, frictionlessly guided. It will now be seen that a variation in the pressure in the chamber C will act on the surface of the mercury in container H, and cause the float L to rise or fall. This movement is communicated through a lever MN to a pilot-valve of normal type, operating an oil or

water-servo-motor, shown towards the bottom of the section. A rise of the float L will push the pilot-valve down, causing the servo-motor to be moved to the left; this movement will, however, raise the lever MN by the pin P, and restore the pilot-valve to its normal position. There is thus a definite position of the servo-motor for any given pressure in the chamber C. The servo-motor controls the cut-off in the low-pressure cylinder.

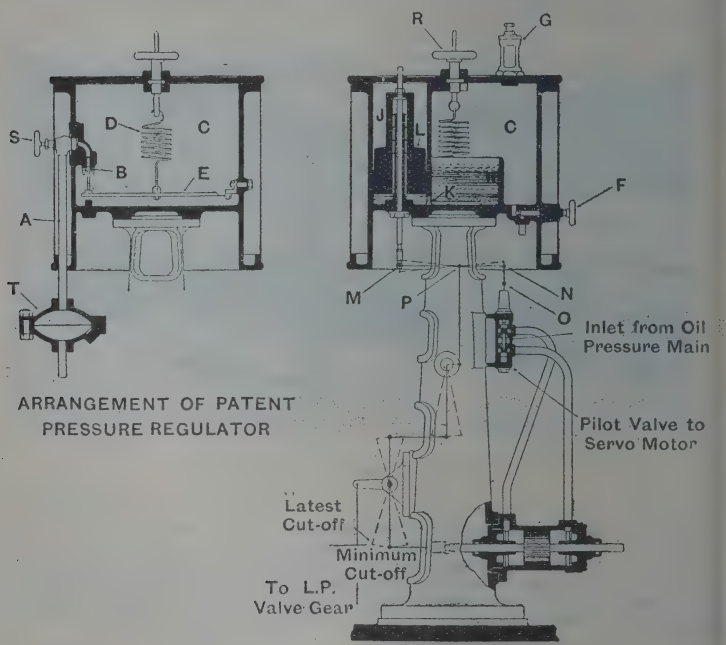


FIG. 21c.—The Galloway Steam Pressure Regulator.

In some combined power and heating schemes conditions arise where the demand for heating steam exceeds that available from the engine at the power at which it is called upon to work at the moment, and it becomes necessary to supplement the supply from the high-pressure main through a reducing valve. The regulator described is able to perform the extra duty of controlling this additional supply. The apparatus is also quite suitable for use independently of a heat-extraction engine for maintaining a constant pressure in a main, or for controlling a reducing valve.

ENGINE DESIGN.

The type of engine is first settled from a consideration of duty, steam consumption, price of fuel, space available, working conditions, water supply, first cost, etc.

Cylinder proportions and speed of revolution are then fixed. Typical British cylinder ratios and mean effective pressures are given in the tables below. On the European Continent the cylinder ratios adopted are usually considerably below the tabular values. That is, a larger high-pressure cylinder is adopted. This makes for economy with superheated steam, but for a two-crank engine tends towards unequal distribution of load on the two cranks which is not altogether desirable. This objection does not apply in the case of tandem engines. These remarks are illustrated by the test results tabulated on page 1767.

TYPICAL MEAN EFFECTIVE PRESSURES AT NORMAL FULL LOAD IN LBS. PER SQ. IN.

Boiler Pressure—Gauge	80	100	120	140	160	180	200
Simple Condensing, about	30	34	37	—	—	—	—
„ Non-Cond. „	35	40	43	—	—	—	—
Compound Condensing	25	27	28	29	30	31	32
„ Non-Condensing	26	30	34	37	40	—	—
Triple Condensing	—	—	—	27	29	30	30·5
Uniflow Condensing	30	33	35	37	38	39	40
„ Non-Condensing, about	26	30	34	37	40	—	—

Note.—The above are often exceeded 5 or 10 per cent.

USUAL BRITISH CYLINDER RATIOS. HORIZONTAL. CUT-OFF GOVERNING.

Boiler Pressure, lbs. Gauge	100	120	140	160	180	200
Initial Piston Press., absolute	110	130	150	170	190	210
Compound Non-Condensing	2·3–2·5	2·5–2·7	2·8–3·0	3·0–3·2	—	—
Compound Condensing	3·0–3·3	3·2–3·5	3·7–3·8	4·0	4·3–4·6	4·5–4·7
Triple Condensing:						
L.P. to H.P.	—	—	5·2–5·6	5·6 –6·0	5·9–6·3	6·0–6·6
I.P. to H.P.	—	—	2·3–2·36	2·36–2·45	2·43–2·5	2·45–2·67

Having fixed the cylinder sizes the probable steam pressures on the pistons are put down, and from these the total piston loads are obtained. From these, by allowing suitable stresses and bearing pressures the principal sizes are fixed.

Usual stresses in high-class engines are as follows:—

USUAL ENGINE STRESSES.

Crank and crosshead pins, up to	9,000 lbs. sq. in.	Connecting rod bolts	4,000–6,000 lbs. sq. in.
Crankshaft journals	7,000–9,000 „	Main studs and bolts	5,000 „
Piston rod, net tension at cotter hole	5,000–6,000 „	Lesser „ „	4,000–6,000 „
Piston rod, gross tension (direct plus bending in body)	9,000 „	Connecting rod body, small end	3,000–6,000 „
		Shear on cotters	3,000–5,000 „
		Bending on cotters	up to 7,000 „
		General forgings	4,000–8,000 „

Cast Iron in Tension.

Simple frames, direct pull	700–900 lbs. sq. in.	Flywheel arms (C.F.)	1,500–2,500 lbs. sq. in.
Frames, with some bending	500–800 „	Cylinder barrels, new	1,200–2,000 „
Complex frames, with bending	500–600 „	„ „ usual	1,500 „

It should be noted that in calculating the above frame tensions only the direct pull is included. If bending is calculated separately and added on, very high figures are sometimes reached.

As an example, take the case of a cotton mill engine of 1,500 i.h.p. normal load, the engine to be of the cross-compound condensing type; boiler pressure 160 lbs.

The cylinder ratio we take to be 4 nominal, piston rods being ignored. We aim at equal loading on the two cranks so that of the total drop in pressure from stop valve to condenser one-fifth will take place in the low-pressure (l.p.) cylinder. Allowing 12 lbs. vacuum and losses of 5 lbs. and 8 lbs. at the steam pipe and intermediate receiver respectively, the total effective pressure drop is 159 lbs., of which 32 takes place in the l.p. cyl. and 127 in the h.p. If the engine has a stroke of 5 ft. and runs at 66 r.p.m. (higher speeds are coming into favour), the piston speed is 660 ft. per min., and the area of the l.p. cylinder for a m.e.p. of 30 lbs.

$$= \frac{1,500 \times 33,000}{660 \times 30} = 2,500 \text{ sq. ins.}$$

This is taken as the gross piston area, giving a diameter of 56·5 inches. The actual m.e.p. would therefore be about 31 lbs. The h.p. cylinder should then be 28·25 ins. diam., but odd dimensions are unsatisfactory, and the cylinders will be fixed at 28 and 56 inches, giving a nominal m.e.p. of 30·5 lbs., which is rather below modern practice, which tends rather to higher m.e.p. than given in the table above.

Ignoring the piston rods, the gross load on the l.p. piston is $32 \times 2,500 = 80,000$ lbs. The load on the h.p. piston is the same. Owing to the effect of the rods this value is rather high, but the difference may be ignored, and 5 per cent. added to cover variations in the load distribution, making the total piston load 84,000 lbs. Taking bearing pressures of 1,250 and 850 lbs. per sq. in. on the crosshead pin and crank pin, the projected areas of these become 67·2 and 98·8 sq. ins. respectively. We may thus fix the pin bearings (diam. × length) as 6·75 × 10 and 10 × 10. ins.

HORIZONTAL ENGINE BEARING PRESSURES.

Bearing.	Lbs. per Sq. In.	Bearing.	Lbs. per Sq. In.
Crosshead pins	1,200–1,300	Second motion bearings	100–200
Crank pins	800– 950	Crosshead slides	40– 50
Crankshaft journals (steam load)	100– 150	Intermediate piston rod slides	20– 40
Crankshaft journals (combined loads)	150– 200		

USUAL BEARING PRESSURES FOR VERTICAL HIGH-SPEED ENGINES.

Bearing.	Lbs. per Sq. In.	Bearing.	Lbs. per Sq. In.
Main bearings	200– 300	Crosshead slippers	40–50
Crank pins	400– 550	Eccentric straps	60–70
Crosshead pins	1,000–1,200		

Inertia should be allowed for in special cases.

Journal speeds are rarely taken into account, but there is at present a tendency to do so, especially in Germany. The influence of speed is complex. In many cases it improves the load which can be carried, but it also increases the heat developed per second, and where the pressures are not such as to endanger the oil film, may limit the safe load on the bearing by the tendency towards overheating. For this a rule of the form—

Pressure per sq. in. × journal speed in ft. per sec. = constant,

is used, but the 'constant' varies so widely that its value in the present state of knowledge is limited.

We now turn to the size of the crankshaft neck. The bending 'arm' from centre of crank pin to centre of main crankshaft neck, we estimate at about 26 ins., so that the bending moment is $M = 84{,}000 \times 26 = 2{,}180{,}000$ inch lbs. The twisting moment is

$$T = 84{,}000 \times 30 = 2{,}520{,}000 \text{ inch lbs.}$$

The equivalent bending moment is

$$M_e = \tfrac{1}{2}\left[M + \sqrt{M^2 + T^2}\right] = 2{,}755{,}000.$$

Adopting a stress of 8,000 lbs. per sq. in., the modulus of the neck section is

$$Z = \frac{2{,}755{,}000}{8{,}000} = 344.$$

For a solid neck of diam. d, $Z = 0{\cdot}0982d^3$. Hence $d = 15{\cdot}2$ ins., say 15·5 ins. The length of the neck must be determined to give a suitable bearing pressure from dead weight and steam load.

The piston rod diam. is next fixed, and partly from it and partly directly from the load the proportions of the connecting rod. The piston rod is proportioned so that the stress round the cotter hole at the crosshead is about 5,000 to 5,500 lbs., whilst the total direct tension plus tension due to bending (assuming a tail support to the rod) does not exceed about 9,000 lbs. The net section of the frame will lie between about 100 and 170 sq. ins. according to type, the highest stresses being allowed where there is least bending.

The size of the crosshead slipper is determined as follows:—If the connecting rod is 5 cranks long, centre to centre, divide the total piston load by 5. The result, 16,800 lbs. in this case, is approximately equal to the maximum load on the slide due to piston pressure. To this should be added the dead weight in the case of a horizontal or inclined engine, giving, say, about 18,000 lbs. in all. Taking a pressure of 45 lbs. per square inch (less if the pressure is steady and not highly variable), gives a slipper area of 400 sq. ins.

Testing Crankshaft Alignment.

Place the crankshaft, fig. 22, on its top centre and set either a micrometer gauge or a gauge made of round iron between the crank webs at the bottom. Turn the crankshaft

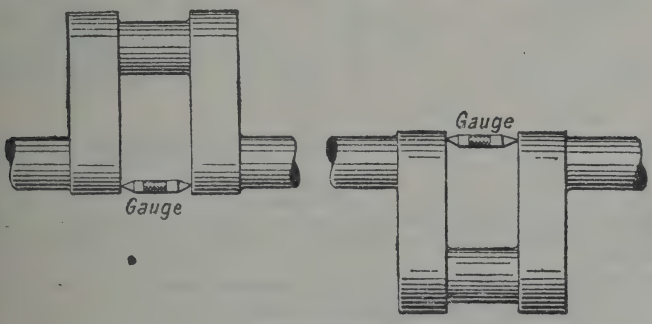


FIG. 22.

around till it is in its bottom position and gauge again. In many cases it will be found that the gauging in the two cases is different, indicating incorrect alignment. Usually, it is the bearing on the driving side that is low. (*A. Bennett, in 'Power.'*)

A simple form of crankshaft alignment indicator, of dial reading type, has been introduced by Messrs. Ruston & Hornsby, Ltd., Lincoln. This instrument is set between the crank webs, and the dial read after turning the shaft into various positions, want of alignment being indicated by differences in the reading.

(See also 'Alignment of Crankshafts and Engine Parts,' p. 1951.)

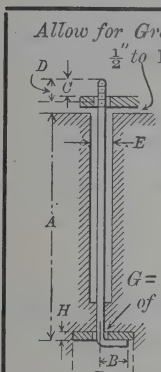
FRAMES.

Bedplates and other frames are almost invariably of strong cast iron. They should be so formed as to reduce bending to a minimum consistent with convenience for the engine attendant and reasonable cost. To secure this they should be as nearly as possible symmetrical on both sides, and also above and below the centre line. This does not mean strict geometrical symmetry, as this is very rarely attainable except as regards the two sides; but it implies an approximately equal distribution of stress. Circular bored and turned joints make for truth in alignment and often for cheapness in manufacture. Ample bearing surface on the foundations must also be allowed.

Foundation Bolt Dimensions.

For bolts 2 ins. or over in diameter, a nut is used under the washer or anchor plate, instead of the bolt being clinched, as indicated by dimension *B*.

STANDARD DIMENSIONS FOR SETTING FOUNDATION BOLTS.



Foundation to rest on Hard Pan, Ledge or Piling.

Bolts. (Inches.)						Washers. (Inches.)		
Dia.	A	B	C	D	E	F	G	H
¼	—	—	—	—	—	—	—	—
⅝	—	—	—	—	—	—	—	—
½	12	2½	¾	1	2	5 by 5	1	5/16
⅝	15	2½	1	1¼	2	5 by 5	1	5/16
¾	18	2½	1⅛	1⅜	3	5 by 5	1	5/16
⅞	21	3	1⅜	1	3	6 by 6	1¼	5/16
1	24	3	1½	2	3	6 by 6	1¼	5/16
1⅛	27	4	1⅝	2½	4	8 by 8	1⅝	1
1¼	30	4	1¾	2½	4	8 by 8	1⅝	1
1⅜	36	5	2	3	4	10 by 10	2	1¼
1¾	42	5	2⅛	3½	5	10 by 10	2	1¼
2	48	Nut	3	4	5	12 by 15	2¼	1
2¼	54	Nut	3⅜	4½	6	12 by 15	2¼	1
2½	60	Nut	3¾	5	6	12 by 20	3	1½

(*'Machinery,' Mar.* 24, 1921.)

CYLINDERS.

Cylinders should be hard and strong. Apart from questions of strength, for information on which see the table of stresses on page 1791, the following important points should not be overlooked :—

(1) The clearance volume should be as small as reasonably possible.

(2) The clearance surface should be reduced to a minimum.

(3) The exhaust and inlet ports are better separated.

(4) The ports should be short, direct, and not too large. Large ports involve increased clearance surface.

(5) The covers which, however, are closely influenced by the piston details, should be free from recesses and curves.

(6) Where there are jackets the steam should be arranged to have a decided through flow, the more rapid the better.

(7) Proper relief valves and drainage should be provided.

(8) Metal bosses and projections connecting to the frames or atmosphere facilitate heat radiation, and should be kept small.

The clearance surface is specially important. Some particulars of usual practice are given in the table of tests on p. 1766, and in the following :—

TYPICAL CLEARANCE SURFACES.

Cylinder and Valves. (Piston Area × 2 = 100%.)	Surface, Per cent.	Authority.
H.P. slide valve	200	J. Stumpf
L.P. trick valve	180	,,
H.P. piston valve	300	,,
L.P. piston valve	220	,,
Double-beat drop valve	182	,,
Corliss valve	170	,,
Uniflow, double-beat valve	133	,,
H.P. Corliss valve	210–320	Foster
L.P. Corliss valve	180–300	,,
H.P. drop-piston valve	210–300	,,
L.P. drop-piston valve	200–300	,,

The port sizes are based on a steam velocity of 100 to 125 feet per second for inlet ports, and 90 to 120 feet per second for exhaust ports when using saturated steam. With superheated steam these speeds are increased to 130 or even 150 feet per second.

BEARINGS.

With very rare exceptions oil is dragged into a bearing by the relative movement of the two so-called rubbing surfaces by a kind of wiping or dragging action. To prevent loss of lubrication the oil must not be allowed to escape from the bearing except at the proper place. Ordinary crosshead pin bearings work mostly by suction. The slight pulsation of the pin in the bearing draws in oil on alternate strokes. On the return of the pressure the oil has not time to escape.

Oil grooves should be looked upon as local supply reservoirs.

Bearing clearances should not increase so rapidly as the diameter of the journal. They vary according to the class of work.

The use of white metal bearings (see page 2725) is a safety precaution in case of overheating. It also has constructive merits.

Usual bearing pressures are given on page 1792.

For the Michell bearing see page 2408.

Rubber *v.* Metal Bearings.

In many commercial uses metal is now being replaced by rubber.

On a harbour tug rubber bearings showed no wear after ten months. They stand the hard use better than bearings of metal, and speeds as high as 5,000 revolutions per minute have been reported with bearings of this type. One great advantage of rubber bearings is that they are not injured by sand or grit. Such particles imbed themselves in the rubber and work out into the grooves in the bearing, whence they are washed away by the water, the only lubricant necessary, without having scratched or cut any part of the machine. In addition, rubber bearings greatly reduce vibration and noise, and for that reason are being used more and more on yachts, house-boats, and other passenger craft.

The contrast in the wearing qualities of rubber and bronze is shown in the case of a mixing machine. Its arms of bronze lasted six weeks, and gave considerable trouble, but its arms when covered with ½ in. of rubber were working satisfactorily after many months of use. Rubber linings have been known to increase the life of flues carrying gases containing abrasive dust, and also the service of sheet-metal chutes.

Alignment Pins.

'Alignment,' 'steady,' or 'fixing' pins are brought into service in the erection of machinery details for the purpose of ensuring that one particular piece shall be superimposed upon another piece in its precise and correct position, no matter how many times the respective pieces may be separated. The use of such pins is far preferable to fitting bolts to each and every hole; the holes for the bolts should be 'clearance' holes, *i.e.* holes through which the bolts can pass freely.

Fig. 23 shows a pin which has been used frequently in small engines, dynamo-electric machinery, and, notably, in the casings of large steam turbines, with unqualified success.

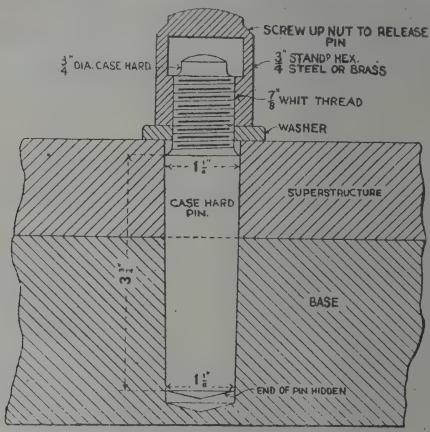


FIG. 23.

It will be observed by those familiar with the use and application of these alignment pins, that a pin such as is shown in the figure is all but imperatively necessary where it is required to fit it to a blind bottom, as represented above. (*'The Electrical Review,'* Sept. 17, 1920.)

FLYWHEELS.

A = Area of turning moment curve per revolution = Work done per revolution in ft. lbs.
a = Excess or deficiency of turning moment curve from resistance curve (usually taken as the mean steady load) = k A.
k = Coefficient of energy fluctuation.
I = Moment of inertia of flywheel in lbs. ft.²
d = Diameter of gyration of wheel in feet.
D = „ rim face „ „
C = Number of complete turning-moment cycles per revolution.
G = Total weight of wheel in lbs.
W = Effective „ „ „ if placed at rim face, diameter D, velocity V.
V = Linear velocity of rim face, ft. per sec.
N = R.P.M.
X = Cyclic irregularity of turning.
Y = Angular deviation from true uniform turning.
F = Frequency of (electric) alternations per second.
p = Number of poles in alternator field magnets.

$$K = \text{Flywheel coefficient} = \frac{\text{Stored energy in flywheel}}{\text{Work done per revolution}} = \frac{WV^2}{2gA}.$$

Then (the suffixes $_1$, $_0$, and $_2$ referring to maximum, mean, and minimum),

$$X = \frac{N_1 - N_2}{N_0} = \frac{V_1 - V_2}{V_0} = \frac{k}{2K} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$K = \frac{k}{2X} = \frac{a}{2AX} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$Y_1 - Y_0 = 28{\cdot}65\,\frac{X}{C} \quad . \quad . \quad . \quad . \quad \text{mechanical degrees} \quad . \quad . \quad . \quad . \quad (3)$$

$$= 14{\cdot}32\,\frac{pX}{C} \quad . \quad . \quad . \quad . \quad \text{electrical degrees} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$= \frac{1719\,FX}{NC} \quad . \quad . \quad . \quad \text{electrical degrees} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The formulæ (3), (4), and (5) are based on sine curves for the turning moment, and are rarely strictly correct as regards the angular deviation $Y_1 - Y_0$, but formulæ (1) and (2) are always correct if the value of a is properly determined.

Considerable uncertainty arises as to the value of a in the case of multi-crank engines.

It is usual to specify that for alternators the angular displacement must not exceed $2\frac{1}{2}$ electrical degrees. In that case, we obtain from equation (4) the relationship

$$\text{coefficient of irregularity } X = \frac{1}{5 \cdot 73} \frac{C}{p} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In the B.E.A.M.A. standardisation rules for electrical machinery, the rule is given

$$\text{cyclic speed irregularity} = \frac{k}{6p} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where

k = engine impulses per revolution ; p = number of poles.

This formula differs from (6) only in replacing 5·73 by 6, but, as already pointed out, these formulæ depend upon the form assumed for the turning moment curve, and variations are therefore not unlikely and do not indicate any error in principle.

Certain flywheel data are given in the three following tables. It will be understood that these are typical values, and that considerable variations occur in practice.

TYPICAL VALUES OF ENERGY COEFFICIENTS, k.

Engine.	Cranks.	Double or Single Acting.	Cycles per rev. C.	k	Crank Angles.
Steam engines :					
Simple	1	Double	2	0·12 -0·16	
Tandem	1	,,	2	0·11 -0·14	
Cross-compound	2	,,	4	0·06 -0·09	90
Triple	3	,,	6	0·025-0·03	120
Uniflow	1	,,	2	0·11 -0·13	
Gas engines, 4-cycle :					
Tandem, two cylinders	1	Double	2	0·13 -(0·2)	A
,, four ,,	2	,,	4	0·06 -(0·1)	90 A
One cylinder	1	,,	0·5		
One cylinder	1	Single	0·5	0·2 -2·4	
Two cylinders, tandem	1	,,	1	0·9 -1·1	360
Two cylinders, twin	2	,,	1	0·9 -1·0	360
Two cylinders, opposed	1	,,	0·5	1·3 -1·5	180
Three cylinders	3	,,	1·5	0·5 -0·6	120
Four cylinders	4	,,	2	0·1 -0·13	180
Six cylinders (tandem)	3	,,	3	0·06 -0·08	120

$k = \dfrac{\text{maximum excess energy}}{\text{work done per revolution}}$ A indicates figures in brackets, adopted to cover misfiring.

TYPICAL CYCLIC IRREGULARITIES X AND FLYWHEEL COEFFICIENTS K.

Driving.	Connection.	Engine.	No. of Cranks.	X	K
Alternators in parallel	Direct	Large	—	$\frac{1}{250}$	—
,, ,,	,,	High-speed	—	$\frac{1}{320} - \frac{1}{500}$	—
D.C. dynamos	,,	Steam	—	$\frac{1}{100} - \frac{1}{125}$	—
,,	,,	Large gas	—	$\frac{1}{150}$	—
,,	,,	Small gas	—	$\frac{1}{80} - \frac{1}{125}$	—
,,	,,	Diesel	—	$\frac{1}{100} - \frac{1}{125}$	—
,,	Ropes	Various	—	$\frac{1}{80} - \frac{1}{125}$	—
Best factory	,,	Steam	1	$\frac{1}{185}$	12
,, ,,	,,	,,	2	$\frac{1}{200} - \frac{1}{340}$	7–12
General factory	,,	,,	1	$\frac{1}{125} - \frac{1}{165}$	8–10
,, ,,	,,	,,	2	$\frac{1}{170} - \frac{1}{200}$	6– 9
Pumping, reciprocating	Direct	,,	3	—	·15–·5
Pumping, usual	,,	Triple vert.	3	—	·3

VALUES OF FLYWHEEL COEFFICENTS K FOR VARIOUS VALUES OF X AND k.

Engine.	Cranks	k	X					
			$\frac{1}{75}$	$\frac{1}{100}$	$\frac{1}{125}$	$\frac{1}{150}$	$\frac{1}{200}$	$\frac{1}{250}$
Steam :								
Double acting	1	0·13	4·9	6·5	8·1	9·8	13·0	16·3
" "	2	0·07	2·7	3·5	4·4	5·3	7·0	8·8
" "	3	0·03	1·2	1·5	1·9	2·3	3·0	3·8
Gas : double acting tandem	1	(0·2)	7·5	10·0	12·5	15·0	20·0	25·0
" " " "	2	(0·1)	3·8	5·0	6·3	7·5	10·0	12·5
Gas : 4-cycle single-acting :								
One cylinder	1	2·3	86	115	144	173	230	288
Two cylinders tandem	1	1·0	37·5	50·0	62·5	75·0	100·0	125·0
Two cylinders opposed	1	1·4	52·5	70·0	87·5	105·0	140·0	175·0
Three cylinders	3	0·55	20·6	27·5	34·4	41·2	55·0	68·8
Four cylinders	4	0·13	4·9	6·5	8·1	9·8	13·0	16·3
Six cylinders	3	0·07	2·7	3·5	4·4	5·3	7·0	8·8

NOTE.—The values of k are based on the assumption of a uniform engine load, and do not apply accurately to engines driving pumps, blowers, or even electric alternators. (*Foster.*)

Example.—Tandem compound engine of 1,200 i.h.p. normal load at 94 r.p.m., driving an alternator of 50 cycles. The deviation must not exceed two electrical degrees on either side of the mean position.

From the tables we see that k is about 0·13, and C=2.
In formula (5) we have

$$C = 2,\ Y_1 - Y_0 = 2,\ F = 50,\ N = 94$$

Hence $$X = 0{\cdot}00437 = \frac{1}{229}.$$

Inserting the value of X in formula (2) we obtain K = 14·9.
The work done per revolution is

$$A = \frac{1{,}200 \times 33{,}000}{94} = 421{,}000 \text{ ft.-lbs.}$$

The stored energy in the flywheel is KA or 6,280,000 ft.-lbs.
If the flywheel is 18 ft. diam., the rim velocity is 88·6 ft. per sec., and the equivalent weight at this diameter is, therefore, 51,500 lbs. The actual flywheel weight should be about 70 per cent. in excess of this, say 87,500 lbs. This makes no allowance for the flywheel effect of the alternator rotor, which is usually considerable and need not be ignored.

For engines driving alternators, the flywheel effect should be such that the displacement $Y_1 - Y_0$ does not exceed 2·5 electrical degrees, nor should X as a rule exceed $\frac{1}{250}$. Where several units have to work in parallel the flywheel effect must also be such as to avoid resonance, i.e. the natural period of oscillation of the rotor about the position of uniform turning must not coincide with the period of any periodic impulses due to the engine. The determination of the oscillation period requires knowledge of the electrical characteristics of the alternators.

Alternator builders commonly state the flywheel quantity of their alternators in terms of GD^2, which is short for weight multiplied by the square of the diameter of gyration. If the units employed are kilogrammes and metres, the corresponding GD^2 in lbs. and feet can be obtained by multiplying by 23·7.

$$\text{Stored energy} = GD^2 \times \left(\frac{\pi N}{60}\right)^2 \times \frac{1}{2g} = \frac{GD^2 \times N^2}{23{,}500}.$$

If G, D are in lbs. and feet, the stored energy is in ft.-lbs. The stored energy at the revolutions of the machine is readily calculated by assuming any convenient diameter of gyration, calculating the corresponding weight and velocity and thence the kinetic energy. The flywheel effect is sometimes stated as T tons (or lbs.) at 1 ft. radius. The GD^2 is then T × 4 in tons (or lbs.) × feet^2. The actual diameter need not be known, which is a convenience of this method of expression. Occasionally the moment of inertia is given, which is equal to GD^2 divided by $4g$, which is 128·8 in ft.-lb. units and 39·24 in kg. metre units. (This gives the moment of inertia in 'engineers' units,' i.e. mass × length^2 ÷ g.)

SPEED OF FLYWHEELS

The rim of a flywheel is subjected to stress on account of centrifugal force, and this stress is independent of the cross-section. For a particular material it depends only on the linear speed of the rim.

For cast-iron wheels the safe rim speed is customarily taken as 6,000 ft. per minute. For a given r.p.m. this fixes the wheel diameter.

Where higher speeds are desired with consequently lighter wheels for the same amount of stored energy, cast steel may be used, or the wheel may be made with discs of steel plate.

A steel plate wheel with wire-wound rim has been run at 15,000 ft. per minute.

Crank Connecting-Rod Mechanism.

If r = crank radius; l = length of connecting rod; n = R.P.M.; θ = crank angle (measured from inner dead centre); x = per cent. stroke of piston (measured from end of stroke remote from crank),

then the following relationships are nearly exact:

$$x = \frac{1 - \cos\theta}{2} + \frac{r}{8l}\left(1 - \cos 2\theta\right);$$

$$\text{piston velocity} = 2\pi nr\left(\sin\theta + \frac{r}{2l}\sin 2\theta\right) = 2\pi r \times k_1;$$

$$\text{piston acceleration} = 4\pi^2 n^2 r\left(\cos\theta + \frac{r}{l}\cos 2\theta\right) = 4\pi^2 n^2 r \times k_2.$$

Table of Crank Angles and Factors for Piston Velocity and Acceleration.

θ = angle of crank for out-stroke.
Angle for in-stroke = 180 − θ, measured from outer dead centre.

Stroke per cent.		$\frac{l}{r}$ = infinity.			$\frac{l}{r} = 5$			$\frac{l}{r} = 4$		
Out.	In.	θ	k_1	k_2	θ	k_1	k_2	θ	k_1	k_2
0	100	0	0	1·00	0	0	1·20	0	0	1·25
1	99	11·5	0·20	0·98	10·5	0·22	1·17	10·3	0·22	1·22
2	98	16·3	0·28	0·96	14·8	0·305	1·14	14·5	0·31	1·19
4	96	23·1	0·39	0·92	21·1	0·43	1·08	20·7	0·435	1·12
6	94	28·3	0·475	0·88	26·0	0·515	1·02	25·4	0·525	1·06
8	92	32·9	0·54	0·84	30·1	0·585	0·965	29·5	0·60	1·00
10	90	36·9	0·60	0·80	33·8	0·65	0·905	33·1	0·66	0·94
15	85	45·6	0·715	0·70	41·9	0·765	0·765	41·1	0·78	0·785
20	80	53·1	0·80	0·60	48·9	0·855	0·63	48·0	0·87	0·64
25	75	60·0	0·865	0·50	55·4	0·915	0·495	54·3	0·93	0·50
30	70	66·4	0·915	0·40	61·5	0·96	0·37	60·4	0·975	0·365
35	65	72·5	0·955	0·30	67·3	0·995	0·245	66·1	1·01	0·235
40	60	78·5	0·98	0·20	73·0	1·01	0·125	71·8	1·02	0·11
45	55	84·3	0·995	0·10	78·7	1·02	0·01	77·3	1·03	−0·007
50	50	90·0	1·00	0·0	84·3	1·015	−0·10	82·9	1·02	−0·12
55	45	95·7	0·995	−0·10	90·0	1·00	−0·20	88·6	1·01	−0·225
60	40	101·5	0·98	−0·20	95·8	0·975	−0·295	94·3	0·98	−0·32
65	35	107·5	0·955	−0·30	101·8	0·94	−0·39	100·3	0·94	−0·41
70	30	113·6	0·915	−0·40	108·0	0·89	−0·47	106·6	0·89	−0·495
75	25	120·0	0·865	−0·50	114·7	0·83	−0·55	113·2	0·83	−0·565
80	20	126·9	0·80	−0·60	121·9	0·76	−0·62	120·5	0·75	−0·63
85	15	134·4	0·715	−0·70	129·9	0·67	−0·675	128·6	0·66	−0·68
90	0	143·1	0·60	−0·80	139·2	0·555	−0·73	138·1	0·545	−0·715
92	8	147·1	0·54	−0·84	143·6	0·495	−0·745	142·5	0·485	−0·73
94	6	151·6	0·475	−0·88	148·5	0·435	−0·76	147·6	0·425	−0·735
96	4	156·9	0·39	−0·92	154·4	0·355	−0·775	153·5	0·345	−0·745
98	2	163·7	0·28	−0·96	161·9	0·25	−0·79	161·3	0·245	−0·748
99	1	168·5	0·20	−0·98	167·2	0·175	−0·795	166·7	0·175	−0·749
100	0	180·0	0	−1·00	180·0	0	−0·80	180·0	0	−0·75

The positions of piston and crank for zero piston acceleration are as follows:

	$\frac{l}{r} = \infty$	$\frac{l}{r} = 6$	$\frac{l}{r} = 5$	$\frac{l}{r} = 4$	$\frac{l}{r} = 3$	$\frac{l}{r} = 2$
Stroke per cent.	50	46·1	45·4	44·4	43·2	41·7
Crank angle (degrees)	90	80·8	79·1	76·7	73·2	67·7

Crank Effort and Turning Moment.

The crank effort is the force exerted by the connecting rod on the crank pin in the direction of motion of the pin.

The turning moment (at a particular crank) is the crank effort multiplied by the crank radius.

The total turning moment of an engine is the sum of the moments at all the cranks.

To find the crank effort: From the indicator diagram (the assumed probable diagram in the case of design) and the cylinder area, the total force exerted on each side of the piston by the steam is found for any point of the stroke, and hence also the nett steam force on the piston.

To this must be added, with due regard to algebraic sign, the inertia force, *i.e.* the force required to accelerate (or retard) the reciprocating masses. If the engine is vertical, the weight of the moving parts must also be allowed for.

Thus the force P, say, acting at the crosshead in the direction of motion is found.

To find the inertia force at any position of the piston, it is usually sufficient to find the inertia at the ends of the stroke and to find the position at which the inertia is zero, thus fixing three points on the diagram, fig. 24. A fair curve drawn through these points gives the inertia line RRR.

At the inner dead centre, the acceleration $\alpha = 4\pi^2 n^2 r\left(1 + \frac{r}{l}\right)$; at the outer dead centre $\alpha = 4\pi^2 n^2 r\left(1 - \frac{r}{l}\right)$, and $\alpha = 0$ at a position depending on the ratio $\frac{l}{r}$ (see above table).

The inertia force = mass of reciprocating parts $\times \frac{\alpha}{g}$.

Fig. 24 shows the form of a typical diagram of forces. AB is the stroke, A the inner and B the outer end. PPP represents the resultant force of the steam on the piston during the out-stroke and QQQ that during the in-stroke. RRR is the inertia line. Ordinates measured from RRR represent the forces at the crossheads in the direction of motion. (For a vertical engine, the line RRR is lowered by an amount representing the weight of the parts.)

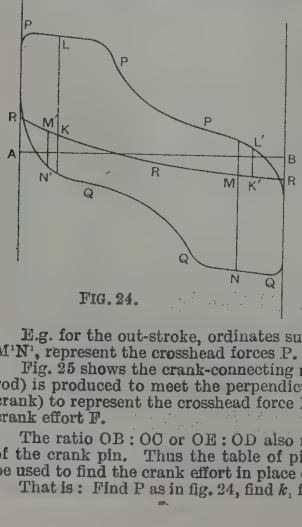


Fig. 24.

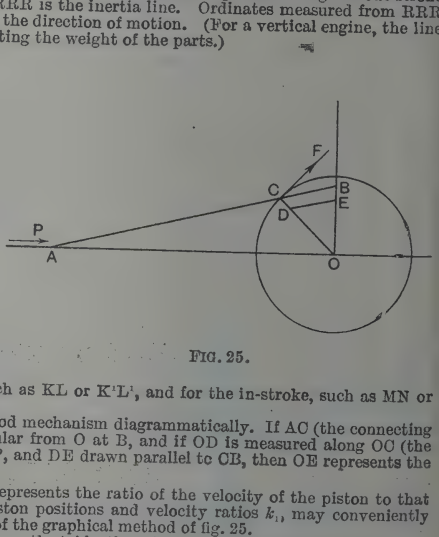


Fig. 25.

E.g. for the out-stroke, ordinates such as KL or K'L', and for the in-stroke, such as MN or M'N', represent the crosshead forces P.

Fig. 25 shows the crank-connecting rod mechanism diagrammatically. If AC (the connecting rod) is produced to meet the perpendicular from O at B, and if OD is measured along OC (the crank) to represent the crosshead force P, and DE drawn parallel to CB, then OE represents the crank effort F.

The ratio OB : OC or OE : OD also represents the ratio of the velocity of the piston to that of the crank pin. Thus the table of piston positions and velocity ratios k_1, may conveniently be used to find the crank effort in place of the graphical method of fig. 25.

That is: Find P as in fig. 24, find k_1 from the table, then the crank effort = force P $\times$ k_1.

Starting Torque of Two-Crank Engines.

Engines which have to start against load, such as locomotive engines, winding engines, etc., have usually two cranks at right angles. They should be large enough to start from any crank position with full steam pressure in the cylinders. The starting torque has minimum values at four points in the revolution occurring just after one crank has passed the position of cut-off. At these points, when the steam stop-valve or throttle-valve is opened, only one of the cylinders receives steam and its crank may be in a very unfavourable position.

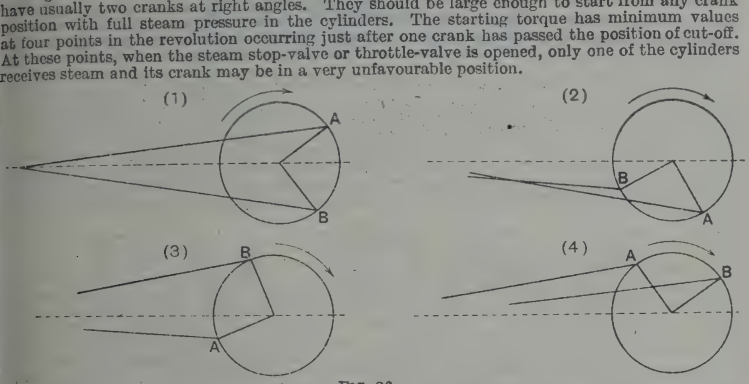


Fig. 26.

The four positions of minimum torque are shown in Fig. 26. In position (1) crank A has just passed the cut-off position on the out-stroke; in (2), B has just passed cut-off on the in-stroke; in (3), A, and in (4), B have just passed cut-off. The worst position is (1).

The ratio of the minimum starting torque to the torque produced by the steam load in one cylinder acting at full crank radius, or as it is often termed 'the equivalent crank ratio,' depends on the point of cut-off. For an engine in which the connecting-rod crank ratio is 5, its values are shown in the following table:

Cut-off per cent.	Position 1.	Position 2.	Position 3.	Position 4
70	0·25	0·39	0·56	0·37
75	0·34	0·475	0·66	0·49
80	0·44	0·56	0·755	0·62
85	0·54	0·645	0·845	0·74
90	0·66	0·74	0·92	0·855
95	0·79	0·84	0·99	0·96

For estimating stresses in the shaft, etc., the maximum torque must also be known.

The combined torque due to two cranks at late cut-off reaches maximum values at four points in the revolution. Two of these points are when the cranks are both above the centre line and at 45°, and when both are below at 45°. The ratio of the torque to that due to one cylinder at full crank radius is then 1·414. Another maximum position is when crank A is at 135° from the inner and B at 45° from the outer dead centre, the ratio being then 1·214. The fourth position is with A at 135° from the outer and B at 45° from the inner dead centre, and this gives the largest ratio of all, namely 1·614.

If the cut-off is sufficiently early, the steam valve of one cylinder will close before the above positions are reached, and the steam pressure in that cylinder will have fallen due to partial expansion: the torque will thus be reduced somewhat as compared with late cut-off.

Annealing Connecting Rod Bolts.

In the annual report of *The British Engine, Boiler & Electrical Insurance Co., Ltd.*, for 1924, attention is drawn to the serious results caused by the defective annealing of the connecting rod bolts of an engine.

The Company state that the heat treating of bolts, shafts, or other parts by rough and ready methods cannot be too strongly condemned.

The malpractices, which take place when 'annealing,' have arisen owing to the prevalence of a vague idea that it is possible to restore metal which has been overstrained in service to its original condition by some form of heat treatment.

A common practice of heating parts to an indefinite temperature and for an indefinite period, and following up by protracting the rate of cooling without having any regard to the quality of the material can only lead to trouble.

The following remarks describe a treatment which is suitable for restoring a machined article such as a connecting rod bolt made of plain carbon steel, to a state of passivity, providing th deformation caused by the overstrain has not been sufficient to set up an incipient internal flaw in this latter contingency any form of heat treatment is only likely to intensify the defect, and th bolt should be scrapped. The recommendation is based on the assumption that the steel wa initially supplied to the user in a suitable condition with regard to heat treatment, and in making it consideration has been given to the uncertainty as to the past history and exact analysis of th bolt :—

The bolt should be heated uniformly in a specially designed muffle furnace to a temperatur in the neighbourhood of 550° C., and at any rate not exceeding 600° C., for a sufficient time t enable it to reach a uniform temperature throughout. In general, with the temperature named the actual rate of cooling adopted is not of great importance as long as it does not exceed tha which takes place in still air ; in certain cases, however, the maximum rate named is to be pre ferred, and is perhaps therefore the most suitable for a general recommendation. Whatever method of cooling be adopted, care must be taken to ensure that cooling is uniform throughou the mass of the steel. Under no consideration should the bolt be cooled on a metal floor o exposed to a draught.

GOVERNORS.

It is the function of the governor to adjust the quantity of steam to the load on the engine The sensitiveness of the governor should depend on the nature of the load, but in all cases th governor should be as free from friction (which also applies to all the valve mechanism operate by the governor) as possible. Friction tends to coarse governing and hunting. On the othe hand, a very sensitive governor, especially if of great power on an engine with insufficient fly wheel, tends to produce hunting, which should be corrected by an oil dashpot on the governo mechanism. In governor design attention must be paid to the levers and connections so a to give a reasonably equal ratio of governor movement to speed variation at all loads.

The plain Watt fly-ball governor is rarely used, being deficient in power. When loade with a central weight (Porter governor) it is satisfactory on typical factory engines, especiall if carried on ball-bearings and knife edges throughout. The centre weight makes it somewha sluggish in following changes of speed, and springs replace the weight in many modern governors The springs need not be vertical.

If the governor is mounted on the crankshaft it may become bulky owing to its slow speed, bu has some merits where eccentrics or valve rods have to be moved directly. Shaft governors owing to their bulk, tend to be sluggish and to lag behind the engine when the speed changes This inertia effect has been utilised in the inertia shaft governor, in which it is the falling behin of the governor weights due to inertia and not their outward movement under centrifugal forc which operates the valve gear.

Relay Governors.

In relay governors the movement of the valve gear is effected by a motor, usually taking th form of a cylinder and piston operated by oil pressure. The movement of the piston is controlle by a small sensitive governor, usually of the centrifugal type. This governor has only to move th oil valve and can be relatively small, whilst the force exerted by the relay piston may be anythin desired. The oil is supplied by a reciprocating or, more usually, a rotary pump. A simpl drum or toothed-gear pump is entirely satisfactory. Any pressure can be obtained, but 5 or 60 lbs. sq. in. is a convenient value. In calculating the pump capacity allow for the maximun reasonable movement of the relay piston, and for 25 to 50 per cent. slip at the pump accordin to the speed, size, and pressure of the pump. These governors are common on large turbines an growing in favour for large oil, gas, and steam engines. Unlike the ordinary centrifugal governo insufficient power shows itself chiefly by slow action and not very much by a large difference i the rising and falling speeds. In short, the relay governor is, under these conditions, slow bu accurate.

Governors are best driven by gears, but chains may be used and even belts or ropes if th last two are in duplicate or triplicate to minimise trouble in case of one belt or rope breaking.

Governors are best arranged to knock off at over speed, but this function may be arrange for by a simple separate governor.

Governors are often termed 'expansion' or 'throttle' governors, but these expression refer to the valve gear rather than the governor. Expansion control is the more economica in most cases, but more difficult to arrange for except in the case of engines having Corliss o drop valves and running at moderate speeds only.

Area of Steam Passages and Valves.

The area is usually calculated from the mean piston speed. Thus if the pipe or valve are is one-tenth the piston area and the piston speed is 600 ft. min. or 10 ft. sec. the steam spee through the pipe or valve is 100 ft. sec.

Usual values for steam and exhaust valves, ports, and pipes :—

Saturated steam	100 ft. per sec.
Superheated steam	125 ,,

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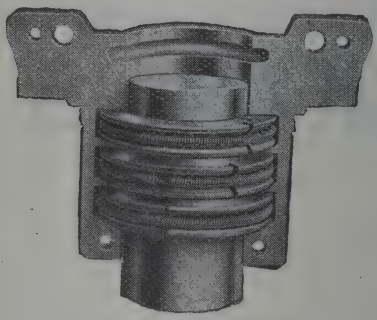
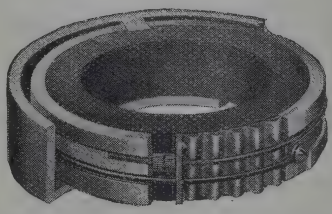


PACKING RINGS IN HOUSING
Photograph of Standard Locomotive Packing.



PACKING RINGS IN CHAMBER
Photograph of Carbon Packing for use on Steam Turbines.

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[See Editorial pages 1263, 1805, 1844 and 1949].

For drop-seated valves add about 50 per cent. at high speeds, and up to 100 and 150 per cent. for uniflow engines.

For steam turbines base on actual weight of steam, but assumed saturated, and allow 90 ft. per sec. This is equal to about 120 ft. sec. for steam superheated about 150° Fah. at the turbine. A rough rule is 1000 lbs. of steam per hour at rated load per sq. in. of pipe area.

For the main steam range, unless this is very short, base on actual volume, assumed saturated, flowing at about 90 ft. per sec.; rather less, say 75 to 80 ft. per sec., for reciprocating engines or pipes below 4 ins. in diameter.

PACKINGS.

General Notes.

A packing may operate on two principles. It may, as its name implies, pack the stuffing box as tight as possible, stopping every channel of escape and relying on the quality and lubrication of its materials to prevent undue friction; or it may employ accurately fitting stop-plates and rings adjusted to give minimum friction and thus permitting a very trifling leakage, which if sufficient to be noticeable is sucked away to the intermediate steam pipe or exhaust, as the case may be. All the old and many of the new packings were on the first principle. Some of the new are on the second; and for valve spindles, where friction is most undesirable, the second should always be adopted. In turbines the second is almost universal, the fitting being very slack but not casual, and the leakage considerable.

Hard and fast rules cannot be established as to the composition of the materials which should be used, as these depend on the actual running conditions, but long experience has shown that packing rings of a metallic structure are far superior to the older forms of soft packing; in fact, modern conditions have made the necessity of the change from the one to the other imperative.

The remaining factor in the efficiency of a packing is the design, and it is indisputable that the best results are secured when adjustments to wear and change in pressures are obtained automatically, since the care of machinery is not always entrusted to experienced and skilled workmen.

The United States Metallic Packing.

This packing is made in four distinct forms: 1, block type of packing; 2, cone or locomotive type of packing; 3, duplex type, consisting of combination of the block and cone types; 4, atmospheric-duplex type, specially designed for use on low-pressure condensing cylinders.

The United States Duplex Packing.

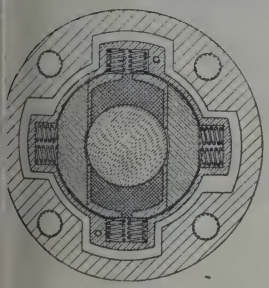

FIG. 27.

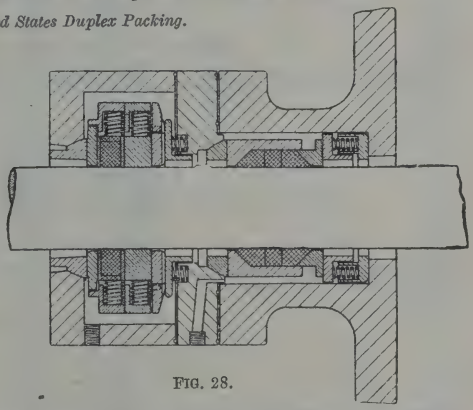

FIG. 28.

Figs. 27, 28, show the duplex type of packing. The block portion consists of eight blocks which are held in strong rings, having pockets or horns holding springs. The packing blocks are put together in sections, four blocks to a section. Each section is, therefore, composed of two working blocks, babbit lined, and two guide blocks. The joints between the blocks in one section are at right angles to those in the other section, thus breaking joint. The blocks are regulated by springs, which merely keep the parts in place when steam is shut off, as when the steam is applied the steam pressure regulates and sets the packing. A ball-joint on one side and follower with springs on the other give the packing free play and keep it steam-tight, without regard to the vibration of the rod. It works equally well whether the rod vibrates or not, and, causing no friction, it does not wear the rod, but gives it a high polish. With efficient lubrication the blocks wear very slowly, many of the packings having given over twenty-four years' service without renewal of the blocks.

The cone portion of the duplex packing consists of three white metal rings placed in a floati cup, the interior of which is partly conical. This cup rests against ball and socket-ring, and t whole is kept in place by a follower with suitable springs, which allow the packing free play in all its movements. The whole is enclosed in a strong case, and bolted to the cylinder head with the usual stud bolts. The packing is steam setting, hence the friction is reduced at least 50 per cent. as compared with non-steam-setting packings. Drain valves are provided for removal of water, core sand, or other accumulations.

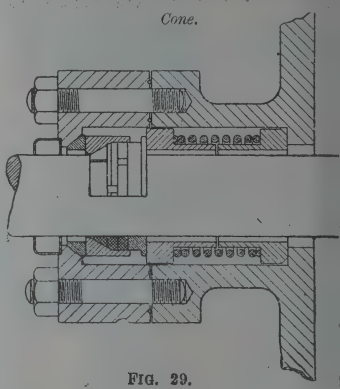

FIG. 29.

The block type of packing is used for pressures under 100 lbs. per square inch. The duplex type is employed for pressures over 100 lbs. Either packing can be arranged for working with steam superheated to 700° F.

Fig. 29 shows the cone or locomotive type of packing, which is practically similar to the cone packing described above. The white metal rings are the only parts which require renewal, and it is no uncommon thing for locomotives to run 80,000 to 100,000 miles without requiring adjustment of packing. All packings can be arranged to pass over enlarged ends.

THE UNITED KINGDOM SELF-ADJUSTING ANTI-FRICTION METALLIC PACKING.

The arrangement of this packing is shown by fig. 30. The only wearing parts are the rin C, D, L, M, which are of special anti-friction metal. These rings are fitted on the rod in segmen

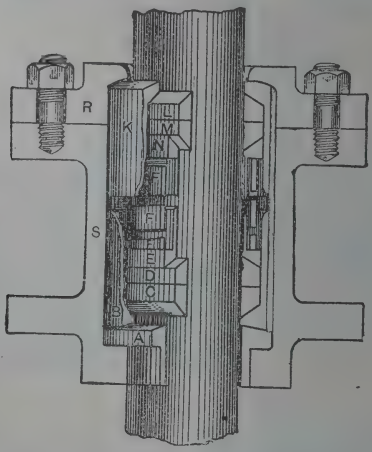

FIG. 30.—A, Neck Bush; B and K, Gunmetal Sleeves; C, D, L and M, Special Anti-Friction Metal Rings; E and N, Gunmetal Spring Rings; F, Steel Coil Spring; R, Gland; S, Stuffing Box.

taking the shape of a truncated cone held together by gunmetal sleeves (B and K) and ke in their place by gunmetal spring rings (E and N), which in their turn are compressed by th steel coil spring (F) placed between them. At the end of the sleeves (B and K) are concentri spherical bearings which allow of free lateral motion where there is any inaccuracy in the runnin of the rod.

The angle on the rings for the purpose of wedging them on the rods to make a steam-tigh joint being more than double that in general use in metallic packings, the friction on the ro

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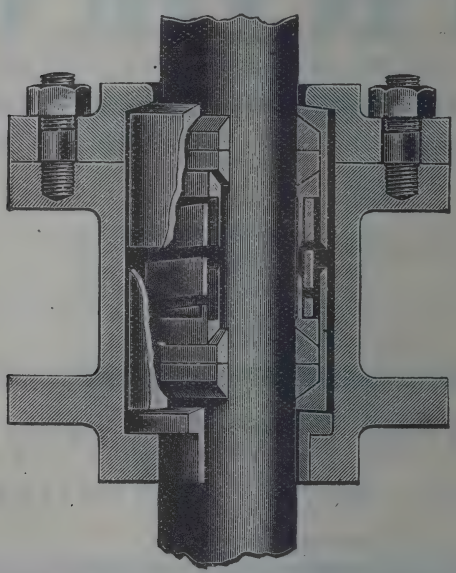
Prevents undue wear to Rods.
Admits of Drain Cock in spring space



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F. 1805

is extremely small, thus reducing the wear on the special metal rings and the rod itself to a minimum.

For swell-ended and large rods a slightly different arrangement of the gunmetal rings is adopted but under no circumstances are screwed parts necessary.

A special feature in the arrangement of the 'United Kingdom' packing is that it cannot be tampered with. It yields freely to all vibrations of the rod which it packs, and also tends to support it, because the concentric spherical bearings at the end of the brass sleeves, which contain the wearing parts, will not allow the packing to drop vertically, although it can angle in any direction, pivoting about the piston head.

It is claimed that the friction is less than one-fourth that with any other existing form of packing, this result being effected by the packing being double, an inner packing throttling the steam in the stuffing-box, so that instead of the outer packing having to withstand the full cylinder pressure, it has only the wire-drawn steam in the stuffing-box between the two packings to contend with.

In addition to the reduced friction, the wearing parts are much larger than is usually the case. It is stated that this packing has for a test been run for six months on an engine doing hard work, without any other lubrication than there is in the steam, and that it was in perfect order at the end of that time, the rods showing no sign of wear.

'BRITIMP' BRAND METALLIC PACKINGS, SINGLE RING TYPE.*

(*British Metallic Packings Co., Ltd., 7 Princes Street, Westminster, S.W.* 1.)

This patent packing consists of three or more rings (fig. 31), each ring forming a complete packing in itself. Each ring is in three segments, which are held together by a garter spring. The joints between consecutive segments overlap in such a way that the combined resistance of the rings to steam leakage is such that perfectly steam-tight glands are ensured. Moreover, the joints are so designed that the parts are reduced to the smallest possible number. Attention is drawn to the fact that there is an entire absence of locating pins which in the course of time are apt to either become loose or be sheared off.

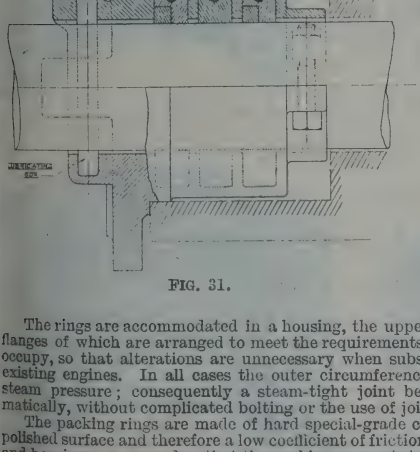


FIG. 31.

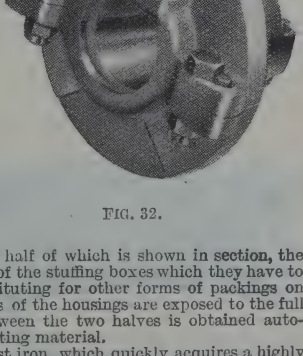


FIG. 32.

The rings are accommodated in a housing, the upper half of which is shown in section, the flanges of which are arranged to meet the requirements of the stuffing boxes which they have to occupy, so that alterations are unnecessary when substituting for other forms of packings on existing engines. In all cases the outer circumferences of the housings are exposed to the full steam pressure; consequently a steam-tight joint between the two halves is obtained automatically, without complicated bolting or the use of jointing material.

The packing rings are made of hard special-grade cast iron, which quickly acquires a highly polished surface and therefore a low coefficient of friction. All contact surfaces between packings and housings are ground so that the packing responds to any lateral movements of the piston rod with a minimum of resistance.

A lubricating box is provided. In cases where there is dust present in the atmosphere this box is provided with a metal scraper ring, which prevents foreign matter from entering the packing.

* See also pp. 1263, 1844 and 1949.

'LION' METALLIC PACKING.
(James Walker & Co. Ltd., Lion Works, Woking, Surrey.)

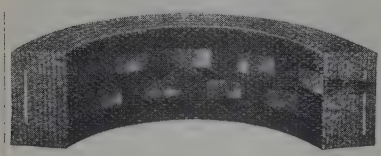


FIG. 33.—'Lion' Block Packing for Steam.

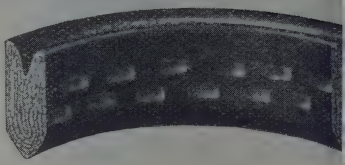


FIG. 34.—'Lion' Expanding Packing for Ste

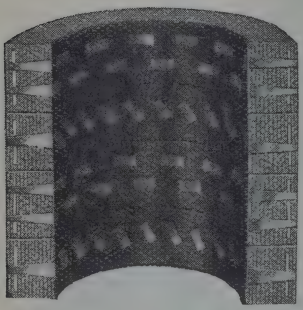


FIG. 35.—Set of 'Lion' Block Packing (in Section).

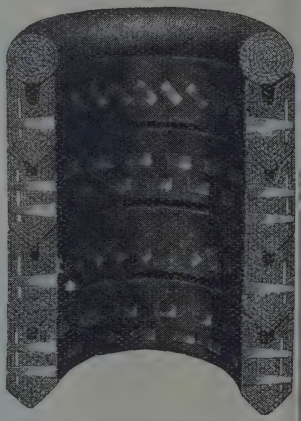


FIG. 36.—Set of 'Lion' Expanding Packing (in Section).

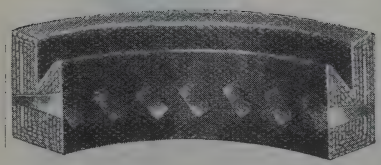


FIG. 37.—'Lion' Automatic Packing for Pumps and Hydraulic Work.

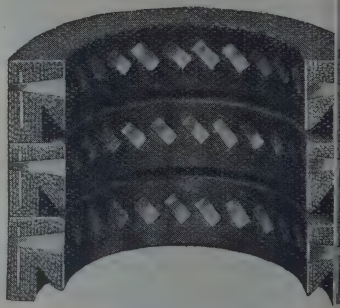
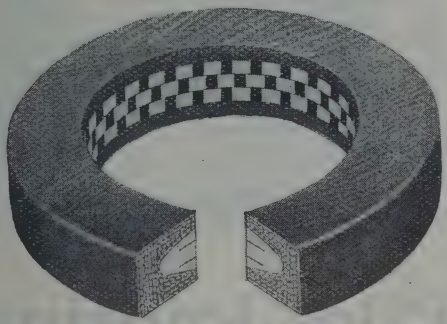


FIG. 38.—Set of 'Lion' Automatic Packing (in Section).

Beldam's "V" Pilot



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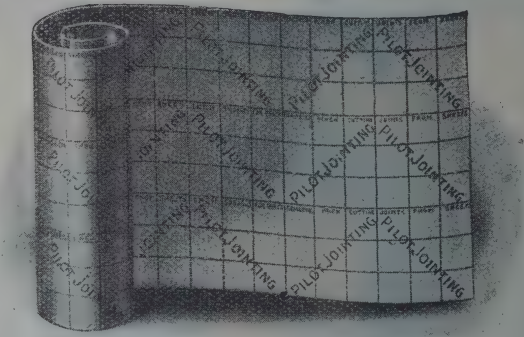

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'Lion' Metallic Packing.

(James Walker & Co., Ltd., Lion Works, Woking, Surrey.

Fig. 33 (p. 1806) shows the Block type of this packing. The packing is made in folds and not in layers, the fabric being taken and folded up on itself, so that the steam getting between these folds causes it to expand both to the rod and the box. This was the original type made by Messrs. James Walker & Co. Ltd., and it is still largely used.

Fig. 34 shows a more recent type of packing. This 'Lion' Expanding packing is made on an expanding principle, and in this instance, instead of the pressure acting upon the folds of cloth, there is a V recess in the top of the packing, into which the pressure finds its way and causes an expansion to the rod and the box.

It will be seen that with either of these types of packing, when there is no pressure there is no friction, and when the pressure is on the friction is reduced to the smallest minimum on account of the internal pressure alone being required to ensure tightness, no pressure from an external gland being necessary. Both the above types of packing are used for steam purposes, and the expanding type for hydraulic work.

Fig. 35 shows a set of Block packing in section, and fig. 36, a set of the Expanding type in section.

The Automatic type of 'Lion' packing shown in fig. 37 is used principally for hydraulic work. The recess is made on the face of the packing, an arrangement which, it is claimed, is unlike any other type. The action of the Automatic packing is practically the same as that in a ram leather, and the pressure getting at the back of the lip causes it to swell out to the ram of the accumulator or pump.

Fig. 38 shows a set of packings in section; between each turn of packing there is a recess, and the pressure getting into these recesses is baffled. The Automatic packing will stand a test pressure of over 4,000 lbs. per sq. in.

One very important feature with regard to these packings is that a metallic wearing face is formed by the introduction of white metal studs or pins, in order to form in a stuffing-box the same principle of a white metal bearing that is obtained in an ordinary bearing; that is to say, there is a white metal lateral bearing. The studs are so placed that they touch the rod at all points, thus securing a complete metallic wearing surface which reduces friction, does away with the scoring of the rod, and lengthens the life of the packing.

Beldam's Patent Excelsior Metallic Rings (Duplex Type).

(The Beldam Packing & Rubber Co., Ltd., 16 Gracechurch Street, London, E.C. 3.)

These packing rings are specially adapted for superheat, the highest steam pressures, and for L.P. rods of the reciprocating and turbine combination engines.

This packing has been designed in order that the pressure of steam through the neck bushes of the cylinders shall be gradually counterbalanced and cushioned by the pressure of the receivers.

With this system the rings are maintained in equilibrium, thereby preventing any undue wear, the rod being subjected to a minimum of friction.

All the rings are self-adjusting and interchangeable.

Beldam's Patent 'V' Pilot (Tri-Bar) Packing (for Highest Steam Pressures).

(The Beldam Packing & Rubber Co., Ltd.)

This packing is constructed from a single flexible white metal bar, pure asbestos, and high quality steam-resisting rubber, and is specially designed to stand the highest pressures.

The advantages claimed are as follows:—

(1) It ensures an entirely metallic bearing surface on the rod on the slightest pressure of the gland.

(2) The single bar is so constructed that when formed in the 'V' shape the slots on the face are staggered, thus preventing any possibility of the steam escaping down the rod.

(3) These slots also serve a useful purpose in holding oil, thus ensuring the rod being well lubricated.

(4) Rods will not be scored, but, on the contrary, will be kept in perfect condition.

(5) The packing is very strong and pliable, and easily bent round the smallest rod.

Under steam this packing expands so much that the gland nuts require to be only finger tight, and the gland should enter the stuffing box the depth of one turn of packing to allow for slackening back of gland nuts.

Beldam's 'A' Serpent Packing.

(The Beldam Packing & Rubber Co., Ltd., 16 Gracechurch Street, London, E.C. 3.)

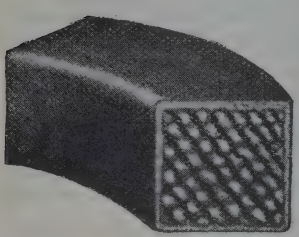

Fig. 39.

This packing, fig. 39, is for superheat and high pressure steam, and is specially recommended for expansion glands and boiler mountings. Owing to its cross-expansion construction, it is claimed to keep a gland steam or water tight with a minimum of friction on the rod.

The packing is built of alternate layers of metal and cloth placed diagonally, thus forming—as can be seen from the illustration—a series of sliding surfaces each of which comes into play on the slightest pressure of the gland.

The main feature of this packing is that the character of the wearing surface never varies, there being no flaking of material, as is the case with rolled cloth packings.

Bell's Patent 'Reefer' Packing

(Bell's United Asbestos Co., Ltd., Southwark Street, London, S.E.1.)

'Reefer,' figs. 40 and 41, is a high-grade semi-metallic packing made in two forms—for steam and hydraulic work. The packing is constructed with a channelled core of anti-friction white metal with side and rear cushions of Bell's Pure Asbestos Cloth (Duck for hydraulic work), proofed with india-rubber and impregnated with best quality plumbago; this form of construction gives a remarkable economy in weight; its design provides for the maximum

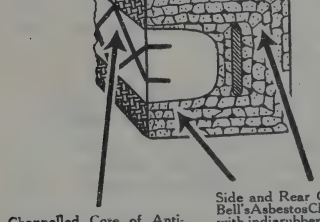

Fig. 40.

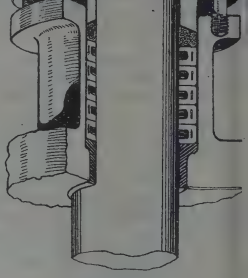

Fig. 41.

surface of anti-friction metal in contact with the piston rod, while using the minimum weight of metal required to give this surface. 'Reefer' is stated to be much lighter than any other packing of its class; it adapts itself to variations in pressure, temperature, and sudden load and keeps the piston rods in first-class condition, giving smooth silent service with the minimum of attention. In several instances 'Reefer' has run without replacement for twelve months while in one case a set of 'Reefer' packing rings ran 12,000 miles on high pressure work and were then in sufficiently good condition for transference to the intermediate pressure, where they gave a further spell of duty. 'Reefer' packings, both steam and hydraulic, are supplied in cylindrical tin boxes, each containing the necessary header material. All sizes from ⅜ in. to 1½ in.

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Reefer – the Packing

is the only Asbestos and Anti-friction Metal Packing which provides a perfect bearing surface to the rod without a corresponding increase in weight. The Asbestos Cushions expand under heat, automatically keeping the Stuffing Box tight, and do not harden under the action of temperature and pressure, but remain elastic throughout the life of the packing.

'REEFER' is thus unrivalled for wear, and being 20/30 per cent lighter than other forms of semi-metallic Packing, gives a degree of economy with efficiency hitherto unattainable.

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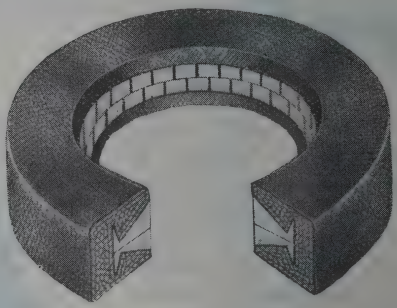

LASCAR 'V' PACKING, DUPLEX TYPE

Less Friction
Less Wear
Greater Durability

You cannot buy better

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F. 1809

THE LASCAR 'V' PACKING (DUPLEX TYPE).

(*Beldam Asbestos Co., Ltd., Hounslow.*)

The bearing surface of this packing, fig. 42, consists of a number of white metal sections presenting an unbroken and continuous antifriction wearing surface to the rod.

The packing is automatic in its action and allows the rods perfect freedom to move in any direction, owing to the expansive and elastic quality of the sleeve, with the result that the gland nuts need only be finger tight. It is very flexible, being easily bent round the smallest rods.

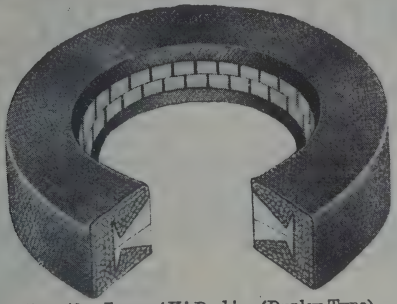

FIG. 42.—Lascar 'V' Packing (Duplex Type).

PISTONS.

THE ROWAN PATENT PISTON.

In the Rowan patent piston (*John Hind & Sons, Ltd.*) absolute steam tightness and absence of friction are obtained by the use of three separate springs, one contained within each packing-ring for outward expansion, and the third lying between the two rings and keeping them in close contact with the piston flanges. These springs are so arranged as to give a *predetermined pressure*

FIG. 43.

FIG. 44.

against the sides of the cylinder. Fig. 43 shows the form of these rings for use with solid piston heads (fig. 44).

'ROWAN' SLOW-ACTION PACKING.

The '*Rowan*' *Slow-Action Packing* (*Hind's Patent*) is a recent development designed to meet the requirements of modern conditions as to high-pressure, high speed, and superheat. In this packing the rings, which are of angle section, have annular grooves turned on the inner side of the flanges, into which is fitted a band of flat steel, which is coiled twice round the inside of the rings, against which it bears. Inside this steel band are two cast-iron spring rings, exerting pressure upon it, and between these is a wave-spring which presses them against the flanges of the piston-ring, thus keeping the latter in steam-tight contact with the flanges of the piston. There are no small or loose parts, the entire packing consisting of six pieces, viz.: Two angle section rings, one steel band, two cast-iron spring rings, and one wave-spring.

The rings are so designed as to give the minimum pressure against the walls of the cylinder consistent with steam-tightness, and, should wear take place, will automatically adjust themselves to the diameter of the cylinder. Should steam get behind the rings, the effect is that the coils of the steel band are pressed together, and the friction so produced absorbs the additional pressure and prevents its being applied to the walls of the cylinder. It is impossible for the steam to get between the steel band and the rings and exert pressure on the rings alone.

Similar action takes place should the rings be subject to circumferential pressure, due to over-running the counterbore or bell-mouth of the cylinder, the pressure of steam being transmitted through the rings to the steel band which is reinforced by the spring rings, when the friction between the coils of the band prevents the rings collapsing.

As these rings will not open and close so freely as the ordinary type of piston rings, they are not suitable for use in worn cylinders, and the makers do not recommend them for such cases but where the bore of the cylinder is in good order they will give satisfaction under the most severe conditions.

The slow-action rings (Class 'S.A.') are not suitable for springing over solid pistons, and pistons which are to be fitted with these rings must be provided with junk-rings.

The Class 'S.A.' rings may, if desired, be arranged to fit into two separate grooves in the piston, instead of one, as illustrated. In this form it is described as Class 'S.A. Divided.'

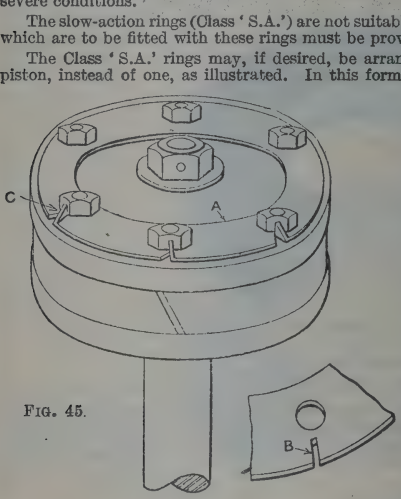

FIG. 45.

It will be obvious from the foregoing that the principle involved renders the 'S.A.' rings suitable, not only for high-pressure pistons, but also for piston valves in which capacity they are stated to give every satisfaction.

NUT-LOCK PLATE.

Fig. 45 shows a lock plate used to hold on the follower plate nuts of a steam engine piston. The circular ring, or plate A, is $\frac{3}{32}$ in. plate steel: the holes are drilled for the studs or bolts and a slot cut on the outside edge to within $\frac{1}{4}$ in. of each hole, as shown at B. The lock plate is put on and the nuts all set up tight; then with a cold chisel the tab is bent up against the flat of the nut side, as shown at C.

(*Machinery.*)

SLIDE VALVE GEAR.

(*Revised by W. C. Popplewell, M.Sc., A.M.Inst.C.E.*)

The movements of an ordinary eccentric driven slide valve are shown by A, fig. 46. S and S_1 are ports leading from the steam chest to the back and front of the piston respectively; E is the port leading to exhaust. The valve itself is shown sliding on the port face. As shown by A, the valve is in mid-position; *ef* is the outside lap, and *gh* the inside lap. As the valve is moved upwards by the eccentric, it reaches a position B where *e* has come opposite *b*, and the steam port S_1 is opening to the steam chest; the amount by which the valve is open at the beginning of the piston stroke is the 'lead.' In position C the steam port is fully open; the valve then returns to D, thus shutting off the supply of steam to the cylinder. This point is 'cut off.' The movement continues until *h* reaches *c*, as at E, when communication is effected between S_1 and E. This point is called 'exhaust.' After opening S_1 fully to exhaust, the valve returns to F, where the exhaust is closed and the point 'compression' reached. This completes the cycle for one end of the valve.

The movements of slide and other eccentric driven valves are analysed by such diagrams as the 'Valve Ellipse' (II, fig. 47), 'Zeuner's Valve Diagram' (fig. 48), and several others designed for the same use. Of these the Valve Ellipse can be made to take account of obliquity of both connecting rod and valve rod, and so yield accurate results. Zeuner's Diagram makes no allowance for obliquity, and in consequence is only approximately accurate, but for purposes of design, where existing data are not available, the Zeuner is the more useful, as it enables the principal dimensions to be approximately fixed. In such a case final adjustments may be completed by using the Valve Ellipse.

Valve Ellipse.

To set this out, begin by drawing the crank circle as at I, fig. 47, and dividing it into a number of equal angles (in this case 8), the crank-pin points being 0, 1, 2, 3, 4, 5, 6, 7. Take the connecting-rod length 1, 1_1, and set it off successively from the crank-pin positions, marking off points on the stroke line 0_1, 1_1, 2_1, 3_1, 4_1. These are positions of the piston corresponding

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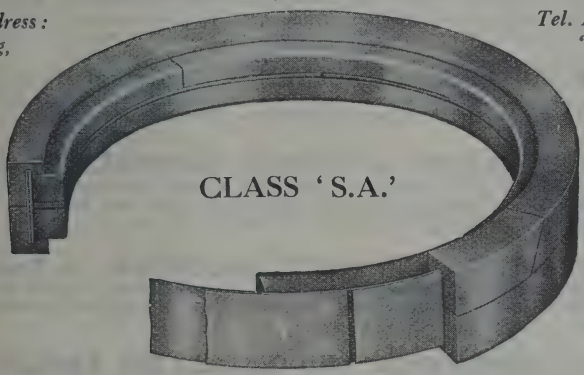

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Unlike 'Limit' rings, they possess the quality of automatic adjustment, while they are not affected by either circumferential pressure or 'steam packing.'

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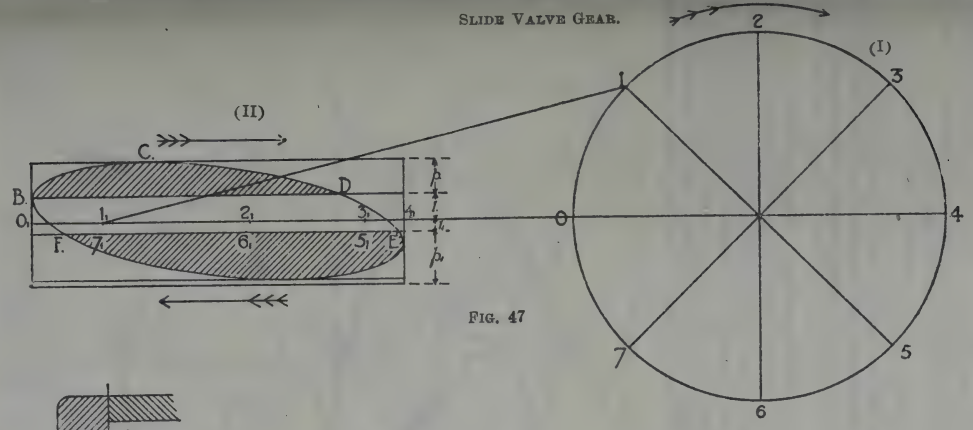


FIG. 47

FIG. 48

FIG. 46.

to 0, 1, 2, 3, 4, of the crank-pin, and are seen at II. A similar construction is followed out for the eccentric circle at III (fig. 48). This is turned through a right angle as compared with I, and the 'angle of advance' is marked $\theta°$. The distances of the valve from its mid-position, corresponding to the successive positions of the piston, are shown below the eccentric circle. These are set up as ordinates from the horizontal points on II, and a smooth curve drawn through the points so found. Thus from $1_{,}$ on the line of piston travel at II is plotted an ordinate which represents the distance of the valve from its central position when the piston is at $1_{,}$; this is the distance from ZZ to the line marked 1 at III. Next draw a horizontal line at distance l above $0_{,}$, $4_{,}$, in II, this is the 'lap' line; also a second line at a distance p beyond the lap line, which is the 'port opening.' Similarly below $0_{,}$, $4_{,}$, are two further lines at $l_{,}$, 'inside lap,' and $p_{,}$, 'exhaust opening.' The points where the ellipse cuts these lines represent the chief incidents in the cycle. They are B (admission), where the valve is just opening to steam; C (full port); D (cut-off); E (release); F (compression).

In the case of the back plate of a gear of the Meyer type, separate ellipses must be drawn for the edge of the plate, and the points where these cut the main ellipse noted.

Zeuner Diagram.

A few of the principal cases are given in what follows. The results are not strictly accurate, because they are vitiated by the angularity of the eccentric rod. But with reasonable proportions a design will be sufficiently near what the diagram shows. Fuller information may be found in Zeuner's treatise, or in the small book of Cowling Welch, who reduced Zeuner's methods to practice.

Reversing gears which do not employ two eccentrics usually derive motion from some point on the connecting rod. Such are the Joy gear and others, for all of which special advantages are claimed under certain conditions, though as valve movements it is doubtful if any give better results than plain link gears. The newer motions often involve considerable sliding movement of a block in an inclined link, this link being pivoted so as to reverse its inclination, whereby the valve, driven by the block which slides up and down in the inclined link, has its movement reversed or varied according to the degree of inclination either way of the link. Such valve movements are best studied by the aid of models, with variable dimensions; made from flat bars of cedar or baywood.

Simple Slide Valve.

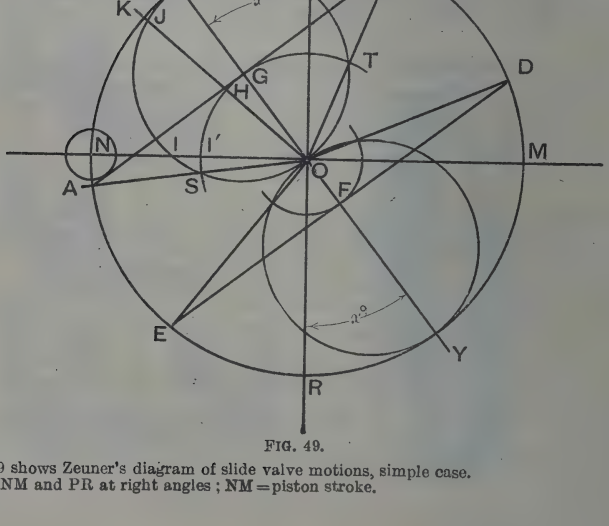


FIG. 49.

Fig. 49 shows Zeuner's diagram of slide valve motions, simple case.
Draw NM and PR at right angles; NM = piston stroke.

OP = OR = valve travel each side of centre point; OA = crank when steam is admitted; OB = crank at cut-off.

Bisect AB. Join OX, OY perpendicular to AB.

$x° + 90°$ = angular advance of eccentric; SGT = outside lap circle: cuts 'valve' circle at ST; OS = position of valve from centre when admitting steam; OT = position of valve from centre when cutting off steam; OF = inside lap; OD = crank when exhaust commences; OE = crank when exhaust closes.

The intercena of any radius from O, cut off by valve circles, shows distance of valve from its midstroke for that crank angle. Thus when crank is at OK valve has moved a distance OJ from its centre and steam port is open a width HJ.

DY = YE. AX = BX. Lead = small circle N = 2 II'.

Double Back-Plate Cut-off.

Figs. 50 and 51 show Zeuner's expansion valve diagram, Meyer valve.

Draw AB, XY at right angles, OD at angular advance $\phi°$ = half travel of main valve; OR = crank at admission: ON = lap circle. Draw OP slightly in advance of latest opening of main valve as shown by point *t*. This gives a minimum cover *ts*. Join PD, and draw OE parallel to it and DE parallel to OP. Then OE = half travel and position of the cut-off eccentric which will

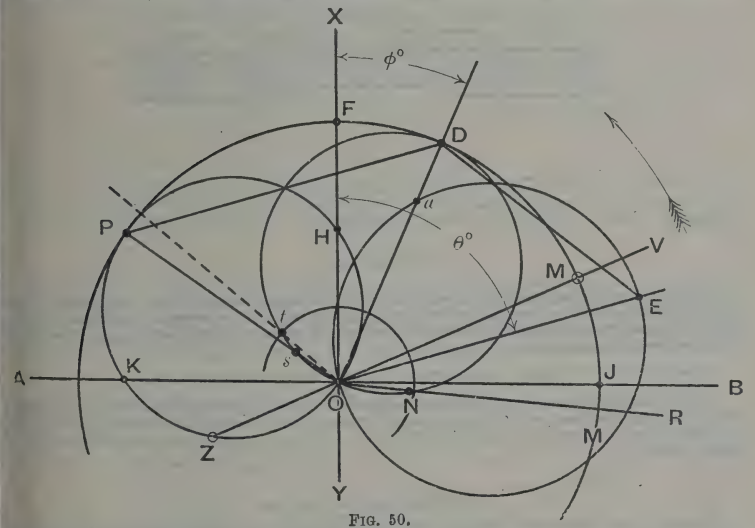


Fig. 50.

cut off steam when the crank, OR, reaches the position OP. It need not cut off later than this, for then the main valve has already acted.

The radius O*a* or any other vector of the cut-off valve circle shows the movement of the cut-off valve from its middle position, OE being the half throw of the cut-off eccentric, and $\theta°$ its angular advance. Any radius vector of the auxiliary circle OP will show the relative displacements of the main and cut-off valves from each other. At the crank position OP the cut-off plates are drawn close together. Draw the large circle APDM through P. Then for any position OV of desired cut-off the length of the cut-off valve must be increased by separating the two cut-off plates of the right and left screw to the amount MZ. To cut off at OX of the crank would demand the movement FH, while to cut off at the dead point OB the movement of the plates would be JK. The length over the steam ports in the back of the main valve will be equal to the sum of the length of the cut-off plates plus twice OP. The edges of the cut-off plates when fully extended have a maximum distance from the main valve centre of JK (or MZ if OM is the earliest desired cut-off). But at no moment must the inside edges of the cut-off plates uncover the inside edges of the ports in the main valve. These ports have a width *a*. At the latest cut-off, viz. at OP, the cut-off plates will be drawn together so that x = nil.

To find movement of cut-off plates from centre for any point of cut-off, as with crank at OV, the plates must be screwed out a distance x = MZ. If cut-off is at OF position of crank, then x = FH.

Taking the position of earliest cut off at OV, to find the proportions L and l of valves which will be a maximum :—

Calling FE = y = L − l − x for earliest cut-off, the maximum relative movement of the valve centres by the eccentrics is OP. Since at the position OV the valve centres are the opposite way removed from cut-off by the amount OZ and that OP is the maximum relative movement, we have L − l = OP when x=nil and x must be OP+OZ = MZ for earliest cut-off. When the crank reaches OP the cut-off valve is moved out already a distance x = MZ and it is moved a further distance OP by the eccentric, so that the outer edge of the cut-off plate is a distance OP+OP+OZ from the middle of the main valve. And when so far the inner edge of the cut-off plate must not overrun the inner edge of the back port a. Therefore L−a=2OP+OZ ∴ L=OP+OP+OZ+a and L−l=OP ∴ l=OP+OZ+a. Since the main valve has cut-off at the position Ot there is safety lap of ts on the main port below even, if the inner edge of the cut-off plate then reaches the port a.

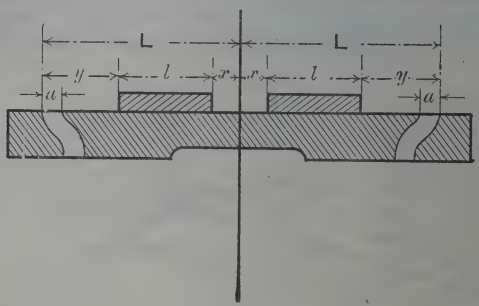


FIG. 51.

In the figure the main valve travels $4\frac{1}{4}$ ins. and the cut-off valve $5\frac{1}{8}$ ins. The cut-off plates are each moved out by screws at earliest cut-off x=$3\frac{1}{2}$ ins., and by eccentric movement $2\frac{1}{8}$ ins. relative to main valve, or a total of $5\frac{5}{8}$ ins. The main valve has a length L=$5\frac{5}{8}$ +a and the cut-off plate (or L−OP=l) a length of $3\frac{1}{4}$ ins. + a.

If a=1 in. then L=$6\frac{5}{8}$ ins. ; l=$4\frac{1}{4}$; x=$2\frac{1}{8}$ ins. maximum plus $3\frac{1}{4}$ screw-out.

If early cut-off is desired in the general working of the engine with quick action the auxiliary circle OP should be near to 90° from the cut-off position of the crank. Thus at the position OD the two valves are moving at high relative speed. It is usual to give the greater travel to the cut-off valve.

LOCOMOTIVE LINK MOTIONS.

These may be investigated also by the Zeuner method. A link motion is simply built up with two eccentrics, either of which may be made to bear fully and directly on the valve spindle and cause an engine to run forwards or backwards. This is accomplished by connecting the two eccentric rods by a link in which the end of the valve spindle is carried. At the extreme end position the spindle is wholly driven by one eccentric, while at intermediate positions the two eccentrics combine to give a gradually shorter movement to the valve.

There are three general link gears. 'Stephenson's,' in which the link is raised or lowered to give the desired position of the spindle block or link block ; and the link is concave to the axle and has a radius equal to the length of the eccentric rods.

'Gooch's,' with link convex to the axle and not movable up and down ; movement of the block being effected by a radius rod and the link having this radius of curvature.

'Allen's,' in which the link is straight and both link and radius rod are raised and lowered in opposite directions.

All three forms are made with open or crossed rods, the former giving greater lead of the valve near the middle position of the link block, and the latter giving less lead towards the middle position. In Gooch's motion the lead is of course always constant.

STEPHENSON LINK MOTION

Open Rod Design.

In fig. 52, AE=link. BD=link block in forward and backward gear. OJ=virtual single eccentrics to give requisite travel to B or D in full gear. Join OB, cutting valve circle on OJ at K. Join JM through K. Then the arc struck from c through JMJ will contain the ends of all the eccentric radii or valve circle diameters for all positions of the slider B or D. Dividing this arc in the same ratio as B divides the link AE will give the ends of the valve circles for each point of the link. And the real eccentrics will have the position and half travel OF, OF just as the ends of the link lie beyond B and D. If the link end-pin comes opposite the extreme

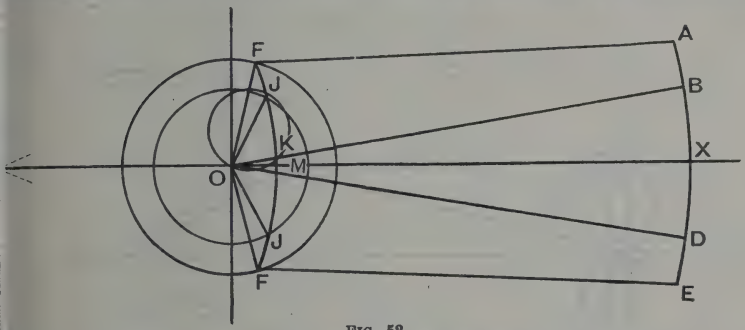


FIG. 52.

positions BD of the block then OJ become the real eccentrics in position and in half throw, i.e. XB : XA : : MJ : MF. Rods are said to be *open* when they are as FA, FE when the eccentric arms point towards the link. With open rods the valve lead increases with the expansion.

Crossed Rod Design.

In fig. 53, AE=link. BD=link block in full forward or backward gear. OJ=virtual single eccentric that would give requisite valve travel in full gear. Join OD, cutting upper valve circle on OJ at L. Join JN through L. N is on the line OX. Then the arc struck from O through JNJ contains the ends of all the valve circles for every position of the slide block, the arc JNJ being divided for each diameter in the same ratio as the slide block divides the link AE.

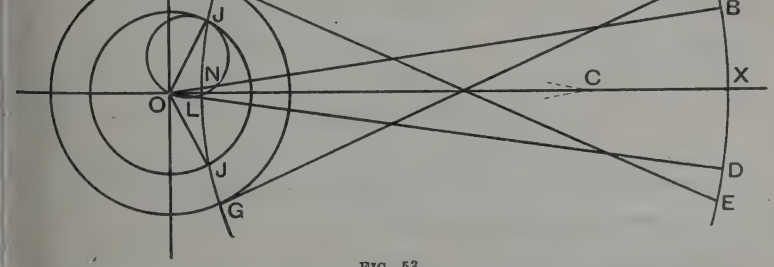


FIG. 53.

Thus OG, OG become the actual eccentric arms, and NJ : NG : : XB : XA. Rods are said to be *crossed* when they are as GA, GE, the eccentric arms pointing towards the link. With crossed rods the lead of the valve decreases with increased expansion. Specially note that OD cutting the valve circle at L is employed in this construction, whereas OB is the line used in the open-rod diagram.

Gooch's Link Motion.

In this motion, fig. 54, the 'curve' of valve circle centres is a straight line aa distant from O an amount $f = \frac{r}{2}\left(\sin\delta^\circ + \frac{c}{l}\cos\delta^\circ\right)$ for the open rod design, and $\frac{r}{2}\left(\sin\delta^\circ - \frac{c}{l}\cos\delta^\circ\right)$ for the crossed rod design, where

r = eccentricity of eccentric or OE;

m is the point from which the link is hung and is a fixed point;

the versed sine of the link arc is $\frac{c^2}{2l_1}$;

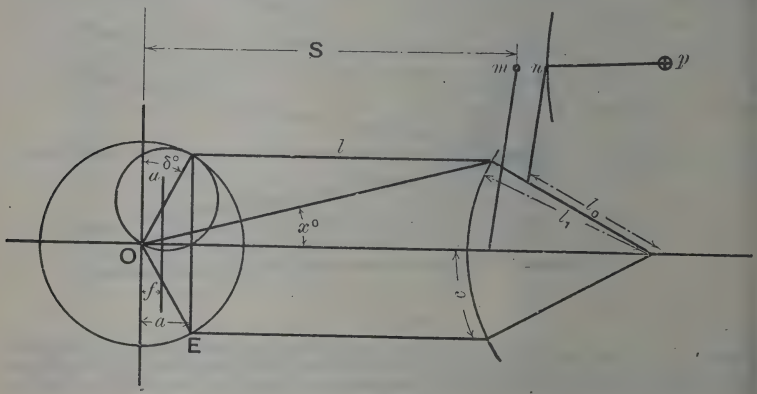


Fig. 54

m is distant from O a length $S = -\frac{c^2}{2l_1}$;

n is the point from which the radius rod is hung;

$On = l + l_1 - l_0 - \frac{c^2(l+l_1)}{2ll_1}$.

The point n should move in a parabola whose parameter $= 2l_1$ or a circular arc of radius l_1.

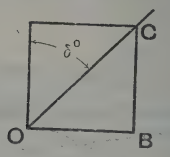


Fig. 55.

The co-ordinates of any point on the curve of centres are as per fig. 55, where

for open rods, $OB = \frac{r}{2}\left(\sin\delta^\circ + \frac{c}{l}\cos\delta^\circ\right)$;

for crossed rods, $OB = \frac{r}{2}\left(\sin\delta^\circ - \frac{c}{l}\cos\delta^\circ\right)$.

$BC = \frac{r\,u}{2c}\left(\cos\delta^\circ \pm \frac{c}{l}\cos\delta^\circ\right)$, according as the rods are open for $-$ or crossed for $+$ signs, where c = half length of the link and u = the variable position distance of the slider block from the middle of the link.

The lead is constant at all grades of expansion. The link is so hung that its middle point moves to and fro horizontally by the combined effect of the arc of swing and the cant due to slope of the link, the suspension link being pinned at the centre of the chord of the link.

The radius rod l_1 is so hung that its to-and-fro motion produces a minimum of sliding of the link block in the link. The extreme positions of n being known the actual arc in which it moves is arranged in practice with a shorter arm np than theory demands, the best compromise possible being accepted which can be arranged under the conditions. The Gooch gear, for any given distance between axle and cylinder, has very short rods compared with the Stephenson gear. Also the angle $\delta°$ in fig. 55 is equal to the angle $x°$ as found in fig. 49, p. 1812, for the simple slide valve, plus the angle $\delta°$ in fig. 54, p. 1816.

ALLEN'S STRAIGHT LINK MOTION.

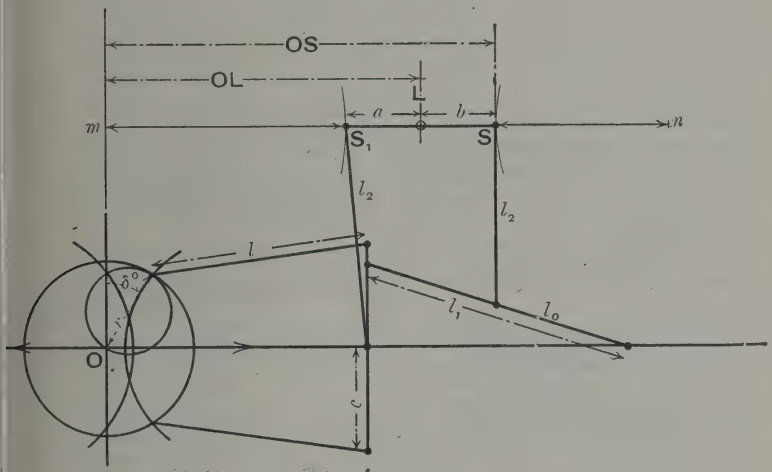


FIG. 56

$$\frac{b}{a} = \frac{l_o}{l}\left(1 + \sqrt{1 + \frac{l}{l_1}}\right); \; n = 1 + \left(\frac{l_1}{l_o}\,\frac{b}{a}\right).$$

Curve of centres is a parabola whose vertex is distant from $O = \frac{r}{2}\left(\sin\delta + \frac{c}{l}\cos\delta\right)$ for open rods, and $\frac{r}{2}\left(\sin\delta - \frac{c}{l}\cos\delta\right)$ for crossed rods, and is concave towards O for open rods, and convex for crossed rods. Parameter for both open and cross rods $= \frac{nlr}{2c\cos\delta}\cos\delta \mp \left(\frac{c(n-1)}{nl}\sin\delta\right)^2$ for which a circular arc may be substituted of one half the parameter.

S and S_1 should move in parabolas of $2l_1$ and $2l$, or in arcs of l_1 and l radius.

As arranged in practice $a + b = (l_1 - l_o) +$ a little extra l_2 as long as possible.

$$Os_1 = \left(l - \frac{c^2}{2l}\right); \; OL = l + a - \frac{c^2}{2}; \; ms_1 = l; \; ns = l_1; \; Os = l + l_1 - l_o - \frac{c^2(l + l_1)}{2ll_1}.$$

Lead increases with expansion with open rods and decreases with crossed rods.

WALSCHAERT GEAR.

(See page 689.)

SECTION XXX

PART IV

STEAM TURBINES.*

FLOW OF STEAM—NOZZLES—BLADE EFFICIENCY—LOSSES—PACKINGS—ROTORS—MATERIALS—TEST DATA—TURBINE TYPES—REDUCTION GEARS.

(Contributed by H. L. Guy, Wh. Exh., A.M.Inst.C.E., A.M.I.Mech.E.)

In this section the following symbols have been used in the indicated significance, except where otherwise stated :—

c = absolute velocity in ft. per sec.
g = constant of gravitation = 32·2 ft. per sec.^{2}
H.λ. = heat drop in B.Th.U.
N = speed in r.p.m.
P = pressure in lbs. per sq. ft.
p = pressure in lbs. per sq. in.
t = temperature °F.
T = absolute temperature °F = (460 + t).
U = peripheral velocity in ft. per sec.
v = specific volume in cubic ft. per lb.
W = weight of steam in lbs. per sec.
w = relative velocity in ft. per sec.
λ = ratio of the specific heats of a gas.
ω = angular velocity in radians per sec.
J = Joule's Equivalent = 778 ft. lbs. per B.Th.U.

FLOW OF STEAM.

When steam flows through a simple orifice from a chamber (denoted by suffix 1) into a space (denoted by suffix 2) the velocity with which discharge takes place is always dependent on the steam conditions existing before the orifice, and sometimes dependent upon those existing on the discharge side.

If the pressure, P_1, in the chamber is maintained constant, while that beyond the orifice is gradually reduced from an initial value equal to P_1, the velocity and quantity of discharge gradually increase and depend on the pressure drop over the orifice, until a critical value is reached corresponding to a definite value of the ratio $\frac{P_2}{P_1}$.

Dr. Zeuner† has shown theoretically, and the result is borne out by experiment, that the critical drop is reached when

$$\frac{P_2}{P_1} = \left(\frac{2}{\lambda+1}\right)^{\frac{\lambda}{\lambda-1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For saturated steam $\lambda = 1{\cdot}135$, and $\frac{P_2}{P_1} = 0{\cdot}577$.

For superheated steam $\lambda = 1{\cdot}3$, and $\frac{P_2}{P_1} = 0{\cdot}546$.

* See also Marine Steam Turbines, Section XXXVI, p. 2363.
† *Technical Thermodynamics*, Dr. Zeuner.

After this *Critical Pressure Drop* has been reached, the quantity and velocity of discharg remain constant for smaller values of P_2, the discharge being accompanied by strong acousti vibrations.

Dr. de Laval was able to obtain—and used in his turbine—much higher velocities than th critical velocity, by adding a conically divergent nozzle to the orifice. In this way the vibration are eliminated, and although the velocity of exit from the nozzle may be considerably greate than the critical velocity, the velocity at the minimum section or throat of the nozzle and th weight of steam discharged remain unchanged from the values which would exist in a simpl orifice.

From this it will be apparent that there is a discontinuity in the phenomena accompanyin discharge of steam through an orifice or nozzle, and that the equations existing between th various terms entering into the formulæ of steam flow must be considered in two groups.

(a) When the Pressure Drop is less than the Critical Drop.

i.e., when $P_2 > 0{\cdot}577\ P_1$, for saturated steam ; $P_2 > 0{\cdot}546\ P_1$, for superheated steam.

The theoretical velocity c_1 with which discharge takes place, can be calculated from the formul due to Wantzel and St. Venant,

$$c_1 = \sqrt{2g \frac{\lambda}{\lambda - 1} (P_1 v_1 - P_2 v_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The actual velocity of discharge c_2 is less than c_1, on account of the friction and eddy losses in the orifice, and is given by

$$c_2 = \phi\, c_1,$$

$$\text{where } \phi = \text{velocity coefficient} = \frac{\text{Actual velocity of discharge}}{\text{Theoretical velocity of discharge}}.$$

The value of ϕ for various cases is given in Table II., page 1824.

The weight of steam discharged per second is given by the relation

$$W = k\, S \frac{c_2}{v_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where,

v_2 = specific volume of the steam in the lower state, in cubic ft. per lb.
S = the sectional area in sq. ft. of the smallest section or throat of the orifice.
k = coefficient of discharge (see Table II.).

The expansion takes place with very great rapidity and for purposes of calculation it may be assumed to be adiabatic without serious error. The validity of this assumption has been questioned, but Dr. A. Loschge* has proved its approximate correctness by obtaining equal discharge through duplicate nozzles made of metal and of porcelain, and it need only be added that formulæ deduced from this basis agree very closely with experimental results.

For adiabatic expansion—

$$P_1 V_1^{\lambda} = P_2 V_2^{\lambda} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

from which, by combination with (2) and (3), we get

$$W = k S \sqrt{2g \frac{\lambda}{\lambda - 1} \frac{P_1}{v_1} \left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{\lambda}} - \left(\frac{P_2}{P_1}\right)^{\frac{\lambda+1}{\lambda}} \right]} \quad . \quad . \quad . \quad . \quad (5)$$

Alternative Method.

The following method of dealing with such problems, due to Dr. Zeuner, is often more simply manipulated than that already given, especially when used in conjunction with the Mollier or other entropy diagram.

If

H_1 = total heat of 1 lb. of the steam in the higher condition in B.Th.U. ;
H_2 = total heat of 1 lb. of steam in the lower condition in B.Th.U. ;
h_a = the heat drop available for adiabatic expansion = $H_1 - H_2$.

* *Engineering*, October 17, 1913.

Then

$$c_1 = \sqrt{2g \cdot J \cdot h_a} \quad . \quad . \quad . \quad (6), \quad \text{and } c_2 = \phi \cdot c_1.$$

W can be calculated as before from (3); h_a can either be measured directly off a Mollier diagram or calculated from steam tables in the following manner:—

If $t°$ = degrees of superheat; L_1 = latent heat corresponding to P_1; T_1 = absolute temperature corresponding to P_1; h_1 = sensible heat corresponding to P_1; X_1 = dryness fraction of the steam in the higher state; T_2 = absolute temperature corresponding to P_2; h_2 = sensible heat corresponding to P_2; X_2 = dryness fraction of the steam in lower state; ϕ_1 = entropy of the liquid in the higher state; ϕ_2 = entropy of the liquid in the lower state;

then

$$X_2 = \frac{T_2}{L_2}\left[\frac{X_1 L_1}{T_1} + C_p \log_e\left(\frac{T_1 + t}{T_1}\right) + \phi_1 - \phi_2\right],$$

and

$$h_a = X_1 L_1 + C_p \cdot t \cdot + h_1 - X_2 L_2 - h_2.$$

In these formulæ the mean value of the specific heat of superheated steam at constant pressure C_p for the range of the superheat should be taken.

Nozzles which are designed for a smaller pressure drop than the critical are wholly convergent and must be sized according to the methods given in this section.

Simple orifices, the nozzles of Rateau or Zoelly turbines, and both the rotating and stationary blades of Parsons turbines, fall into this class.

(b) When the Pressure Drop is Greater than the Critical Drop.

i.e., when $P_2 < 0{\cdot}577P_1$, for saturated steam; $P_2 < 0{\cdot}546P_1$, for superheated steam.

In this case let the suffix m denote the conditions in the minimum section or 'throat' of the nozzle.

Then whatever the total pressure difference over the nozzle, that from P_1 to the throat pressure is always equal to the critical value, and the nozzle must be convergent to the throat.

By combining (1) with (2) and (4), the velocity in the throat is obtained.

$$= \sqrt{g\lambda \cdot P_1 V_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

if $\phi = 1{\cdot}0$.

(7) is identical with the expression for the velocity of sound in the conditions present in the throat, so that the velocity in the throat, or the critical velocity, is equal to sound velocity.

By substituting from (1) and (4) in (5)—

$$W = k S_m \sqrt{2g \frac{\lambda}{\lambda + 1}\left(\frac{P_1}{V_1}\right)\left(\frac{2}{\lambda + 1}\right)^{\frac{2}{\lambda - 1}}} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

from which the discharge per second can be obtained, S_m being the area at the throat in square feet.

The nozzle from the throat to the mouth must be divergent, the area at the mouth being calculated from the relation

$$S_2 = S_m \cdot \frac{V_2}{V_m} \cdot \frac{c_m}{c_2} = S \left[\left(\frac{2}{\lambda + 1}\right)^{\frac{1}{\lambda + 1}} \left(\frac{P_1}{P_2}\right)^{\frac{1}{\lambda}} \sqrt{\frac{\frac{\lambda - 1}{\lambda + 1}}{1 - \left(\frac{P_2}{P_1}\right)^{\frac{\lambda - 1}{\lambda}}}}\right] \quad . \quad . \quad (9)$$

Expressions involving λ are strictly applicable only when the expansion takes place wholly in either the superheated or the saturated region, the corresponding value of λ being introduced.

The following expressions will be found to give approximately the same results as (9).

For Superheated Steam.

If $P_1 = (1{\cdot}732 \text{ to } 20)\ P_2$ $\quad S_2 = S_m\left(0{\cdot}7175 + 0{\cdot}163\ \frac{P_1}{P_2}\right)$

$P_1 = (20 \text{ to } 100)\ P_2$ $\quad S_2 = S_m\left(1{\cdot}5 + 0{\cdot}125\ \frac{P_1}{P_2}\right)$

For Saturated Steam.

If $P_1 = (1{\cdot}832 \text{ to } 25)\ P_2$ $\quad S_2 = S_m\left(0{\cdot}777 + 0{\cdot}1216\ \frac{P_1}{P_2}\right)$

$P_1 = (25 \text{ to } 100)\ P_2$ $\quad S_2 = S_m\left(1{\cdot}875 + 0{\cdot}0812\ \frac{P_1}{P_2}\right)$

Introducing the numerical value of λ (1·135 for saturated steam and 1·3 for superheated steam), and with $g = 32{\cdot}2$, formula (7) becomes—

For Saturated Steam. $\quad c_m = 70{\cdot}2\ \phi\ \sqrt{p_1 v_1}$

For Superheated Steam. $\quad c_m = 72{\cdot}38\ \phi\ \sqrt{p_1 v_1}$

In the same way formula (8) would produce two expressions for the discharge depending on the condition of the steam as regards superheat. Researches by Loschge* and Bendemann have however shown that the numerical coefficient of the formula for nozzles having a convergent entrance is the same both for saturated and superheated steam, and that this value is 2 per cent. higher than is obtained by inserting $\lambda = 1{\cdot}135$.

This is in accordance with the previously known fact that for saturated steam the discharge from such a nozzle exceeds the theoretical amount.

Just prior to the publication of these researches Mr. H. M. Martin* propounded the ingenious theory that with steam initially saturated an unstable condition exists in the throat, cooling taking place below the saturation temperature without condensation. The decrease in specific volume which results from this 'Under-Cooling' would account for the measured excess in discharge over that calculated on the assumption of adiabatic expansion.

Prof. Stodola has suggested that this under-cooled steam obeys the same law of expansion as superheated steam, so that the experimental fact that the discharge both for saturated and superheated steam is given by one formula is rational and in line with theory.

The formula for discharge deduced from Loschege's experiments is :—

$$W = 44{\cdot}11\ k\ S_m \sqrt{\frac{p_1}{v}}$$

Table I., giving the critical velocity and the discharge per square inch of throat area, has been calculated on the assumption that $b = 1{\cdot}0$ and $k = 1{\cdot}0$; the necessary correction for other values will be obvious.

The following simple formulæ, the first due to Napier and the second to Rankine, are often useful when an error of a few per cent. is admissible.

For Dry Saturated Steam.

$$P_1 > \frac{5}{3}P_2,\ W = \frac{s \cdot p_1}{70}; \qquad P_1 < \frac{5}{3}P_2,\ W = 0{\cdot}029\ s\ \sqrt{p_2(p_1 - p_2)},$$

where s = area of orifice in square inches.

Design of Nozzles.

The values of ϕ and k as determined by experiment are given in Table II. for orifices and nozzles of various kinds.

The coefficient of discharge k depends amongst other things upon the friction loss, the coefficient of contraction, and usually for a pressure drop below the critical, upon the ratio $\frac{P_2}{P_1}$.

Professor Rateau found that for nozzle C the value of k was slightly greater than unity when P_2 is less than $0{\cdot}5P_1$.

* *Engineering*, October 17, 1913.

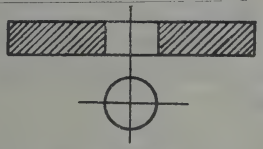
TABLE 1.—DISCHARGE OF DRY SATURATED STEAM WHEN $P_2 < 0{\cdot}57\ P_1$.

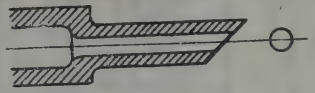
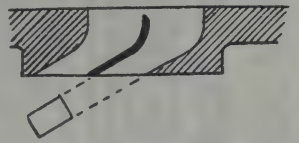
Pressure before nozzles.—Lbs. per sq. in. g.	260	220	200	180	160	140	120	100	80	60	40	20	10	0
Steam velocity in throat.—Ft. per sec.	1510	1508	1504	1500	1496	1492	1486	1480	1472	1465	1450	1432	1415	1392
Discharge.—Lbs. per sec. per sq. in. throat area	3·92	3·55	3·07	2·8	2·51	2·24	1·94	1·67	1·39	1·09	0·813	0·523	0·376	0·229

TABLE 1A.—DISCHARGE OF SUPERHEATED STEAM WHEN $P_2 < 0{\cdot}54\ P_1$.

Pressure before nozzles.—Lbs. per sq. in. g.	Superheat °F.	260	220	200	180	160	140	120	100	80	60	40	20	10	0
Discharge.—Lbs. per sec. per sq. in. throat area	100	3·61	3·1	2·84	2·59	2·32	2·07	1·81	1·55	1·29	1·02	0·755	0·486	0·35	0·211
Discharge.—Lbs. per sec. per sq. in. throat area	200	3·39	2·91	2·67	2·43	2·19	1·94	1·70	1·45	1·20	0·96	0·712	0·457	0·329	0·198
Discharge.—Lbs. per sec. per sq. in. throat area	300	3·19	2·76	2·53	2·31	2·08	1·85	1·61	1·38	1·15	0·913	0·673	0·434	0·311	0·190

TABLE II.

Type of Orifice.	Velocity Coefficient ϕ and Discharge Coefficient k.	Name of Experimenter.	Reference.
A Circular Hole in Thin Plate.	$\phi = 0{\cdot}86$	Rosenhain	Proc. Inst. C.E. vol. cxl.
	$\frac{P_2}{P_1} = 0{\cdot}95 \quad 0{\cdot}8 \quad 0{\cdot}6 \quad 0{\cdot}4$ $k = 0{\cdot}63 \quad 0{\cdot}68 \quad 0{\cdot}77 \quad 0{\cdot}83$	Rateau	'Flow of Steam' A. Rateau
B  Cylindrical Hole	$\frac{P_2}{P_1} = 0{\cdot}95 \quad 0{\cdot}8 \quad 0{\cdot}7 \quad 0{\cdot}6$ and smaller values $k = 0{\cdot}79 \quad 0{\cdot}83 \quad 0{\cdot}86 \quad 0{\cdot}88$	Gutermuth	Z. Ver. Deutsch. Ing. January 1904
C Straight Convergent Nozzle.	$c_e = 500 \quad 900 \quad 1{,}300$ ft. per sec. $\phi = 0{\cdot}936 \quad 0{\cdot}965 \quad 0{\cdot}993$ Saturated steam $\phi = 0{\cdot}954 \quad 0{\cdot}967 \quad 0{\cdot}98$ Superheated steam	Loschge	Z. Ver. Deutsch. Ing. January 11, 1913
	$\frac{P_2}{P_1} = 0{\cdot}95 \quad 0{\cdot}8 \quad 0{\cdot}7 \quad 0{\cdot}6$ smaller values $k = 0{\cdot}94 \quad 0{\cdot}967 \quad 0{\cdot}975 \quad 0{\cdot}99 \quad 1{\cdot}0$	Rateau	'Flow of Steam' A. Rateau
D Rectangular Orifice.	$\frac{P_2}{P_1} = 0{\cdot}95 \quad 0{\cdot}8 \quad 0{\cdot}7 \quad 0{\cdot}6$ smaller values $k = 0{\cdot}8 \quad 0{\cdot}88 \quad 0{\cdot}91 \quad 0{\cdot}93 \quad 0{\cdot}93$	Gutermuth	Z. Ver. Deutsch. Ing. January 1904

Type of Orifice.	Velocity Coefficient ϕ and Discharge Coefficient k.	Name of Experimenter.	Reference.
E  Convergent-cylindrical Nozzle. Circular Throat.	$c_1 =$ 200 500 1,000 1,500 ft. per sec. $\phi =$ 0·923 0·935 0·95 0·97	Briling	Z. Ver. Deutsch. Ing. February 1910
	$\frac{P_2}{P_1} =$ 0·95 0·5 $k =$ 1·0 1·0	Hirn ('Experiments on Air')	'Flow of Steam' A. Rateau
F Straight Convergent-divergent Nozzle. Circular Throat.	For a nozzle 3 ins. long $\phi = 0·95$ " " 6 " " $\phi = 0·915$	Sibley and Kemble	Journal Amer. Soc. M.E. November 1909
	$\frac{P_2}{P_1}$ Less than 0·89 $k = 0·98$	Gutermuth	Z. Ver. Deutsch. Ing. January 1904
G  Turbine Convergent Nozzle. Rectangular Throat.	$c_1 =$ 1,200 1,400 1,600 ft. per sec. $\phi =$ 0·86 0·89 0·91 $k = 1·0$	Christlein	Z. für G. Turbinenwesen January 1912
H Turbine Divergent Nozzle. Circular or Rectangular Throat.	$c_1 =$ 1,700 2,000 2,200 2,700 3,300 4,000 ft. per sec. $\phi =$ 0·92 0·92* 0·93 4·94 0·95 0·955 $k = 1·0$	Christlein *Loschge	Z. für G. Turbinenwesen January 1912 Z. Ver. Deutsch. Ing. January 1913.

In reference to nozzles G and H, which are of the types used in impulse turbines, it should be mentioned that although the value $k = 1{\cdot}0$ has been inserted in Table II., Dr. Christlein found that the actual discharge exceeds the theoretical by a few per cent. This effect had already been observed by Mr. Rosenhain for nozzles of form F having well-rounded entrances, and he concluded from his experiments that a loss in efficiency results, and was, therefore, led to recommend that the entrance should be only slightly rounded.

These facts are confirmed by Dr. A. Loschge's researches and explained by Mr. H. M. Martin's theory, which is referred to in the preceding paragraph.

The value of ϕ for nozzle G cannot be very satisfactorily determined from Dr. Christlein's experiments; for a given value of ϵ_1, ϕ appears to increase with the pressure and to decrease with the superheat before the nozzle.

Unfortunately, the results of Mr. Rosenhain's experiments, like those of Messrs. Siberly and Kemble, are vitiated by the fact that the wetness of the steam during the experiments was not measured.

Nozzles of type B are useful for approximate measurements of the amount of steam flowing through a pipe line. It is only necessary to put a thick plate having a cylindrical hole in it between two of the pipe flanges. If the pressure is observed before the plate (P_1) and also in the cylindrical hole (P_2) by means of a hole drilled from the rim through the centre thickness of the plate, the flow can be calculated from formula (5).

Of course, the hole in the plate should be of such a diameter that the ratio $\frac{P_2}{P_1}$ is not less than 0·6.

Several steam meters operate on this principle.

The nozzles of turbines are usually of rectangular cross-section, and the steam in passing through them turns through an angle of about 70°, as indicated in figs. G and H, p. 1825. It is important to bear this in mind when employing data relating to ϕ and k deduced from straight nozzles of circular cross-section—the type usually favoured by experimentalists.

For a given ratio of expansion the length of the nozzle depends on the angle of divergence. If this angle is too great the steam does not completely fill the cone, which results in considerable loss. If the angle is too small the length of the nozzles becomes very great, and many experiments indicate that the friction loss depends on the length. An angle of divergence of 10° is very common.

The experiments of Mr. Rosenhain, and more recently of Messrs. Siberly and Kemble, show that there is no appreciable difference in efficiency for angles varying from 9° to 20°.

If the ratio $\frac{S_2}{S_m}$ is less than that theoretically required, expansion is completed beyond the nozzle. Rateau's experiments demonstrate that when this *under-expansion* is small, little loss results. On the other hand, if $\frac{S_2}{S_m}$ is greater than that theoretically required, the steam is expanded in the nozzle below the condition into which it discharges. Such *over-expansion* results in steam shock with great loss of efficiency.

When the divergent nozzles of a turbine are correctly designed for the normal load, over expansion takes place at overloads, and under-expansion at partial loads, with nozzle cut-out governing.

The entrance of divergent nozzles should be smoothly rounded off, with a radius about equal to the throat diameter; larger radii are unnecessary and should be avoided.

Since the efficiency of a nozzle depends upon the smoothness of the surfaces with which the steam is in contact, the material of which it is constructed should be capable of withstanding erosion and oxidisation—nickel steel or a bronze highly polished is usually employed for the divergent nozzles of De Laval and Curtis turbines where high steam velocities are encountered, while cast in mild steel plates have given quite satisfactory results with the large nozzle areas and moderate velocities used in the convergent nozzles of Rateau and Zoelly turbines.

The state of knowledge on the efficiency of steam nozzles has been recently advanced by the researches carried out for the Nozzle Research Committee of the Institution of Mechanical Engineers by Professor Stoney and Mr. Telford Petrie.

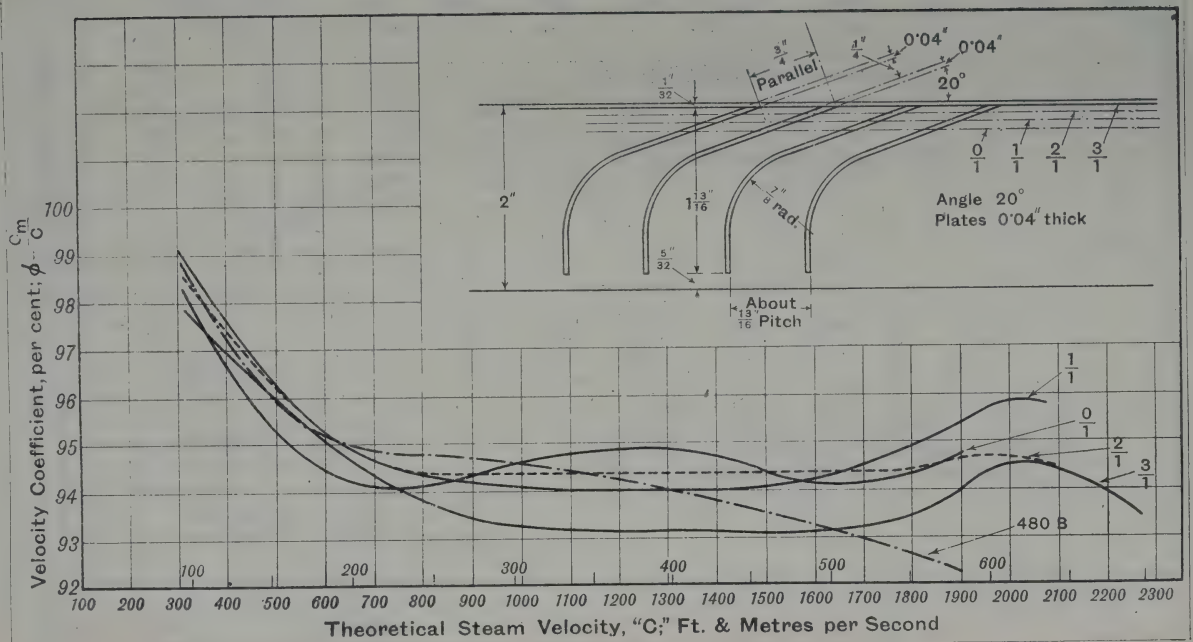
The apparatus used is of the impact plate type, largely designed by Mr. H. M. Martin. The first two reports dealt with tests taken on 1-in. wide reaction blading having a nominal outlet angle of 20°, and on impulse nozzles having an outlet angle of 20° with guide blades 0·04 in thick.

STEAM NOZZLES RESEARCH COMMITTEE—VELOCITY COEFFICIENTS.

Impulse Nozzles : Nominal Angle 20°. Plates—0·04 in. thick.

Reaction Nozzles : Parsons Normal 480 B. Normal Angle, 20°.

Ratio $\frac{\text{Parallel Exit}}{\text{Throat}} = \frac{0}{1}, \frac{1}{1}, \frac{2}{1}, \frac{3}{1}$.



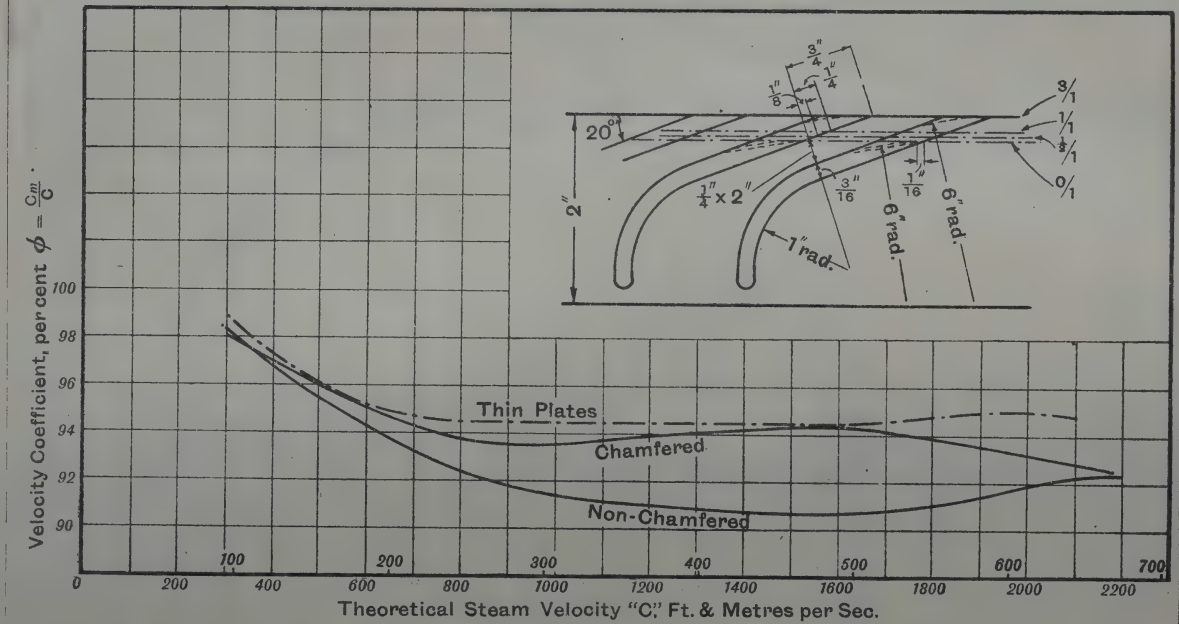

Velocity Coefficient, per cent $\phi = \frac{C_m}{C}$
100
98
96
94
92
90
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
100
200
300
400
500
600
700
Theoretical Steam Velocity "C." Ft. & Metres per Sec.
Thin Plates
Chamfered
Non-Chamfered
20°
2"
3/4"
1/4"
1/8"
1/4" x 2"
3/16"
1/16"
1" rad.
6" rad.
6" rad.
3/1
1/1
1/4
0/1

FIG. 1.

The mean velocity coefficient (ϕ) values for the impulse nozzles obtained on those tests are shown on p. 1827, for nozzles with throats of various proportions. The corresponding curves for the reaction blading are shown by the dotted curve.

The notable feature of these tests is that they were carried out as large-scale experiments on commercial blades and nozzles.

The character of the curves, particularly for the impulse nozzles showing a rising value at low velocity, is particularly notable, as the region was not previously explored in published researches.

The third report of the Nozzle Research Committee of the Institution of Mechanical Engineers contains the results obtained with thick plate impulse nozzles summarised in diagram, fig. 1.

It will be observed that although the efficiency of the thick plate nozzles is materially lower than that of thin plate nozzles, the efficiency of the former can be improved to that of the latter by suitably chamfering the outlet.

In this report the experimental results on the efflux angle of the discharged steam suggest that its value is equal to $\sin^{-1}\frac{o}{p}$, and not to the geometrical angle (see fig. 2, and table C).

Experiments were also carried out on straight nozzles well radiused at the inlet and having long parallel throats equal to about three diameters in length.

The efficiency of this nozzle was very high, giving a velocity coefficient θ of about 0·98 for 500 ft./sec., 0·97 for 300 ft./sec., and 0·98 for 1,700 ft./sec.

The experiments also lead to the conclusion that the efficiency of a nozzle is decreased as the superheat is increased.

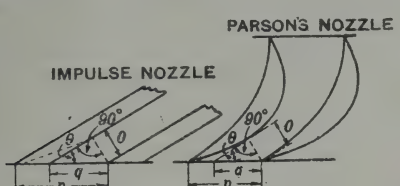


FIG. 2.—Efflux Angles.

TABLE C.

—	$\frac{o}{q}$	θ Degrees.	$\frac{o}{p}$	δ Degrees.	Angle of Exit. Degrees.	Difference Degrees.
20° thin plate	0·34	20	0·308	18·0	17·0	−1·0
20° thick plate	0·34	20	0·190	11·0	14·0	+3·0
Ditto champered	0·34	20	0·190	11·0	10·5	−0·5
12° thin plate	0·21	12	0·178	10·3	10·5	+0·2
12° thick plate	0·21	12	0·121	7·0	6·0	−1·0
1 in. parsons	0·61	37	0·350	20·5	18·5	−2·0
⅝ in. parsons	0·61	37	0·350	20·5	18·5	−2·0

Turbine Efficiency.

The 'Overall Efficiency' of a turbine is obtained by comparing the work actually done per lb. of steam, with that which would be performed by an ideal engine working on the Rankine cycle and having the same initial and final steam conditions as the turbine.

TABLE IIIA.—ADIABATIC HEAT DROP IN B.TH.U./LB.

Vacuum 30 ins. Barm.	Superheat °F.	Pressure Lbs. per Sq. In. Gauge. 350	300	275	250	220	200	180	160	140	120	100	80	60
27″	0	357·7	348·3	343·0	337·2	329·4	323·7	317·3	310·3	302·4	293·3	282·7	270·1	254·5
	100	381·8	371·5	365·6	359·3	350·8	344·6	337·6	330·0	321·4	311·7	300·3	286·9	270·2
	200	407·4	396·3	390·0	383·2	374·2	367·5	360·1	352·1	343·0	332·8	320·8	306·6	289·2
	300	434·2	422·5	415·8	408·7	399·2	392·2	384·6	376·1	366·7	356·0	343·6	328·9	310·8
27·5″	0	366·3	357·0	351·8	346·0	338·3	332·6	326·3	319·3	311·5	302·5	291·9	279·5	263·9
	100	390·9	380·6	374·8	368·5	360·1	353·9	347·0	339·4	330·9	321·2	310·0	296·6	280·0
	200	416·8	405·7	399·5	392·8	383·8	377·1	369·9	361·8	352·8	342·6	330·8	316·7	299·4
	300	443·9	432·2	425·6	418·6	409·2	402·2	394·6	386·2	376·8	366·2	353·9	339·3	321·3
28″	0	376·7	367·5	362·3	356·5	349·0	343·3	337·1	330·1	322·4	313·4	303·1	290·7	275·3
	100	401·7	391·5	385·8	379·6	371·2	365·1	358·3	350·7	342·3	332·7	321·5	308·3	291·9
	200	428·1	417·1	410·9	404·2	395·3	388·7	381·5	373·5	364·6	354·5	342·8	328·8	311·6
	300	455·5	443·9	437·4	430·4	421·1	414·2	406·6	398·3	389·0	378·4	366·2	351·7	334·0
28·25″	0	382·8	373·7	368·5	362·8	355·2	349·6	343·4	336·5	328·8	319·9	309·6	297·3	282·0
	100	408·2	398·0	392·3	386·0	377·8	371·7	365·0	357·4	349·0	339·5	328·5	315·2	298·8
	200	434·7	423·8	417·6	410·9	402·1	395·6	388·4	380·5	371·6	361·5	349·8	335·9	318·9
	300	462·4	450·8	444·3	437·4	428·1	421·2	413·8	405·4	396·2	385·6	373·5	359·1	341·4
28·5″	0	389·8	380·7	375·5	369·9	362·4	356·7	350·5	343·7	336·0	327·2	317·0	304·7	289·5
	100	415·4	405·3	399·6	393·5	385·2	379·1	372·4	365·0	356·6	347·1	336·1	323·0	306·8
	200	442·2	431·4	425·2	418·7	409·9	403·4	396·2	388·3	379·5	369·4	357·9	344·0	327·0
	300	470·2	458·7	452·2	445·3	436·0	429·2	421·8	413·5	404·3	393·8	381·7	367·4	349·8
28·75″	0	397·8	388·8	383·6	378·1	370·6	365·1	358·9	352·1	344·5	335·8	325·6	313·4	298·3
	100	423·9	413·8	408·1	402·0	393·9	387·8	381·1	373·7	365·4	356·0	345·0	332·1	315·9
	200	451·0	440·2	434·1	427·6	418·8	412·3	405·2	397·4	388·6	378·7	367·1	353·4	336·6
	300	479·2	467·8	461·3	454·5	445·3	438·5	431·1	422·9	413·7	403·3	391·3	377·1	359·6
29″	0	407·6	398·7	393·6	388·1	380·6	375·1	369·1	362·3	354·8	346·1	336·0	324·0	309·0
	100	434·1	424·2	418·6	412·5	404·4	398·3	391·7	384·4	376·1	366·8	355·9	343·0	327·0
	200	461·6	450·9	444·8	438·3	429·7	423·2	416·2	408·4	399·7	389·8	378·4	364·8	348·1
	300	490·1	478·8	472·4	465·6	456·5	449·7	442·4	434·2	425·1	414·8	402·9	388·8	371·5

The figures in the above table have been taken from the useful and compact 'Heat Drop Tables' published by the British Electrical and Allied Manufacturers' Association.

This latter amount of work is equal to the mechanical value of the change in total heat contents (h_a B.Th.U.) which takes place during adiabatic expansion from the steam conditions before the governor valve, to those obtaining in the turbine exhaust.

h_a is referred to as the 'adiabatic heat drop' or the 'available heat drop,' and its value for the steam conditions usual in practice is given in Table IIIA, p. 1830.

TABLE IIIB.—ADIABATIC HEAT DROP IN B.TH.U. DRY SATURATED STEAM.

Vacuum 30 ins. Barm.	Pressure Lbs. per Sq. In. Absolute.				
	14	15	16	17	18
27·0	144·0	148·0	152·5	156·5	161·0
27·25	149·0	153·0	157·5	161·5	166·0
27·5	154·5	158·5	162·5	166·5	171·0
27·75	160·0	164·0	168·0	172·5	176·5
28·0	166·5	170·5	175·0	179·0	183·5
28·25	174·0	178·0	182·0	186·0	190·5
28·5	182·5	186·5	190·5	194·5	199·0
28·75	192·0	196·0	200·5	204·5	209·0
29·0	203·0	207·0	211·0	215·0	219·5

If

d = steam consumption in lbs. per S.H.P. hour; N_T = overall efficiency of the turbine,

then

$$N_T = \frac{2,545}{d.\,h_a} \times 100 \text{ in per cent.}$$

If

d_1 = steam consumption in lbs. per K.W. hour; N_G = generator efficiency in per cent.,

then

$$N_T = \frac{3,414}{N_{G1}.d_1.h_a} \times 100 \text{ in per cent.}$$

The total steam consumption of the turbine is given by

$$W = \frac{d\ (\text{S.H.P.})}{3,600} \text{ lbs. per sec., or, } W = \frac{d_1\ (\text{K.W.})}{3,600} \text{ lbs. per sec.}$$

While the efficiency calculated with h_a as already defined is the true index of the performance of a turbine when running, it is sometimes the practice—and it is one which has a special value to turbine designers—to calculate the efficiency by taking the heat drop h'_a as that available between the conditions existing after the governor valve, that is, before the nozzles, and the exhaust of the turbine.

This is equivalent to eliminating the consideration of the pressure drop through the governor valve, which is rightly regarded as not being an inherent loss to any given turbine.

Suppose, for example, that two turbines are sold as 1,000 k.w. units to operate with certain steam conditions, and that one is actually capable of developing a load of 1,100 k.w., while the second can only pull a load of 950 k.w.

If these two turbines are tested on a load of 1,000 k.w., the latter will show the better steam consumption, because with the former the steam will be throttled at the governor to the greater extent. Of course, the first machine is in every way the better from the customer's point of view, provided the excess of power is not too great to be carried by the generator.

The steam consumption which can be used for estimating purposes when using steam at 200 lbs. per square inch, 200° F., and exhausting into a vacuum of 28 ins., is shown by fig. 3 for 1,500

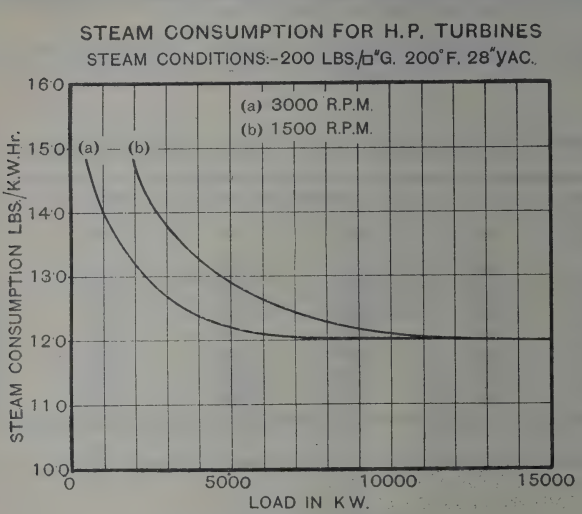


FIG. 3.

and 3,000 r.p.m. The former speed is the highest which can be used for 25-cycle generators, while the latter can be used for either 25 or 50 cycles. These curves illustrate the effect of speed

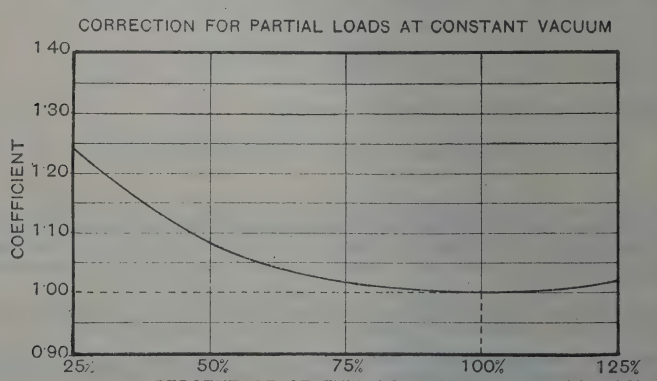
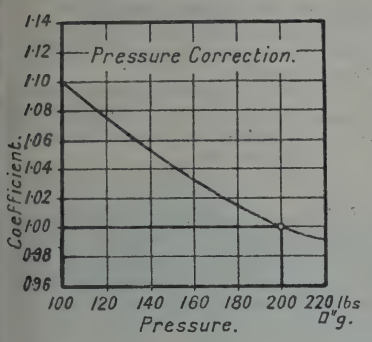


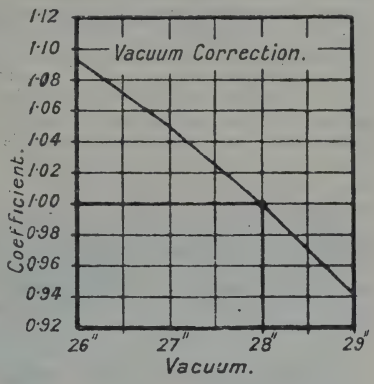
FIG. 4.

on efficiency. Fig. 4 enables the consumption at fractional loads to be estimated when th consumption at full load is known.

The steam consumption which can be obtained for other steam conditions can be approxi mately obtained by means of the correction curves shown in fig. 5.

STEAM CONSUMPTION CORRECTIONS FOR TURBINES DESIGNED FOR VARIOUS CONDITIONS.





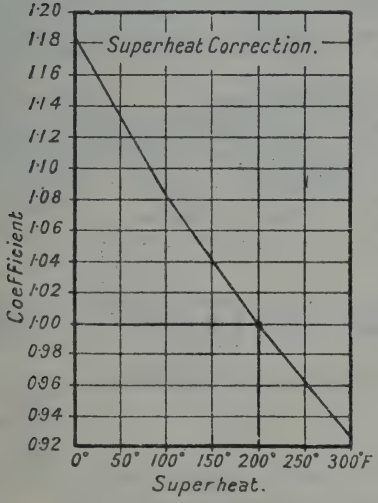


FIG. 5.

STANDARD STEAM CONDITIONS:

200 lbs. per sq. in. g.

200° F.

28 in. Vac.

For other steam conditions, multiply the consumptions obtained from fig. 3 (page 1832) by the coefficients obtained from the curves.

IMPULSE TURBINES.

A pure impulse turbine is one in which the available heat energy of the steam is completely converted into kinetic energy in stationary nozzles.

The steam jet thus produced performs mechanical work by impinging on a rotating row of blades or successive rows of rotating and guide-blades placed immediately before the nozzles.

An impulse turbine in which the whole pressure drop available is utilised in a single set of nozzles is said to consist of one *pressure stage*. If the pressure drop is subdivided between two, three, or more successive sets of nozzles, it consists of two, three, or more pressure stages.

When the kinetic energy of the steam jet is utilised in one row of rotating blades, the turbine is said to have one *velocity stage* per pressure stage. If, after the first row of rotating blades, a guide blade is placed to reverse the direction of steam so as to impinge on a second row of rotating blades, the turbine is said to have two ' velocity stages,' and so on.

Since a minimum nozzle height will be fixed by practical considerations (not less than $\frac{1}{4}$ in. even in the smallest turbines), the arc over which the nozzles will extend depends upon the total nozzle mouth area required. In the high-pressure stages this may be less than the mean circumference of the blades. Such a turbine is said to be working with partial admission, and the arc over which the nozzles extend is termed the ' arc of admission.'

This arrangement lends itself especially well to conveniently and efficiently dealing with overloads, it being only necessary to increase the ' arc of admission ' by admitting steam to additional sets of nozzles.

In the same way it is possible to divide the total number of nozzles into blocks controlled by separate cutout valves. Thus one block of nozzles can be designed to give all loads from 0 to $\frac{1}{2}$ full load, while these together with a second block give $\frac{1}{2}$ to $\frac{3}{4}$ and so on.

By this means the loss of pressure through throttling at the governor valve is reduced to a minimum, and substantial economies can be effected on partial loads. The nozzle cutout valves may be operated automatically or by hand. Nozzle cutout governing is not possible with reaction turbines.

(a) Single Pressure Stage Turbine with a Single Velocity Stage.

The nozzles of all impulse turbines can be designed by the methods already indicated, while the work done and the efficiency can be obtained by drawing the triangles of velocity a_1 and a' (see fig. 6). All velocities are in feet per second.

Let

W = total weight of steam through nozzles in lbs. per sec.; c_1 = absolute velocity leaving nozzles; U = peripheral velocity at mean diameter of blades; w_1 = relative velocity at entry

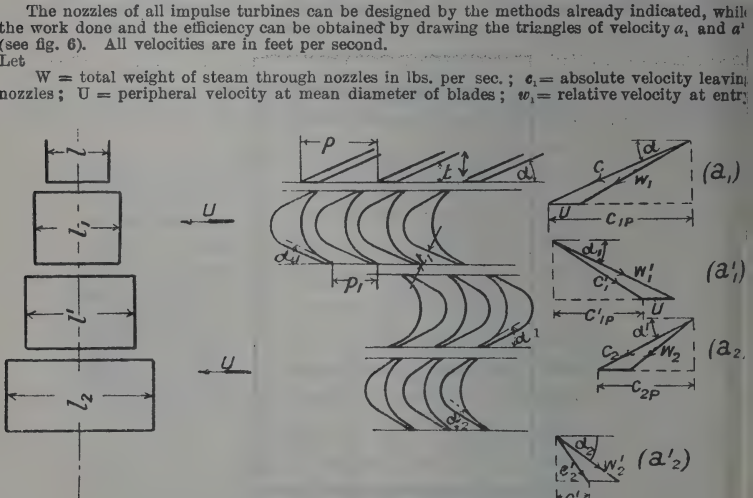


FIG. 6.

to moving blades; w_1' = relative velocity at exit from moving blades; c_1 = absolute velocity leaving the moving blade; c_{1p} $c_1'_p$ = the peripheral components of c_1 and c_1', respectively.

Then

$$w_1' = \psi w_1,$$

where $(1 - \psi_1')$ is the loss of velocity due to friction in the blade (see fig. 10, page 1838)' ψ is called the *velocity coefficient* for the blades.

BROTHERHOOD STEAM TURBINES

5

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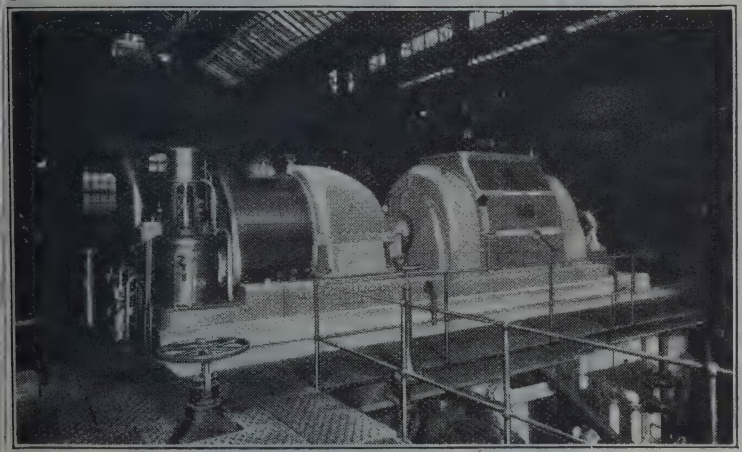

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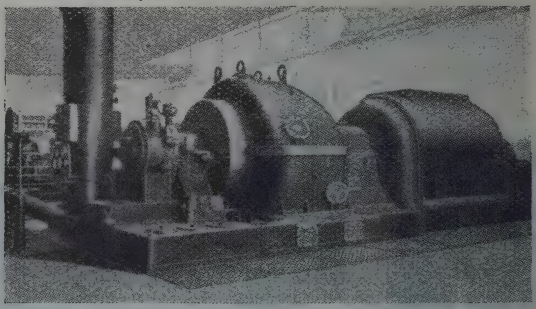

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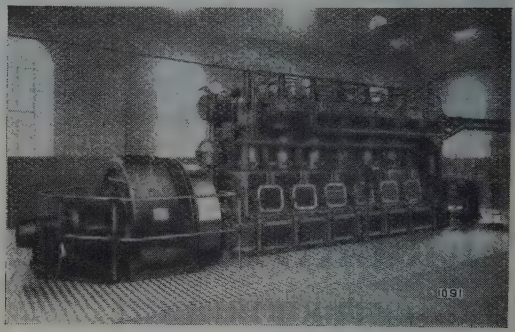
(AIR INJECTION DIESEL TYPE.)



400 K.W., 600 B.H.P., 350 R.P.M. set in a Corporation
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BIRMINGHAM.

ESTABLISHED 1852.

The total work done, or
The indicated work $= \frac{W\,U}{g}(c_{1P} + c_{1P}')$ ft. lbs. per sec.

The blading efficiency $\eta_B = \frac{\text{(total work in ft. lbs. per sec.)}}{W.\,J.\,g.\,h_a}$

If

l = the required nozzle height; l_1 = the required blade height;

then

$$l_1 = l \cdot \frac{c_1}{w_2} \cdot \frac{l}{l_1} \cdot \frac{p_1}{p}$$

The de Laval turbine, which is of this type, is made in sizes from 5 to 500 h.p., running at 30,000 r.p.m. in the smallest size, and 10,000 r.p.m. in the largest outputs.

The peripheral speeds are as high as 1,300 ft. per second, and the steam velocity at exit from the nozzles as high as 4,000 ft. per second.

It can be shown that the efficiency varies with $\frac{U}{C_o}$ where C_o is the velocity theoretically obtained if $\phi = 1{\cdot}0$.

For a maximum efficiency, $\frac{U}{C_o}$ should be about equal to 0·5 (see fig. 8, page 1837, which gives the results obtained experimentally by Dr. O. Lasche).

(b) Single Pressure Stage. Two Velocity Stages.

In this case the work done in the first row of blades is obtained in exactly the same way as in case (*a*).

The guide-blade returns the steam jet towards the direction of U, the steam leaving it with an absolute velocity $c_2 = \psi_2 c_1'$.

The relative velocity of exit from the second rotating blade is $w_2' = \psi_2' w_2$, knowing which, the velocity triangles $a_2 . a_2'$ can be drawn. In a_1 and a_1' the same symbols are employed as in a_1 and a_1', a suffix 2 denoting the guide-blade, while a dash denotes the second moving blade.

The total work per second is now

$$= \frac{W\,.\,U}{g}\left\{(c_{1P} + c_1') + (c_2 + c_2')\right\} \text{ ft. lbs. per sec.}$$

WORK DONE IN 1ST AND 2ND ROWS OF VELOCITY WHEELS. 3,000 R.P.M.

Initial conditions :—200 lbs. per sq. in. g., 200° F. supf.; steam pressure in casing = 34 lbs. per sq. in. g.; temperature in casing = 410° F.

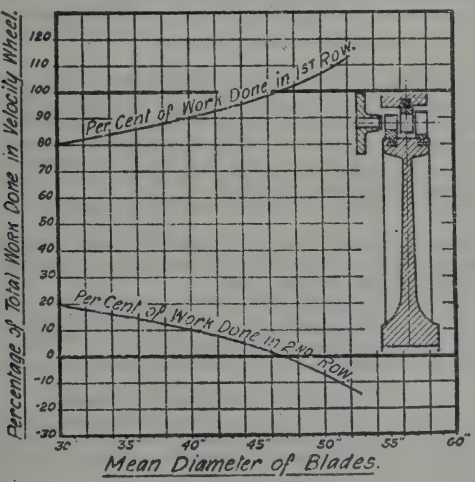


FIG. 7.

and

$$\eta_B = \frac{\text{(Total work in ft. lbs. per sec.)}}{W \cdot J \cdot g \cdot h_a}$$

The height of the guide-blade $l^1 = l \cdot \frac{c_1}{c_2} \cdot \frac{t}{t^1} \cdot \frac{p^1}{p}$

The height of the second rotating blade $l_2 = l \cdot \frac{c_1}{w_2^1} \cdot \frac{t}{t_2} \cdot \frac{p_2}{p}$

As the mean peripheral velocity of the blades increases the proportion of the work done in the first row increases. This effect is illustrated in fig. 7, from which it will be seen that for the condition stated the second row does no positive work if the mean diameter of the blades exceeds 47½ ins.; it can therefore be dropped with advantage. For this reason two-row wheels are rarely used in modern high-speed machines.

(c) Single Pressure Stage. More than two Velocity Stages.

The solution of this case can be obtained from (*b*) in exactly the same way as (*b*) was obtained from (*a*).

Single-wheel Curtis stages belong to classes (*b*) and (*c*) and are very much employed for small high-speed turbines, where efficiency is not the first consideration.

The peripheral speeds for Curtis wheels are as high as 600 ft. per second, and the steam velocity 2,500 ft. per second.

For a maximum efficiency $\frac{U}{C}$ should be about 0·23 for two rows of moving blades, and 0·18 for three rows (see fig. 8, page 1837).

(d) Multi-Pressure Stage Turbine with Single Velocity Stages.

In order that reasonable efficiencies may be reached with practicable peripheral speeds, it becomes necessary to limit the heat drop utilised in each set of nozzles to some value considerably less than the total available between the conditions before the turbine stop valve and those present in the exhaust.

Up to a certain point, which is rarely reached in the conditions of actual design, the efficiency of each stage increases with the value of the ratio $\frac{U}{C_o}$ (see fig. 8, page 1837).

When the value of $\frac{U}{C_o}$ is known, which corresponds to the desired turbine efficiency, the value of C_o and hence of h_a the heat drop to be utilised per stage can be calculated, since U will be fixed by mechanical considerations.

Then for an equal distribution of energy over the pressure stages,

If H_a = the total heat drop available for the whole turbine,

$$\text{The required number of stages } n = e \cdot \frac{H_a}{h_a}$$

where e is the '*reheat factor*' which depends on the amount of friction and eddy losses, the number of stages, the stage efficiency, etc., and varies between 1·03 and 1·07.

It is usually the practice to give the first stage a larger heat drop than the remainder, thus reducing the total number of wheels required, and having the considerable advantage of reducing the maximum temperature and pressure to which the turbine casing is subjected.

Having apportioned the heat drops, the steam conditions at each stage can be found—most conveniently by the Mollier diagram—and each stage can be designed as indicated under case (*a*).

The Rateau and Zoelly turbines are of this type.

In practice U varies from 350–600 ft. and the steam velocities from 800–1,600 ft. per second.

(e) Multi-Pressure Stage Turbines with Multiple Velocity Stages.

In precisely the same way as has been explained under (*d*), two- or three-row velocity wheels may be employed in the individual pressure stages.

The heat drop which can be advantageously used per pressure stage is then greater than in the case where a single row of blades is used, and thus the required number of pressure stages is reduced, but the efficiency is somewhat decreased, as may be deduced from fig. 8, page 1837.

The general design of each stage is similar to that of case (*b*).

The Curtis turbine is of this type.

(f) Combination Impulse Turbines.

It has become a common practice to construct pressure-compounded impulse turbines of type (*d*) with a Curtis wheel having two rows of blades in the first stage. By this means a large heat drop can be employed in the first stage with reasonable efficiency and with the consequent advantages already mentioned.

The Curtis-Rateau and Curtis-Zoelly turbines are of this type.

Diagram showing the best efficiencies obtained in Dr. O. Lasche's experiments on Impulse Wheels. The efficiencies have been corrected for disc friction.

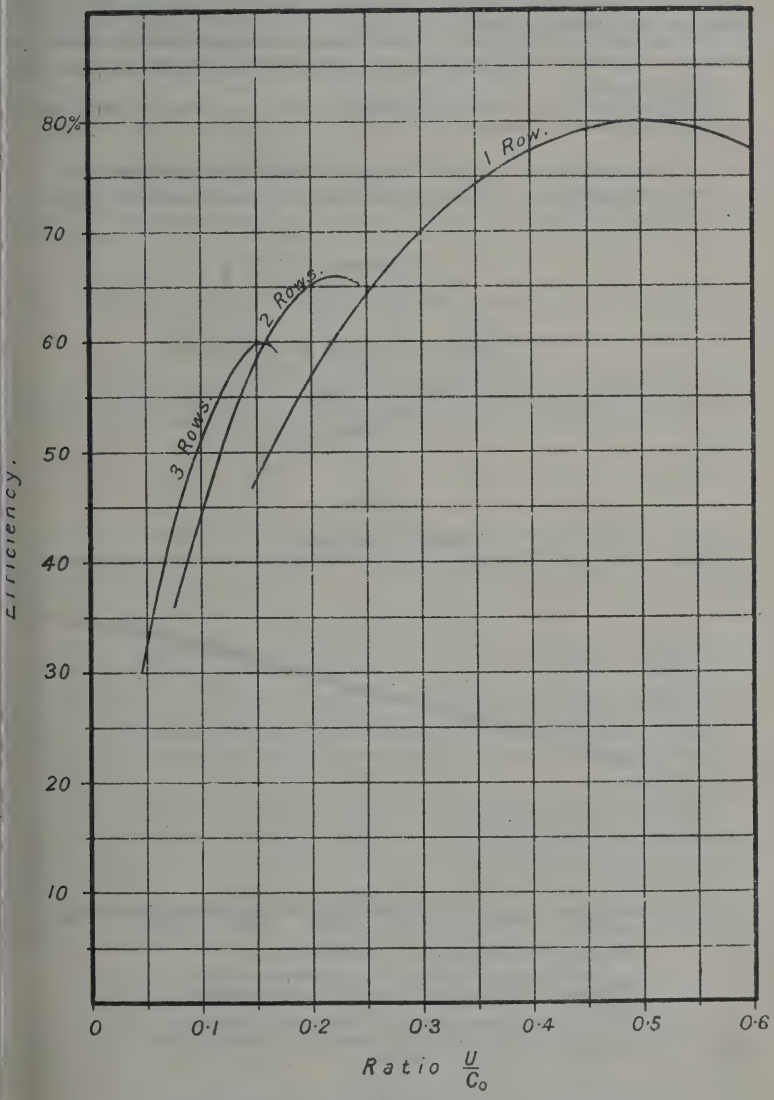


FIG. 8.

CARRY-OVER ENERGY.

In pressure-compounded impulse turbines, the kinetic energy of the steam leaving the last blade of any pressure stage—except the last—is not entirely lost; part of it at least being recovered in the succeeding stage.

The total energy available in the succeeding stage is then greater than the adiabatic heat drop by an amount equal to $\frac{a c^2}{2g}$, where c is the absolute velocity of exit from the velocity blade and a is a constant.

For full admission, Prof. Rateau has suggested the value $a = \frac{2}{3}$, while for partial admission the value $a = \frac{1}{2}$ may be taken.

THE VALUE OF ψ, THE VELOCITY COEFFICIENT FOR BLADES.

The value of ψ has been the subject of researches by Prof. Rateau* and Dr. N. Briling.†

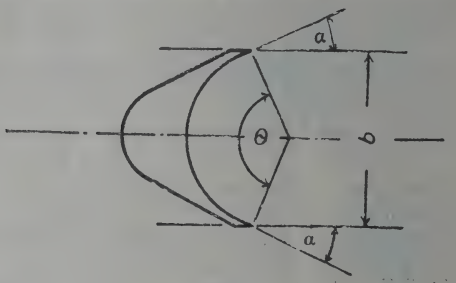
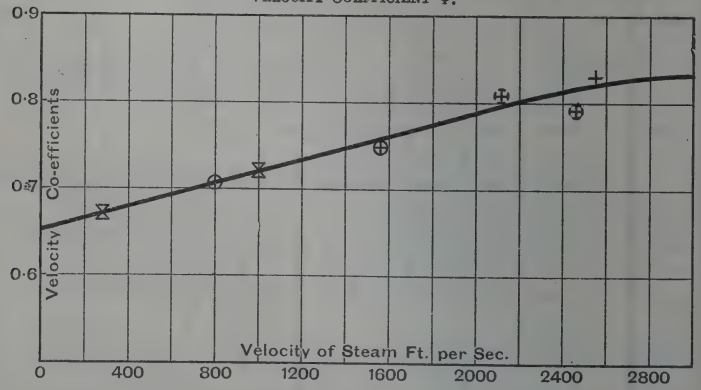


FIG. 9.



⊕ *Rateau. (Engineering 10/12/09) Mean Values.*

⊕ *Values deduced from Rateau's experiments on Bucket Reaction; Congrès International de Mécanique Appliquée 1900.*

⧖ *Briling's Experiments with 20 m/m Buckets (Engineering 29/4/10).*

\+ *Stodola "Steam Turbines" deduced from Delaporte's Test of a de Laval Steam Turbine.*

FIG. 10.

* *Engineering*, December 10, 1909. † *Z. Ver. Deutsch. Ing.*, January 1906.

Prof. Rateau found that ψ was a characteristic of each type of blade depending on their size and spacing and slightly increasing with velocity.

Dr. Briling, whose experiments covered a wider field, found that ψ increased with velocity, decreased with the width of the bucket, and appeared to be principally dependent upon the angle through which the steam was diverted in the blade.

Briling deduced the following formula from his experiments:

$$\psi = \psi_o - 0{\cdot}000432\,\theta^{\frac{4}{3}}$$

where θ = total angle in degrees through which steam is turned in the blade (see fig. 9, p. 1838).

ψ_o = 0·90–0·97 for blades with rounded inlet edges.
= 0·95–0·99 for blades with sharp edges.

Mr. H. M. Martin* has given a useful diagram combining Rateau and Briling's results with others deduced from various tests, which is reproduced in fig. 10; from this the following expression can be deduced:

$$\psi = 0{\cdot}65 + \frac{w}{15{,}000}$$

w being the velocity of the steam relatively to the blade in ft. per sec.

PITCH OF IMPULSE BLADES.

The best value of the pitch p has been determined experimentally by Dr. Briling † as being connected with the blade angle $\alpha°$—which he takes as being the same at the inlet and outlet—and the blade width by the following relation:

$$p = \frac{r}{2 \sin \alpha°}$$

$$r = \frac{b}{2 \cos \alpha°}$$

Briling is of the opinion that 30° is the most suitable angle for impulse blading.

In practice, the blade angle varies from 20° to 50°, the largest angles being used at the exhaust end of a turbine when it becomes difficult to provide sufficient area. The pitch varies from 0·5 to 0·75 of the blade width.

REACTION TURBINES.

In a reaction turbine the available heat energy of the steam is converted into kinetic energy both in the stationary and the moving blades.

In the most usual case—*considering a stage as consisting of a fixed blade and the following moving blade*—one-half of the available heat drop per stage is utilised in the fixed blade and the remainder in the moving blade. The turbine is then said to have a half degree of reaction.

Thus, both the fixed and moving blades perform the function of a nozzle in precisely the same way, and are identical in form and thermodynamic purpose.

Since there is a heat drop in the moving blades, there must also be a pressure drop across them. This is a characteristic of the reaction turbine as compared with the impulse turbine.

A second characteristic lies in the fact that the arc of admission to the first stage of a reaction turbine must extend around the complete circumference. For this reason nozzle cutout governing is not possible, and overloads can only be dealt with by admitting steam at some intermediate point in the expansion.

The steam enters the moving blades with a relative velocity approximately in an axial direction, and leaves them at a higher velocity in a direction inclined to the plane of rotation, the blades being impelled forward by the reaction of the leaving steam.

Reaction Blading with Half Degree of Reaction.

In this case since the outlet angles of the fixed and moving blades are the same, and the heat drop utilised in both is the same, the velocity triangles at inlet to and exit from the moving blade are identical (see fig. 11, p. 1840).

* *Steam Turbines—their Theory and Construction*, H. M. Martin.
† *Z. Ver. Deutsch. Ing.*, January 1906.

Hence

$$c_1 = w_1^1 \; ; \; c_1^1 = w_1.$$

If h = heat drop in any stage (one fixed and one moving blade) and with the remaining symbol as were used when considering impulse turbines—

$$c_1 = \frac{1}{2\,U\cos\alpha}\,(25{,}050\,\zeta\,h + U^2);$$

where $(1 - \zeta)$ is the energy loss in the conversion of heat to velocity.

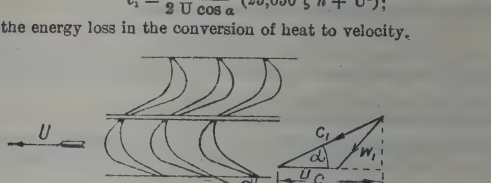


FIG. 11.

Capt. Riall Sankey has given 0·8 as the value of ζ, whereas the statement of Sir Chas. Parson that the blading efficiency in the low-pressure end of the turbines of the 'Mauretania' reache the value of 85 per cent., shows that ζ may be as high as 0·86 under those conditions, while th efficiencies reported to have been obtained with the Ljungström turbine of quite small capacitie could only be reached if ζ was as much as 0·85.

U and α being known, the velocity triangles can be drawn.

The work done per stage

$$= W\,\frac{(c_1^2 - c_1'^2)}{2g}, \text{ or, } = W\,\frac{(2k\cos\alpha - 1)}{g}v^2, \text{ where } k = \frac{c_1}{U}.$$

The blading efficiency

$$\eta_B = \frac{c_1^2 - (c_1'^2)}{2g\,J\,.\,h}, \text{ or, } = U^2\,\frac{(2k\cos\alpha - 1)}{J\,.\,g\;\;h}.$$

The required blade length can be obtained from the relation

$$\pi\,.\,D_m\,.\,l\,.\,q = \frac{W\,.\,v_2}{W_1},$$

where D_m = mean diameter of annulus in feet; l = radial length of annulus in feet = (blad height) + (tip clearance); v_2 = the specific volume after the moving blade in cubic feet per lb. q = annulus area factor.

At any stage the 'annulus area factor' is the ratio of the available area of the channels a exit from the blades in a direction at right angles to α, to the area of the annulus between th drum and the casing at that stage.

The properties of Parsons blading, with the exception of q and α, were published b M. Lelong,* and will be found in Table IV.

As in the case of impulse blading, the blading efficiency varies with $\frac{U}{c_1}$ and reaches a maxi mum when $\frac{U}{c_1} = 0{\cdot}945$ if $d = 19°$, the normal angle for all but the last stages of reaction turbine Under this condition U becomes equal to $c_1 \cos\alpha$. Such a high value is not practicable i ordinary working conditions, nor is it necessary for the realisation of high efficiency, because th curve connecting $\frac{U}{c_1}$ and η_B is very flat in the region of its maximum.

Fig. 12 (p. 1842), which gives this relation for $\zeta = 0{\cdot}8$, is due to Stodola.†

The efficiency for changes of ζ within the limits actually to be met with can be obtained b increasing the efficiency as obtained from fig. 9 by the same percentage as ζ exceeds 0·8.

In electrical work $\frac{U}{c_1}$ varies from 0·5 to 0·8.

The peripheral velocity of forged steel drums may be as high as 400 ft. per second, and eve higher speeds are possible with solid drums, or drums made from special steels of high ultimat strength.

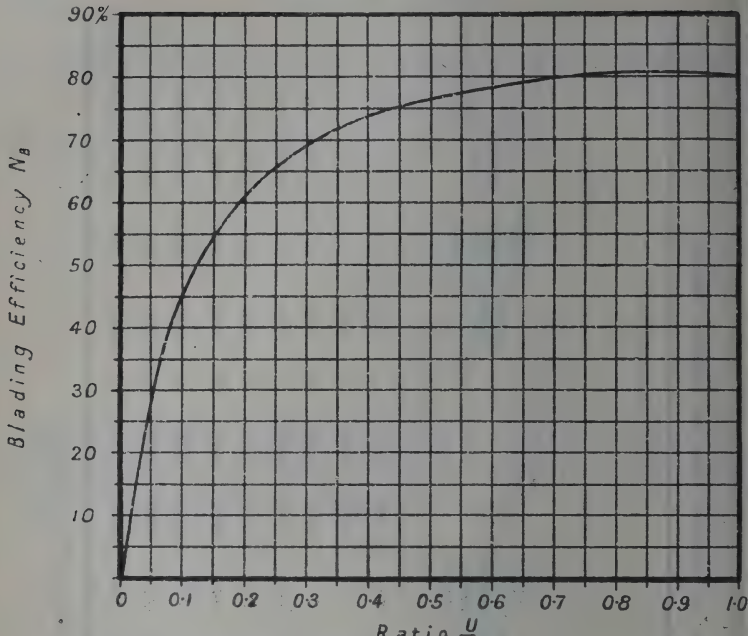
---

* *Turbines à Vapeur Marines*, R. Lelong; and *Engineering*, March 1, 1912.
† *Die Dampfturbinen*, 4th Ed., A. Stodola.

TABLE IV.—DATA RELATING TO BLADES AND CAULKING PIECES FOR PARSONS TURBINES.

Blades.						Caulking Pieces.								
						Casing.					Drum.			
									Grooves.				Grooves.	
Section Number.	Class of Blade.	Exit Angle of Blade α. in deg.	Annulus Area Factor q.	Weight per foot run.	Usual Limits of Length.	Section Number.	Number Required per in. run.	Weight per foot run.	Width.	Depth.	Section Number.	Number Required per in. run.	Weight per foot run.	Width.	Depth.
									In.	In.				In.	In.
120B	Normal	20	0·3	0·041	Up to $\frac{3}{4}$ ins.	120C	5·8	0·106	0·243	$\frac{1}{4}$	120C	5·8	0·106	0·243	$\frac{1}{4}$
130B	Normal	20	0·3	0·089	$\frac{3}{4}$ in. to 4 ,,	130C	3·7	0·264	0·364	$\frac{1}{4}$	130S	5·2	0·159	$\frac{23}{64}$	$\frac{1}{4}$
130B	Semi-Wing	35	0·53	0·089	$\frac{3}{4}$,, ,, 4 ,,	131C	3·3	0·315	0·415	$\frac{1}{4}$	131S	3·7	0·300	$\frac{13}{32}$	$\frac{1}{4}$
132B	Wing	45	0·68	0·077	$\frac{3}{4}$,, ,, 4 ,,	132C	3·2	0·400	0·406	$\frac{1}{4}$	132S	3·6	0·320	0·400	$\frac{1}{4}$
240B	Normal	20	0·3	0·180	4 ,, ,, 8 ,,	240C	2·75	0·450	0·510	$\frac{3}{8}$	240S	3·4	0·400	0·510	$\frac{3}{8}$
240B	Semi-Wing	35	0·53	0·180	4 ,, ,, 8 ,,	241C	2·54	0·643	0·540	$\frac{3}{8}$	241S	3·2	0·450	0·540	$\frac{3}{8}$
250B	Normal	20	0·3	0·246	8 ,, ,, 12 ,,	250C	2·2	0·783	0·610	$\frac{3}{8}$	250S	2·7	0·600	0·610	$\frac{1}{2}$
250B	Semi-Wing	35	0·53	0·246	8 ,, ,, 12 ,,	251C	2·1	0·917	0·661	$\frac{3}{8}$	251S	2·6	0·670	0·661	$\frac{1}{2}$
252B	Wing	45	0·68	0·237	8 ,, ,, 12 ,,	252C	1·96	1·080	0·716	$\frac{3}{8}$	252S	2·44	0·79	0·716	$\frac{1}{2}$

For Double Wing Blades α 60°; $q = 0·85$ in.



EFFICIENCY OF REACTION BLADING FOR $\zeta = 0{\cdot}8$.

FIG. 12.

The velocity of the steam c varies from 300 ft. per second in the initial to 1,000 ft. per second in the final stages.

In marine work $\frac{U}{c_1}$ varies from 0·3 to 0·45, and for the high-pressure stages the peripheral velocity varies from 80 to 120 ft. per second.

REACTION TURBINE DESIGN.

The blades of Parsons turbines are not usually increased in height from row to row, but are arranged in groups having the same height and the same mean diameter. The angles of the blades of any one group are usually the same, but in some cases they are gradually increased so as to obtain the correct progression of areas for constant steam velocity relatively to the blade.

The blades of such turbines for land purposes are generally placed on three-drum diameters of increasing size, referred to as the H.P., I.P. and L.P. expansions.

The relative distribution of heat drop between the different expansions and their relative geometric properties are given in the following table :—

Expansion.	H.P.	I.P.	L.P.	H.P.	I.P.	L.P.
Adiabatic heat drop used . .	1	1	2	1	1	1
Number of groups of blades .	1	1	2	1	1	1
Mean diameter of annulus . .	1	$\sqrt{2}$	2	1	$\sqrt{2}$	2
No. of rows of blades per group .	1	$\frac{1}{2}$	$\frac{1}{4}$	1	$\frac{1}{2}$	$\frac{1}{4}$
No. of rows of blades per expansion	1	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{4}$

The first of these arrangements is that most commonly adopted.

In electrical work there are from two to three groups of blades in the H.P. expansion.

In any given turbine and for groups of blades with the blade angle the same, the ratio $\frac{D^2 l}{v}$ should be constant, where D = mean diameter of the blades, l = their length, and v = the mean specific volume of the steam in the group.

The last three rings on the L.P. expansion were formerly made the same height, but with increasing discharge angle, the latter corresponding respectively to 'normal,' 'semi-wing' and 'wing.' By this means the final ring (*i.e.* wing blades) has double the discharge area of the ring of 'normal' blades of the same height, but without any increase in the centrifugal stresses. The practicable height ratio of $\frac{\text{blade height}}{\text{rotor diameter}}$ was $\frac{1}{7}$ with blades cut from rolled parallel strip. In modern practice a still larger height ratio ($\frac{1}{4}$) is obtained, with a view to obtaining still larger discharge area in the final ring, by the use of twisted blades which are also, if necessary (on account of centrifugal stresses), tapered from root to tip. In these blades the discharge opening ratio $\frac{o}{p}$ is kept constant from root to tip and equal to about 0·71 (*i.e.* wing), but the discharge angle is progressively varied by twisting. The guide ring is made complementary to the final rotating ring, being twisted, but not tapered.

In order to reduce the unsupported length between bearings, and to enable the tip clearance to be kept small, it is becoming the practice in turbines of 5,000 kw. and over to use two cylinders. The first cylinder contains the H.P. expansion only and can be made of cast steel, very fine clearances being possible by eliminating the danger due to the growth of cast iron.

e_1, for any particular stage, can be calculated from the formula already given when the heat drop h is known.

The blading efficiency throughout the turbine can be found from fig. 12 when the ratio $\frac{U}{e_1}$ is known.

For groups of blades having the same angles and height:

if

n = number of blades in the group considered; R = ratio of expansion over the group; H_a = adiabatic heat drop for the group,

then the heat drop used in the first stage

$$h_1 = \frac{(1+\epsilon)H_a}{\left[0{\cdot}07 + \left(\frac{R^2-1}{R^{\frac{2}{N}}-1}\right)\right]}$$

The heat drops for the other stages of the groups form with h_1 a geometric progression having $R^{\frac{2}{N}}$ as a common ratio.

In most cases it will be sufficient to calculate the first and last stages of any one group.

Disc and Drum Type.

Just as in the development of the pure impulse turbine combinations of the simple types have been evolved, so the disc and drum type has been introduced into the sphere of the reaction turbine.

In this case the high pressure and less efficient part of the reaction turbine is replaced by a Curtis wheel having as a rule two rows of blades. This design possesses the advantages already mentioned in connection with combination impulse turbines, and in addition it results in a considerably shorter and stiffer rotor than in the pure Parsons machine.

TURBINE LOSSES.

Diaphragm Gland Loss.

The diaphragms of a pressure-compounded impulse turbine must obviously be provided with a clearance between themselves and the shaft, thus providing a leakage area through which steam can pass.

The diaphragm gland is usually made either as a labyrinth packing or as a closely fitting white metal bush.

Although the clearances may originally be very small they are greatly increased by whipping of the shaft, or even by the static deflection.

The percentage leakage can be estimated as being equal to the ratio of the clearance area to the nozzle area in any diaphragm.

In order to reduce this loss, some designers employ carbon packings held together by garter springs in the diaphragms.

The diaphragm clearance is usually from $\frac{10}{1000}$ ins. to $\frac{30}{1000}$ ins. radially.

PACKINGS.

Labyrinth Packings.

The glands at the cylinder ends are usually of the labyrinth packing type.

In impulse turbines the labyrinth is invariably of the radial clearance type, while in Parsons turbines the packing at the thrust block end is of the axial clearance type, the other being of the radial clearance type.

Mr. H. M. Martin* has deduced the following formulæ:

$$\text{Weight of leakage steam} = 68 \cdot A \sqrt{\frac{p_o\left(1-\frac{1}{r}\right)}{v_o\,(N + log_e\, r)}} \text{ lbs. per sec.,}$$

where

p_o = pressure before the gland in lbs. per sq. in.; v_o = specific volume of steam in cu. ft. per lb. r = ratio of expansion through gland; N = number of labyrinths; A = sectional area of leakage path in sq. ft.

If the velocity with which the steam flows out of the last labyrinth is greater than sound velocity, this formula should be amended, but the correction is small, and as it is in the nature of a reduction in the weight of the leakage steam, it can safely be neglected where N is greater than 8, which is the usual case in practice.

N varies between wide limits and may be from 8 in the case of low-pressure glands of impulse turbines to 30 for the high-pressure glands of Parsons turbines.

The clearance usually allowed varies from $\frac{10}{1000}$ in. to $\frac{20}{1000}$ in., but this may increase in actual working in the same manner as the diaphragm clearances.

In order to reduce the loss of turbine efficiency due to gland loss, which might otherwise be considerable, the high-pressure packing is usually connected at one or two points in its length to some intermediate stage in the turbine.

The leakage over each of these sections can be calculated by the formulæ already given, r now being the ratio of expansion over any section, and p_o, v_o the conditions before that section.

Except in those cases where a water gland is used, the gland at the exhaust end is sealed by steam at a higher pressure than atmospheric, taken from a stage in the turbine, and in order to ensure that air is not leaking into the exhaust, the pressure is adjusted until a small quantity of steam is seen escaping into the engine-room.

The cylinder glands of the A.E.G., Zoelly, and Curtis turbines are of the carbon type, for which a considerable reduction in leakage is claimed.

The advantages of these are questionable since they cannot be renewed or adjusted without opening the turbine, and in some designs it is even necessary to strip the rotor.

The carbon rings which are in segments are kept together and caused to bear on the shaft by garter springs.

'Britimp' Brand Metallic Packings.†

(*British Metallic Packings Co., Ltd., 7 Princes Street, Westminster, S.W.* 1.)

Each packing of this brand consists of two complete rings of carbon, X, X (fig. 12A). Each ring is in three sections. The outer circumferences of the rings are coned in opposite directions and the coned surfaces are shrouded by a light metal ring Y, which is also in three sections.

This ring is kept in contact with the carbon rings by a coiled wire and spring. The spring is so formed that the possibilities of breakage are very remote.

Each packing unit is enclosed in a chamber ring Z of L section. The relative positions are made definite by stops.

The joints of the sections of all the rings are staggered to ensure steam tightness.

The coned circumferences of the packing rings produce radial and axial contact pressures between the carbon rings X, X, and the metal ring Y.

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* *Steam Turbines—their Theory and Construction*, H. M. Martin.

† See also pp. 1263, 1805, and 1949.

The radial components give the necessary contact pressures between the packing rings and he shaft, while the axial components produce contact pressures between the packing rings and he sides of the chambers. The side pressures serve two purposes—viz. they produce surface

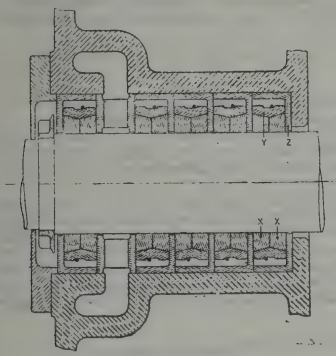

FIG. 12A.

friction which supports the weight of the packing units, and they also ensure steam-tight joints between the packings and walls of the chambers. As the shaft is relieved of the weight of the packing it is subjected only to uniform radial contact pressures, with the result that the wear on both the shaft and packings is reduced to a minimum. Means for adjusting the contact pressures are provided on the coiled wire.

Dummy Loss.

In the majority of single-flow Parsons turbines the axial thrust on the blades and drum is balanced by dummy pistons. A labyrinth packing is formed on the periphery of the dummy pistons to reduce the leakage of steam which would otherwise take place across the dummy piston to the exhaust to which they are connected on one side.

The loss of steam through the dummy clearances can be calculated in precisely the same way as the loss through a labyrinth packing.

The double-flow type of turbine obviating the necessity of balance pistons eliminates this loss.

Disc Friction.

A considerable amount of work may be absorbed in rotating the discs of impulse turbines in the dense steam present in the first stages of a pressure-compounded (disc) turbine.

Professor Stodola * has given the following formula for the disc friction loss :

$$\text{B.H.P.} = \frac{6.1}{10^8} D^2 U^3 \gamma,$$

where,

D = mean diameter of blades in feet ; U = mean peripheral velocity feet per sec. ; γ = density of steam in lbs. per cu. ft.

The experiments upon which this formula is based were performed either in air, superheated steam, or in steam whose exact condition as regards wetness was unknown.

Professor Lewicki has demonstrated that the combined work of disc friction and windage falls off with superheat, some of his experiments showing a reduction of 10 per cent. in the work done for an increase of superheat of 100° C. As the total loss due to disc friction is usually of the order of a few per cent. of the output of the turbine, the reduction with superheat is of little importance.

On the other hand, it seems probable that the disc friction would increase rapidly with the wetness of the steam, but there are at present no data for estimating this increase. For these reasons, the disc friction loss for any given turbine cannot be calculated with certainty.

* *Die Dampfturbinen*, 4th Ed., Prof. A. Stodola.

Windage.

In addition to the disc friction, loss results from the fanning action of the blades as th rotate.

The laws governing this action cannot be regarded as established, the range of experime has been limited, and results by the same experimenters are discordant. Professor Stodola* gi the following formula :

$$\text{B.H.P.} = \frac{4.6}{10^7} \cdot D \cdot l^{1.6} \cdot U^3 \cdot \gamma,$$

where,

l = blade length in inches ; D = mean diameter of blades in ft. ; U = mean periphe velocity in ft. per sec. ; γ = density of steam in lbs. per cubic ft.

Mr. W. Kerr carried out some careful tests on this subject, and by comparing his o results with those of Professor Stodola and Dr. Lasche, suggests that for wheels carrying t rows of blades the work calculated by the above formula must be multiplied by 1·23, for thr rows by 1·8, and for four rows by 2·9.†

When mixed pressure turbines are working with low-pressure steam the high-pressure end rotating idly in an atmosphere of steam, and with disc turbines the work done in disc fricti and windage is not negligible. With reaction turbines a windage loss alone is present, and this mainly due to the fanning action of reaction blading. Sir C. A. Parsons has stated that in the ca of a reverse element of a marine turbine rotating in a vacuum the loss is of the order of 1 p cent., so that the loss due to the rotation of the high-pressure element of a mixed-pressure Parso turbine rotating in steam twelve times as dense as a 28-in. vacuum may be considerable.

Water Glands.

An interesting feature in the development of turbine design consists in the introduction the water gland.

In this type, an air-seal is produced by a paddle-wheel acting as a centrifugal pump. Th

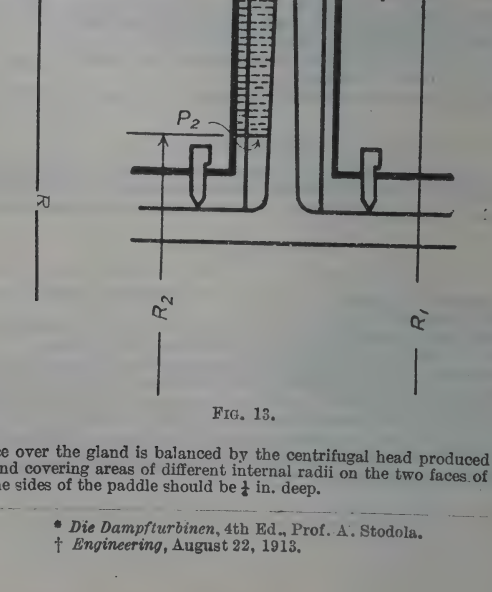

FIG. 13.

pressure difference over the gland is balanced by the centrifugal head produced in the water a it is whirled around covering areas of different internal radii on the two faces of the paddle.

The ribs on the sides of the paddle should be ¼ in. deep.

* *Die Dampfturbinen*, 4th Ed., Prof. A. Stodola.
† *Engineering*, August 22, 1913.

If P_1 (fig. 13) = the pressure on the high-pressure side in lbs. per square ft.; P_2 = the pressure on the low-pressure side in lbs. per square ft.; R_1 = inner radius in ft. of the whirling water on the H.P. face; R_2 = inner radius in ft. of the whirling water on the L.P. face; ρ = density of water = 62·3; ω = angular velocity of paddle in radians per second.

Then

$$P_2 - P_1 = \frac{\omega^2 \rho}{240\,A}(R_1^2 - R_2^2) \text{ and } P_3 - P_1 = \frac{\omega^2 \rho}{240\,A}(R_3^2 - R_1^2)$$

The value of A varies from 0·9 to 1·10″.

Although the water gland when first introduced gave rise to troubles, it has proved successful when used in conjunction with a labyrinth packing, for the purpose of preventing air leaking into the turbine casing.

Since a sufficient centrifugal head to form a seal is not developed until the turbine is running at some speed near the normal, it is necessary to steam-seal the glands as the turbine is started up.

The gland must be supplied with a constant stream of water to make up the loss which takes place by evaporation on the vacuum side of the seal. The water is admitted at the periphery of the gland, and should be supplied from a head of about 15 ft. This will, of course, be equal to $(P_3 - P_1)$.

A water gland cannot be used to seal against steam at a pressure above atmospheric, because the water boils and the seal is destroyed.

Tip Clearance Loss.

As has already been pointed out, there is always a difference of pressure over both the fixed and rotating blades of a reaction turbine. In consequence of this there is always a leakage of steam

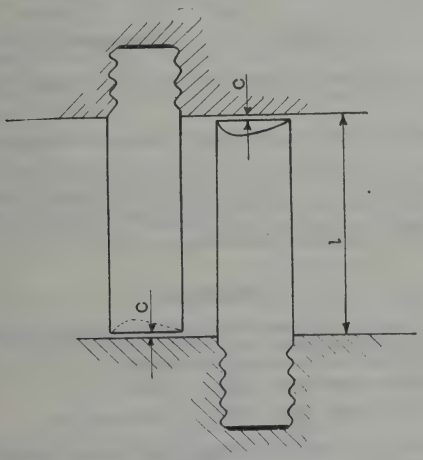

FIG. 14.

at the tips of the blades through the working clearances which have to be provided. In parallel flow reaction turbines there are two principal ways of providing these clearances:

(1) By means of radial clearance reaction blading (see fig. 14).

(2) By means of axial clearance or ' end tightened ' reaction blading (see fig. 15).

The clearance C usually allowed in design varies approximately between the following limit for radial blading, all dimensions being in inches :

$$c = 0{\cdot}0008\,d \text{ to } c = 0{\cdot}0008\,d + 0{\cdot}004\,l + 0{\cdot}015,$$

where,

d = mean diameter of blades ;

l = blade height.

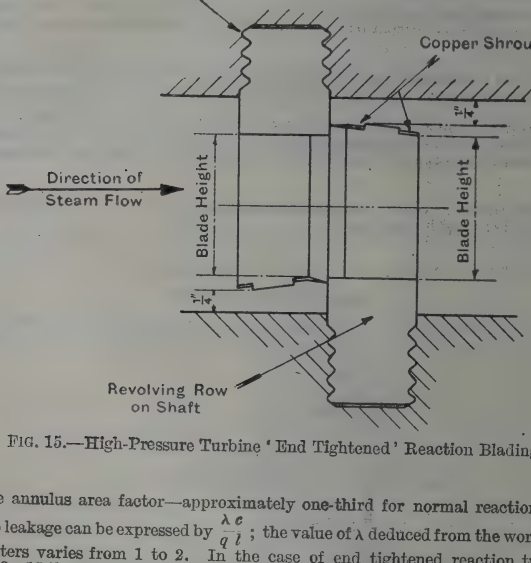

FIG. 15.—High-Pressure Turbine ' End Tightened ' Reaction Blading.

If q is the annulus area factor—approximately one-third for normal reaction blading—the loss due to tip leakage can be expressed by $\frac{\lambda c}{q l}$; the value of λ deduced from the work of a number of experimenters varies from 1 to 2. In the case of end tightened reaction turbine blading illustrated in fig. 15 the fine clearances are arranged in an axial instead of a radial direction. This type of blading is usually confined to the high-pressure end of the turbine, and an adjustable thrust block is provided to enable this clearance to be adjusted.

Bearings.

l = the length of a bearing in inches ; d = diameter of journal in inches ; p = pressure on bearing per square inch projected area ; N = speed of turbine in R.P.M. ; μ = coefficient of friction ; v = peripheral speed of journal in feet per second.

Then the work done in overcoming the bearing friction is

$$\text{Friction work} = \frac{\mu \pi l d^2 p N}{720} \text{ ft. lbs. per sec.}$$

The heat equivalent of this work must be carried away from each bearing if they are to remain at a constant temperature.

According to Lasche's experiments, if $t°$ F. is the final steady temperature of the bearing, the coefficient of friction is given by the following relation :

$$\mu \,.\, p \,.\, (t° - 32°) = 51{\cdot}2.$$

For turbine bearings $t°$ should be from 120° F. to 150° F.

Assuming a temperature of 140° F., which is about an average value, these expressions can be reduced to:

$$\text{Work done in friction} = 3{\cdot}75\left(\frac{l}{10}\right)\left(\frac{d^2}{100}\right)\left(\frac{N}{1{,}000}\right) \text{ b.h.p.}$$

With average bearings bedded in the normal way, it is found that the work done exceeds the amount just given, being usually about twice as great.

One of the striking features of the recent developments in steam turbines has been the successive increases in the specific loadings and rubbing speeds on bearings.

This rating up of bearings has been accompanied by uniform success in all cases where the natural requirements of good lubrication have been safeguarded.

The oil supplied to the bearing has two functions to perform: it must sustain the oil film, and it must flush the bearing copiously to carry away the heat generated in shearing the oil film.

The quantity of oil required by the latter consideration is by far the greater of the two: the necessary amount of oil can readily be estimated from the relation that for ordinary turbine oils—

1·0 b.h.p. in oil friction raises 1·0 gallon of oil per minute by 10° F.

In the average case the temperature of the oil passing through the bearings is such that its temperature rise in passing through the bearing is from 20° to 40° F.; therefore, for 40° F. rise in temperature the oil quantity which should be supplied to a bearing is given by oil which

$$\text{should be supplied} = 2 \times \frac{3{\cdot}75ld^2N}{40 \times 10^5} \text{ gals. per min., or, approximately, } = \frac{2ld^2N}{10^5} \text{ gals. per min.}$$

This represents the minimum quantity required, and may be increased up to double this amount with advantage.

The lengths of turbine bearings vary from $l = 2{\cdot}5d$ to $l = d$, the former value being usual for lightly loaded slow-speed bearings of older design, and the latter being approached with modern high-speed high-rated bearings.

At the present state of the art it is impossible to state the upper limits for permissible loading and rubbing velocity. Bearings are now quite common with loadings up to 110 lbs. per sq. in. and with rubbing velocities up to 130 ft. per sec.

According to modern ideas and practice, the old rules of the form pv = constant are quite unsound—in fact, when p is increased, v can and should be increased.

After leaving the bearings the oil is passed through an oil cooler, where it is cooled to some temperature usually below 110° F., although, of course, the actual temperature depends upon that of the cooling water available.

Turbine bearings give remarkably little trouble, provided the oil is kept clean and there is no tendency to emulsify.

In very small turbines the bearings are sometimes ring-lubricated, and in such cases the peripheral speed should not exceed 40 ft. per sec.; at higher speeds the oil tends to be thrown to the outside of the ring by centrifugal force.

Even in very small turbines there is now a tendency to fit a forced lubrication system provided with an oil cooler.

Centrifugal Stresses in Drums and Discs.

Stresses in thin Ring or Drum.

$$\text{Mean tangential stress} = 2\,(D)^2\left(\frac{N}{1000}\right)^2 \text{lbs./sq. ins.}$$

Solid Parallel-sided Disc.

If U_2 = peripheral velocity at the outside diam. in ft./sec.,

then radial stress at any radius x is $\sigma_r = \frac{4{\cdot}36U_2^2}{100}\left[1 - \frac{x^2}{x_2^2}\right]$ lbs./sq. ins.

and the tangential stress $\sigma_t = \frac{U_2^2}{100}\left[4{\cdot}36 - 2{\cdot}51\,\frac{x^2}{x_2^2}\right]$ lbs./sq. ins.

The maximum stress at the centre is given by

$$\sigma_{r\,max} = \sigma_{t\,max} = \frac{4{\cdot}36\,U_2^2}{100} \text{ lbs./sq. ins.}$$

If the diameter of the disc = D inches, this can be written

$$\sigma_{t\,max} = 0{\cdot}835\,(D)^2\left(\frac{N}{1000}\right)^2 \text{ lbs./sq. ins.}$$

Parallel-sided Disc with Hole in Centre.

At any radius x

Radial stress $\sigma_r = \frac{4{\cdot}36}{100}U_2^2\left[1 + \frac{(x_1^2 - x^2)}{x_2^2} - \frac{x_1^2}{x^2}\right]$ lbs./sq. ins.

Tangential stress $\sigma_t = \frac{U_2^2}{100}\left[4{\cdot}36\left(1 + \frac{x_1^2}{x_2^2} + \frac{x_1^2}{x^2}\right) - 2{\cdot}51\,\frac{x^2}{x_2^2}\right]$ lbs./sq. ins.

Dimensional symbols as shown in fig. 16.

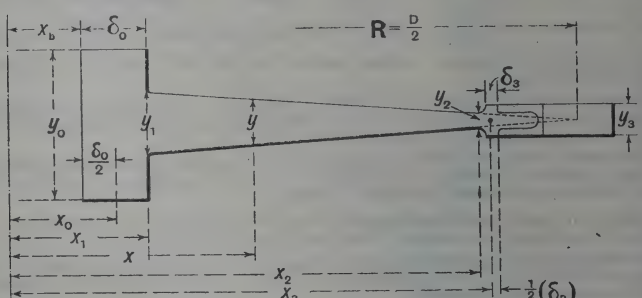

FIG. 16.

Disc with Hyperbolic Profile.

If the profile can be expressed as a hyperbolic function of the form $y = \frac{(\text{constant})}{x^a}$, the following analysis can be used :

Let

ω = angular velocity in radians/sec. $= \frac{N \times 2\pi}{60}$;

E = Young's modulus of elasticity = 30×10^6 lbs./sq. in. for steel;

ν = Poisson's ratio = 0·3 for steel;

σ_3 = load on outer edge of disc due to blade loading in lbs./sq. in. ;

σ_0 = stress at bore due to pinch fit;

μ = mass per unit volume ;

then $$a = \frac{\log\left(\frac{y_2}{y_1}\right)}{\log\left(\frac{x_1}{x_2}\right)}.$$

f $$\psi_1 = \frac{a}{2} + \sqrt{\frac{a^2}{4} + a\nu + 1}, \quad \psi_2 = \frac{a}{2} - \sqrt{\frac{a^2}{4} + a\nu + 1}.$$

and $$a = -\frac{(1-\nu^2)\mu\omega^2}{E[8-(3+\nu)a]},$$

hen radial stress at any point

$$\sigma_r = \frac{E}{(1-\nu^2)}\left[(3+\nu)a x^2 + (\psi_1+\nu)b_1 x^{\psi_1 - 1} + (\psi_2+\nu)b_2 x^{\psi_2 - 1}\right] \quad \ldots.(1)$$

nd tangential stress

$$\sigma_t = \frac{E}{(1-\nu^2)}\left[(1+3\nu)a x^2 + (1+\psi_1\nu)b_1 x^{\psi_1 - 1} + (1+\psi_2\nu)b_2 x^{\psi_2 - 1}\right] \ldots.(2)$$

In order to calculate constants b_1 and b_2, make use of the boundary conditions:—

Extension at outside, where $x = x_2$

$$\xi_2 = \frac{x_3^2}{E\delta_3 y_3}\left(\sigma_3 y_3 + \mu\omega^2\delta_3 y_3 x_3 - \sigma r_2 \frac{x_2 y_2}{x_3}\right) \quad \ldots.(3)$$

Extension at inside, where $x = x_1$

$$\xi_1 = \left(\frac{x_0^2}{E\delta_0 y_0}\sigma_0 y_0 + \mu\omega^2\delta_0 y_0 x_0 + \sigma r_1 \frac{x_1 y_1}{x_0}\right) \quad \ldots.(4)$$

But $$\xi_1 \text{ also} = a x_1^3 + b_1 x_1^{\psi_1} + b_2 x_1^{\psi_2} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

and $$\xi_2 = a x_2^3 + b_1 x_2^{\psi_1} + b_2 x_2^{\psi_2} \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

By equating (3) and (6), also (4) and (5), the two resulting equations can be solved for b_1 and b_2.

When these values are put in (1) and (2) the radial and tangential stresses at any point in the disc can be obtained.

Disc with Straight-sided Taper Profile.

Treating a disc as having a conical profile, Mr. H. M. Martin * has derived a means of arriving at the stresses, which, together with the amendment to incorporate the effect of the hub, as suggested by Mr. B. Hodkinson,† provides a useful method.

The stresses throughout a conical disc are:

$$\text{Radial} = \sigma_r = Tp_c + Ap_1 + Bp_2 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{Tangential} = \sigma_t = Tq_c + Aq_1 + Bq_2 \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where T = stress in a thin ring

$$= 2D^2\left(\frac{N}{1{,}000}\right)^2 \text{ lbs./sq. in. for steel.}$$

D = diameter of completed cone.

$p_c, p_1, p_2, q_c, q_1, q_2$, are given in the curves, fig. 17, p. 1852, co-ordinated with the ratio $\frac{x}{R}$.

The constants A and B have always to be found by writing 'boundary conditions.' Thus at the inner limit of the conical portion where it joins the hub:

$$\sigma t_1 = \left\{\sigma_4 \frac{2x_b^2}{x_1^2 - x_b^2} + 2\left(\frac{N}{500}\right)^2 (0{\cdot}175 x_1^2 + 0{\cdot}825 x_b^2)\right\}$$

$$+ \sigma_{r_1}\left\{\frac{y_1}{y_0}\left[\frac{x_1^2 + x_b^2}{x_1^2 - x_b^2} - 0{\cdot}3\right] + 0{\cdot}3\right\} \ldots\ldots\ldots\ldots\ldots(3)$$

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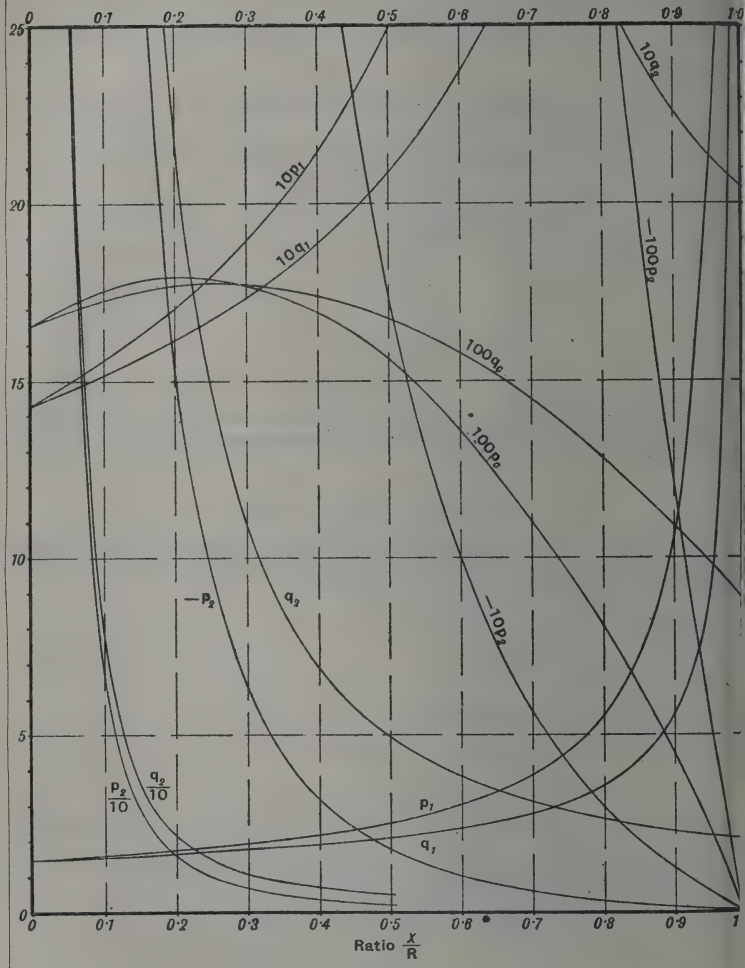
* See *Engineering*, 5th & 26th January 1923.
† See *Engineering*, 31st August 1923 and 7th September 1923.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15
10
5
0
10p1
10q1
10q2
−100p2
100q2
100p2
−10p2
−p2
q2
p2/10
q2/10
p1
q1
Ratio X/R

FIG. 17.

here σ_1 is the 'pinch' pressure inside the bore in lbs./sq. in. At the rim

$$\sigma_{t_2} = \left\{ \frac{\text{Total centrifugal force of blades}}{2\pi\delta_2 y_3} + 2x_3^2\left(\frac{N}{500}\right)^2 \right\} - \sigma_{r_2}\left\{\frac{x_2 y_2}{\delta_2 y_3} - 0{\cdot}3\right\} \quad \ldots (4)$$

Putting in equations (1) and (2) the values of p_0, p_1, p_2, q_0, q_1, q_2, at the inner radius of the me, and using the resulting expressions as σ_{r_1} and σ_{t_1} in equation (3), an equation involving only and B is obtained. Writing similarly for the outer radius of the cone a second equation volving A and B, these constants can be calculated, whence the stresses anywhere in the disc e known.

The stresses throughout the hub then are:

$$\sigma_r = \sigma_{r_1}\frac{y_1(x^2-x_b^2)x_1^2}{y_0 x_1^2 - x^2 x^2} - \sigma_4\frac{x_b^2}{x^2}\frac{(x_1^2-x^2)}{(x_1^2-x_b^2)} + 0{\cdot}825\left(\frac{N}{500}\right)^2\left(x_1^2 + x_b^2 - x^2 - \frac{x_b^2 x_1^2}{x^2}\right).$$

$$\sigma t = \sigma_{r_1}\frac{y_1(x^2+x_b^2)x_1^2}{y_0(x_1^2-x_b^2)x^2} + \sigma_4\frac{x_b^2}{x^2}\frac{(x_1^2+x^2)}{(x_1^2-x_b^2)} + 0{\cdot}825\left(\frac{N}{500}\right)^2\left(x_1^2 + x_b^2 - 0{\cdot}575\,x^2 + \frac{x_b^2 x_1^2}{x^2}\right).$$

Pinch fit for Discs and Drums.

In order to ensure that the wheels shall be tight on the shaft at normal speed, they must be ressed on the shafts with an interference fit at least equal to the elastic expansion of the bore ue to centrifugal stresses.

This condition can be fulfilled without the maximum stresses in the wheel being greater hen the shaft is at rest than the centrifugal stress at normal speed, because in wheels of normal roportions the wheel bore expands during pressing on by only about two-thirds of the pinch llowance, the shaft diameter compressing by the remaining one-third.

Lubrication System.

In all cases except where ring lubrication is employed for small turbines, an oil pump is rovided to maintain a pressure of about 10 lbs. per sq. in. in the lubricating system. It should e emphasised that the actual oil pressure is of secondary importance, the prime object being to ush the bearings with a copious flood of oil, and that for this purpose 2 lbs. per sq. in. may be ufficient in a properly designed system. The oil on leaving the pump passes through a cooler f sufficient capacity to maintain the temperature of the oil leaving the bearings at about 0–68° F. above that of the inlet cooling water, bearing temperatures of 150° F. being quite ermissible. The main oil pump is usually driven by gearing from the turbine shaft, and the ormal pressure is reached when the turbine motor is running at about one-third the normal peed. A hand pump is usually provided to supply oil under pressure during starting up or hutting down, when the speed of the set is less than one-third the normal. An oil strainer hould be placed on the suction side of the pumps to prevent grit being circulated. Two to three allons of oil should be taken out of the tank daily and carefully filtered, the level of the tank eing kept constant by making up with freshly filtered oil or, when necessary, new oil. Once n each twelve months the oil tank and all accessible portions of the lubricating system should e emptied and cleaned; the tank should then be filled sufficiently with paraffin oil to enable the whole system to be flushed by operating the hand pump. The paraffin oil dissolves any gummy natter which may have deposited from the lubricating oil and thoroughly flushes away all dirt o the oil tank; the paraffin can then be removed and new or freshly filtered oil put in. These imple precautions will result in a real economy in oil consumption and a freedom from troubles nd maintenance charges which will amply repay the trouble involved.

There is a large number of lubricating oils supplied by makers of standing, all of which vill give satisfactory results in operation. For turbines driving geared installations an oil to the ollowing specification has been found to give satisfactory results:

Heavy turbine oil.

The specific gravity at 60° F. should be from 0·89 minimum to 0·91 maximum.
The flash point taken by a closed test should not be less than 390° F.
The viscosity measured with a Redwood viscometer should be within the following limits:

At 68° F.	Minimum 650 seconds.	Maximum 800 seconds.
At 140° F.	„ 90 „	„ 100 „

The acidity expressed as SO_3 should not exceed 0·005 per cent.

One of the most important properties lies in the freedom of a suitable oil from a tendency to form an emulsion. Suitable oils should satisfactorily pass the following test:

When steam is passed into 100 c.c. of oil until the total volume of the condensate and oil measures 200 c.c., the whole of the oil shall separate out within ten minutes, leaving the water clear.

The sludge value of the oil carried out, according to Dr. Michie's test, should not exceed 1·2 per cent.

The following specification would apply to oils suitable for steam turbines driving generators, etc., direct:

Light turbine oil.

The specific gravity at 60° F. shall be 0·87 minimum to 0·89 maximum.
The flash point of the oil measured by a closed test shall not be less than 365° F.
The viscosity measured with a Redwood viscometer shall conform to the following :

At 68° F.	Minimum 300 seconds.	Maximum 400 seconds.
At 140° F.	,, 60 ,,	,, 75 ,,

The acidity expressed as SO_3 shall not exceed 0·005 per cent.
When steam is passed into 100 c.c. of oil until the total volume of condensate and oil measures 200 c.c., the whole of the oil shall separate out within five minutes, leaving the water clear.
The sludge value, measured by Dr. Michie's test, shall not exceed 1·2 per cent.

See also ' Lubrication,' p. 1062.

Critical Speeds of Turbine Shafts.

At the critical speed of a loaded shaft, a small disturbance sets up vibrations which may reach a dangerous magnitude. For a uniform shaft, when the obliquity of the loading masses may be neglected, the critical speed coincides with the natural frequency of transverse vibration.
Although turbines have been run for considerable periods at their critical speeds without failure, this is a very dangerous proceeding and should be carefully avoided. It follows, therefore, that the critical speed should always be estimated, and should be at least 30 per cent. removed from the running speed.
This particularly applies to turbines of the disc type, and the calculation can be made with some degree of certainty. In drum turbines, the calculation is much more difficult, but in such cases as usually arise the critical speed is much above the running speed.
Table V. gives the formula for calculating the critical speeds of shafts of uniform diameter in certain standard cases.
Dunkerley has evolved theoretically, and demonstrated experimentally, a law from which can be determined the critical speed of a loaded system which corresponds to any combination of the standard cases.
By means of Table V. in conjunction with Dunkerley's formula, the first critical speeds of sensibly uniform shafts can be approximately calculated for any combination of loading, and any method of fixing the shaft at the bearings.
Thus if a rotor consists of a uniform shaft loaded with weights $W_2 W_3$ etc. as external loads,

n_1 = the critical speed of the shaft without the external loads ;

n_2, n_3, etc. = the critical speed of a massless shaft loaded with weights $W_2 W_3$ etc. ;

then the critical speed N of the system is given by

$$\frac{1}{N^2} = \frac{1}{n_1^2} + \frac{1}{n_2^2} + \frac{1}{n_3^2} + \ldots$$

In those cases of rotors having shafts stepped in diameter, as is usually the case in practice, the method already given is only a rough approximation, owing to the difficulty of judging the diameter of the equivalent uniform shaft.
Such cases may be dealt with by obtaining the maximum static deflection y of the shaft under various loads, by the graphical methods due to Mohr.
Then if

N = critical speed in R.P.M. ;

$N^2 y = C$, where C is constant.

For impulse turbine shafts supported in bearings which do not fix the direction of the shaft Mr. K. Baumann* has found that the value of C varies from 37,700 to 38,000 if y is in inches.

See also p. 1079.

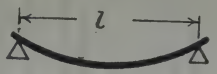
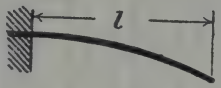
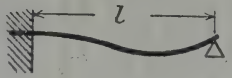
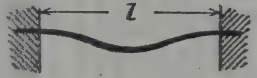
MATERIALS FOR TURBINE CONSTRUCTION.

The use of such high peripheral speeds as are common in turbine practice introduced a new consideration into machine design ; because, unlike the conditions existing in reciprocating engine parts, the stresses in the various members are in the main due to centrifugal forces resulting from their own rotation. The stresses in a given turbine will, therefore, be proportional to the square of the numbers of revolutions per minute, and to the density of the material.

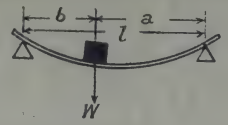
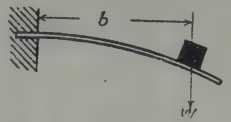
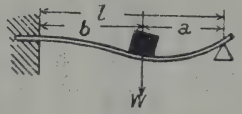
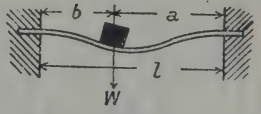
With an increase in the possible speed of rotation of a given turbine, the efficiency will in general be improved, since the average ratio $\frac{U}{C_0}$ in the various stages will be increased, or a greater heat drop can be utilised with the original efficiency.

* *Recent Developments in Steam Turbine Practice*, Inst.E.E., April 1912.

Uniform Shaft with Distributed Load.

Method of Support.	Critical Speed in R.P.M.
	$N = \frac{1,853}{l^2}\sqrt{\frac{E.I}{w}}$
	$N = \frac{662}{l^2}\sqrt{\frac{E.I}{w}}$
	$N = \frac{2,960}{l^2}\sqrt{\frac{E.I}{w}}$
	$N = \frac{4,200}{l^2}\sqrt{\frac{E.I}{w}}$

Concentrated Load Carried by a Weightless Shaft.

Method of Support.	Critical Speed in R.P.M.
	$N = 325\sqrt{\frac{E.I.l}{W.a^2.b^2}}$
	$N = 325\sqrt{\frac{E.I}{W.b^3}}$
	$N = 246\sqrt{\frac{E.I.l^2}{W.a^3.b^3}}$ Approximate; holds if load near centre.
	$N = 325\sqrt{\frac{E.I.l^3}{W.a^3.b^3}}$ Approximate; holds if load near centre.

N = Critical Speed in R.P.M.
w = Weight of Shaft or other Distributed Load in lbs. per inch run.
W = Weight of Concentrated Load in lbs.
a, b, or l = Length of Span in ins.

E = Young's Modulus of Elasticity in lbs. per sq. in.
I = Transverse Moment of Inertia in inch units = $\frac{\pi d^4}{64}$ for Round Shafts.
d = Diam. of Shaft in ins.

Note Units employed.

On the other hand, the available heat drop per stage might be increased, so that the required number of stages for a given efficiency can be correspondingly reduced, or with the same number of stages the mean diameter of the blades can be reduced inversely as the revolutions per minute, both of which alternatives would result in a cheaper turbine.

Hence, it will be seen that in turbine work it is eminently desirable to use the highest possible peripheral speeds, the limit of which will be determined by the ultimate strength of the material employed.

British Electrical and Allied Manufacturers Association's Specifications for Turbine Forgings, Etc.

The following particulars have been extracted from the Association's specifications for forgings for turbine discs, shafts, and general forgings for use on land turbines.

The following table gives the minimum physical properties acceptable for each of four grades of materials:

Grade	I.			II.			III.			IV.		
*	L.	T.	R.	L.	T.	R.	L.	T	R.	L.	T.	R.
Minimum u.t. tensile tons per sq. in.	30	30	30	35	35	35	40	40	40	48	48	48
Yield point	15	15	15	17½	17½	17½	20	20	20	30	30	30
Minimum elongation per cent.	30	23	20	25	20	18	22	18	16	17	14	12
Minimum reduction in area, per cent.	45	40	38	40	35	32	35	32	30	40	35	30
Bending Angle	180°	160°	150°	180°	150°	135°	180°	150°	120°	180°	130°	100°
Test radius	⅜″	⅜″	⅜″	½″	½″	½″	¾″	¾″	¾″	¾″	¾″	¾″

* L.=Longitudinal. T.=Tangential. R.=Radial.

Grades Nos. I, II, and III are for carbon steels, whereas grade IV applies to an alloy steel. A margin of 3 per cent. below the reductions in area given in the above table is allowed to the steel maker providing this is compensated by a corresponding increase of 3 per cent. on the elongation.

Bend Tests.

A cold bend test is made upon test pieces having a rectangular section of ¾ in. by ¾ in. These test pieces shall be machined and the edges rounded to a radius of $\frac{1}{16}$nd. The test pieces shall be bent over the thinner section, and the bending shall be done by pressure or by blows. The test pieces must withstand being bent around the radii and through the angles given in the table without fracture.

Additional Test before Rejection.

If either tensile or bending test fail to fulfil the test requirements, and the inspector agrees that the test piece does not clearly represent the quality of the material, two duplicate specimens may, if the maker wishes, be tested, and if the results from both are satisfactory the quality of the material shall be judged therefrom, and not from the original test which failed. If, however, either of the duplicate tests fail the material represented will not be approved, and the manufacturer shall have the option of retreating and again presenting for test.

Table VI. gives the physical properties of steels used for steam turbine blading, the data for which have been supplied by the courtesy of Messrs. Thomas Firth & Sons, of Sheffield.

The blades of Parsons turbines are commonly of brass, the usual mixture being alloy of 63 per cent. copper to 37 per cent. zinc, having an ultimate strength of 20 tons per sq. in., an elastic limit of 12 tons per sq. in., and an elongation of 40–50 per cent.

The blades of impulse turbines are usually made of 5 per cent. nickel steel, although bronze blades are sometimes called for.

The physical properties of a bronze are greatly dependent on the treatment to which it may have been subjected, cold working having the effect of raising the ultimate strength and reducing the ductility.

Such an increase in the ultimate strength is to a large extent artificial, the material returning to its virgin state under the influence of high temperature or vibration.

The importance of this effect will be emphasised by the figures published by M. Breuil† and reproduced in Table VII. respecting the effect of temperature on some materials used for blading.

† *Engineering*, July 5, 1912.

TABLE VI.—PHYSICAL PROPERTIES OF STEELS USED IN STEAM TURBINE CONSTRUCTION.

Nature of Material.	Yield Point, Tons per sq. in.	Ultimate Strength, Tons per sq. in.	Elongation on 2-in. Gauge Points.	Purpose for which Material is Employed.	Remarks.
			Per Cent.		
5 per cent. nickel steel sheets	25	40	20	Turbine blades and shrouding strips supplied mild in sheets for stamping and bending	—
5 per cent. nickel steel sheets	—	35–42	20–24	Turbine blades and shrouding strips	Higher carbon content than above
5 per cent. nickel steel bars	30–35	40–45	25	To be drawn into blade sections	—

For some years so-called rustless irons and steels have been used for turbine blades. These aterials can now be regarded as of proved usefulness for turbine blading, owing not only to eir comparatively high resistance to erosion and corrosion, but to their attractive mechanical operties.

Rustless steels are a chromium alloy, usually for turbine blading of composition within the llowing limits : carbon, 0·10 to 0·40 per cent. ; chromium, 12 to 15 per cent. Ultimate strength,) to 50 tons/sq. in. ; yield point, 30 tons/sq. in ; elongation, 25 per cent. ; izod test, 25 ft./lbs.

Most non-ferrous alloys suffer under high temperatures in a loss of mechanical strength and ther desirable physical properties.

The following table illustrates the effect of temperature on some typical materials :

TABLE VII.—MATERIALS FOR TURBINES.

Nature of Material.	Elastic Limit, Tons per Sq. In.	Ultimate Strength. Tons per Sq. In.	Elongation.	Temperature.
			Per Cent.	
70 per cent. copper . 28 per cent. pure zinc .	34·9	36·2	11	Ordinary
	34·3	36·2	8·5	100° C.
	32·7	34·3	11	200°
	22·2	24·1	30	300°
	7·6	12·7	75	400°
85 per cent. copper . 15 per cent. manganese .	38·7	41·3	10·2	Ordinary
	36·8	40·0	10·5	100° C.
	37·5	41·0	11·0	200°
	32·0	36·8	21·0	300°
	21·0	24·1	68·0	400°

From this it follows that before figures relating to the strengths of alloys can be accepted as orking data the effect of temperature and the previous history of the specimens fractured in the est should be known.

Phosphor bronze has been largely employed for impulse turbine blading when conditions were uch that abnormal corrosion was expected, and gives satisfactory results with dry steam where he steam velocities are moderate and the stresses induced in the blades relatively small. The ollowing represent the average properties of this material as given by Mr. W. B. Parker.*

Maximum tensile stress . .	Not under 24 tons per sq. in.
Elastic limit	„ 12 „
Elongation on 2 ins. . .	13 per cent.
Modulus of elasticity . .	16,000,000 to 17,800,000 lbs. per sq. in. within a stress range of 0 to 10 tons per sq. in.

The average composition is as follows :

Tin	From 3 to 5 per cent.
Copper	From 94·9 to 96·9 per cent.
Phosphorus	Not less than ·1 per cent.

* *Steam Turbine Blading*, Institute of Metals, September 1915.

Nickel-copper alloys are now being used for the manufacture of turbine blading, the be known being Monel metal (*Messrs. G. & J. Weir, Ltd.*). This metal when drawn into the form turbine blading has the following properties :

	At 60° F.	At 750° F.
Ultimate stress	41·9 tons per sq. in.	36·4 tons per sq. in.
Yield point	37·7 „	31·2 „
Elongation on 2 ins.	24 per cent.	16·5 per cent.
Reduction of area	60 „	60 „

Modulus of elasticity : 22,500,000 lbs. per sq. in. over a stress range of 1 to 15 tons per sq. in.

The composition (tests by the National Physical Laboratory) is as follows :

Nickel	67%
Copper	28%
Iron	1–2%
Manganese	1–2%
Lead, tin, and antimony	Nil.
Also silicon and carbon	

See also p. 2718.

PROCEDURE IN STARTING UP LARGE TURBINES.

While the general guidance given in the following remarks is, in the main, intended apply to relatively large units (say turbines of 10,000 kw. capacity and larger), the procedu is an excellent one to follow on smaller sets.

The time intervals indicated can be reduced as the size of the set is reduced.

First operation.—Start up condensing plant and obtain 20 ins. to 24 ins. vacuum.

Second operation.—To warm up turbine, open stop valve sufficiently to start it rotating, th close it down until a steady speed of not more than 10 per cent. of the normal speed is obtaine Maintain this condition for ten to fifteen minutes during which vacuum is increased.

Third operation.—Increase the speed by gradual and steady increments at a rate of fro 5 per cent. to 10 per cent. per minute.

Fourth operation.—Synchronise set and switch on to bus bars.

Fifth operation.—Build up load on set at a steady rate of from 5 to 10 per cent. per minute

The procedure here outlined is a safe one to be recommended in normal practice ; in an em gency the time intervals can, of course, be reduced.

TURBINE TEST CORRECTIONS FOR STEAM CONDITIONS.

While it is rarely possible to make tests upon a turbine under the exact steam conditio for which it has been designed, the performance which may be expected under the design conditions can be estimated from the steam consumption actually obtained during the test.

The usual practice consists in correcting the test consumption for the difference between t steam superheat, pressure, and vacuum during the test, and that which is specified for the turbi

These 'corrections' are arranged as coefficients by which the observed consumptions mu be multiplied, and are determined for any steam conditions from consideration of the chan in available heat-drop and turbine efficiency which take place with any change in that co dition.

A very complete list of these corrections has been published by Mr. K. Baumann,* and t values he gives are incorporated in this section.

Superheat Correction.

Where the superheat is different from that specified, the following corrections should made, both for high-pressure or low-pressure turbines.

Between :—

0–100° F. superheat 1 per cent. improvement of steam consumption for every 10° F. sup heat.

100–200° F. superheat 1 per cent. improvement of steam consumption for every 12° F. sup heat.

200–300° F. superheat 1 per cent. improvement of steam consumption for every 14° F. sup heat.

Correction for Initial Wetness of Steam.

For each 1 per cent. wetness the steam consumption, if measured as condensed water, w be 2 per cent. too high.

* *Recent Developments in Steam Turbine Practice*, Inst.E.E., April 1912.

Pressure Correction.

The correction which is to be made for the pressure depends upon whether the change in ssure is before the stop valve or before the nozzles.

Thus, if in the case of a high-pressure turbine working on a constant generator load the ssure before the stop valve is raised, say 10 lbs. per sq. in., the governor valve closes slightly, the pressure before the nozzle will be very little altered, the only result being that the steam hrottled to a greater extent than formerly.

The effect of such an increase of pressure will be that the steam consumption will be improved the small amount corresponding to the superheat due to the additional throttling.

In such cases the steam consumption will be improved by 0·5 per cent. for every 10 per cent. rease of pressure.

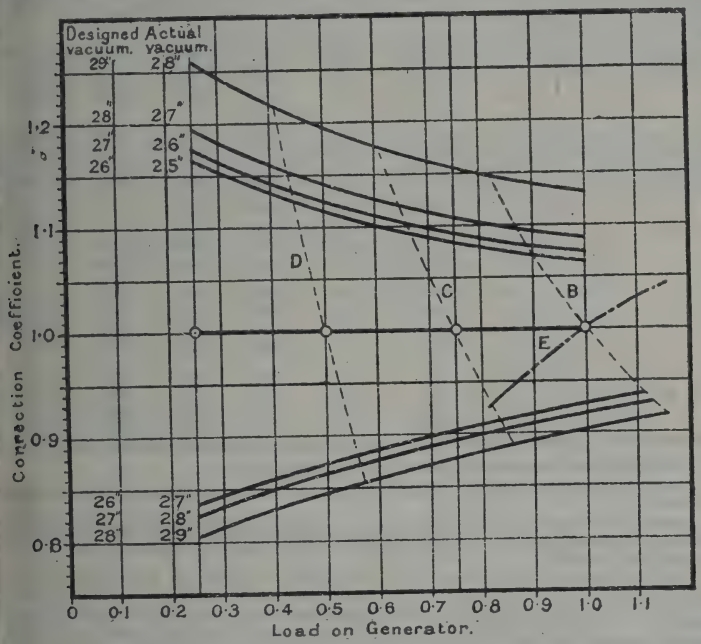


FIG. 18.—Vacuum Correction for Low-pressure Turbines.

When, on the other hand, the pressure before the nozzles is increased, the correction is of lite different magnitude and is:

For high-pressure turbines, an improvement of 1½ per cent. in steam consumption for 10 per cent. increase in pressure.

For low-pressure turbines, an improvement of 4 per cent. in steam consumption for 10 per cent. increase in pressure.

Vacuum Correction.

In any test, the correction for vacuum is usually of greater magnitude than that for pressure superheat. Although every care has been exercised in estimating these corrections, it is viously desirable that the total correction should be as small as possible, and if only for this ason every effort should be made to obtain during a test a vacuum as little different as practicable om that for which the turbine was designed.

Table VIII. gives the correction for vacuum which should be employed for various designed onditions with high-pressure turbines or mixed-pressure turbines, working with high-pressure team.

TABLE VIII.—VACUUM CORRECTION FOR HIGH-PRESSURE AND MIXED-PRESSURE TURBIN

Partial loads are expressed as fractions of the full load for which turbine is designed.

The correction is to be made when the turbine is run on a vacuum other than that for wh it was designed.

Designed Steam Conditions.			Theo. Corr. for 1 in. Vac. Variation.	Actual Correction for 1 in. Vac. Variation.								Range o Vac. Variatio Ins.
Pressure, Lbs. per sq. in. g.	Supt. °F.	Vacuum ins.		H.P. ⅝ Load	M.P. ½	H.P. ¾	M.P. ¼	H.P. ½	M.P. ¼	H.P. ¼	M.P. ½	
180	150	26	4·4	3·0		3·8		4·8		6·5		24—26—2
		27	5·5	3·7		4·6		5·6		7·6		25—27—2
		28	7·0	5·1		6·2		7·5		9·7		26—28—2
		29	10·3	7·5		8·5		10·2		12·8		28—29
140	150	26	4·7	3·2		4·2		5·0		6·9		24—26—2
		27	5·8	3·9		4·8		5·9		8·0		25—27—2
		28	7·3	5·3		6·3		7·8		10·2		26—28—2
		29	11·0	7·8		8·8		10·7		13·5		28—29
100	150	26	5·0	3·5		4·5		5·5		7·5		24—26—2
		27	6·2	4·2		5·3		6·4		8·7		25—27—2
		28	7·9	5·7		6·6		8·4		10·9		26—28—2
		29	11·9	8·5		9·5		11·5		14·5		28—29
75	150	26	5·4	3·8		4·8		6·0		8·0		24—26—2
		27	6·6	4·6		5·6		6·9		9·4		25—27—2
		28	8·5	6·1		7·1		9·0		11·6		26—28—2
		29	12·7	9·1		10·3		12·3		15·5		28—29
50	150	26	5·9	4·3		5·2		6·7		8·7		24—26—2
		27	7·2	5·0		6·0		7·7		10·3		25—27—2
		28	9·2	6·6		7·7		9·9		12·6		26—28—2
		29	13·5	9·9		11·3		13·3		16·8		28—29

The Theoretical Correction is given for 150° F. Superheat.

The actual correction given for various loads can be used for any superheat between saturat and 300° F.

It should be noted that at any load and for the same designed steam conditions and act vacuum, the correction in the case of a mixed-pressure turbine (M.P.) is greater than for a hi pressure turbine (H.P.).

Thus, for example, the correction for a M.P. turbine at full load and working with hi pressure steam is the same as for a H.P. turbine on half load. The assumption underlying t is that the M.P. turbine is designed to give the same output on H.P. as on L.P. steam, and th therefore, the conditions in the nozzles and blading of the L.P. end of the M.P. turbine are same as that of a H.P. turbine designed for twice that output. Changes in vacuum only aff the conditions in the last few stages of a turbine, and these in a M.P. turbine on H.P. steam operating under the same conditions as those of a H.P. turbine at half load.

Vacuum corrections for low-pressure turbines or for mixed-pressure turbines working w low pressure steam are still larger than those already considered.

In fig. 18 a coefficient will be found for various loads on the generator which is the ratio :—

$$\frac{\text{(Steam consumptions for 1 in. } \begin{matrix}\text{above}\\ \text{or}\\ \text{below}\end{matrix} \text{ the designed vacuum.)}}{\text{(Steam consumption for the designed vacuum.)}}$$

While the corrections as given above can be applied to the generality of cases, special con tions may arise where corrections must be separately considered.

Thus, it is possible to obtain little or no benefit by increasing the vacuum with a turbi designed for a certain load at a certain vacuum and modified to operate on a considerably higt load and a higher vacuum; in such a case the velocity in the exhaust would be exceedingly hig and may even approximate to sound velocity.

In back pressure turbines, or the high pressure end of reducing turbines, all corrections will considerably larger than those given above, and these require separate consideration in each cas

It cannot be too strongly emphasised that every endeavour should be made to arrange t test conditions in such a way that all corrections are as small as possible.

TYPES OF TURBINES.

Turbines may be classified according to the steam conditions under which they operate. It ould be noted that the energy available in adiabatic expansion of steam from 180 lbs. per sq. g. and 100° F. superheat to 28 ins. vacuum, is about twice that available if the expansion is ried down to atmospheric pressure only. Hence the addition of condensing plant approxi- tely doubles the amount of work which can be done per lb. of coal, without necessitating any rease in boiler capacity.

High-Pressure Turbines.

High-pressure turbines take their steam directly from the boilers, and expansion takes place the turbine down to the pressure in the condenser. This may be regarded as the fundamental ss of turbine. The steam conditions are usually 350–150 lbs. per sq. in. g. pressure, 0°–300° F. perheat, and 27½ ins. to 29 ins. vacuum (30 ins. Barm.). Of course, the range of possible ditions is greater than these: for instance, in collieries and steelworks, steam pressures of)–50 lbs. per sq. in. are to be met with, while steam temperatures of 800° F. will probably adopted in the near future.

Low-Pressure Turbines.

Low-pressure turbines take their steam at about atmospheric pressure, the source almost ariably being the exhaust from non-condensing reciprocating engines. The initial steam essure is usually from 20–15 lbs. per sq. in. abs., and should in all cases be above atmospheric essure in order to eliminate the risk of air leakage into the steam pipe line. Low-pressure rbines require no governor gear if connected either mechanically or electrically to the recipro-

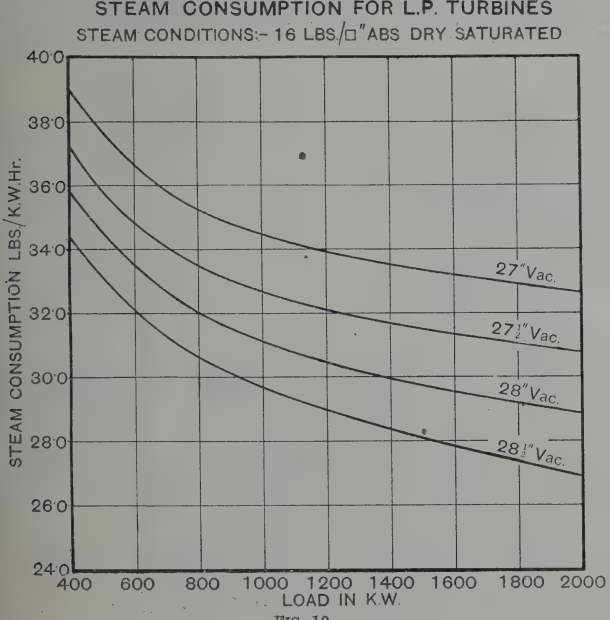


FIG. 19.

ting engine from which they obtain their steam. In the event of the engine being shut down e turbine is supplied with steam from the boilers through a reducing valve.

The efficiency with which low-pressure steam can be used naturally depends not only on the ze and speed of the plant, but also on its capacity and costliness. As an average the steam nsumption shown in fig. 19 can be used for estimating purposes when dry steam is supplied to a w-pressure turbine at a pressure of 16 lbs./sq. in. absolute.

Back-Pressure Turbines.

Back-pressure turbines take their steam directly from the boilers and exhaust at or abov atmospheric pressure. Such turbines may be used in cases where the exhaust steam is require for heating purposes, and the back pressure usually ranges from 1 to 20 lbs. per sq. in. g.

In certain cases the back pressure may be as high as 40 lbs. per sq. in. g.

Back-pressure turbines are used to a considerable extent to drive the auxiliaries, their exhau steam being utilised for feed heating ; by this means the losses in the turbine are recovered in th feed heater, and an overall efficiency for back-pressure turbine and feed heater of over 90 per cen is obtained.

Mixed-Pressure Turbines.

When L.P. steam is utilised in an L.P. turbine it is obviously desirable that the turbine set ma be operated at will independently of the reciprocating engines from which it obtains its steam, a that in the event of the engine being shut down the turbine may operate with reasonable economy This becomes possible by the addition of what is really a B.P. exhausting into the L.P. turbin and having a common casing and spindle. This combination forms a mixed-pressure turbin which can operate not only on either H.P. or L.P. steam, but if sufficient L.P. steam is not availab to carry the load, the deficit is automatically supplied by admitting H.P. steam to the H.P. en of the turbine.

The governor gear is automatic and adjusts itself so that all the L.P. steam available is us in preference to H.P. steam.

In mixed-pressure turbines the governor gear is of special importance, as for successful workin in parallel with other alternators the changes from L.P. steam to H.P. steam must be effecte without any appreciable change in speed or load of turbo-alternator.

Reducing Turbines.

With a B.P. turbine the amount of steam available for heating purposes, and the work don by the turbine, are directly connected. In most installations it is desirable to be able to vary the quantities independently of each other, and to meet this demand 'Reducing' turbines we introduced.

Power Obtained from Heating Steam.

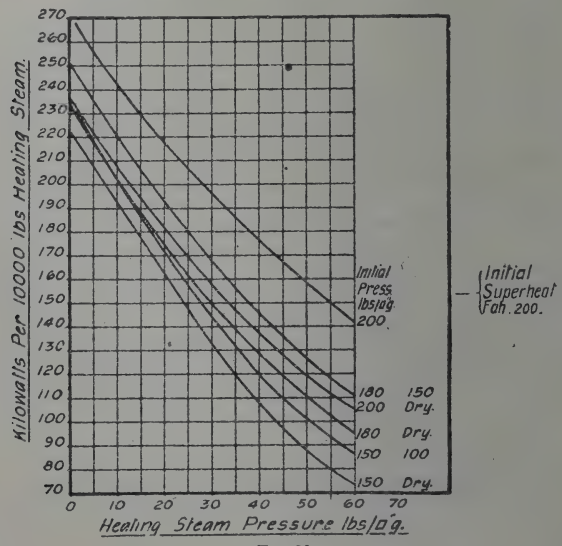


Fig. 20.

An R.P. turbine consists of a B.P. turbine to which an L.P. turbine is added. The B. turbine is designed for the maximum amount of steam required by the heaters it supplies.

As the demand for heating steam decreases, an automatic governor gear by-passes the supp to the L.P. end of the turbine, and at the same time the supply of steam to the H.P. end decreased.

In this way the load the generator can carry is independent of the amount of heating steam uired.

The governor gear should be operated in such a way that the pressure of the heating steam ains constant.

An increasing demand for this type of machine has arisen in recent years as a result of the remely economical results which can be obtained in those manufacturing works requiring h electrical power and heating steam.

In order to obtain the best result the pressure at which steam is taken from the turbine for ting purposes should be as low as possible in view of the requirements of the heating cess. The effect of back pressure on the consumption of heating steam can be seen from following table, while the variation in the power which can be obtained from back pressure reducing turbines is shown in fig. 20 for various steam conditions.

In recent years marked improvements have been made in the efficiency which can be obtained H.P. ends of steam turbines. Whereas formerly the first step in expansion was accomplished h an efficiency of from 50 to 60 per cent., efficiencies of from 70 to 80 per cent. can now be lised in turbines of reasonable size and of other than the cheapest construction. It follows that back pressure or reducing turbines of some considerable size, elaboration and costliness, the kw. tainable per 10,000 lbs. of steam per hour can, in such cases, exceed those given in fig. 20 by ne 25 per cent.

TABLE IX.

RCENTAGE CHANGE IN STEAM CONSUMPTION OR WORK CAPACITY OF HEATING STEAM FOR A CHANGE IN HEATING STEAM PRESSURE OF 5 LBS. SQ. IN. G.

Initial Pressure. lbs. sq. in.	Initial Superheat. Degrees F.				
	Dry.	50	100	150	200
200	6·85	6·5	6·15	5·8	5·45
190	7·3	6·92	6·52	6·15	5·77
180	7·75	7·35	6·9	6·5	6·1
170	8·22	7·75	7·25	6·82	6·37
160	8·7	8·15	7·6	7·15	6·65
150	9·25	8·65	8·1	7·5	6·95

ECENT DEVELOPMENTS IN STEAM CONDITIONS AND MODIFICATION IN OPERATING CYCLE.

The component elements in a modern steam turbine and boiler plant are indicated in fig. 21.*

The various parts shown of steam turbine, regenerative feed heaters A, B, C, and D, economisers,

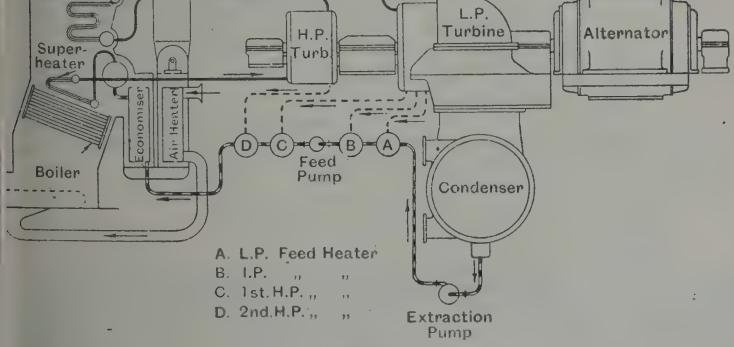


FIG. 21.

* This figure, together with the others used in this Section, is taken from *The Economic alue of Increased Steam Pressure*, by H. L. Guy. Institution of Mechanical Engineers, 1927.

boiler, superheater, resuperheater and air preheater, may be used all together, or one or othe the various elements may be omitted. For instance, the resuperheater appears desirable if ste pressures above 500 lbs./sq. in. are used, while air preheating will usually be employed if the f water is heated above 230° F. by the turbine feed heaters. In order to consider the influence these elements on plant efficiency, the influence of steam pressure, regenerative feed heating a resuperheating will be considered separately.

Increased Steam Pressure.

The influence of steam pressure on heat consumption of the steam turbine itself is shown fig. 22 by curve G; while curve M shows the corresponding gain when the effect of the turb and boiler auxiliaries is taken into account. The meaning of the remaining curves in the figu will be evident.

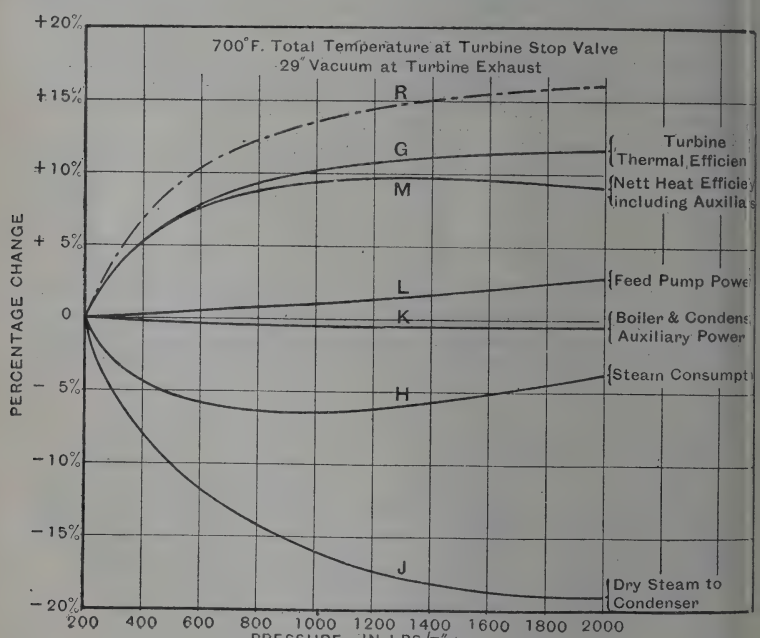


Fig. 22.

Curve R shows the way in which the gain flowing from the use of increased steam pressure increased by the use of four stages of regenerative feed heating, and therefore represents t relative gain which can be realised in a fairly elaborate modern installation of reasonable capacit The last reservation arises from the fact that the gain which can be obtained by using increas pressure depends very much on the capacity and speed of the installation. The figures giv apply to an installation of about 20,000 k.w. capacity if the speed is 3,000 r.p.m., or 40,000 k capacity if the speed is 1,500 r.p.m. For much larger installations the returns will be ver slightly increased. For sensibly smaller capacities the gains will be materially reduced. Fro curve R the following table has been deduced, showing the pressure steps and pressures whic correspond to definite gains in coal consumption of 3 per cent. each time:

INCREMENTS OF PRESSURE FOR 3 PER CENT. THERMAL GAIN.

Accumulated Thermal Gain %	Corresponding Increment in Pressure Lbs. sq. in. g.	Change in Pressure Lbs. sq. in. g.	Approximately Corresponding Pressure Lbs. sq. in. g.
3	65	200–265	250
6	95	265–360	350
9	140	360–500	500
12	255	500–755	750
15	570	755–1325	1300

The absolute values of the most important quantities entering into the calculation of the curves ig. 22 are given in Table X. The figures given in lines 21 and 22 under 'Plant Efficiency' are ed on a generator efficiency of 96 per cent. and a boiler efficiency of 84 per cent. It should be ted that all the preceding figures are based on an initial temperature of 700° F. and on a vacuum 29″. The relative position is not sensibly affected by increased steam temperature, but net gains increase as the vacuum is decreased. For instance, the gain with 28″ vacuum at 00 lbs./sq. in. is some 2 per cent. greater than that shown for 29″ vacuum.

Regenerative feed heating.

In recent years the practice of heating the feed water progressively by feed heaters supplied h steam tapped from the main turbine at various points in the expansion has developed until as become standard. From one to four feed heaters are used, depending on the size and

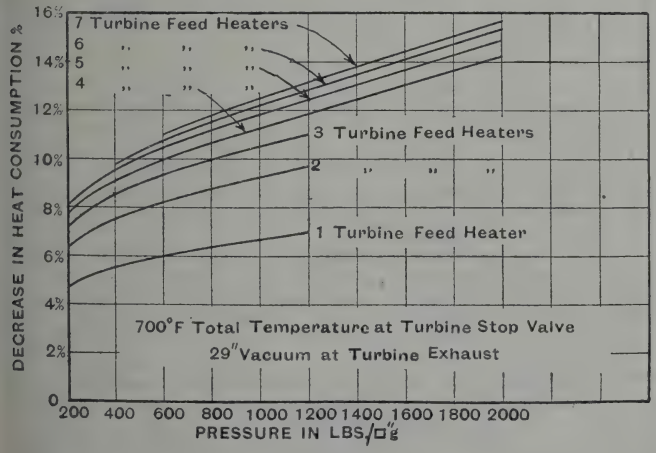


FIG. 23.

oration of the plant. The gains in coal consumption which can be expected at various steam ssures with from one to seven feed heaters are shown on fig. 23 for installations including an nomiser and air preheater. If no air preheating is done, these gains are reduced to about two- rds of those shown in this figure.

TABLE X.—VARIATION IN EFFICIENCY WITH STEAM PRESSURE.
(700° F., 29 in. Vacuum.)

1	Initial pressure (Lbs./sq. in. g.)	200·0	285·3	385·3	485·3	585·3	785·3	985·3	1185·3	1385·3	1585·3	1785·3	1985·3
2	Initial pressure (Lbs./sq. in. Abs.)	214·7	300·0	400·0	500·0	600·0	800·0	1000·0	1200·0	1400·0	1600·0	1800·0	2000·0
3	Superheat (°F.)	321·1	282·2	254·5	231·4	211·7	179·1	152·7	130·3	110·7	93·3	77·6	63·2
4	Total heat from 78·9° F. (B.Th.U/Lb.)	1330·7	1326·2	1321·1	1315·9	1310·7	1300·4	1290·0	1279·2	1269·4	1259·0	1248·7	1238·4
5	Available heat to 29-in. vac. (B.Th.U/Lb.)	453·2	470·2	484·1	494·1	501·6	512·3	519·1	523·6	526·3	527·7	528·4	528·2
6	Theoretical thermal effy. (%)	34·06	35·45	36·64	37·55	38·27	39·39	40·24	40·91	41·46	41·91	42·32	42·65
7	Reheat factor	1·0601	1·0597	1·0594	1·0592	1·0594	1·0604	1·0620	1·0624	1·0666	1·0686	1·0701	1·0711
8	Final dryness	0·9050	0·8875	0·8720	0·8595	0·8490	0·8300	0·8130	0·7980	0·7855	0·7755	0·7675	0·7615
9	Turbine losses factor	1·0000	0·9952	0·9910	0·9878	0·9852	0·9810	0·9778	0·9752	0·9729	0·9711	0·9694	0·9679
10	Comparative turbine effy. (%)	80·00	79·04	78·10	77·33	76·69	75·53	74·60	73·79	73·07	72·44	71·86	71·39
11	Comparative thermal effy. of turbine (%)	27·25	28·02	28·62	29·04	29·34	29·75	30·02	30·19	30·30	30·36	30·41	30·45
12	Power to feed pump (%)	0·35	0·45	0·58	0·71	0·85	1·14	1·42	1·74	2·07	2·41	2·77	3·15
13	Power to boiler auxiliaries (%)	1·50	1·46	1·43	1·41	1·39	1·37	1·36	1·35	1·35	1·35	1·34	1·34
14	Power to condenser auxiliaries (%)	2·00	1·91	1·85	1·80	1·77	1·72	1·68	1·65	1·64	1·63	1·62	1·62
15	Total power to auxiliaries (%)	3·85	3·82	3·86	3·92	4·01	4·23	4·46	4·74	5·06	5·39	5·73	6·11
16	Thermal effy. of turbine corr. for aux. (%)	26·20	26·94	27·51	27·89	28·17	28·50	28·68	28·75	28·76	28·72	28·67	28·58
17	Decrease in heat cons. with 4 F.H. (%)	7·72	8·42	8·99	9·36	9·86	10·60	11·21	11·83	12·43	13·02	13·60	14·20
18	Thermal effy. of turbine with 4 F.H. (%)	29·53	30·59	31·56	32·04	32·55	33·28	33·81	34·23	34·60	34·90	35·19	35·49
19	Total power to aux. with 4 F.H. (%)	3·42	3·40	3·42	3·45	3·51	3·79	4·11	4·52	4·98	5·42	5·96	6·44
20	Thermal effy. of turbine corr. for aux. with 4 F.H. (%)	28·53	29·55	30·38	30·94	31·41	32·02	32·41	32·69	32·88	33·01	33·09	33·20
21	Plant effy. without F.H. (%)	21·12	21·72	22·18	22·49	22·72	22·98	23·14	23·19	23·20	23·17	23·12	23·06
22	Plant effy. with 4 F.H. (%)	23·01	23·83	24·50	24·95	25·33	25·90	26·13	26·36	26·51	26·62	26·68	26·77

Resuperheating.

If steam is taken out of the turbine after partial expansion and passed through a superheater, he thermal efficiency is improved and consequently the coal consumption reduced. This gain in fficiency varies with the points in expansion at which resuperheating takes place. The upper art of fig. 24 shows the percentages given of the total expansion which should precede resuper-

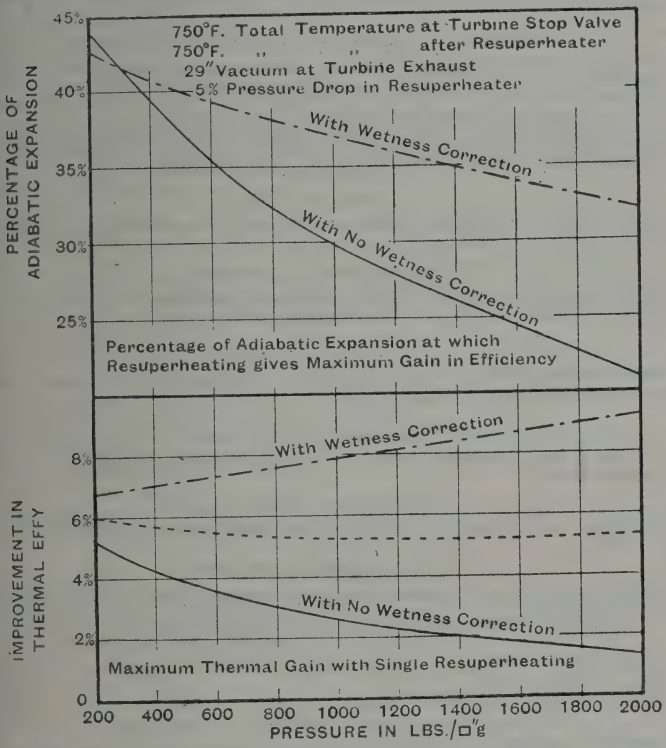


FIG. 24.

heating. The two curves shown should be treated as giving two limits. Again, in the lower portion, the two curves show the two limits for the reduction in coal consumption. The dotted curve shows the mean value and represents about the percentage which has so far been obtained by resuperheating.

BRITISH ENGINEERING STANDARDS SPECIFICATION FOR STEAM TURBINES FOR ELECTRICAL PLANT.*

No. 132–1920 (Abstract).

RATING.

The rating of the steam turbine shall be the rated output of the generator to which it is coupled. (The British Engineering Standards Committee have laid down that the rating of the generator shall be the load which it is capable of carrying continuously with a temperature rise of 40° C.)

* By permission of the British Engineering Standards Association.

Margin of Capacity of Steam Turbine.

The steam turbine shall be provided with means for developing 10 per cent. greater loa than the rated load of the generator with the specified steam conditions. This margin is provide with a view to allowing the turbine to drive the generator at its rated capacity when the stea conditions are worse than those specified, and is not provided with the object of obtainir overloads on the generator.

Output of the Turbine when Working Non-Condensing.

If the specified steam pressure is not less than 165 lbs. per sq. in. absolute, and the rated outpu of the turbine is not more than 3,000 kw., the turbine shall be capable of developing 30 per cen of its rated output when exhausting to the atmosphere. For turbines of larger capacity th output must be settled between the purchaser and the manufacturer.

Note.—It is undesirable to work high-pressure steam turbines exhausting to the atmosphe and this should only be done in cases of emergency. Even under this condition, the turbi should not operate in this way for a longer time than is absolutely necessary.

Maximum Speed.

The turbine shall be capable of withstanding for five minutes, without injury, a speed 15 pe cent. in excess of the rated speed.

Governing Characteristics.

When the rated load is taken off or on the permanent speed variation shall not exceed 3 pe cent., nor shall the momentary variation exceed 6 per cent.

Governing Adjustment.

Means shall be provided to enable the speed to be adjusted by plus or minus 5 per cent when working under synchronising conditions.

Emergency Cut-off Speed.

The emergency governor shall be set to shut off steam if the speed exceeds 9 to 11 per cen of the rated speed.

Economic Rating of the Turbine.

The turbine shall be designed to give a minimum steam consumption at 80 per cent. of i rated output.

Guarantee Steam Consumptions.

If steam consumptions are guaranteed for various outputs, the average steam consumptio shall be obtained by

Mutiplying the steam consumption at the rated output by 3,
" " " 80 per cent. of the rated output by 4,
" " " 60 " " " 3,
" " " 40 " " " 2,
and dividing the sum by 12.

Load at which Steam Consumption is Guaranteed.

The load or loads at which the steam consumption is guaranteed shall be stated in the orde Unless otherwise specified, the guaranteed steam consumptions shall be deemed to be the avera steam consumptions as defined above.

Tolerance.

For the purpose of comparing test consumptions with the guarantee performance a toleran calculated as follows shall be allowed:—

Percentage tolerance (+ or —) =

$$\frac{\text{Arithmetical sum of percentage corrections} - 5}{4} + 2\tfrac{1}{2} \text{ per cent.}$$

Hydraulic Test for Parts Exposed to Full Boiler Pressure.

All parts exposed to the rated steam pressure shall be tested with a hydraulic pressu 50 per cent. in excess of the rated pressure. The machine as a whole shall be tested with hydraulic pressure of 15 lbs. per sq. in. gauge.

Critical Speed of Shaft.

The critical speed of the turbine shaft shall not be within 30 per cent. above or 35 per cen below the rated output.

TURBINE SPEED-REDUCTION GEAR.*

The speed at which it is most desirable to run a turbine is limited only by the strengths of the aterials used in its construction. Unfortunately this limit of speed cannot be approached hen the turbine is employed for direct driving of propellers, D.C. generators of large output, lling mills, line shafting, etc., and in such cases where comparatively low speeds are essential ot only does the turbine become heavy, costly and inefficient, but direct turbine drive is often ite out of the question.

For this reason several systems of speed reduction have been introduced, and are being ccessfully applied.

Double Helical Gears.

Speed reduction by means of double helical gears was employed in the earliest days of turbine gineering by Dr. Delaval, whose turbines, running at speeds of the order of 10,000 r.p.m., uld not be directly coupled to electric generators. The gearing of these turbines gave re-arkably little trouble, and although the outputs were low it is notable that even to-day this is e most successful system of speed reduction.

Double helical gearing for large turbines was introduced by Sir C. A. Parsons, who with aracteristic courage first introduced the system in the famous case of the propelling machinery the s.s. 'Vespasian,' and the drive of a rolling mill at Calderbank Steel Works.

In the earlier installations difficulties were experienced through minute inaccuracies of the ar teeth, which gave rise to very noisy working. This was traced to errors in the gearing of e table of the gear-cutting machine by Sir C. A. Parsons, who has very materially reduced the ouble by arranging a 'Creeping' table giving the gear blank an advance of 1 per cent. latively to the main table of the machine. The improvements in modern gear-cutting machines ve eliminated the inaccuracies referred to, so that the creeping device is no longer essential.

The helix angle adopted varies from 20° to 45°, the usual angle in modern practice being 30°.

The teeth of modern double helical gears are of the standard involute type, the pressure gle adopted by different makers varying from 14½° to 20°.

If p = average pressure in lbs./inch tooth face.
L = total length of tooth face in inches.
D = diam. of pitch circle of pinion in inches.
R = revs. per minute of pinion.

V = pitch speed in feet per second $= \frac{\pi D}{12} \times \frac{R}{60} = \frac{\pi D}{720} \times R.$

Then

$$\text{Horse-power transmitted} = P = \frac{pLV \times 60}{33{,}000} = \frac{pLV}{550}.$$

Professor Stoney states that V should be kept between the limits 100 and 130 ft./sec. He so gives the maximum permissible pressure $p = 120d$ for pinions smaller than 5 inches ameter, and $p = 175\sqrt{d}$ for larger pinions.

Fig. 25 shows curves co-ordinating p and d, published by Mr. F. H. Hodgkinson *Engineering*, Jan. 10, 1919).

With pinions having two bearings where E = Young's modulus of elasticity = 30×10^6 os./sq. inch,

$$I = \text{the moment of inertia of the pinion} = \frac{\pi D^4}{64}.$$

$$\text{Transverse deflection at the centre} = \delta_1 = \frac{5}{384} \cdot \frac{pL^4}{EI}.$$

This is one of the determining factors in design, and, according to Stoney, should not exceed 0002 inch.

For pinions having three bearings, the maximum deflection on each portion of the pinion etween two bearings should not exceed 0·0002 inch, and in most cases this is not the ndition determining the diameter.

Another condition fixing the design of the pinion arises from the fact that the torsional eflection opens the teeth, thus preventing uniform distribution of pressure on them. This orsional opening, δ_2, according to Stoney, must be limited to less than 0·0001 inch, and is iven by the following expressions :

$$\text{For two or three bearing pinions } \delta_2 = \frac{OL}{10 \times 10^4} \text{ inches over one helix.}$$

In the Melville-McAlpine gear, manufactured and developed by the Westinghouse Machine o., the pinion is supported in a floating frame which permits its axis to take up a slight inclina-

* See also 'Reduction Gear for Propulsion,' p. 2369.

DOUBLE HELICAL GEAR CURVES.

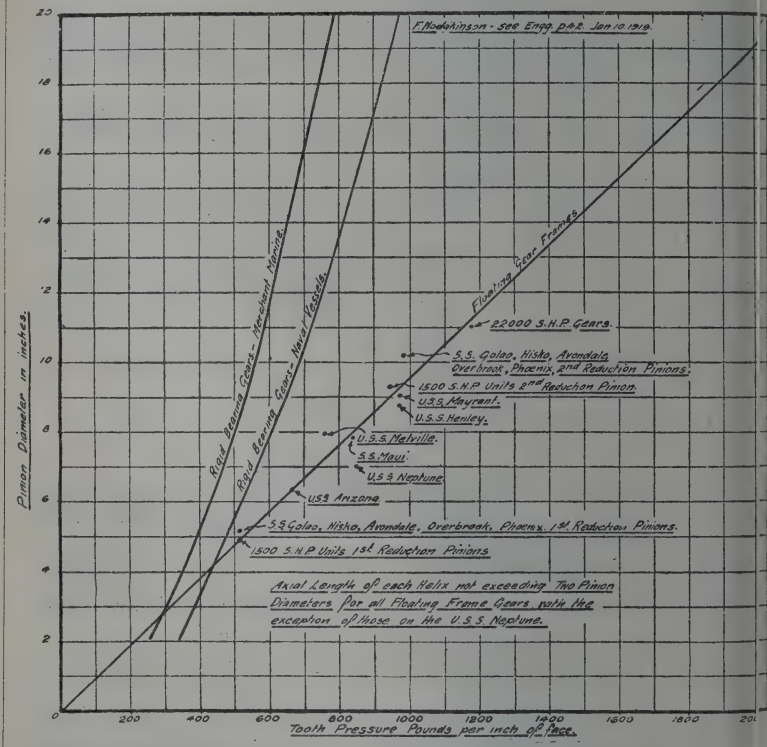


FIG. 25.

on in the vertical plane relatively to the slow speed shaft. The torque on the pinion tends to crease the helix angle of one half of the pinion and decrease that of the other half, so that if the lix angle of the pinion is the same as that of the wheel, as load comes on, the helix angles become fferent. If the axis of the pinion is inclined in a vertical plane relatively to the wheel, the ange in the helix angle with load can, it is claimed, be very largely compensated, so that ith the floating pinion larger torques can be transmitted through a given size pinion than rough a pinion supported in rigid bearings. According to the inventors, the floating frame so corrects to a certain extent errors in the teeth and in alignment of the gears.

The action of this gear is well explained, together with some authoritative notes on double lical gearing, in a series of articles by Mr. J. H. McAlpine, which appeared in *Engineering*, mmencing May 5, 1916.

In these articles Mr. McAlpine suggests the use of the 'Power Constant' for comparing fferent gears; these he defines as follows:

D = pitch diameter of pinion in ins.; L = length of tooth face in ins.; p = average essure in lbs. per in. of tooth face; R = r.p.m.; C = power constant; P = horse-power ansmitted;

Then

$$P = \frac{\pi D R p L}{33000 \times 12}.$$

For correctly designed gears, p and L vary as D, therefore

$$P = C (D^3 R),$$

d

$$C = \frac{P \times 1000}{D^3 R}.$$

For gears having the pinion supported in two rigid bearings, the power constant 'C' should t exceed 1·5.

'C' is usually from 1·2 to 3·0, for gears having three bearings on the pinion.

Gears having the pinion supported in a floating frame have worked very successfully with a wer constant of 4.

The ratio $\frac{L}{D}$ should preferably be equal to 4-in. gears having the floating frame.

For best results the pinions for all sizes should have from 26 to 30 teeth; if the number is preciably reduced interference takes place.

The efficiency in double helical gearing varies from 98·5 per cent. in large gears to 97·5 per nt. in small sets, so that from 1·5 per cent. to 2·5 per cent. of the heat equivalent of the power ansmitted has to be dissipated in the lubricating oil cooling system.

The gears are usually lubricated by spraying the oil on the teeth at the point of contact.

The success of a gear depends to a larger extent than is generally supposed on the rigidity d correct design of the gear-box and lubricating system, and where experienced engineers are sponsible for these details every confidence can be placed in a turbo-geared proposition.

Table XI, p. 1873, gives some particulars of notable installations of geared turbines.

Rapid advances have been made in the application of steam turbines to the ercantile marine, by the introduction of double reduction gearing. Single reduction gears ving ratios larger than 15 to 1 are scarcely practical for ship propulsion, but a reduction of, y, 42 to 1 can be commercially obtained by a double reduction gear having two trains of heels, the first having a reduction of, say, 6 to 1 and the second 7 to 1.

Such double reduction gears are now being used having efficiencies at full load of about per cent.

Now that such large ratios of reduction are commercially practicable, both the turbine and e propeller can be run at the speed most suitable for each respectively.

See also p. 1022, and 'Reduction Gear for Propulsion,' p. 2369.

Hydraulic Transmission.

Prof. Fottinger has invented an ingenious system of speed reduction in which the turbine rives a centrifugal pump which delivers water into a water turbine to which the propeller or enerator is coupled.

The possibilities and limitations of this type of transmission are illustrated by the follow figures given by Prof. Fottinger.*

No. of Stages.	Gear Rates.	Estimated Efficiency.
1	5 to 1	90 per cent.
2	7½ to 1	90 ,,
3	10 or 12 to 1	88 ,,

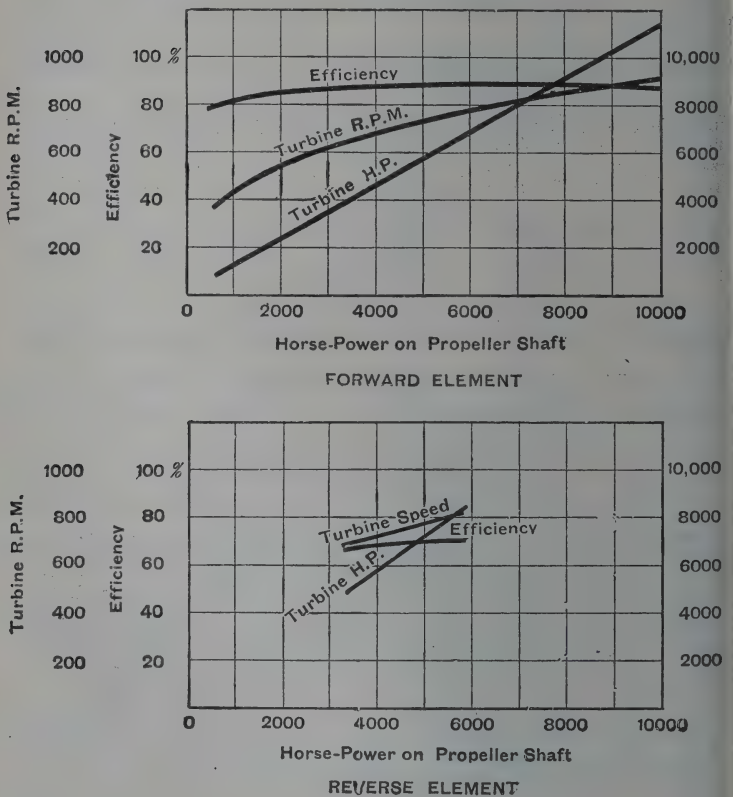


FIG. 26.

Unfortunately the ratios usually required for marine purposes are from 10 to 1 up to 20 to and as it is doubtful if more than single stage transmitters could be commercially adopted, it v be seen the field open to this type is limited. A distinct advantage lies in the fact that the d charge from the turbine pump element can be diverted to a reverse water turbine, by which mea reversal can be easily and economically effected. The water used in the transmitter is usua the boiler feed, and in this way some of the losses can be recovered in feed water heating, but is difficult to see how the gain can possibly exceed 1 per cent. measured at the driven shaft.

Fig. 26 shows the results of tests on a 10,000 B.H.P. transmitter.†

* *Engineering*, March 14, 1913. † *Z. V. d. I.*, May 16, 1913.

Name of Installation.	Kind, Maker.	Face Width.	Angle of Helix.	in Lbs. in W.D.	Speed. Ft. per Sec.	Power Constant.	÷ Pinion. Diam.	Efficiency of Gear.	Reference.
Hope Natural Gas Company	American Westinghouse Co.	40	30°	715	65·5	2·26	4·0	—	'Engineering,' May 26, 1916.
Cleveland Elec. Illuminating Company	,,	40	30°	925	81·5	2·72	3·85	—	,,
U.S.S. Melville	,,	32	30°	720	47·5	3·02	4 12	—	,,
Cruising Gears, U.S.S. Arizona	,,	24	30°	662	69·2	3·12	3·78	—	,,
S.T.D. 1000 Gear Kw.	,,	20	30°	625	81·5	3·66	3·85	—	,,
U.S.S. Pennsylvania	,,	22	30°	526	37 75	3·99	4·57	—	,,
Swedish Cruisers T.S.	,,	31	30°	825	118·0	3·61	4·13	—	,,
Prop. for U.S. Torpedo Boat Destroyer W.M. Co.	,,	39	30°	1,255	95·0	3·88	3·94	—	,,
	,,	27	30°	830	104·0	4·03	4·07	—	,,
	Rigid Gear	27	—	710	129·0	1·32 H.P. 0·497 L.P.	2·51 H.P. 1·54 L.P.	—	,,
T.S. Vespasian	C. A. Parsons	24	20°	394	31·8	3·00	4·8	98·5%	'Engineer,' April 7, 1911.
S.S. Transylvania and Tuscania	,,	About 48	—	442	70·7	1·80	5·05	—	'Engineering,' May 26, 1916.
S.S. Ciudad de Buenos Aires and Ciudad de Monte Video	,,	About 28	—	450	63·0	2·58 H.P. 1·29 L.P.	4·5 3·18	—	,,
Rolling Mill, Calderbank Steel Works	,,	—	23°	270	62·4 24·7	8·75 4·2	—	—	'Engineer,' April 7, 1911.
Melville-McAlpine	American Westinghouse Co.	—	30°	—	92	—	—	98·99%	'Engineering,' Dec. 3, 1909.
Melville-McAlpine Geared D.C. Gen.	,,	—	30°	—	79	2·85	—	—	'Engineering,' Jan. 31, 1913.
T.S. King Orry	C. A. Parsons	—	44° 22½′	—	—	—	—	—	'Engineering,' June 27, 1913.
	Power Plant Co.	—	—	325	100	1·49	—	—	'Engineer,' Oct. 1, 1915.
Melville-McAlpine	American Westinghouse Co.	26·5	30°	404	110	1·86	3·93	98·5%	'Steam Turbines for Land Purposes,' Manch. Assoc. of Eng., Jan. 27, 1917.
Messrs. C. & J. Hirst	D. Brown	11	32° 12′	275	65·5	0·96	2·2	98%	
Birmingham Corporation.	Power Plant Co.	12	23°	132	46·3	0·696	2·83	—	

Electrical Transmission.

Various schemes of electrical reduction of speed have been suggested at various times, which an overall efficiency of from 90 to 92 per cent. is claimed.

The General Electric Company * have installed an electrical transmission of considera importance in the collier 'Jupiter' for the U.S.A. Navy, the following particulars of which of interest :—

The ship is of 20,000 tons displacement, and is driven by a six-stage Curtis turbine, in wh each wheel has two rows of blades and runs at 2,000 r.p.m., coupled to a bipolar 3 P.H. genera supplying current at 2,200 volts to two motor-driven propellers. The motors have 36 poles, that the ratio of synchronous speed reduction is 18 to 1. The efficiency of the motors is 95 per ce

At the designed speed of 14 knots the propeller speed is 110 r.p.m., and the output at propellers 5,600 s.h.p.

Under these conditions the consumption on test was 12 lbs. per s.h.p., with a steam press of 190 lbs. per sq. in., dry saturated steam, and exhausting into vacuum of 28½ ins. Hg. 30 i Baro. Thus the thermal efficiency of the turbine generator and motors is 19 per cent., but t does not include any loss in switchgear or cables.

Variations in speed are obtained by varying the speed of the turbine, the gear ratio remain constant, and in the process of reversal water-cooled resistances are put in circuit with the rot of the motors.

A system which is virtually an electrical speed reduction has been introduced where dir current is desired with steam turbines as the prime movers, in which the turbine drives an alt nator which is electrically coupled to a rotary converter. As compared with direct-curr generators driven by double helical gearing, it appears that in plants of over 1,500 kw. capac the pure electrical scheme may be the more advantageous. Other considerations peculiar a particular installation often arise demanding the electrical scheme for smaller outputs th 1,500 kw.

Very large installations of electrically driven ships have been completed for the Uni States Navy, and this system may possess certain advantages for such ships as oper for a large proportion of their time at speeds very much less than the maximum which they able to develop. In such cases the turbines can run at their normal speed independently of t speed of the propeller. Further, the main turbines can be disposed in any convenient posit in the ship without reference to the position of the propeller. These conditions are important in the case of the majority of ships in the mercantile marine.

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* *Engineering*, August 23, 1912.

SECTION XXX

PART V

STEAM CONDENSERS—HEAT TRANSMISSION IN SURFACE CONDENSERS—AIR PUMPS—ROTARY AIR PUMPS—STEAM JET EJECTOR AIR PUMPS—FEED PUMPS—COOLING TOWERS—STEAM ACCUMULATORS.

(Revised by T. B. Morley, D.Sc., M.I.Mech.E.)

STEAM CONDENSERS.

The principal types of condenser are:—

(1) Jet condensers, in which the condensing water mixes with the steam.

(2) Surface condensers, in which the cooling water and the steam are kept separate.

The jet type involves much less initial cost than surface condensing plant, and requires less attention and cleaning, but requires more power to operate it. The choice of type depends to a very large extent on the nature and cost of the water available for cooling and for boiler feed.

Jet condensers are preferred to surface if the cooling water is fit for boiler feed or if a suitable boiler feed, other than the condensed steam, is available.

If ample water is available, but not suitable for boiler feed, the surface condenser is advisable. In some cases the water may be too bad even for use in surface condensers, causing choking of tubes or serious corrosion; jet condensers may then be used and boiler feed obtained from a limited supply of good water, even though the price of the good water is high.

Jet Condensers.

With low-level jet plants it is necessary that the cooling water should be drawn in by virtue of the vacuum, and an efficient vacuum breaker be fitted whereby, in the event of the pumps connected to the condenser suddenly shutting down, the vacuum will be broken, thus stopping the flow of the injection water, and preventing it from entering the L.P cylinder.

The mixture of cooling water and condensed steam is preferably withdrawn at the bottom of the condenser, and the air is taken off near the top. This involves separate air and water pumps, but in the case of engines of moderate power having their own jet condenser one pump for both air and water is commonly used. In the barometric or elevated type of jet condenser no water extraction pump is required, as the condenser being fixed at the barometric height is self-draining. Usually, however, an injection pump is required to lift the water partly up to the condenser, as the vacuum can be utilised to a certain extent for drawing the water into the condenser the same as in the low-level plant. These condensers are more expensive than the low-level type, and, due to a long exhaust pipe being necessary, require to maintain a slightly higher vacuum for an equivalent exhaust pressure at the turbine or engine exhaust flange.

The capacity of a contra-flow jet condenser should not, according to *Sim*, be less than one-quarter of the volume of the cylinder or cylinders exhausting to it, and need not be more than one-half. For quick-running engines one-third is generally sufficient. For turbine work or continuous steam flow, 0·008 to 0·011 cub. ft. per lb. of steam per hour is reasonable.

Surface Condensers.

Cooling water should be arranged to pass through the tubes and steam to flow over the tubes. It is usual to divide the tube element in two, three, or four passes according to the design of the plant, the passes being arranged so that the hottest water meets the hottest steam.

Large spaces should be allowed between the tubes at the condenser inlet to obtain a good flow of steam into the heart of the condenser. The steam flow should always be as direct as possible, changing the direction of flow should be avoided, and to ensure an evenly distributed flow over the top of the tubes a dome should be formed on the top of the condenser body.

Internal guide plates are used by some makers, in order to distribute the entering steam uniformly over the tubes.

It is important that the drop of pressure across he groups of tubes should be reduced to a minimum. Baffles in the tube space are not recommended, as their total effect is harmful.

The pitch of the tubes should be such that they will allow sufficient area for the flow of steam without an excessive pressure drop through the condenser.

The number of tubes which can be fixed in a square foot of plate is,

$$N = \frac{166}{p^2};$$

where,

N = number of tubes per sq. ft. of plate; p = pitch of tubes in ins.

Air in the condenser must not be allowed to remain stagnant round the tubes.

Frequently a section of the condenser next the air pump suction branches is partitioned off to act as a cooler for the air passing to the air pump. The first water pass takes place through the tubes in this section. The cooling of the air reduces the volume to be dealt with by the air pump.

Mr. Allen has used a short overflow pipe upstanding in the condenser so as to keep immersed the lower tubes which serve to cool the water going to the air-pump and so improve the vacuum.

Tube Plates.

These are usually of rolled brass alloy of copper 62 per cent., zinc 37 per cent., and tin 1 per cent., and are generally made of a thickness equal to tube diameter + 0·25 in.

Tubes.

These are of solid drawn brass alloy, of copper 67 per cent., zinc 32 per cent., tin 1 per cent., or where salt or corrosive water is used, of Admiralty mixture alloy, of copper 70 per cent., zinc 29 per cent., tin 1 per cent. A still better tube to use where corrosion is liable to occur is copper of 99·5 per cent. purity, but the initial cost of these is often found prohibitive. Tinned tubes should be avoided, since unless the tinning is absolutely perfect, serious pitting is liable to occur. The Admiralty practice is to adopt untinned tubes of the alloy referred to.

The unsupported length of tubes should not exceed 100 times the diameter, and where the length of the condenser exceeds this dimension, tube-supporting plates should be fixed. The tubes should be secured in the tube plates by tape packing and ferrules, the latter having an internal lip to prevent 'creeping' of the tubes.

Ferrules should allow a space for free movement of the tube ends, and should be rounded, so as to reduce to a minimum the loss of head of the water at its entry into the tubes.

According to Stanton, in a condenser of a given surface for maximum efficiency, the tube length should be as great as possible. As regards tube diameter he says that condensers will be equally efficient in which the ratio $\frac{l^{n-1}}{d}$ = constant, where l = length in feet, n = number of tubes, d = external diameter of tube in feet. Tube diameters should be chosen which offer the least aggregate resistance to flow. Resistance is, he finds, proportional to l^{4-2n}, and is therefore least when the tubes are the smallest practical diameter. He considers the best position for tubes is vertical and the water movement downward.

Tube diameters may vary from $\frac{1}{2}$ in. to 1 in., but are usually $\frac{5}{8}$ in. or $\frac{3}{4}$ in., in fact $\frac{3}{4}$ in. diameter and 18 S.W.G. (0·048 in.) thickness are practically standard.

Unannealed hard-drawn condenser tubes tend to become corroded more readily than tubes that have been annealed.

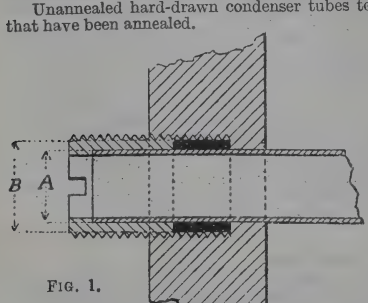

Fig. 1.

Tube Packing.

'Compressed Asbestos Fibre Tube Gromets' (*Turner Brothers Asbestos Co., Ltd., Rochdale*) are illustrated in fig. 1. The Gromets are essentially for packing the tube ends of surface condensers, feed-water heaters, etc.; they are a sliding fit between the tube and the tube plate, making a perfectly tight joint with a few turns of the screw, after which no 'following up' is necessary.

When ordering, the dimensions at 'A' (the outside diameter of tube) and at 'B' (the apex of thread in socket), together with the length of Gromet required, should be given; the necessary clearance is allowed for in manufacture.

British Standard Specification for Condenser Tubes and Screwed Glands for Condensers for Marine Purposes.

(No. 3000-1921).*

(*Abstract.*)

1. The material of the shells from which the tubes for condensers and for screwed glands are drawn shall be an alloy of copper and zinc as follows:—

* By permission of the British Engineering Standards Association.

For Condenser Tubes: 70/30 Alloy.—Containing not less than 70 per cent. of metallic copper nd not more than a total of 0·75 per cent. of materials other than copper and zinc (except that, if so specified, it may contain 1 per cent. of tin or 1½ to 2 per cent. of lead).

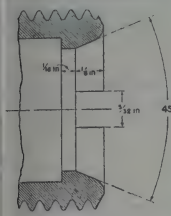

FIG. 2.
iew of Outer End of crewed Glands for ⅝ in. nd ¾ in. External Dia- eter Condenser Tubes.

For Screwed Glands: 60/40 Alloy.—Containing not less than 60 per cent. of metallic copper and not more than a total of 0·75 per cent. of materials other than copper and zinc (except that, if so specified, it may contain 1 per cent. of tin or 1½ to 2 per cent. of lead).

3. The condenser tubes shall be of ⅝ in. or ¾ in. external diameter as may be specified—and they shall not be larger than, nor more than 1½ per cent. smaller than, the specified external diameter. The tubes shall be of uniform diameter throughout and the thickness shall be 18 S.W.G. within the usual manufacturing margins.

5. For ⅝ in. external diameter condenser tubes the average weight per 100 ft. run shall be not more than 32¾ lbs. and not less than 31½ lbs. and for ¾ in. external diameter condenser tubes the average weight per 100 ft. run shall be not more than 40 lbs. and not less than 83 lbs., *i.e.* 2½ per cent. above or below the theoretical weight.

6. Each condenser tube shall be tested internally by water pressure to 600 lbs. per square inch.

Heat Transmission in Surface Condensers.

Let K = coefficient of heat transmission from steam to cooling water, i.e. the number of B.Th.U. transmitted per hour per sq. ft. of cooling surface per degree F. of mean temperature difference.

$\frac{1}{K}$ represents the resistance to the flow of heat. This resistance is made up of:—

(1) The resistance to the flow of heat from the steam to the external surface of the condenser tube, $\frac{1}{k_1}$ say;

(2) resistance to conduction through the tube = $\frac{t}{k_2}$ where t = thickness of tube in inches and k_2 = conductivity of metal in B.Th.U. per hour per sq. ft. per temperature gradient of 1° F. per inch; and

(3) the resistance to flow of heat from the tube to the water = $\frac{1}{k_3}$ say.

The total resistance $\frac{1}{K} = \frac{1}{k_1} + \frac{t}{k_2} + \frac{1}{k_3}$.

For brass tubes, 18 S.W.G. thick, the middle term $\frac{t}{k_2}$ is negligible in comparison with the thers.

k_1, the coefficient for flow from steam to metal, depends on the velocity with which the steam ows over the tubes, the presence of air in the condenser, and the cleanliness of the tubes.

k_3, the coefficient for transmission from tube to water, is the most important term. It epends upon the water velocity, the diameter of the tube, cleanliness of tube surface, and also n the mean temperature, there being evidence that the heat transmitted is greater at higher emperatures even though the temperature *difference* is the same.

For the usual tube sizes and usual temperatures, it will be seen that the chief variable factor nfluencing the overall transmission rate is the water velocity.

Data for k_1 and k_3 are not yet thoroughly established, and the data given by various experi- nenters for the coefficient K also vary widely. This is due not only to experimental error, but o the fact that frequently some of the factors influencing the transmission rate are not taken nto account at all.

For high-class condensers, with clean tubes and small air leakage, the following transmission ates are probable:—

Water velocity, ft. per sec.	3	4	5	6	7	8	9	10
K, B.Th.U. per hour per sq. ft. per deg. F.	470	570	660	740	820	890	960	1,020

(*Weir* '*Trans. Inst. E. and S.*,' 1912–13.)

The increased transmission rate—and consequently reduced cooling surface necessary—du to high water velocities is not all gain, however, for high velocity means increased power to circu late the water. The final design must be decided with reference to cost of pumping as well a initial cost of plant.

Fig. 3 shows the head lost in friction per 10 foot of tube element for $\frac{5}{8}$ in., $\frac{3}{4}$ in., and 1 in external diam. by 18 S.W.G. smooth brass tubes. For application it is necessary to take th total length of the tube element (the length of the tubes multiplied by the number of water passes and add the 'loss at entry (including loss at exit also) per pass,' values for which are given o the bottom curve.

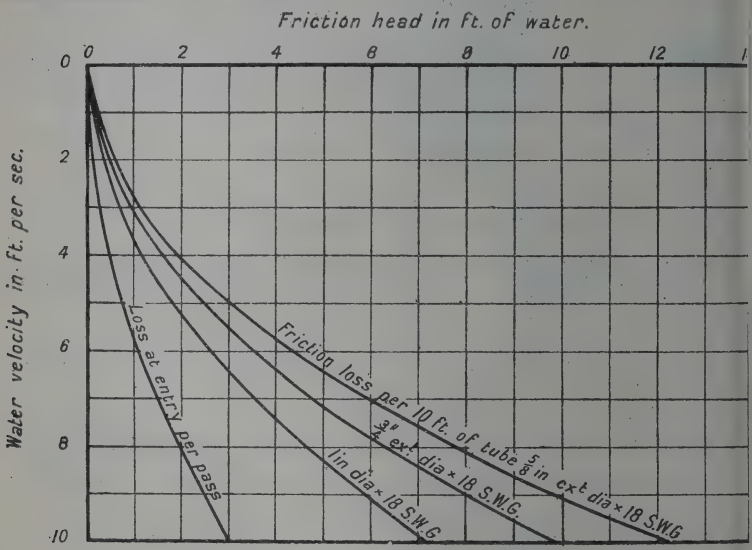

FIG. 3.

MEAN TEMPERATURE DIFFERENCE.

The true mean temperature difference for condensers, heaters, coolers, etc., in which heat i transmitted between two fluids separated by a metallic wall is not the difference of the arithmeti mean temperatures.

If one of the fluids is cooled from T_1 to T_2 and the other heated from t_1 to t_2, then,

$$\text{mean temperature } t_m = \frac{(T_1 - t_1) - (T_2 - t_2)}{\log_e \frac{T_1 - t_1}{T_2 - t_2}}$$

Fig. 4 enables t_m to be readily determined from the maximum and minimum temperatur differences $T_1 - t_1$ and $T_2 - t_2$.

COOLING SURFACE.

If

t_m = mean temperature difference between steam and water; t_1 = inlet water tempera ture; t_2 = outlet water temperature; T = steam temperature in condenser; K = heat transmis sion B.Th.U. per hour per sq. ft. per F.°; then,

$$\text{Cooling surface per lb. steam per hour} = \frac{1{,}050}{K \times t_m}$$

(1,050 is the number of B.Th.U. given up by 1 lb. steam in the condenser, under usual conditions)

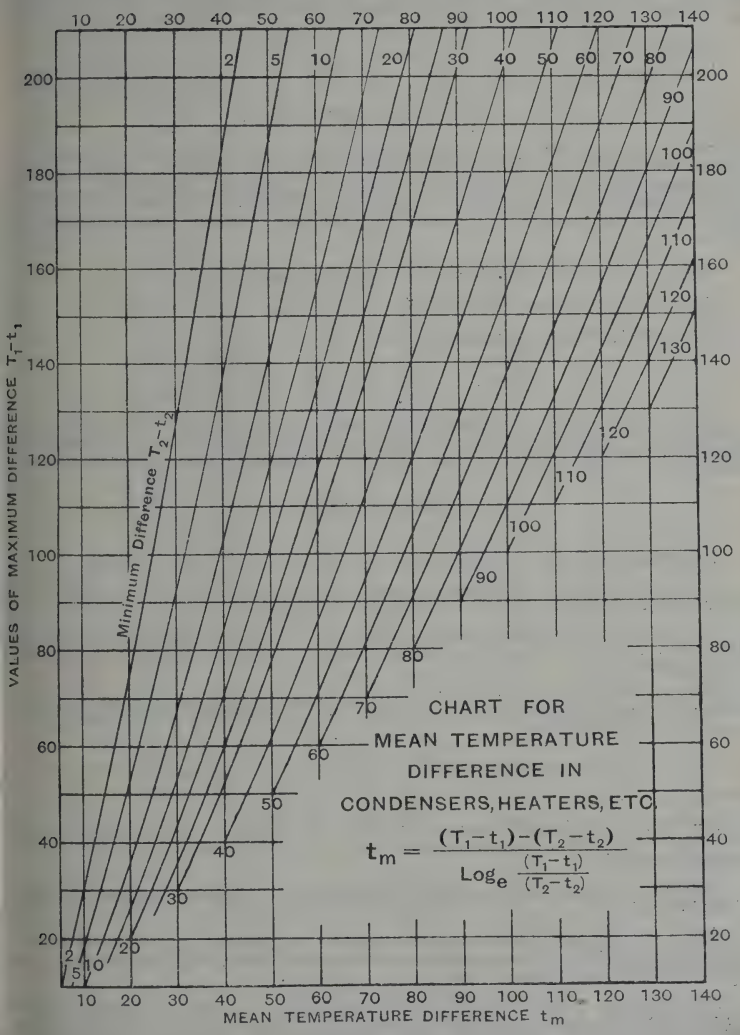
CHART FOR
MEAN TEMPERATURE
DIFFERENCE IN
CONDENSERS, HEATERS, ETC.
$t_m = \frac{(T_1 - t_1) - (T_2 - t_2)}{\text{Log}_e \frac{(T_1 - t_1)}{(T_2 - t_2)}}$
Minimum Difference $T_2 - t_2$
VALUES OF MAXIMUM DIFFERENCE $T_1 - t_1$
MEAN TEMPERATURE DIFFERENCE t_m

FIG. 4.

For rough approximations, surface condenser cooling surface may be based on 6 lbs. of steam per square foot of surface; 10 pounds is sometimes adopted, but is too severe unless the temperature of the cooling water is low, say 60° F., or less. For tropical countries the lower rate of condensation should be taken, and even less when very hot condensing water is anticipated.

Quantity of Cooling Water.

If T_1 = temperature of cooling water at inlet to condenser; T_2 = temperature of cooling water at outlet of condenser; T_3 = temperature of steam at inlet, corresponding to the vacuum; T_4 = temperature of the condensed water at outlet; h_3 = sensible heat at inlet; h_4 = sensible heat of the condensed water at outlet; L = latent heat in B.Th.U. per lb. of steam; W = steam weight; Q = water weight; R = ratio of water and steam quantity; x = dryness fraction then,

Heat (in B.Th.U.) given up by exhaust steam = $W\left\{xL + (h_3 - h_4)\right\}$;

Heat (in B.Th.U.) gained by cooling water = $Q(T_2 - T_1)$.

In practice h_3—h_4 may be neglected, therefore

$$WxL = Q(T_2 - T_1), \quad \text{and,} \quad \frac{Q}{W} = R = \frac{x\,L}{T_2 - T_1}.$$

To allow a small margin, x—which generally varies between 0·8 and 1·0—can be neglected and as L only varies slightly with the vacuum, it is generally assumed to be a constant for all vacua at 1,050 B.Th.U. per lb. of steam. Therefore the general equation for all vacua can be taken as

$$R = \frac{Q}{W} = \frac{1050}{T_2 - T_1}.$$

For surface plants, T_2—T_1 ranges from 8° to 20° F., and for jet plants, 4° to 8° F.

The ratio of the amount of cooling water to that of the steam to be condensed usually varies from 35 to 40 for jet, and from 60 to 70 for surface condensers.

It is important that the condensed steam should be at as high a temperature as possible, since this water is usually returned to the boilers, therefore it is essential that all the heat possible should be recovered.

Every 8°–10° F. difference in the hot-well temperature means approximately 1 per cent difference in fuel consumption. The gain obtained with an increase in hot-well temperature can be calculated as follows:—

$$\text{Percentage gain in B.Th.U.} = \left(\frac{100\,T}{H_T + T - T_4 + 32}\right) \times \frac{100}{B_p}$$

where,

T = difference in hot-well temperature (F.°); T_4 = final hot-well temperature (F.°); H_T = total heat of steam at boiler pressure (B.Th.U. per lb.), reckoned from 32° F.; B_p = percentage boiler efficiency.

In surface condensers for turbines, $(T_3 - T_4)$ is about 5° to 8°, and for reciprocating engines about 10° to 15°.

Vacuum Efficiency may be expressed as the ratio of the vacuum at the condenser inlet to vacuum corresponding to the temperature of the condensed steam; it is dependent both upon the design of the condenser and the air pump.

The *Efficiency of a Condenser* is best stated as a 'Coefficient of Performance,' which measures the extent to which the two conditions are fulfilled that (1) the condensate should be cooled as little as possible below the steam temperature, and (2) the quantity of cooling water should be a minimum, and hence its rise of temperature a maximum.

Sim takes as 'Coefficient of Performance' the ratio $(T_2 - T_1) \div (T_3 - T_4 + 10)$, and states that it should be 1·0 to 1·2 for good surface condensers.

Degree of Vacuum.—The maximum vacuum obtainable is dependent upon the inlet circulating water temperature. For engine work 26 ins. to 27 ins. is the maximum vacuum desirable, owing to the limitations in size of the low-pressure cylinder and ports, etc. For turbine work high vacua are necessary. The most economical vacuum depends upon individual installations, and is generally decided by the power required to be expended by pumping the cooling water, price of coal, available water supply, etc.

The following may be taken under average conditions to be the maximum commercial vacua.

Temp. of inlet water, F.°	55	60	65	70	75	80	85
Vacuum in ins. (baro. 30 ins.)	28·8	28·6	28·5	28·3	28·0	27·8	27·5

PROPERTIES OF SATURATED STEAM AT LOW PRESSURES.

Per Increment of Vacuum reduced to 30 ins. Baro.

Inches of Vacuum.	Absolute Pressure Lbs. per Sq. In.	Temp. °F.	Spec. Vol. Cub. Ft. per Lb.	Inches of Vacuum.	Absolute Pressure Lbs. per Sq. In.	Temp. °F.	Spec. Vol. Cub. Ft. per Lb.
0	14·69	212	26·79	25	2·45	133·8	143·5
1	14·20	210·3	27·64	25·2	2·35	132·1	149
2	13·71	208·5	28·54	25·4	2·25	130·5	155
3	13·22	206·7	29·52	25·5	2·21	129·8	158·5
4	12·73	204·9	30·61	25·6	2·16	128·9	161·5
5	12·24	202·9	31·75	25·8	2·06	127·2	169
6	11·75	201	32·95	26	1·96	125·3	177
7	11·26	198·9	34·37	26·1	1·91	124·4	181
8	10·77	196·8	35·80	26·2	1·86	123·4	185·5
9	10·29	194·6	37·35	26·3	1·81	122·4	190
10	9·80	192·3	39·1	26·4	1·76	121·4	195·5
10·5	9·56	191·1	40	26·5	1·71	120·4	200·5
11	9·31	189·9	41	26·6	1·67	119·6	206
11·5	9·07	188·7	42	26·7	1·62	118·4	212
12	8·82	187·4	43·15	26·8	1·57	117·3	218·5
12·5	8·58	186·1	44·25	26·9	1·52	116·2	225
13	8·33	184·8	45·5	27	1·47	115·1	232
13·5	8·09	183·4	46·8	27·1	1·42	113·9	239·5
14	7·84	182	48·2	27·2	1·37	112·6	247
14·5	7·60	180·6	49·6	27·3	1·32	111·3	255
15	7·35	179·1	51·2	27·4	1·27	110	265
15·5	7·11	177·6	52·8	27·5	1·23	108·7	276
16	6·86	176·1	54·6	27·6	1·18	107·3	286
16·5	6·62	174·4	56·4	27·7	1·13	105·8	298
17	6·37	172·8	58·3	27·8	1·08	104·3	310
17·5	6·13	171·1	60·5	27·9	1·03	102·7	324
18	5·88	169·3	63	28	0·98	101·1	339
18·5	5·64	167·4	65·5	28·1	0·93	99·4	356
19	5·39	165·5	68·4	28·2	0·88	97·6	374
19·5	5·15	163·5	71·4	28·3	0·83	95·7	395
20	4·90	161·4	74·7	28·4	0·79	93·8	418
20·5	4·66	159·3	78·4	28·5	0·74	91·7	444
21	4·41	157	82·5	28·6	0·69	89·5	474
21·5	4·17	154·7	86·9	28·7	0·64	87·1	508
22	3·92	152·2	92·1	28·8	0·59	84·6	548
22·5	3·68	149·6	97·7	28·9	0·54	81·9	597
23	3·43	146·8	104·3	29	0·49	79	653
23·5	3·19	143·9	112	29·1	0·44	75·8	721
24	2·94	140·7	121	29·2	0·39	72	806
24·5	2·70	137·4	131	29·3	0·34	68	913
24·6	2·65	136·7	133·5	29·4	0·29	63	1060
24·8	2·55	135·2	138·3	29·5	0·25	59	1230

AIR IN CONDENSERS

Air enters the condenser in the following manner :—

1. With the steam entering from the boiler having been dissolved in the feed water ; this is usually a small amount in the nature of 1 to 3 per cent. of the total volume of feed water.

2 Air leakage from the atmosphere through the glands of the prime mover or other sources ; this cannot easily be measured, and an allowance has to be made accordingly to cover contingencies.

3. In jet condensers air in solution with the cooling water which is released when in the vacuu space; this varies from 1 to 5 per cent. of the total volume of water.

Due to air contained in the cooling water in the case of a jet condenser, a much larger a pump is required than for a surface plant of similar duty.

For turbine work to cover cases (1) and (2) it is usual to allow for 6 to 8, and, in the cas of low-pressure turbines, up to 11 lbs. of air per 10,000 lbs. of steam.

For engines, about two or three times this amount is required according to the type of engin

These figures are for one unit only; if two or more turbines or engines exhaust to the on condenser an extra margin of 10 or 15 per cent. per extra turbine or engine, respectively, shoul be allowed.

(See also page 897.)

The Ejector Condenser.

This condenser is at once an air-pump and a condenser. It acts on the principle that steam will flow into a vacuum at a velocity of many hundred feet per second. The water supply to th ejector should flow to it under a head of several feet. The steam condenses in the jet of water and the combined jet has a velocity which is a mean of the velocity of the steam and of th water. Thus let the water approach at a velocity 30 feet per second and the steam at 1,200 fee per second. Let the combined jet be assumed to have a temperature of 100° F. and the water t be supplied at 60° F. The water gains 40° F. The steam loses say 1,100 B.Th.U. Ther 1,100 ÷ 40 = 27 = ratio of water weight to weight of steam. The total weight of combined jet is 28 The velocity difference is 1,200 − 30 = 1,170, to be divided over a mass of 28, or $\frac{1,170}{28} = 42$ feet pe second nearly. Add the initial velocity of the water 30, and the final velocity is 72 feet per secon

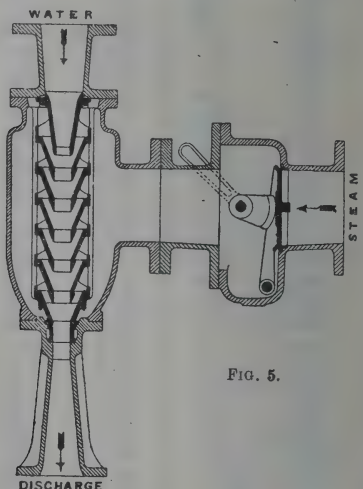

Fig. 5.

This corresponds with a head of H = (72 ÷ 8)² = 81 feet; and since 1 foot of water column equals 0·43 pounds, 83 feet will represent 36 pounds nearly. Since a perfect vacuum is only 14·7 pounds, it follows that with ordinary ratios of water and steam an efficiency of less than 50 per cent. should give an excellent vacuum.

The apparatus (fig. 5) consists of a converging water nozzle into which water is directed from a centrifugal pump or other pressure source, or from an overhead source of 15 to 20 feet head. This jet flows downwards through a series of steam cones to which the exhaust steam has admission at their upper wide portion. The steam flows down each of these short cones and imparts further velocity to the jet as it condenses, and finally the jet flows into a divergent discharge cone at a velocity as above indicated, carrying with it any air that has come in with the steam, and discharging it. The degree of vacuum is of course that proper to the jet temperature, and the proportion of water can, as seen, be sufficiently great to admit of a moderate final

jet temperature and therefore a good vacuum. The ejector condenser occupies very little space and for jet condensing is very simple. The centrifugal water supply pump is conveniently direct driven by an electric motor. While the jet final temperature is amply low for good vacua, the velocity of the combined jet is still more than sufficient to run freely against atmospheric external pressure; but it is always desirable to give the water a fair initial velocity, and there is nothing lost by giving the discharged jet a good fall in a long tail pipe.

The Barometric Condenser is a simpler form of ejector condenser, in which the water enters the head of the apparatus as a spray about the steam entrance, and the vacuum is produced by the fall of the water down a tail pipe of at least 30 feet in vertical drop. By suitable formation of the head the air which enters with the steam is entrained with the water, or, by means of a special surface condenser at the side of the head the air is drawn over cold tubes and carried down to a lower point in the draught tube, whereby it is withdrawn from the head at a minimum temperature, with the object of securing a maximum degree of vacuum.

Mirrlees-Delas-Ginabat Surface Condenser.

(Patented.)

(The Mirrlees Watson Co., Ltd., 45 Scotland St., Glasgow.)

In this condenser it is claimed that every tube does its equal share of work. The tube area opposed to the inlet steam is very large and the steam path through the tubes very short ; the tubes are particularly free from air or water blanketing, and the kinetic energy in the steam and

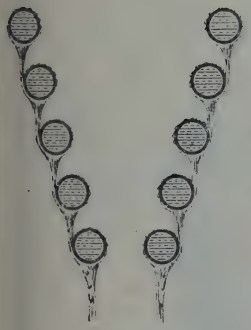

FIG. 6.

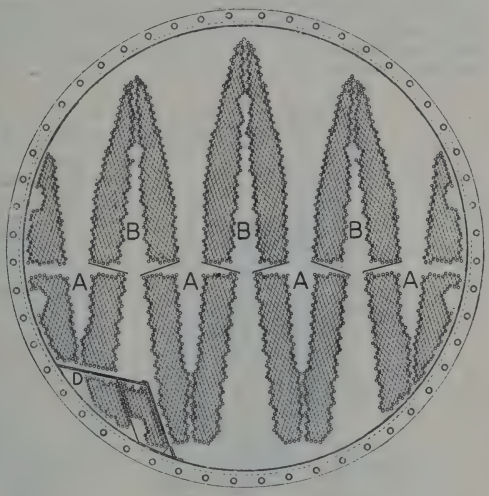

FIG. 7.

condensate passing through the condenser is fully used in reheating the condensate, and to such an extent that the condensate may be removed at a temperature several degrees higher than the inlet steam temperature, and an absolute pressure at the bottom of the condenser slightly higher than the absolute pressure at the condenser inlet ; this is a distinctive feature of the arrangement.

Fig. 6 shows the pitching of the tubes. By the arrangement the water of condensation falling from any one tube meets the tube immediately below tangentially to its surface, and thus flows over only $\frac{1}{4}$ of its circumference, leaving the other $\frac{3}{4}$ dry as far as falling water is concerned. Also the water of condensation may be made to travel to the right or left, according as to whether the lower tube is arranged to the right or left of the higher tube.

The method of grouping the tubes is shown in fig. 7. The tubes are arranged in shallow banks, leaving very deep V-shaped openings for entry of steam, thus giving maximum area of contact ; the V-shaped openings being carried almost to the bottom of the condenser, all tubes are equally effective. There are also correspondingly deep inverted V openings on the under side.

As stated, the condensate can be made to traverse a tube path into this centre inverted space, and, doing so, passes over a very small number of tubes and then over only ¼ of the circumference.

As there is very little resistance to the steam and incondensible vapours passing through thes shallow banks of tubes, the kinetic energy is used in giving a compression effect to the incondensibl gases at the bottom of the condenser, and an increment of heat to the condensate: the com pression effect is enhanced by the unrestricted fall of condensate through the inverted V-shape openings.

The heat transmission of the condenser is very much higher than anything previously recorde in practice; in several installations a transmission of 1,000 B.T.U.'s per sq. ft. per deg. temperatur difference has been attained.

A recent test gave the following results:

Steam condensed in lbs. per hour	442,000
Steam condensed per sq. ft. cooling surface	16·3 lbs.
Absolute pressure at condenser inlet	0·81 in. Hg.
Temperature of inlet circulating water	45·5° F.
Temperature of outlet circulating water	55·9° F.
Heat transmission B.Th.U./sq. ft./deg. Fah. temp. diff./hr. =	756

The 'Weir' Regenerative Surface Condenser.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

This condenser has been introduced to eliminate the temperature loss which exists in the con densate from the vacuum temperature in normal type condensers, and also to give a condense which delivers its condensate practically air or oxygen free, consequently, although this con denser is suitable for any feed system, it is pre-eminently suitable for fitting to a closed circui feed water system.

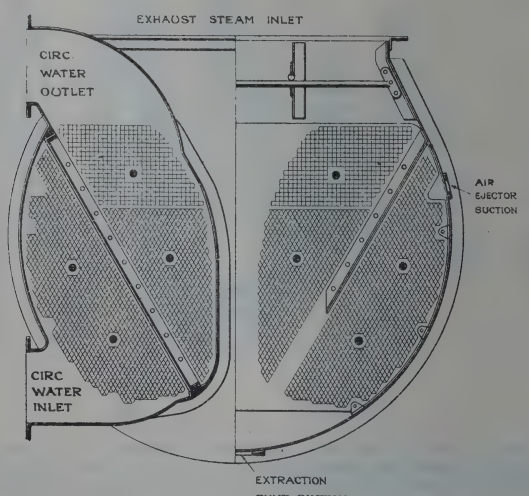

FIG. 8.

The design is the result of a series of researches carried out by Messrs. G. & J. Weir, and in its present form is shown in fig. 8.

It will be seen that a large lane is provided down the middle of the condenser, so that steam can penetrate right down to the bottom; this steam re-heats the condensate dropping from the lowest row of tubes to practically steam temperature. Tests from actual plants show that the difference between the condensate temperature and the vacuum temperature does not vary by

ıore than 2° F. This result is independent of the air leakage present. These tests also show ıat the oxygen contained in the condensate can reach as low as zero oxygen, 0·015 c.c. per litre ·eing quite a normal figure.

A hood plate is fitted on each side of the condenser, thus giving two reflex flows on the steam ide; this arrangement permits a large surface to act as an air cooler if large air quantities are resent, while if the latter are small the air cooling surface will be small. This action is automatic, ne surface acting as an air cooler, automatically adjusting itself to the air quantity. This property esults in the air being drawn off by the air-pump at a minimum temperature for the conditions nd resulting in an enhanced condenser performance. The double arrangement shown lends :self to the twin water box design favoured by many present-day land engineers, the idea being hat one-half can be shut down for cleaning or tube plugging while the other half is working, so hat the main turbine need not be shut down.

The shape of the centre lane, together with the position and length of the hood plate, permit f a large entrance area being presented to the entering steam, with a gradually reducing area to he air suction, so that all the surface is equally effective and a minimum of pressure drop is ttained.

The 'Weir' Water Extraction Pump and Air Ejector.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

To work in conjunction with their 'Regenerative Condenser,' Messrs. G. & J. Weir manufacture ı water extraction pump and air ejector. The water extraction pump is of the vertical spindle ype, driven by a steam turbine of the velocity stage type having three rows of moving blades nounted in a single wheel and two rows of stationary blades mounted in a guide segment; the ıump is shown in fig. 9. To maintain the speed constant under variations of load a speed governor

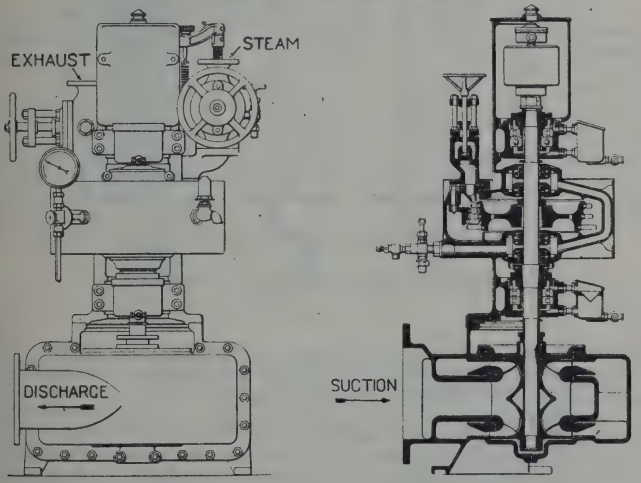

Fig. 9.—Arrangement of Weir Vertical Turbine Extraction Pump Turbine.

is fitted, while in addition a safety governor is fitted which shuts off the steam completely in the event of the pump overspeeding. Auxiliary nozzles under control of the auxiliary stop valves are provided, so that by regulating these the pump may deal economically with large variations in load.

The impellers are located low down at the base of the pump to enable the pump to work satisfactorily under the minimum suction head; the impellers are of the twin type operating in parallel and having the suction placed between the impellers; whirlpool chambers of the diverging

type are employed, and no stuffing gland is fitted at the lower impeller, while a large clearance provided between the top impeller and the stuffing gland, so that the full discharge pressu reaches the stuffing box, thus preventing air leakage into the pump suction.

The weight of the impellers, turbine wheel, shaft, etc., is carried on a ball thrust bearing, wh the shaft is centred by two roller bearings ; both thrust and journal bearings run in an oil ba

The pump end is made of gun-metal, while the framing is of cast iron. The framing and pur end are divided down the centre line, so that the shaft with impellers and turbine wheel can removed for overhaul without disturbing any of the pipe connections.

The most modern type of ejector as developed by Messrs. Weir is shown by fig. 10. It h three stages and can attain the highest vacua. On dry air tests these ejectors have attain vacua within 0·02 in. of the barometer; such extreme vacua, however, is seldom called commercially, but this property enables them to reduce the partial air pressure in normal plan down to the very lowest limits. The saving in steam consumption of the three-stage type ov

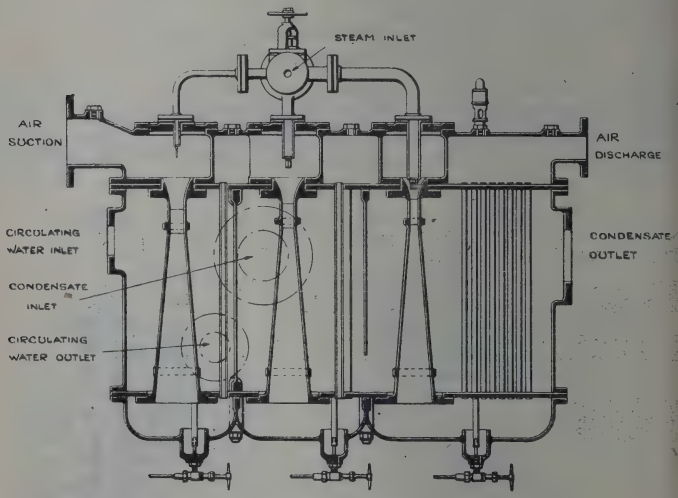

FIG. 10.

the two-stage type is about 30 per cent. at 29 in. vacuum, and increases with higher vacuum The three stages are generally similar in design, but are proportioned to suit the actual a steam, and vapour volumes reigning at the respective stages. The steam nozzles are normal co vergent, divergent steam ones, wherein the pressure energy of the steam is converted into kinet energy ; the steam issuing from the nozzles at high velocity (over 3,000 ft. per sec.) is deliver into a convergent, divergent diffuser nozzle ; entrainment of the air and vapour takes place the convergent portion of the diffuser, and the pressure rise takes place in the diverging portio the combined mass of operating steam and entrained air and vapour pass to first intercooler, whi is of the surface type and is arranged alongside and partly embraces the diffuser ; the operati steam and vapour are condensed out in this cooler, while the air and its associated vapour pa on to the second stage, where the action is repeated, and so on to the third stage, the air bei finally discharged to atmosphere.

The steam nozzles are of Monel metal to resist erosion, while the diffusers are of hard gun-met

On board ship the first and second intercoolers are circulated with sea-water, while the thi or after-cooler is circulated with condensate. On land power stations only the first intercool is circulated with cold circulating water, the second and third coolers being circulated with co densate. On board ship it is imperative that a full vacuum be maintained during manœuvrin

The WEIR REGENERATIVE CONDENSER

A technical development which guarantees permanent savings.

Increasingly adopted by the leading Power Corporations and Steamship Companies throughout the world.

WEIR DIRECT-ACTING FEED PUMPS
STANDARD SIZES. . . . . PROMPT DELIVERY.

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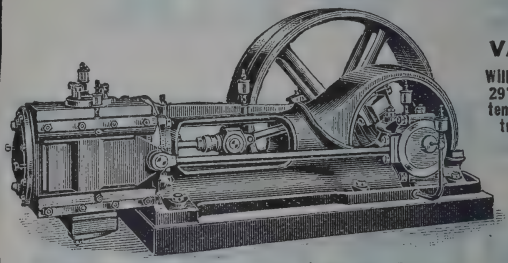
HIGH-PRESSURE
AIR COMPRESSORS
1000 lbs. per square inch and over.

STANDARD DE-AERATING PLANTS.

F. 1886

BAILEY'S PUMPS
AND VALVES



Belt-driven Slide Valve 'Dry' Vacuum Pump.

'K' 'DRY'
VACUUM PUMPS

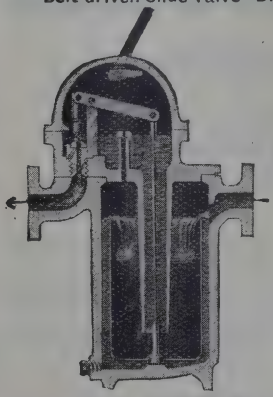
Will maintain a vacuum of over 29·8 ins. of mercury at normal temperature and with a Barometric pressure of 30 ins.

Remarkable for high Efficiency.

No delicate parts to wear out.

SIMPLE AND COMPOUND.

Steam, Belt, or Electric Driven



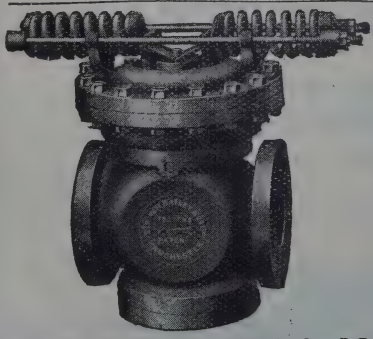
BAILEY'S VACUUM PUMPS are particularly suitable to work as Air Pumps for Condensers for Steam Engines, Central Condensation Plants, Cooling Towers, Condensers for Evaporating Plants, Vacuum Drying Plants, Distillers, etc.

BAILEY'S
'SCAVENGER' STEAM TRAPS
FOR PRESSURES TO 200 LBS.

LARGE CAPACITY, HAND BLOW THROUGH WORKS WITHOUT ADJUSTMENT AT ANY PRESSURE. WORKING PARTS EASILY EXAMINED WITHOUT BREAKING PIPE JOINTS.

'POP' ACTION, NO DRIBBLING. RENEWABLE VALVE AND SEAT.

SAVES TIME IN 'STARTING UP' AS LONG PIPES CAN BE QUICKLY DISCHARGED OF COLD AIR AND WATER.



BAILEY'S 'FOSTER CLASS W'
REDUCING VALVE

FOR SATURATED AND SUPERHEATED STEAM PRESSURE REGULATION.

MAINTAINS CONSTANT DELIVERY PRESSURE IRRESPECTIVE OF VOLUME DEMANDED.

MOST SENSITIVE, DURABLE, AND EFFICIENT OF ALL REDUCING VALVES.

MADE IN ALL SIZES ½ In. to 24 ins.

MANUFACTURERS

Sir W. H. BAILEY & CO. Ltd., ALBION WORKS, SALFORD.

F. 1887

and to enable the air ejector to do this the first and second stage coolers are circulated with sea-water, while the third stage is arranged that when insufficient condensate is circulating the operating steam simply blows through the after-cooler to a sea-water circulated ejector condenser wherein the steam is condensed. This arrangement is automatic, requires no attention from the ship's engineers, and has been found to work well in practice. On land power stations the above arrangement is not called for, but, owing to the condensate being delivered from regenerative condensers at approximately vacuum temperature, it is imperative to circulate the first inter-cooler with cold circulating water to keep down the surface in the intercooler. With this arrangement the heat in the operating steam of the first stage is lost in the cooling water; but since the steam used in this stage is less than 10 per cent. of the total steam used by the ejector, the actual heat lost is very small indeed.

The vertical design of intercoolers allows of the maximum air cooling and devaporising effect, so that the air is cooled and dried to a maximum for the conditions before it passes on to the next stage.

Between the discharge of the second stage and the inlet to the third stage a light plate non-return valve is fitted. This valve has the effect of stabilising the vacuum produced by the third stage should the steam pressure fall below the designed figure. It also allows of the full vacuum being retained should the ejector steam valve require to be shut for any reason whatever; each intercooler is drained separately to the main condenser, the after-cooler drain passing through a trap.

For land work and mercantile marine work these ejectors are manufactured with cast-iron bodies, steel or brass tube plates, copper tubes, gun-metal diffusers, Monel metal nozzles, while for fast naval craft the bodies can be aluminium alloy, brass tubeplates, Monel metal tubes, gun-metal diffusers, Monel metal nozzles.

Air Pumps.

The essential feature of a plant having a high vacuum efficiency is an air-pump capable of operating without cooling the condensed steam. Excepting in small plants where the heat loss is not so appreciable, all surface condensers should be arranged with two pumps working on the vacuum side, *i.e.* an air-pump capable of dealing with all the air entering the condenser and a water-pump capable of dealing with all the condensed steam. This is what is known as a 'dry' system. Cases where only one pump is employed for the combined duty are known as a 'wet' system. In order to cut down the size of the air-pump in the latter system to reasonable proportions, the condensed steam is usually cooled by means of the last few rows of tubes in the condenser being arranged so that they are always flooded, or by an intercooler.

Capacity of Air-Pump in order to Remove given Amount of Air.

The diagram (fig. 11, p. 1888) shows the properties of mixtures of air and steam such as exist at the air-pump suction. Thus, if the temperature is 100° F., and the vacuum 26 ins., the volume of 1 lb. of air (together with the associated vapour) is 204 cu. ft. and the weight of air per lb. of steam is 1·75, *i.e.* 204 cu. ft. of the mixture contains 1 lb. of air and 0·57 lb. vapour.

The scale on the right provides a basis for calculating the air-pump capacity if the air leakage and the temperature and vacuum are known. For example, assume a surface condenser installation for a reciprocating engine in which allowance is to be made for 16 lbs. air per 10,000 lbs. steam, vacuum 27 ins., temperature at air-pump suction 100° F. From the right-hand scale the volume of air per lb. of condensate, measured at the conditions of the air-pump suction, is 0·395 cu. ft. for an air proportion of 10 lbs. per 10,000 lbs. steam. Thus in the present case the volume is

$$0{\cdot}395 \times \frac{16}{10} = 0{\cdot}63 \text{ cu. ft. per lb. steam.}$$

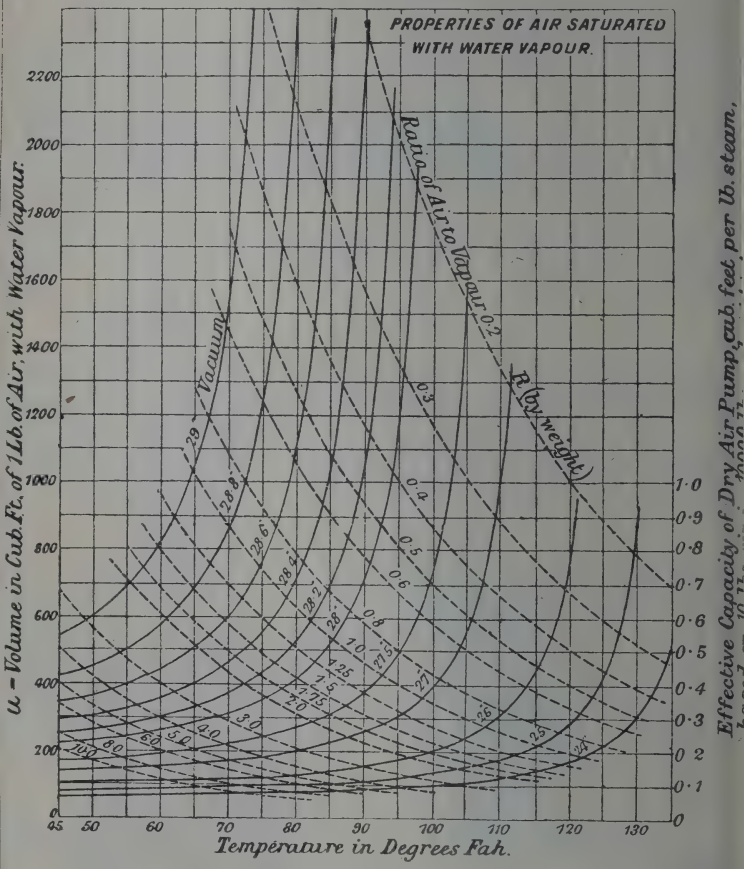
If the steam condensed is 15,000 lbs. per hour, the *effective* capacity of the 'dry' air-pump will then be

$$\frac{15{,}000}{60} \times 0{\cdot}63 = 157 \text{ cu. ft. per minute.}$$

For a 'wet' air-pump the volume of the condensate must be added. The actual capacity of the pump must be greater than the capacity thus found, on account of losses of volumetric efficiency due to clearance, slip, leakage, and valve or port resistance.

The diagram shows the reduction in volume due to cooling of the air-steam mixture before it passes to the air-pump.

DIAGRAM SHOWING THE PROPERTIES OF MIXTURES OF AIR AND STEAM, SUCH AS EXIST AT THE AIR PUMP SUCTION.



(Morley)

FIG. 11

In a jet condensing plant the air introduced by the injection water must also be allowed for.

Leakage of air into the exhaust pipe and condenser should be reduced to a minimum by xercising the greatest care to keep all joints, etc., in good condition.

The amount of air entering the exhaust pipe due to leakage at joints and glands is obviously ot proportional to the amount of exhaust steam, nevertheless air-pumps are frequently designed o give an effective displacement proportional to the amount of exhaust steam, and in fact air- umps for piston engines are frequently proportioned upon the low-pressure cylinder.

Vertical air-pumps are usually single-acting, and low-pressure engine cylinders double-acting. n this basis for ordinary bucket pumps the piston displacement of the low-pressure cylinder is bout 6·5 times that of the pump for jet condensing compound engines in this country and 5·5 imes for India and hot tropical climates. For surface condensers this air-pump ratio varies rom 10 to 12, the lower figure for the smaller and less efficient engines.

Wet-air pumps for jet condensers are frequently proportioned so that their effective displace- ent is about five times the volume of the water (injection plus condensed steam) which they ave to discharge.

Horizontal air-pumps are double-acting, and their volume is therefore one-half that of single- cting pumps.

Air-pumps of the Edwards type usually have about 75 or 80 per cent. as much capacity as he ordinary pumps.

It is tacitly assumed that the vacuum aimed at is about 26 ins., and that considerably greater apacity is necessary for higher vacua.

Air-pump bucket speeds rarely exceed 200 ft. per minute unless the buckets are of the solid lunger type. A usual value is 180 ft. per minute.

The vacuum in a condenser ought to maintain itself an hour with a drop of only 2 lbs.

The smallest air-pump found practicable by Mr. R. W. Allen had 0·5 cu. ft. of displacement er pound of steam condensed.

With circulation water at 65° to 70° F. a vacuum of 28½ ins. at full load with a single-stage ir-pump can be maintained without special accessories. It is not advisable to allow less than ·75 cu. ft. of air-pump volume per 1 lb. of steam condensed, and it ought to be possible to naintain a 98½ per cent. vacuum.

Circulating Pump.

The pump for delivering the required water quantity to the condenser is nearly always of he centrifugal type. The head against which this pump has to deliver is made up of the static lifference in water levels between the inlet and discharge points, plus the pipe and condenser riction. In cases where water is drawn from and returned to a river or canal, the discharge ipe end can be sealed, thus forming a closed or syphon system. In arranging syphon systems are should be taken to ensure that the highest point in the system is never above a vertical listance of 25 ft. from the water level, otherwise the air contained in solution with the water s liable to be released and accumulate, thus breaking the syphon and throwing extra head on he pump.

The Edwards Patent Air-Pump.

In the Edwards Patent Air-Pump, fig. 12, foot and bucket valves are entirely dispensed with. The only valves used are those which in the old type of pump are known as 'the head valves,' but which in the Edwards pump are simply called 'the valves,' as there is no need to distinguish hem in any way.

The condensed steam flows continuously *by gravity* from the condenser into the base of the pump, and is there *dealt with mechanically* by the conical bucket working in connection with a base of similar shape. Upon the descent of the bucket the water is projected *silently and without shock* at a high velocity through the ports into the working barrel, as shown in fig. 13. The rising water is followed by the rising bucket, which closes the ports, and sweeping the air and water before it discharges them through the valves at the top of the barrel.

The essential feature of the Edwards pump is that the water is dealt with *mechanically*, and is in no way dependent on *pressure* in the condenser to drive it up into the pump; consequently,

increase of speed does not impair its efficiency. The speed of the water must correspond with the speed of the bucket, and the pump thus having a regular quantity of water to deal with at each revolution is particularly well suited to work at high speeds.

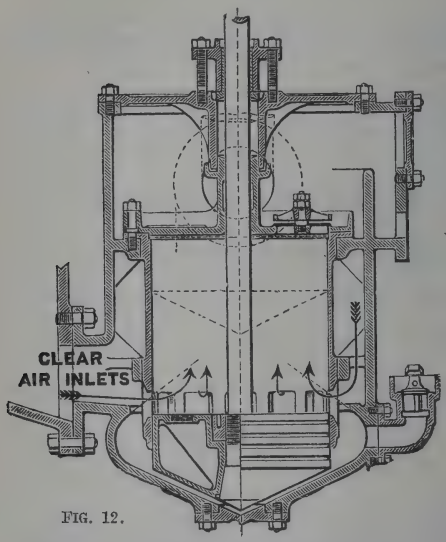


FIG. 12.

Another point of considerable importance in the design of the pump is that *clear air inlets are maintained*. As the bucket descends and the ports open there is absolutely no obstruction between the condenser and the pump. The air has a perfectly free entrance into the barrel, as indicated by the arrow in fig. 13, while immediately afterwards the water is injected at a high velocity; thus, instead of obstructing the entrance of the air, the water tends to compress that already in the barrel, and to carry more air in with it.

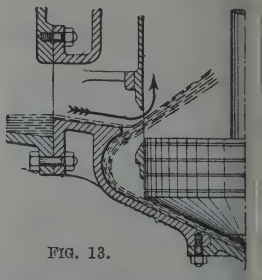


FIG. 13.

Before any air-pump can discharge, all the air in the barrel must be compressed to slightly in excess of the atmospheric pressure, and consequently the greater the amount of air remaining in the clearance water the more inefficient the pump becomes. By reducing the top clearance to a minimum, as is done in the Edwards pump, the efficiency is considerably increased.

SIZE, SPEEDS, AND APPROXIMATE OVER-ALL DIMENSIONS OF THREE-THROW EDWARDS AIR PUMPS WHEN WORKING IN CONNECTION WITH SURFACE CONDENSERS FOR VARIOUS AMOUNTS OF STEAM.

Lbs. of Steam per Hour.	Number of Pump Barrels.	Dia.	Str.	Revs. per Min.	Approximate Dimensions.		
					Height to Centre of Shaft.	Length without Motor.	Width.
10,000 to 12,500	3	8 ins.	8 ins.	160 to 200	5 ft. 1 in.	4 ft. 9 ins.	1 ft. 10 ins
12,500 to 15,000	3	9 ins.	9 ins.	140 to 170	5 ft. 6 ins.	5 ft. 2 ins.	2 ft. 0 ins
15,000 to 20,000	3	9½ ins.	9 ins.	150 to 200	5 ft. 6 ins.	5 ft. 2 ins.	2 ft. 0 ins
20,000 to 25,000	3	10 ins.	10 ins.	160 to 200	6 ft. 0 ins.	5 ft. 4 ins.	2 ft. 1 in.
25,000 to 30,000	3	11 ins.	11 ins.	150 to 180	6 ft. 6 ins.	5 ft. 6 ins.	2 ft. 3 ins
30,000 to 35,000	3	12 ins.	12 ins.	140 to 165	6 ft. 10 ins.	6 ft. 0 ins.	2 ft. 3 ins
35,000 to 40,000	3	13 ins.	12 ins.	140 to 160	6 ft. 10 ins.	6 ft. 6 ins.	2 ft. 5 ins
40,000 to 45,000	3	14 ins.	12 ins.	140 to 160	6 ft. 10 ins.	7 ft. 0 ins.	2 ft. 6 ins
45,000 to 50,000	3	14½ ins.	12 ins.	145 to 160	6 ft. 10 ins.	7 ft. 0 ins.	2 ft. 6 ins
50,000 to 55,000	3	15 ins.	12 ins.	150 to 165	7 ft. 0 ins.	7 ft. 6 ins.	2 ft. 8 ins
55,000 to 60,000	3	16 ins.	12 ins.	145 to 160	7 ft. 0 ins.	7 ft. 6 ins.	2 ft. 8 ins

By means of the door at the top of the pump the only valves used can be readily examined cleaned, and, if necessary, renewed while the pump is at work.

The door also allows the engineer-in-charge to estimate the air duty of the pump, and after a little experience to tell whether there is any serious leakage into the system.

For marine pumps a weir is arranged between the door and the valves (see fig. 13); this enables the door to be taken off while the pump is at work, without loss of water even when there is a heavy list on the ship.

The table on page 1890 gives the dimensions of 3-throw pumps suitable for electrical and other land installations, and for dealing with the stated quantities of steam, when working in connection with *surface* condensers of the ordinary type.

(*The Edwards Air-Pump Syndicate, Ltd.*)

The Leblanc Air-Pump, Simple Jet Type.

In the Leblanc Simple Jet Condenser and Air-pump, water is jetted across the exhaust pipe from the engine by means of a reversed turbine wheel which rotates in a closed casing alongside the pipe, there being an opening into the pipe at a portion of the turbine periphery. There are thus a series of flat sheets of water traversing down the vertical pipe, and serving both to condense and to draw off the steam and air. The water can be used over again if not too hot, and the pump is thus intended for use as a wet and dry air-pump. As there are quite a number of water vanes acting together and moving with great energy down the eduction pipe, there is only a small pressure difference between adjacent vanes, and there is quite a mass of water always acting. The vanes of water practically act like an extension of the metal vanes of the central fan, so that this fan is in a sense an absolute fit in the casing like a scoop wheel, and air is withdrawn between each such vane and the next following. The fan or turbine is practically a water-packed radial-bladed wheel which scoops out the air as it rotates.

The Leblanc Rotary Air-Pump.

In the Leblanc type of Rotary Air-pump, a section of which is given in fig. 14, the air from the condenser is trapped between thin sheets of water thrown out by a series of turbine vanes, which rotate at a high speed in an enclosed casing. The discharge opening in the casing uncovers a certain portion of the turbine periphery where the sealing water, drawn in at centre and passing through the distributor nozzle, gets shot out in sheets from the revolving blade wheel, down the narrowing part of collecting cone discharge pipe, at a high velocity, trapping on its way a certain volume of air between the water sheets discharged.

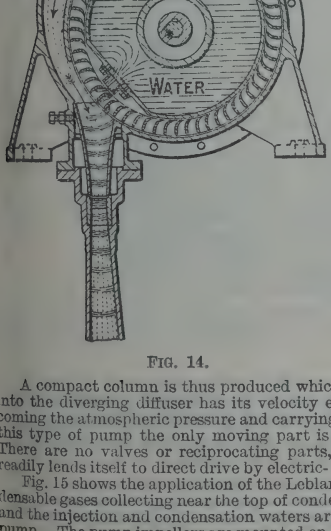


Fig. 14.

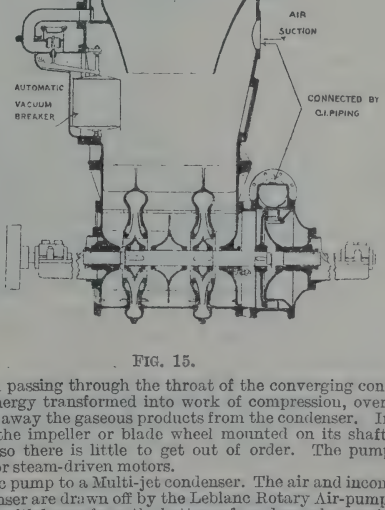


Fig. 15.

A compact column is thus produced which passing through the throat of the converging cone into the diverging diffuser has its velocity energy transformed into work of compression, overcoming the atmospheric pressure and carrying away the gaseous products from the condenser. In this type of pump the only moving part is the impeller or blade wheel mounted on its shaft. There are no valves or reciprocating parts, so there is little to get out of order. The pump readily lends itself to direct drive by electric- or steam-driven motors.

Fig. 15 shows the application of the Leblanc pump to a Multi-jet condenser. The air and incondensable gases collecting near the top of condenser are drawn off by the Leblanc Rotary Air-pump, and the injection and condensation waters are withdrawn from the bottom of condenser by special pump. The pump impellers are mounted on a common shaft and driven by one motor.

Jet or Ejector Air Pumps.

Of recent years great developments have taken place in the design and application of air-pumps in which the vacuum is produced entirely by means of a jet or jets of fluid, which may be water or steam. The air from the condenser mixes with the jet, and the mixture, which just after mixing is at high velocity and low pressure, passes through a 'diffusor' tube of increasing area in which its kinetic energy is as far as possible transformed into pressure energy, so that the mixture may be finally discharged against atmospheric pressure.

Such types of air-pump have the advantage that there are no moving parts in the complete condensing plant, with the exception of a pump for removing the condensate; also they occupy very little space, have little weight, can be located in any convenient situation, and require little attention and maintenance.

The types using steam jets appear to be superseding those with water jets.

It is found advantageous not to carry out the compression of the air from vacuum to atmospheric pressure in one stage, but in two. In order to reduce the work in the second stage, and hence to reduce steam consumption, frequently an auxiliary condenser is used between the first and second stage ejectors.

Under certain circumstances, the flow through the diffusor becomes unstable, causing a drop in the vacuum. To overcome this, some makers provide auxiliary air inlets by which atmospheric air can enter at the throat of the diffusor when required; one firm uses a water jacket round the combining nozzle, and at least one other uses neither of these means, but relies entirely upon the proportions of the nozzles. These forms of the apparatus are described below.

A further recent development is the introduction of an ejector with three stages and two intermediate condensers.

Condensing Plant with Hick-Breguet Ejectair.

(Hick, Hargreaves & Co., Ltd., Bolton.)

The surface condenser is so designed that the whole of the steam comes into intimate contact with the tubes, and the tubes are disposed so as to reduce to a minimum the resistance to the passage of steam.

To ensure the air being withdrawn at maximum density, it is drawn through a 'de-vapourising' chamber formed in the lower pass of the condenser by steel plates enclosing about 8 per cent. of the total number of condenser tubes. The reduction of volume of the air adds to the efficiency of the air-extracting apparatus.

The condenser inlet is usually connected to the turbine exhaust by means of a galvanised wrought-steel bellows pipe which permits of relative expansion between turbine and condenser. The condenser may be mounted on springs, and the bellows pipe dispensed with, but in this case expansion joints are required for all piping connected to the condenser

The jet condenser is of the multiple jet type, the number of nozzles being proportionate to the duty of the plant. The upper portion is designed to eliminate, almost entirely, resistance to the passage of steam on to the finely divided water sprays, condensation thus being immediate and complete.

The air and water are extracted at different points entirely independent of one another, the former being extracted by a steam-jet air pump and the latter withdrawn by a pump of the centrifugal type.

The water extraction pump is single-stage, designed for efficient continuous running under all load variations, and is driven through a flexible coupling by an electric motor or by a steam turbine as required.

The air is extracted from the condenser by the patented 'Hick-Breguet' Ejectair, combining the advantages of a high degree of air extraction with low steam consumption. To meet varying requirements the apparatus is manufactured in the following types:—

Duplex Ejectair with intermediate condenser of the jet or direct-contact type.
Duplex Ejectair with combined intermediate surface condenser and feed heater.
Three-stage Ejectair with combined surface condenser and heater.

In the first-mentioned type, as shown by fig. 16, the first ejector withdraws the air from the condenser, compressing it slightly and discharging it into the intermediate condenser, where the steam from the first ejector is condensed and the air reduced in volume, thereby increasing the volumetric efficiency of the secondary ejector.

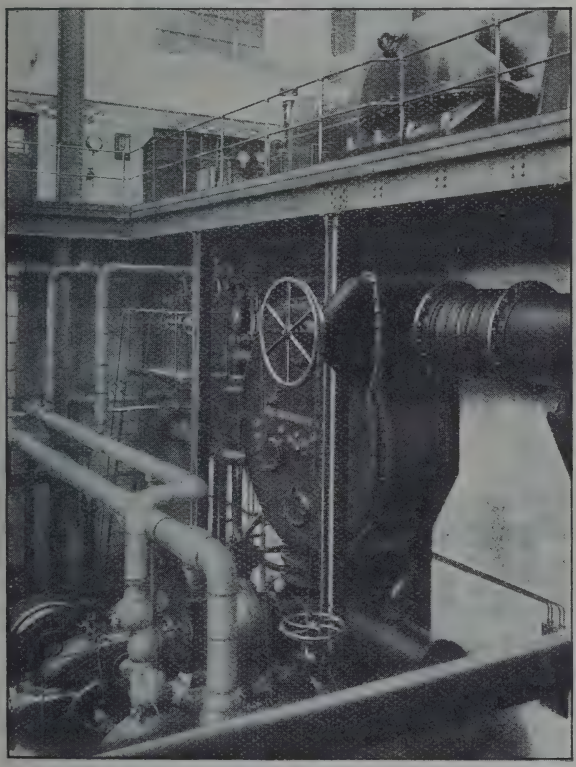
The water from the intermediate condenser along with the condensate of the first ejector is delivered by means of a balance pipe direct to the extraction-pump suction, in this way raising the temperature of the condensate from the main condenser, and conserving the heat in the first jet.

The steam from the second jet, along with the air, is discharged preferably into a surface heater, through which the discharge water from the extraction pump passes; by this means the heat from the second jet is conserved and the temperature of the condensate further raised.

The apparatus is fitted with a patent stabilising valve which automatically regulates the working of the two ejectors at light loads, and prevents them from becoming unstable. Under ordinary conditions of working the stabilising valve is not in operation, the whole energy of the team operating the Ejectair being used for extracting the air from the condenser.

CONDENSING PLANT AND AUXILIARIES

for modern power station duty



18,750 KW. Set Installed at a Municipal Electricity Works

SURFACE and JET CONDENSING PLANT fitted with the HICK-BREGUET EJECTAIR

Rotary Water Strainers (Bailey & Jackson's Patents) for cleansing condensing water, in capacities up to 5,000,000 Gallons per hour.
Independent De-aerating Plant and Closed Feed Systems for complete de-aeration of boiler feed water. Feed Water Heaters.

HICK, HARGREAVES & CO., LIMITED

BOLTON ENGLAND

London Office - - - - - 57 VICTORIA STREET, S.W. 1

3 x 2 F. 1892

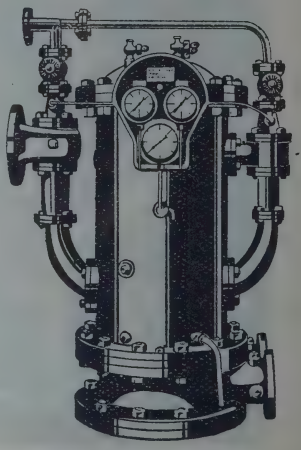
Mirrlees

STEAM EJECTOR AIR PUMP

with

Intermediate Surface Condenser

This is our most modern type of Ejector which we have just placed on the market.



Advantages

Combined air pump and feed water heater in one compact unit. The condensate does not come into contact with the highly aerated steam.

The MIRRLEES WATSON COMPANY LIMITED

ENGINEERS, SCOTLAND ST., GLASGOW

LONDON: Mirrlees House, 7 Grosvenor Gds., S.W.1.

314*

F. 1893

The plant is very simple in construction and requires no attention when put into service, the only moving parts being the extraction pump spindle and impeller. It is put into operation by simply opening the steam valve to the two jets, and closing the switches controlling the circulating pump and extraction pump motors.

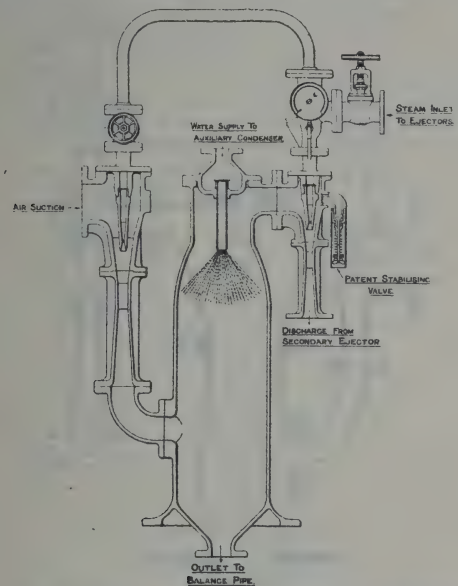


FIG. 16.—Sectional Arrangement of Hick-Breguet Ejectair.

THE MIRRLEES EJECTOR AIR PUMP.

(*The Mirrlees-Watson Co. Ltd.*)

The earlier types of Mirrlees air ejector were provided with groups of small steam nozzles in each stage. Also an auxiliary air inlet was provided at the throat of the second stage ejector. To hasten the production of vacuum when starting, the throat was made larger than necessary for normal working. When the air from the condenser became less than that required to fill the throat, the auxiliary ports admitted atmospheric air and the working of the ejector thus became stable. The latest type of Mirrlees ejector is shown in fig. 17 (p. 1894).

In this design there is a single steam nozzle in each stage instead of a group, the auxiliary air inlet is eliminated, and the consumption of operating steam reduced.

Steam enters at G, the air from the condenser at B. The steam from the first ejector is condensed by injection water entering at F, which also cools the partially compressed air delivered by the first ejector. This cooled air and incondensible gases are led to the second ejector, and discharged at L along with the steam used in the second ejector.

The condenser is self-draining through a U-sealing pipe to the condensate pump suction branch.

The Mirrlees-Watson Co. state that their experiments with water-jacketed ejectors show that the additional complications involved by the water jacket are unnecessary.

In the Mirrlees ejector the convergent cone is cool, and the discharged air and gases do not attain a temperature higher than 215° F.

A standard works test chart for one size of the latest Mirrlees ejector is shown in fig. 18 (page 1894).

The chart shows that there is a great reduction in steam consumption as the air leakage falls below 85 lbs. per hour. In large installations advantage is taken of this by arranging the extractors in batteries working in parallel.

THE MIRRLEES EJECTOR PUMP.
(The Mirrlees-Watson Co. Ltd.)

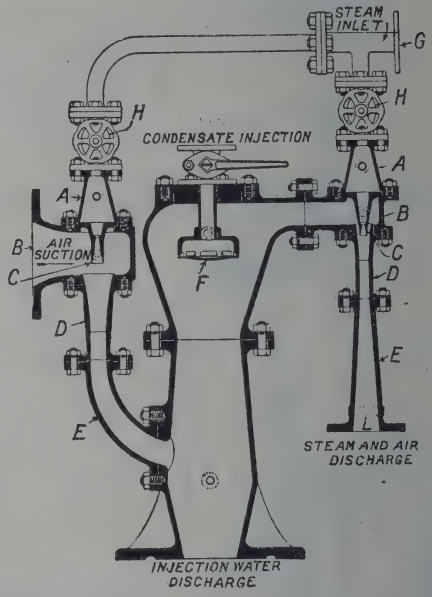


FIG. 17.

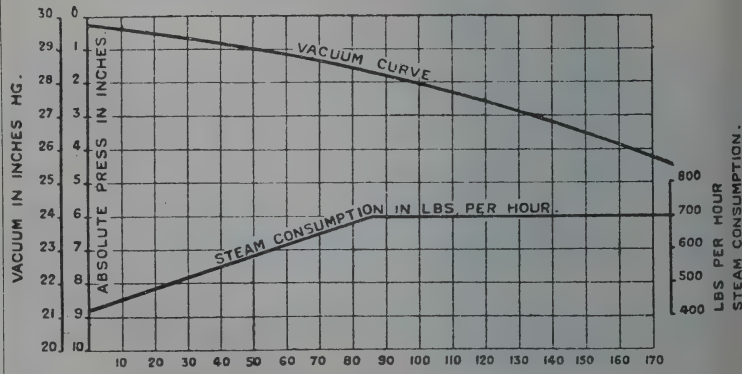


FIG. 18.

Condensing Plant with Radojet Air-Pump.

The construction of the 'straight' type air-pump is illustrated by fig. 19. The arrangement comprises, essentially, two steam ejectors working in series. The first-stage ejector consists of a number of specially designed and arranged tubular nozzles, whilst the second-stage ejector comprises a specially designed radial nozzle with an adjustable nozzle point, so arranged that the steam passing from the nozzle to the diffuser does so in the form of a radial jet and offers a large surface area of steam for the entrainment of the air.

Steam is supplied to the second stage of the 'Radojet' through a steam strainer, and a branch pipe with valve from this strainer controls the supply of steam to the first stage. The steam issues from the first stage nozzles at high velocity, entrains the air withdrawn from the condenser, or other vessel in which it is required to maintain a vacuum, and compresses the air and vapour to a pressure several inches above that at the entrance to the 'Radojet.' The mixture of air

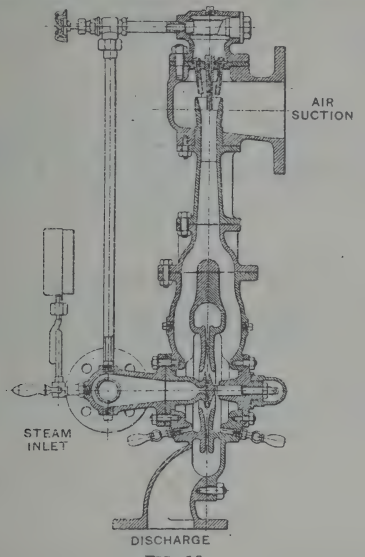


FIG. 19.

and steam then passes through the body of the ejector to the second stage, where it is entrained by the second-stage steam and compressed to atmospheric pressure in an annular diffuser. The whole then passes through the discharge branch to atmosphere, or to some place where the heat of the steam can be utilised.

It will be noted that the second-stage steam compresses not only the air but also the steam coming from the first stage. The air-pump may, however, be arranged with a surface or jet type intercondenser, fitted between the stages, so as to condense the steam used in the first stage, and leave only the air and vapour to be dealt with by the second stage. For equal air handling capacity, this arrangement reduces the steam consumption by about 50 per cent. as compared with an ordinary 'straight' type 'Radojet.' Where it is desired to recover the heat in the steam discharged from the ejector, the discharge pipe may be led direct into the feed tank, or the steam may be led to a feed heater of the direct-contact or surface type.

The 'Radojet' air-pump has been adopted in a great many land installations, and has also been widely applied to marine service. For closed feed systems the first stage discharges into a surface intercondenser, and the second stage into a surface type aftercondenser—both units being incorporated, if desired, in one casing. The air-pump has also been fitted in conjunction with the maker's surface and jet type main condensers for turbine installations up to large sizes, and for uniflow, steam extraction, and slow-speed reciprocating steam-engines. For turbine installations the water extraction and circulating pumps are usually driven by electric motors

or small turbines, and this drive may also be adopted in the case of reciprocating engines, or th pumps may be driven through ropes or belts from pulleys on the engine shaft. Where the vacuum obtainable with existing reciprocating or other type air-pumps is unsatisfactory due to age o any other cause, an improvement may be effected by the substitution of a 'Radojet' equipment Such conversions have frequently been carried out in connection with large reciprocating steam engines, and have been accompanied by an increase in the power and efficiency of the prim mover. If desired, the air-pump may be arranged in the 'Duplex' form, which provides tw complete ejector units with common inter- and after-condensers, and thus affords a spare uni capable of dealing with abnormal loads or air leakages.

The application of the 'Radojet' is not confined to condenser installations, but embraces a processes in which the creation of a vacuum is required, *e.g.* vacuum drying, filtering, and pape making, sugar making and refining, evaporative and chemical processes. In such cases th total absence of moving parts is an important advantage, and the exhaust heat from the air-pump may frequently be used for heating the liquor or other material used in the process. The principl of the radial jet has also been applied to the design of a 'Radojet' Vacuum Augmenter, operate by steam from the auxiliary exhaust range at a pressure of 2 to 5 lbs. gauge. This augmenter i intended for use in conjunction with existing air-pumps where it is desired to increase the vacuum without entailing additional work on the existing pumps.

THE WEIR EJECTOR AIR-PUMP.

(*G. & J. Weir, Ltd., Cathcart, Glasgow.*)

The most modern Weir Ejector Air-Pump is the three-stage type, totally enclosed, eac stage being fitted with after coolers. These three-stage air ejectors have a greater air-handlin capacity than the two-stage types, the ratio of increase naturally varying with the quantity of ai being handled. At normal duties the ratio is roughly 3 to 2 on the same steam consumption.

THE BAILEY AIR-PUMP.

(See p. 1264).

Measurement of Condensed Steam.

The condensate may be measured by passing over a V-notch in a suitably arranged tan the height of the water surface above the apex of the notch being measured at a point at suc a distance from the notch that the water is nearly still.

If h is the height in inches, Q the flow in cub. ft. per minute, and the angle of the notch 90°, then $Q = ch^2\sqrt{h}$, where c is approximately 0·305, but, more accurately, varies from 0·3 at $h = 2$ ins., to 0·301 at $h = 9$ ins. or over. Less heads than 2 ins. should not be used, it bein better to increase the head by using a notch of narrower angle; the discharge is approximatel proportional to the tangent of half the notch angle.

For the 90° notch th ecubic feet of flow per minute$=0{\cdot}305h^2\sqrt{h}$, where h is the depth fro the water level in the still pond above the notch measured down to the point of the V.

If one notch will not pass the water, two may be used, and the reading of the instrume doubled.

In the 'close feed' systems, which are now frequently adopted in power stations, the co densate and the make-up feed-water may be measured by means of Venturi meters included i the pipe system.

Measurement of Air-Pump Water.

THE LEA AUTOMATIC WATER RECORDER FOR MEASURING CONDENSED STEAM.

This instrument, made by *The Lea Recorder Co., Ltd.*, of Manchester, measures the condensa from surface condensers by means of 90°, or smaller, 'V' notches.

A float in a chamber, connected to a measuring tank, which is fitted with 'V' notch plat rises and falls in accordance with the level of water flowing over the 'V' notch.

On the float rod is a toothed rack which turns a pinion on a drum spindle. The pen of th recording mechanism is moved across the record paper (which is clock-driven) by means of th spiral groove cut in the drum. This spiral has an increasing pitch, starting at 0 when the wat is down to zero level, or the apex of the 'V' notch, and increasing in the ratio $h^2\sqrt{h}$, so th the pen movement is always proportional to the volume of water flowing. (See p. 1503.)

An important feature of these recorders is that when measuring hot water they possess a com pensative action, owing to the fact that when the temperature increases, the density of the wat is reduced, and consequently the float sinks slightly, and thus the instrument records a less weigh which is correct. On the other hand, when the temperature falls the float rises, owing to th increased density of the water, and the instrument records a slightly greater weight, which is als correct. The instrument, therefore, remains accurate for changes of water temperature withi wide limits.

By means of this recorder the steam consumption of an engine or turbine can be noted at any time, whilst a chart record is secured of the total discharge over a given period.

Any small changes in the running of the plant can be instantly noted on referring to the diagram produced.

TABLE OF FLOWS THROUGH 90° V NOTCHES.

Depth in Notch in Ins.	Flow per Hour.		Depth in Notch in Ins.	Flow per Hour.	
	Galls.	Lbs.		Galls.	Lbs.
2	654	6,540	9	27,300	273,000
3	1,785	17,850	10	35,600	356,000
4	3,640	36,400	11	45,000	450,000
5	6,350	63,500	12	56,050	560,500
6	9,970	99,700	13	68,400	684,000
7	14,650	146,500	14	82,600	826,000
8	20,300	203,000	15	79,900	979,000

(*Barr.*)

The position of the 'V' notch tank varies with the type of plant, *e.g.* sometimes it is placed in the condenser pit, alongside the extraction pump, and the condensed steam flows from it by gravity to a hot-well, or, alternatively, it is inserted between the extraction pump and a lift pump, the latter drawing water from the end compartment of the notch tank, and delivering to an overhead hot-well or storage tank.

In cases where the 'closed feed' system is in operation the recorder tank can be sealed, and the same degree of vacuum maintained as exists in the condenser, in which case the tank is placed immediately underneath the condenser outlet, and between this and the extraction pump.

This apparatus is also extensively used for the measurement of boiler feed-water, in which case the measuring tank is usually inserted on the suction side of the boiler feed pumps, so that water is drawn from it; the supply of water flowing through the recorder tank being controlled by means of an equilibrium float valve.

These recorders can be obtained in two patterns, *i.e.* the 'Indicating and Recording' type, and the combined 'Indicating, Recording, and Integrating' type. With the latter the total quantity can be read off directly on large dials of the Harding type.

Injection Cocks

Are usually of the hollow plug type, in gunmetal. One per condenser is sufficient. Two or three standard sizes are generally available to choose from. The minimum size can be checked, as in the following example:—

Maximum load under normal conditions	1,000 i.h.p.
Steam per i.h.p. hour	15 lbs.
Steam per second	4·17 lbs.
Condensing water per pound of steam	40 lbs.
" " per second	167 lbs.
" " "	2·67 cub. ft.
Vacuum in condenser, worst	24 ins.
" " in feet of water	27 ft.
Vertical height water level to injection cock	11 ft.
Head of water on injection service, 27-11	16 ft.
Assume spent in friction	50 per cent.
Net head at injection cock	8 ft.
Velocity of water at cock $= 8\sqrt{8}$	22·6 ft. sec.
Hence area of opening	0·118 sq. ft.
" "	17 sq. ins.

If in doubt add a margin of 25 to 30 per cent. It is, of course, understood that the above level, steam consumption, etc., must be modified to suit the actual conditions. Thus in tropical countries 60 should be substituted for 40 lbs. of condensing water per lb. of steam.

Force or Feed Pumps.

When the boiler feed-pump is driven off the engine it is usual to allow sufficient capacity for other works purposes.

The following are frequently adopted :

Textile spinning mills	25 lbs. water per i.h.p. hour
Textile weaving sheds	40 ,, ,, ,,
Mixed spinning and weaving	30 ,, ,, ,,
Flour mills	35 ,, ,, ,,
Bleach works	50 ,, ,, ,,

It will be seen that an ample allowance is made, and for economical superheated-steam engines a reduction of about 5 lbs. can be made. The above are based on actual pump displacement. The plunger speed should not exceed about 200 ft. per minute.

Pump Openings.

The velocity of water in pump openings should not exceed 500 ft. per minute.

Cooling Ponds.

Where the supply of water for condensing purposes is limited, it is necessary to cool the condensing water and use it again and again. One method of cooling is to pass the hot water into an open pond and draw off water for condensing from the opposite side of the pond, the water being cooled simply by evaporation from the surface.

Spray Ponds.

An improvement upon the simple pond is to lay a system of piping over the pond and let the water issue from nozzles in a fine spray. A large amount of water is, however, carried away by the wind and lost.

A spray pond should have 2½ sq. ft. of area per gallon of water to be cooled per minute. This includes the marginal straps necessary for windage, etc.

Water-Cooling Towers.

Water-cooling towers are of two principal types—chimney type and open type. Both act by bringing the water into intimate contact with air currents, and to expose as large a surface of water to the air as possible the water is either broken up by splash bars into fine drops, or made to run down in thin films. In chimney type towers air is admitted at or near the bottom only, and passes up inside the casing usually by natural draught, though sometimes forced draught is used. Forced-draught towers are smaller than natural-draught for the same duty, but require a large expenditure of power in the fans.

Open type coolers have water-distributing arrangements similar to those in the chimney type, but have no external closed casing, the flow of air across the water is dependent upon the action of the wind. To prevent excessive loss of water, the stack is usually surrounded by louvre boarding, but even then the loss of water is large compared with that in the chimney type.

In chimney type towers the water is usually pumped to distribution troughs at a height of 16 to 25 ft.; the height of the chimney is about 60 to 70 ft. if of timber, 100 to 120 ft. if of steel (which is less usual). The width of the tower should not exceed 25 ft. at most, as the difficulty of getting cool air to the centre increases as the width is increased; nor should the tower be narrower than about 15 ft., in order that it may have an adequate margin of stability.

In all cooling towers the heat is extracted from the water partly by (1) direct heating of the air, partly by (2) evaporation of part of the water. Under typical atmospheric conditions in this country evaporation accounts for about 75 to 85 per cent. of the cooling.

The amount of evaporation possible depends upon the amount of moisture already contained in the air entering the tower and its temperatures at inlet and outlet.

PREMIER

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COOLING TOWERS

have been erected by us for many of the important engineering firms.
Combining strength with efficiency, absolutely weatherproof, Premier plant cools over 85,000,000 gallons per hour.

The name that means absolute efficiency —and low— maintenance cost

ADHESIC AIR FILTERS

With its low resistance to air flow, uniform surface and adhesive coating, the "Premier" filtering system is far superior to any other.
Guarantees to remove 98% of all solid impurities.

CLOSED CIRCUIT
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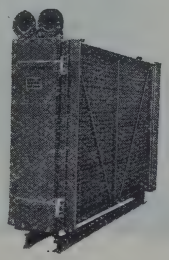
For alternator ventilation, to be found in practically every engineering plant of importance throughout the world. Installations to date exceed 400,000 kw.



HASTE PATENT VALVES

No springs, hinges, corners, angles or pockets; the only working part is the valve itself. For a given size, more water can pass through this valve than any other type.

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STEAM TRAP

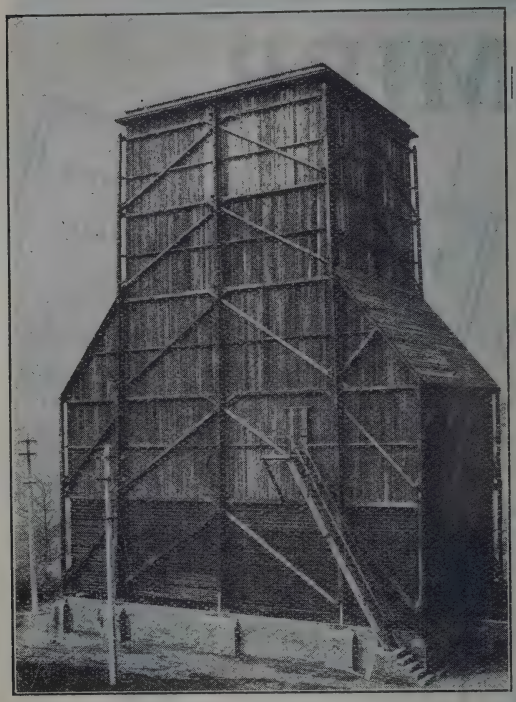
Simple design ensures constant flow of liquid. Works satisfactorily with superheated steam.

OIL SEPARATORS

Simple to install—needs very little attention, no filtering materials required. Guaranteed to separate all oil up to ·33 grains per gallon of steam condensed.

We shall be pleased to supply details of other Premier products upon request.

THE PREMIER COOLER & ENGINEERING Co. Ltd.
Shalford, near Guildford, Surrey.



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It is important, in specifying or judging the capacity of cooling towers, to take into account the humidity or the wet and dry bulb readings.

The 'relative humidity' of the atmosphere is the ratio of the weight of water vapour contained in a certain volume of air to the weight required to saturate this volume at the same temperature, or it may be expressed as the ratio of the vapour pressure at the dew-point to that at the actual air temperature, the dew-point being the temperature to which the air must be cooled in order that it may just become saturated, so that further cooling would cause condensation to begin. The greater the humidity of the atmosphere, the less, of course, is its capacity for taking up moisture by evaporation. The humidity is ascertained by reading wet and dry bulb thermometers and referring to humidity tables.

The quantity of fresh 'make-up' water required to compensate losses by evaporation, etc., in cooling plants is about 3 to 5 per cent. of that in circulation.

It is stated that the loss by evaporation only in natural draught chimney type cooling-towers is approximately 1 per cent. for each 12° F by which the water is cooled in the tower.

(*I. V. Robinson*, '*B.E.A.M.A. Journal*,' *March* 1921.)

The amount of air for which the cooling tower should be proportioned may be calculated as in the following example :—

Let the atmospheric temperature and humidity be 65° F. and 60 per cent. respectively, the atmospheric pressure 14·7 lbs. per sq. in., and let the air leave the tower at 85° F. (saturated with vapour).

From steam tables, the vapour pressure at 65° F. is 0·31 lb. per sq. in., thus the air pressure is 14·7—0·31 = 14·39 lb. per sq. in.; 1 lb. air at this pressure and at 65° F. occupies 13·45 cu. ft ; 1 lb. vapour at 85° F. occupies 990 cu. ft.

$$\therefore \text{weight of vapour per lb. air if saturated} = \frac{13{\cdot}45}{990} = 0{\cdot}0136 \text{ lb.}$$

$$\therefore \text{weight of vapour at 60 per cent. humidity} = 0{\cdot}0136 \times 0{\cdot}6 = 0{\cdot}00816 \text{ lb.}$$

At 85° F. the vapour pressure = 0·6 and air pressure 14·1 lb. per sq. in.; 1 lb. air at these conditions occupies 14·3 cu. ft.; 1 lb. vapour at 85° occupies 541 cu. ft.

$$\therefore \text{vapour per lb. air} = \frac{14{\cdot}3}{541} = 0{\cdot}0264 \text{ lb.}$$

Hence, for each lb. of air passing through the cooling tower, 0·0264—0·00816 = 0·0182 lb. water is evaporated.

Heat to evaporate 1 lb. water from water at 65° F. to vapour at 85° F. = 20 + latent heat = 1,061 B.Th.U.

$\therefore$ heat to evaporate 0·0182 lb. = 0·0182 × 1 061 = 19·3 B.Th.U.
Heat absorbed in heating air = 0·237 × 20 = 4·74 B.Th.U.
Total heat taken from water per lb. air = 19·3 + 4·74=24·04 B.Th.U.

Ratio of cooling by evaporation to total cooling

$$= \frac{19{\cdot}3}{24{\cdot}04} = 0{\cdot}8 \text{ or } 80 \text{ per cent.}$$

If the water is cooled, say 30°, the weight of water cooled per lb. air = $\frac{24{\cdot}04}{30} = 0{\cdot}801$ lb.

Percentage of water lost by evaporation

$$= \frac{0{\cdot}0182}{0{\cdot}0182 + 0{\cdot}801} \times 100 = 2{\cdot}22 \text{ per cent.}$$

Weight of air to pass through cooler per lb. water

$$= \frac{1}{0{\cdot}801} = 1{\cdot}25.$$

Premier Water-Cooling Towers.

(The Premier Cooler and Engineering Co. Ltd., Station Works, Shalford, Surrey.)

'Premier' Cooling Towers, although primarily designed for cooling the water used for condensing purposes in, or in conjunction with, steam engines or turbines, also for cooling the jacket water for internal combustion engines, are equally useful to a degree for other industrial purposes, such as: (1) The liberation of gases in liquids, (2) the evaporation of water in solutions containing certain solids it is desired to concentrate as far as possible by this process.

The Chimney Type Tower, which is almost invariably used for the larger schemes, although usually made in rectangular form with a height ranging from 70 ft. to 100 ft., can, nevertheless, be supplied with chimneys of hexagonal or octagonal construction. The latter type, a considerable number of which have been put into operation in this country, has exceptional strength owing to its shape approaching as near as possible the circular form. The chimneys are designed so as to resist the full wind pressure experienced with a good factor of safety without the assistance of the internal filling or irrigation. The materials used for this class of tower are generally pitch pine and red deal, if of timber construction, but towers can be supplied with steel, concrete, or brick chimneys. In the wooden construction all the bolts, fishplates, grappling irons, etc., are heavily galvanised.

The irrigation system is designed to give the largest area possible for the uprising air, which is brought into contact with the water or other liquid to be cooled or evaporated, in the finest possible form. The towers operate on the splash and film principle, which extensive experience has proved gives the best results. The distributing troughs and gutters are of the open top type, thus allowing the quick removal of solids and foreign matter which invariably accumulate, due to the continuous process of evaporation. The distributing tubes are of 'Venturi' type executed *in acid-resisting earthenware, as also are the splash plates.* The water is thoroughly atomised before falling into the irrigation or lath system. The laths are fixed without the use of nails, being held in place in machined-notched bearers. The design provides for keeping the air in contact as long as possible whilst allowing the maximum amount of air to be circulated through the plant.

The Open type construction, such as is usually employed for dealing with the jacket water for internal combustion engines, is constructed on somewhat similar lines, but the outside faces are louvred to prevent splashing out. Since this type of tower is not fitted with a chimney, the air circulation is much slower, and consequently the space occupied for a given duty is much more than with the natural draught Chimney type construction. In cases where the water volume is comparatively small, and it is desired to reduce the temperature to a very low degree, this type of cooler is especially suitable.

In exceptional circumstances, where the space available is limited, Forced Draught Towers can be supplied with considerable benefit, but such plant is uneconomical from the point of view of running cost, as compared with Natural Draught Plant.

The Film Cooling Tower.

(Film Cooling Towers (1925), *Ltd.*, 124 *Chancery Lane, W.C.* 2.)

The object in view of the 'Film Cooling Tower' is to enable the user effectively to cool larger quantities of water on the same area than has been possible with the older types of cooling towers. In the latter case the water is delivered into a system of troughs, and in its descent to the tank below it is broken up into drops, the rising air cooling the water. Owing to the density of this 'rainfall' a very large resistance is set up against the incoming air, and this had to be taken into account when designing this type of tower. In the 'Film' tower the water is broken up into a thin, flat stream running along the laths inclined in the direction of their length, the bottom end of each lath being cut in such a way so as to allow the water to be delivered into the centre of the next lath, and so on. Owing to surface tension the water will completely envelop each lath and run along the underside as well as along the upperside, whilst the formation of the lath is such as to provide natural passages for the air, thus providing even the centre portions of the cooling tower with an efficient air supply.

In actual practice it has been found that a 'Film' tower of the same capacity when built of the same height as a 'Splash Type Tower' would occupy a ground space about 27 per cent. smaller. The discharge from the troughs takes place through syphonic earthenware tubes on to specially designed splash cups; these tubes, as well as the film lath, are covered by Letters Patent.

Steam Accumulators.

Where, as in the case particularly of rolling mill engines and winding engines, large quantities of steam are exhausted intermittently, this steam may be profitably utilised in exhaust steam turbines. In order to give a steady supply of steam to the turbine, the exhaust from the high pressure is first passed into a storage vessel or heat accumulator, which consists essentially of a large container in which a large mass of material is placed which can absorb the heat of the engine exhaust during its working periods and redeliver it to the turbine during the 'bridge' periods, i.e. when the reciprocating engine is not exhausting any steam.

An exhaust steam turbine working with steam at, say, 16 lbs. per sq. in. abs., and a vacuum of 27·5 ins., will require, with allowance for auxiliaries, about 40 lbs. steam per kw. hour, so that for every 1,000 lbs. exhaust steam per hour available, and deducting 16 per cent. for wetness and leakage, $\frac{1{,}000 - 160}{40} = 21$ kw. can be obtained.

The proportions of the accumulator depend on the bridge period or time of regeneration, the range of temperature allowable, and the material used to store the heat, as well as on the steam rate. Early accumulators were made up of old boilers packed with old rails, etc., but water is a much more efficient material, for iron has a specific heat of about 0·11 and a specific gravity of about 7, so that its volumetric specific heat is only about 0·77.

The range of temperature to be allowed in the accumulator must be decided upon, and from these figures the mass of water to be employed must be calculated. If the accumulator becomes too hot it will reduce the power of the engines which feed it. If it becomes too cold this proves that the turbine is doing more work than can be supplied by the waste steam. It is considered that usually the stops to be bridged by the accumulator are 60 secs. in colliery work and 30 to 45 in rolling mills. The admission to a steam turbine is assumed to be 16·5 lbs. absolute, the range being 15 to 18 lbs., or 10° F. In some plants, pressure rises more than ½ lb. above atmosphere, and it may fall to 12 lbs. absolute or 5½ ins. of vacuum. A reflux valve is arranged in that case to prevent the vacuum getting back to the engine—an important safeguard for a winding engine.

In calculating accumulators,

$$\mathrm{WTL} = wt,$$

where,

W = lb. of steam supply per sec.; T = time of regeneration in secs.;
w = lb. of water in accumulator; L = latent heat of steam per lb.;
t = range of mean water temperature in accumulator.

It should be noted that if the circulation is not perfect, the range of mean temperature (t) of the water will be less than that corresponding to the change of steam pressure. This should be allowed for in using the formula.

It is essential that the steam should mix with the water or this will be locally heated only. Shallow dishes of water piled in tiers with narrow spaces for steam admission between them have been used, or the water may be kept in continuous circulation by a pump which delivers it in a shower through an upper steam space.

In the Rateau-Morison type of steam accumulator, great attention has been paid to efficient circulation. This has been attained by means of a number of vertical open-ended cylinders, each containing a nozzle with upturned star-shaped opening. This is placed 9 ins. below water-level, and sets up a powerful up-flow through the cylinder, which draws from the base of the accumulator and discharges the heated water at the surface.

As many as 30 such circulators are hung on curved branch pipes from each side of the exhaust main which runs along the crown of the accumulator boiler. Below the main is a third row. The accumulator is a plain cylinder laid horizontally with about 6 ft. of water depth. Circulation is so rapid that a difference of only 2° F. occurs between top and bottom of the water. The circulation cylinders have their discharge openings all turned to one end of the accumulator, and all oil is then drifted that way and collected behind two vertical plates and blown off periodically.

Accumulators may be made of old Lancashire boiler shells, or built up of cast-iron segments, or may be of ferro-concrete.

An increase of vacuum from 26 to 28½ ins. will reduce the steam consumption of a turbine by 25 per cent. With this vacuum the condensate will be about 80° F., and if there is any spare steam it should be applied to feed heating. In this case by heating the feed to 200° an economy of 12 per cent. is secured.

The Galloway Steam Accumulator.

This accumulator (figs. 20 and 21) is intended for receiving the exhaust steam at a few lbs. per

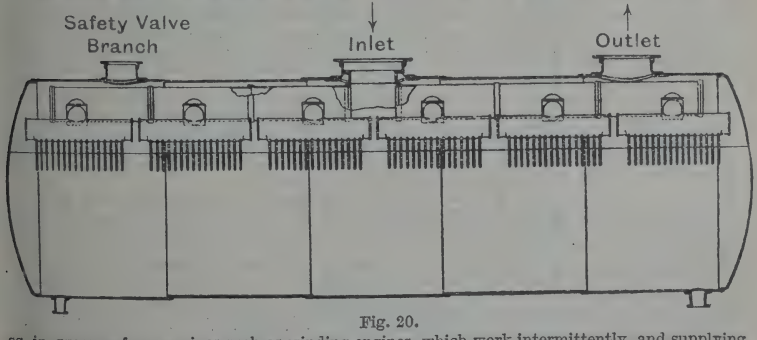

Fig. 20.

sq. in. pressure from engines such as winding engines, which work intermittently, and supplying steam at a steady rate to mixed pressure turbines.

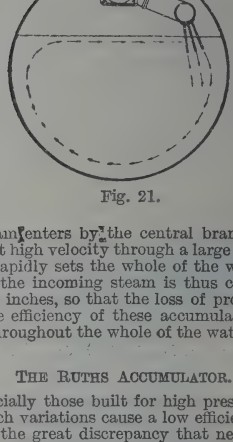

Fig. 21.

As shown in the figs., the steam enters by the central branch through internal distributing boxes, and is led into the water at high velocity through a large number of simple nozzles of small bore, so placed that the steam rapidly sets the whole of the water in the accumulator into circulation. The condensation of the incoming steam is thus carried out very effectively. The nozzles are submerged only a few inches, so that the loss of pressure between incoming and outgoing steam is very slight. The efficiency of these accumulators in operation is evidenced by the uniformity of temperature throughout the whole of the water, the maximum difference being about 1° Fah.

The Ruths Accumulator.

Ordinary steam boilers, especially those built for high pressures, are not well suited to cope with quickly varying loads. Such variations cause a low efficiency in the operation of the boiler plant, which manifests itself in the great discrepancy that nearly always exists between boiler test results obtained at constant load and those obtained under normal practical working conditions. More serious, however, is the detrimental influence which the limited rate of steam supply from the boilers has on the magnitude of the *output of the works* where the boilers are installed. It also happens very often that variations in steam pressure, caused by variable loads, have a serious influence on the quality of the products manufactured.

Investigations made in a great number of different industries show that the actual variations which occur in the steam consumption are usually larger than conceived. Moreover, if the limiting effect on the steam consumption that is exercised by the boilers did not exist, the variations in the steam consumption would be even still larger, as a more intensified work is possible in the factory when steam is always available in sufficient quantities.

By means of the new steam accumulation system of Dr. J. Ruths of Stockholm, all such variations in the steam demand for process and for power purposes, which are detrimental to the work of the manufacturing plant or the boilers, can be completely ' equalised ' and prevented from reaching the boilers. This system will also prevent inevitable unevenness in the quality of fuel or in the fuel supply to adversely affect the operation of the boilers, the overall efficiency of which can thus be materially increased.

The scope of application of the Ruths Accumulator is thus a much larger one than that of earlier steam accumulators as, *e.g.*, the exhaust steam accumulators of Rateau and others. As in these accumulators, the Ruths Accumulator utilises the well-known ability of hot water to accumulate steam at a rising temperature and pressure and to release it again through re-evaporation by the internal heat of the water at falling temperature and pressure. The pressure ranges applied in Ruths Accumulators are much wider than those used in earlier steam accumulators, and although the Ruths Accumulators co-operate with the boilers, the pressure of the latter is under normal circumstances unaffected by the accumulator pressure. The maximum working pressure in a Ruths Accumulator is usually much greater than the minimum pressure. Ranges like 150–40 50–10 lbs. gauge are common. On account of the use of these wide pressure ranges at comparatively low level on the pressure scale, great steam quantities are stored per unit of volume. The practical heat storing capacity or ' steam reserve ' of Ruths Accumulators is as an average 5 to 50 times larger than the maximum ' steam reserve ' that can be obtained at a permissible pressure drop in the steam boilers with which they co-operate.

The Ruths Accumulator is usually built in the form of a large cylindrical steel tank, with hemispherical ends. It is constructed like a steam boiler of riveted steel plates to withstand a certain maximum steam pressure. It contains the hot steam-storing water, and is equipped with arrangements for an even distribution of the charging steam into the water, and for re-discharging steam in a safe way. The accumulator is not directly attached to the boilers, but is usually erected out of doors in a factory yard, etc., in order to be out of the way. By means of a single steam pipe and a few control valves of special type and action the accumulator is connected to the steam system, including the boilers, steam engines, or turbines, and other consumers, in such a way that a *complete and positive equalisation* of all the flow of heat energy in the whole works in question is accomplished. All surplus steam that may occur is absorbed by the accumulator, and any shortage of steam that may arise in the supply to the consumers is

THE RUTHS STEAM ACCUMULATOR.

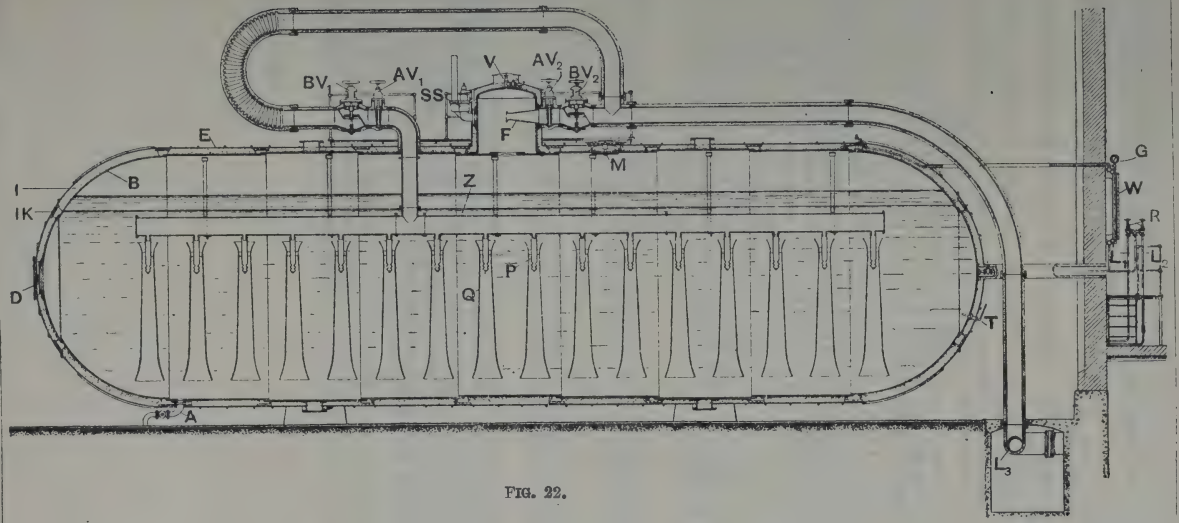

FIG. 22.

automatically made up from the accumulator; the boiler plant can therefore be worked und practically constant load and the boiler pressure remains steady at the set maximum level. Th following are the advantages obtained as a result of this 'thermo-fly-wheel effect' of th accumulator:

1. Steady supply and practically unlimited reserve of steam at constant pressure for a power or process purposes.

2. Maximum economy in the operation of the whole manufacturing plant, as the same ca be intensively utilised.

3. Maximum efficiency in the boiler plant, as ideal load conditions prevail.

4. Reduction in the numbers of boilers in operation, as only so much heating surface is require as corresponds to the average steam requirements of the factory.

The firing of the boilers is guided by a pressure gauge, put up in the boiler-house, which show the accumulator pressure. As long as this pressure is swinging within the limits of the set rang of the accumulator (which is clearly marked on the dial), the firing rate is kept constant.

Fig. 22 shows a section of a Ruths Accumulator. The accumulator is charged through stea entering the check valve BV_1 and passing into the water through the distribution pipe Z, th special nozzles P and the circulation pipes Q. The check valve BV_1 in the steam inlet preven the water flowing backwards out into the steam pipe. When discharging, the steam is passed ou from the steam dome through a 'safety nozzle' F and a cheek valve BV_2, which prevents th charging steam passing this way. Usual boiler mountings are fitted, including a water-gauge W made extra long on account of the great variations in level that are a result of the wide pressu range. No regular supply of feed-water is necessary, but only occasional adjustments of th level in order to make it correspond to the pressure. The accumulator does not require dai attendance. The steam passes in and out (according to the requirements of the factory) witho any noise or vibrations. The vessel is covered all over by a thick cover I of first-class insulatio material, whereby the heat losses are sufficiently reduced as to be negligible. On accumulato erected out of doors the insulation is protected by roofing material E.

The control valves, which govern the proper action of the whole plant, including the co-operatio of the accumulator and the boilers according to the variations in the steam demand, are automat in action and operate on the relay principle with oil as a pressure medium.

The pressure impulses that govern the work of the valves are taken from the various stea pipes, and by suitable combinations of these valves, relays, and impulses, all variations tha occur in the steam system are kept away from the boilers and made to fall on the accumulato This action goes on automatically and accurately without attendance.

Numerous Ruths Accumulators have been working for years with marked success in man different industries and also in purely power stations, especially in Scandinavia and on th Continent. The accumulators are particularly useful in the increasing number of factori where back pressure, pass-out, or mixed pressure steam turbines or engines are employed f producing cheap steam power. In such schemes they work as a very valuable 'clearin department' for handling all the fluctuating requirements of heat and power that are inte linked by means of the steam machinery.

Under the steadying influence which the accumulator exercises on the load and steam pressur it is usually found, in such schemes, that a great deal more power can be produced out of the heatin steam than when the variations in the steam and power demand are left unequalised.

SECTION XXXI

Revised and amplified by A. Vincent Clarke, A.M.Inst.C.E., M.I.Mech.E., A.M.I.E.E.

With contributions by G. A. Burls, M.Inst.C.E., M.Inst.A.E.; A. P. Chalkley, B.Sc., A.M.Inst.C.E.; T. B. Morley, D.Sc., M.I.Mech.E., and G. E. Windeler, M.I.Mech.E.

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SECTION XXXI

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PART I

GENERAL DATA RELATING TO POWER GAS.

Interrelations of Units.

In calculations relating to Power Gas, the following physical data and interrelations of units will be found convenient for reference :—

1 metre = 39·37079 ins. = 3·2809 ft. = 3 ft. 3⅜ ins. (app.).
25·4 millimetres = 1 inch.
1 square inch = 6·4516 square centimetres.
1 cubic inch = 16·387 cubic centimetres.
1 gallon = 8 pints = 277·3 cubic inches (app.) = 4·5435 litres.
1 gallon of pure water at 62° F. weighs 10 lbs.
1 cubic foot = 6·23 gallons.
1 cubic foot of pure water at 62° F. weighs 62·3 lbs. = 28·315 litres.
1 cubic foot of average river water weighs 63 lbs.
1 cubic foot of sea water weighs 64 lbs.
1 litre = 1,000 cub. cm. = 61·03 cub. ins. = 1·761 pints.
1 pound (av.) = 7,000 grains = ·45359 kilogramme.
1 gramme = 15·432 grains = ·0022046 lb.
1 gramme per litre = 70·13 grains per gallon = 436·9 grains per cub. foot.
1 kilogramme = 15,432 grains = 2·2046 lbs.
1 British ton = 2,240 lbs.
1 metric ton = 2,205 lbs. = 0·9844 British ton.
1 atmosphere = 14·7 lbs. per sq. in. = 2116·8 lbs. per sq. ft.
" = 33·977 ft. of water.
" = 26,220 ft. of (homogeneous) air.
" = 30·0 ins. of mercury (app.).
" = 760 mm. of mercury (app.)
1 kilogramme per sq. cm. = 14·22 lbs. per sq. in.
" " = 0·9673 atmosphere.
1 inch of mercury = 0·490 lb. per sq. in.
1 inch of water = 0·0360 lb. per sq. in.
1 British thermal unit (B.Th.U.) = heat necessary to raise 1 lb. of water through 1° F.
" " = 778 ft.-lbs. of work.
1 centigrade thermal unit (C.Th.U.) = heat necessary to raise 1 lb. of water through 1° C.
" " = 1·8 B.Th.U.
" " = 1400·4 ft.-lbs. of work.

1 (major) calorie = heat necessary to raise one kilogram of water through 1°C.
" =2·2046 C.Th.U.
" =3·9683 B.Th.U.
" =3087·3 ft.-lbs. of work.
1 British horse-power=33,000 ft.-lbs. of work per minute.
" " =42·416 B.Th.U. per minute.
" " =2,545 B.Th.U. per hour.
" " =23·564 C.Th.U. per minute.
" " =1,414 C.Th.U. per hour.
" " =10·69 calories per minute.
1 metric horse-power =75 kilogrammetres per second.
" " =0·9863 British horse-power.
1 kilowatt=1·34 British horse-power.
Absolute temperature °F. (T)=460 + ord. temp. °F.
" °C. =273 + ord. temp. °C.

The volume of 1 lb. of a gas varies with its pressure and temperature and for purposes of comparison a definite pressure and temperature are selected. If normal pressure and temperature be one atmosphere and 32°F., this may conveniently be denoted by N.T.P.

Mass and Bulk of some Gases and Vapours at N.T.P.

Air is by *weight*, composed of 77 per cent. nitrogen and 23 per cent. oxygen.
By *volume* its composition is 79 per cent. nitrogen and 21 per cent. oxygen.
One pound of oxygen is contained in $\frac{100}{23}=4{\cdot}35$ lbs. of air.
One cubic foot of oxygen is contained in $\frac{100}{21}=4{\cdot}8$ cub. ft. of air.
One pound of dry air at N.T.P. occupies 12·387 cub. ft.
One cubic foot of dry air at N.T.P. weighs 0·08073 lb.
The following table gives data relating to the heaviness and bulkiness of the more usual gases:—

HEAVINESS AND BULKINESS OF SOME GASES, ETC., AT N.T.P.

Gas.	Symbol.	Specific Gravity; Hydrogen = 1.	Heaviness of 1 Cubic Foot at N.T.P.; Lbs.	Bulkiness of 1 lb. in Cubic Feet at N.T.P.
Column:—	1	2	3	4
Hydrogen	H_2	1	0·00559	178·89
Methane (marsh gas)	CH_4	8	0·04472	22·36
Water (gaseous)	H_2O	9	0·05031	19·88
Acetylene	C_2H_2	13	0·07267	13·76
Carbon monoxide	CO	14	0·07826	12·78
Ethylene (olefiant gas)	C_2H_4	14	0·07826	12·78
Nitrogen	N_2	14	0·07826	12·78
Air	$O_{23}+N_{77}$	14·44	0·08073	12·387
Oxygen	O_2	16	0·08944	11·18
Carbon dioxide	CO_2	22	0·12298	8·13
Normal benzene	C_6H_6	39	0·21801	4·59

p=abs. pressure, in lbs. per sq. foot
=144 {14·7 + pressure in lbs. per sq. in. above atm.}
v=volume of 1 lb. of gas, in cubic feet;
T=absolute temperature in °F.;
=460 + ord. temp. °F.

Then for a perfect gas:—

$$pv = c\,T, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where c is constant for any, the same, gas.

For dry air at N.T.P.:—

p=14·7 × 144=2116·8 lbs. per sq. ft.
v=12·387 cu. ft. (Table, col. 4.)
T=460 + 32=492°F. (abs.).

Whence, by Eq. (1), we have $c=53{\cdot}29$. Thus the characteristic equation for dry air regarded perfect gas, is :—

$$pv = 53{\cdot}29\ \mathrm{T}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Equations (1) and (2) show that in a perfect gas the value of the product pv is proportional he absolute temperature. If the pressure remains **constant,** the volume and absolute tempera- are mutually proportional. So also, if the volume remain constant, the pressure and absolute perature are mutually proportional.

The specific heat of dry air at constant pressure, k_p, is 0·2374 B.Th.U. per lb.

The specific heat at constant volume, k_v, is less than k_p by the heat equivalent of the external k of expansion under constant pressure.

If Eq. (1) be differentiated at constant pressure we have :—

$$p\ dv = c\ d\mathrm{T};$$

s, putting $d\mathrm{T}=1°\mathrm{F}.$, we have $c=p\ dv$; so that c expresses the external work of ex- sion under constant pressure in foot-lbs. As Joule's equivalent, J, is 778 foot-lbs. per Th.U., we have for dry air :—

$$k_v = 0{\cdot}2374 - \frac{53{\cdot}29}{778} = 0{\cdot}1689.$$

The ratio of k_p to k_v is important in the theory of gas engines, and is usually denoted by γ: s for dry air :—

$$\gamma = \frac{k}{k_v} = 1{\cdot}4056.$$

Isothermal and Adiabatic Expansion.

The two fundamentally important modes of expansion of gases are :—

(1) Isothermal expansion.
(2) Adiabatic expansion.

(1) *Isothermal Expansion.*—When a mass of gas changes volume at constant temperature, change is described as 'isothermal.' In the case of perfect gases, Eq. (1) shows that in this e the value of the product pv remains constant. If p_o v_o T_o be respectively the initial values pressure, volume, and (abs.) temperature, and pv any subsequent simultaneous values, we ve in isothermal expansion :—

$$pv = p_o\ v_o = c\ \mathrm{T}_o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The external work W done in expanding from volume v_o to volume v, is expressed by :—

$$\mathrm{W} = \int_{v_o}^{v} p\ dv \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

, in isothermal expansion, $pv = p_o\ v_o$, we have $p = \dfrac{p_o\ v_o}{v}$; hence (4) becomes for this case :—

$$\mathrm{W} = p_o\ v_o \int_{v_o}^{v} \frac{dv}{v} = p_o\ v_o\ \mathrm{Log}_e \frac{v}{v_o} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

is the volume ratio of expansion, and may be denoted by ρ; thus, from (5), we have in othermal expansion :—

$$\mathrm{W} = p_o\ v_o\ \mathrm{Log}_e \rho = c\ \mathrm{T}_o\ \mathrm{Log}_e \rho \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

As the internal energy of a perfect gas depends only on its temperature, it follows that isothermal change the internal energy of the gas remains constant. Hence, in isotherm expansion of a perfect gas the heat given to the expanding gas is the exact equivalent of t

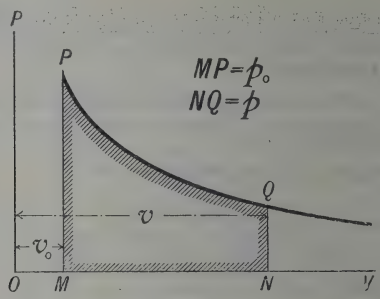


FIG. 1.

external work performed by the gas. And, conversely, in isothermal compression of a perfe gas, the heat that flows from the gas during compression is the exact equivalent of the wo done on the gas in compressing it.

Frequently in engineering thermodynamics it is found that actual expansion and compressi curves of diagrams can be closely represented by an equation of the form :—

$$pv^n = p_0 v_0^n, \text{ a constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where the index n is constant in value.

When $n=1$ we have the particular case of isothermal change, which has just been consider For all other values of n, the external work done during expansion from volume v_0 to volume v represented by the hatched area MNQP of fig. 1—is given by :—

$$W = \int_{v_0}^{v} p \, dv = p_0 v \int_{v_0}^{v} v^{-n} \, dv, \text{ by Eq. (7)}$$

That is,

$$W = \frac{1}{n-1}\left\{p_0 v_0 - pv\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The expanding substance being assumed a perfect gas, we have $p_0 v_0 = cT_0$, and $pv = cT$ hence, in expansion of this type Eq. (8) may also be written :—

$$W = \frac{c}{n-1}\left\{T_0 - T\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Thus if n be greater than unity, expansion is accompanied by a falling temperature. If be equal to unity the temperature remains constant during expansion. While if n be less th unity expansion is accompanied by a rising temperature. Equation (9) shows further that expansion of this type the external work done is proportional to the change of temperature the expanding gas.

Again, the heat expended, H, is equal to the sum of the external work and change of inter energy of the gas ; thus we have :—

$$H = \frac{c}{n-1}(T_0 - T) + k_v(T - T_0)$$

$c = k_p - k_v$, this becomes on reduction :—

$$H = \frac{n\,k_v - k_p}{n-1}(T - T_o) \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

which shows that the heat expended is also proportional to the change of temperature of the expanding gas ; and that the gas expands with an apparent specific heat which is constant, and expressed by $\frac{nk_v - k_p}{n-1}$ B.Th.U. per lb.

(2) *Adiabatic Expansion.*—When a mass of gas changes its volume without any heat communication from without, the changes are said to be adiabatic.

Thus in adiabatic expansion the external work is done wholly at the expense of the internal energy of the expanding gas ; its temperature, and consequently its pressure, rapidly fall during expansion. And contrariwise, in adiabatic compression, the work done in compressing the gas appears as an increase of the internal energy of the gas ; hence, the temperature and consequently the pressure rapidly rise during adiabatic compression.

The adiabatic equation for a perfect gas is at once obtained from Eq. (10). For as, by supposition, there is in this case no heat communication with outside bodies, we have only to put $H = 0$ in Eq. (10), and then deduce the corresponding value of n. But if $H = 0$ we must have $nk_v - k_p = 0$, so that $n = \frac{k_p}{k_v} = \gamma$ in this case.

Hence, the adiabatic equation of a perfect gas is

$$pv^\gamma = p_o v_o^\gamma, \text{ a constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

By aid of Eq. (1) the following two equations are at once obtained from Eq. (11), giving the relation between change of temperature and volume, and change of temperature and pressure respectively, in adiabatic changes :—

$$T = T_o \times \left(\frac{v_o}{v}\right)^{\gamma - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$T = T_o \times \left(\frac{p}{p_o}\right)^{1 - \frac{1}{\gamma}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

For dry air, as $\gamma = 1{\cdot}4056$, we have accordingly from Eqs. (11) (12) and (13) :—

$$pv^{1{\cdot}4056} = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

$$T = T_o \times \left(\frac{v_o}{v}\right)^{0{\cdot}4056} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

$$T = T_o \times \left(\frac{p}{p_o}\right)^{0{\cdot}2886} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Thus, in Diesel engines, the ratio is commonly about 13. Assume the initial temperature of the air to be 70°F., and the pressure to be atmospheric. Then $T_o = 460 + 70 = 530$; and $p = 14{\cdot}7$ lbs. per sq. inch : hence from (15) we have : $T = 530 \times 13^{0{\cdot}4056} = 1500$°F. or $1500 - 460 = 1040$°F. by ordinary scale. This is a sufficiently high temperature to at once ignite the charge of fuel oil on injection. The corresponding pressure from Eq. (14) is 540·8 lbs. per sq. in. abs. = 526 lbs. per sq. in. above atmosphere.

Moisture in Air.

Ordinary air always contains water vapour in greater or less degree, and the presence of this vapour modifies its physical properties.

The pressure of saturated steam formed at temperatures below 212°F. is usually described as the 'vapour tension' of water. In table, page 1912, some data are given relating to the vapour tension of water from 32°F. to 212°F.

DATA RELATING TO AIR SATURATED WITH MOISTURE AT ATMOSPHERIC PRESSURE. ESTIMATED FROM 32°F

Temperature. t°F.	Per 1,000 cu. ft. of Saturated Air.			Cu. ft. of Saturated Air, per Lb.	Cu. ft. of Dry Air, per Lb.	Density ratio of Saturated to Dry Air.	Heat of 1,000 cu. ft. of Sat. Air from 32°F. at t°F.				B.Th.U. per Lb. of Saturated Air.
	Lbs. of Dry Air.	Lbs. of Water Vapour.	Total Weight in Lbs.				B.Th.U. of Heat of Dry Air.	B.Th.U. of rise of Temp. of Water.	B.Th.U. of Vaporisation of Water.	Total B.Th.U. per 1,000 Cu. Ft.	
Column	1	2	3	4	5	6	7	8	9	10	11
32	80·241	0·3046	80·546	12·415	12·387	0·998	0	0	326	326	4·05
40	78·779	0·4073	79·186	12·628	12·56	0·995	149	3·26	434	586	7·4
50	76·943	0·5855	77·529	12·898	12·84	0·995	329	10·54	621	961	12·4
60	75·068	0·8264	75·894	13·176	13·09	0·993	499	23·14	872	1,395	18·4
70	73·112	1·1494	74·261	13·466	13·34	0·991	660	43·7	1,207	1,911	25·7
80	71·042	1·5625	72·605	13·773	13·60	0·987	810	75·0	1,633	2,518	34·7
90	68·821	2·146	70·967	14·091	13·85	0·983	948	124·5	2,231	3,304	46·6
100	66·396	2·833	69·229	14·445	14·10	0·976	1,072	192·6	2,930	4,195	60·6
110	63·691	3·731	67·422	14·832	14·35	0·968	1,179	291·0	3,839	5,309	78·7
120	60·650	4·926	65·576	15·250	14·60	0·957	1,267	433·5	5,041	6,741	102·8
130	57·204	6·329	63·533	15·740	14·85	0·943	1,331	620·0	6,442	8,393	132·1
140	53·269	8·130	61·399	16·287	15·11	0·928	1,366	878	8,230	10,474	170·6
150	48·729	10·309	59·038	16·938	15·36	0·907	1,365	1,217	10,378	12,960	219·5
160	43·498	12·903	56·401	17·730	15·61	0·880	1,322	1,652	12,917	15,891	281·8
170	37·442	16·000	53·442	18·712	15·86	0·848	1,227	2,208	15,925	19,360	362·2
180	30·431	19·802	50·233	19·917	16·11	0·809	1,069	2,931	19,594	23,594	470·0
190	22·406	24·390	46·796	21·369	16·37	0·766	840	3,854	23,992	28,686	613·0
200	13·117	29·762	42·879	23·322	16·62	0·713	523	5,000	29,101	34,624	807·5
210	2·460	35·971	38·431	23·021	16·87	0·648	104	6,403	34,949	41,456	1078·7
212	0·000	37·383	37·383	26·750	16·92	0·632	0	6,729	36,277	43,006	1150·4

DATA RELATING TO THE VAPOUR TENSION OF WATER FROM 32°F. TO 212°F.

At °F.	Absolute Pressure, in Lbs. per Sq. In. P′.	Cu. Ft. Occupied by 1 Lb. *u*.	Latent Heat, in B.Th.U. per Lb.	At °F.	Absolute Pressure, in Lbs. per Sq. In. P′.	Cu. Ft. Occupied by 1 Lb. *u*.	Latent Heat, in B.Th.U. per Lb.
Col.:	1	2	3	Col.:	1	2	3
32	0·089	3,283	1070·5	130	2·209	158	1017·9
40	0·122	2,455	1066·3	140	2·871	123	1012·3
50	0·177	1,708	1060·9	150	3·699	97·0	1006·7
60	0·253	1,210	1055·7	160	4·719	77·5	1001·1
70	0·359	870	1050·3	170	5·970	62·5	995·3
80	0·502	640	1045·1	180	7·492	50·5	989·5
90	0·691	466	1039·7	190	9·310	41·0	983·7
100	0·939	353	1034·3	200	11·496	33·6	977·8
110	1·264	268	1028·9	210	14·09	27·8	971·6
120	1·681	203	1023·3	212	14·70	26·75	970·4

When air contains a maximum of water vapour it is said to be saturated. The quantity of oisture depends only upon the temperature, and is estimated by aid of :—

DALTON'S LAW.—The pressure, and consequently the mass of vapour which saturates a given olume, is the same at the same temperature, whether the volume already contains a gas or is acuous.

Consider a volume of V cubic feet of saturated air at a pressure of P lbs. per sq. in., and temerature t°F. By Dalton's Law this consists of (1) V cubic feet of water vapour at the pressure lbs. per sq. in. corresponding to t°F., as in column 1 of above table, together with (2) V ubic feet of dry air at pressure (P—P′) lbs. per sq. in., and temperature t°F.

Thus the weight, S, in lbs. of 1,000 cubic feet of saturated air at temperature t°F. and pressure lbs. per sq. in. is :—

$$S = \frac{1000}{u} + 80{\cdot}73 \times \frac{492}{460 + t} \times \frac{P - P'}{P} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

e values of u being given in column 2 of table. If the pressure be atmospheric, P = 14·7, and this case :—

$$S = \frac{1000}{u} + 80{\cdot}73 \times \frac{492}{460 + t} \times \frac{14{\cdot}7 - P'}{14{\cdot}7} \quad . \quad . \quad . \quad . \quad . \quad (18)$$

By aid of Eq. (18), the table on p. 1912 has been compiled.

This table may be useful in connection with the heat expended in providing the moisture den air supplied to gas producers.

Efficiency.

The most important thermodynamic cycles are the constant volume (C_v) and constant ressure (C_p) cycles, and the general formulae for efficiency are as follows :—

$$\text{Constant volume efficiency} = 1 - \frac{T_1 - t}{T - t_c}.$$

$$\text{Constant pressure efficiency} = 1 - \frac{\frac{1}{\gamma}(T_1 - t_1) + (t_1 - t)}{T - t_c}$$

here,

t = initial temperature of air ;

t = temperature of compression ;

T = temperature after explosion ;

T_1 = " " adiabatic expansion ;

γ = ratio of specific heat $\frac{C_p}{C_v}$;

$t_1 = T_1 \frac{\text{atmospheric pressure}}{\text{pressure of explosion}}$.

SECTION XXXI

PART II

GAS ENGINES.

Types of Gas Engines.

Gas engines may be classified under the following types:

Type I.—Engines igniting their charge at constant volume, without compression. This pe is obsolete; it included the Lenoir and Hugon.

Type II.—Engines igniting at constant volume without compression, with free piston, id utilisation of vacuum during instroke. This type also is obsolete; it included the Barsanti, enham, and Otto and Langen.

Type III.—Engines igniting at constant pressure, with previous compression of the charge. his type includes the early Brayton and Simon engines, and the modern Diesel engine.

Type IV.—Engines igniting at constant volume, with previous compression. This type cludes the very great majority of gas engines in everyday use.

The vast majority of present-day gas engines are operated upon the Otto, Beau de Rochas four-stroke cycle, wherein the sequence of strokes is suction, compression, working, and exaust; and in most cases, particularly of British engines, the cylinders are single-acting; the rge double-acting engines have been perfected mainly by the great Continental firms.

A number, especially of engines of large size, are built upon the two-stroke cycle, both single nd double-acting, and much attention has been devoted to this type.

Crossley Gas Engines.

Messrs. Crossley Bros. Ltd., of Openshaw, produce annually a very large number of gas engines horizontal and vertical design, working on the four-stroke cycle. The range of power is from to 260 b.h.p., and over 80,000 engines have been supplied.

Horizontal engines of 30 b.h.p. and upwards can be made with two cylinders, the flywheel eing mounted on the crankshaft between the cylinders. These double-cylinder engines are pecially suitable for all purposes where very steady driving is required, as they run with great gularity. The vertical engines, which are of the four-cylinder high-speed design, are also ost suitable for driving dynamos.

The rated powers of the producer-gas engines are obtained when running on gas made from nthracite, bituminous coal, and wood fuel, but are reduced by 6 per cent. when running on gas ade from coke. Working on town gas, the increase in power varies from about 20 per cent. on he small sizes to about 1½ per cent. on the largest size, which develops 130 b.h.p. in one cylinder. he weight of the standard horizontal engine varies from about 2¼ to 3 cwts. per b.h.p., and the eight of the double-cylinder engines is about 2 cwts. per b.h.p.

The sizes from 6 b.h.p. and upwards are now all governed on the throttle, giving a smooth rive and low pressures at reduced engine loads. Fig. 2 shows a recent horizontal single-acting our-stroke design; the girder-type bed and balanced crankshaft will be noted. Other feaures included are the absence of any liner bolts in the water-jackets; adjustable timing to he electric ignition; double ring lubrication to the bearings with forced lubrication to the ylinders and other parts; screw-down producer-gas cock; hardened cams, rollers, and pins; nd a combustion chamber so designed that dust and oil cannot collect at the bottom and form roublesome deposits, but are swept out of the exhaust valve with the burnt gases.

CROSSLEY GAS ENGINE.

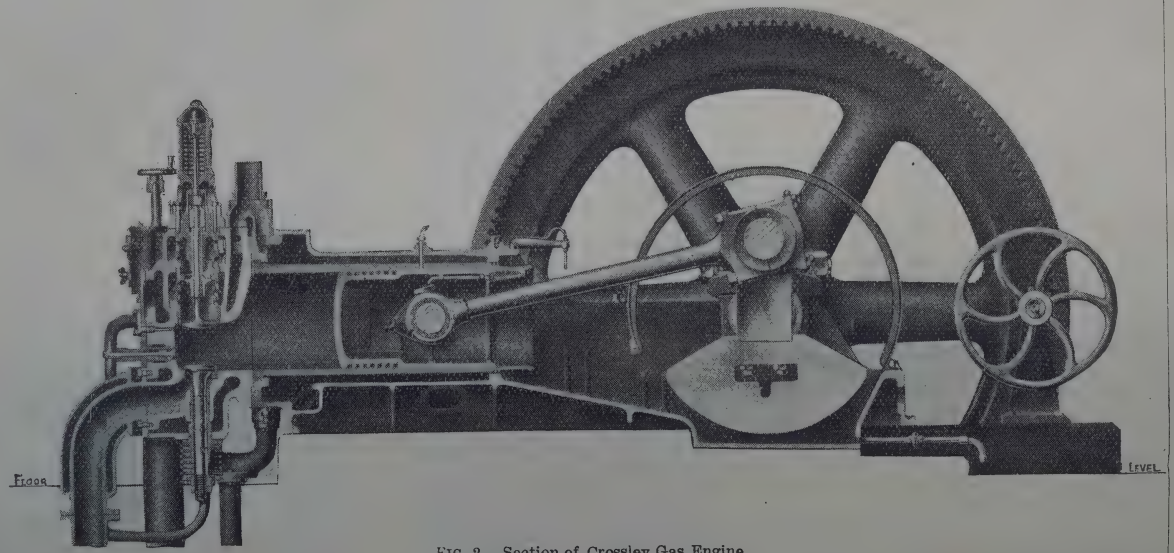


FIG. 2.—Section of Crossley Gas Engine.

Ruston-Hornsby Gas Engines.

The Ruston gas engines and the Hornsby-Stockport engines are now made by Messrs. Ruston Hornsby, Ltd., Lincoln, the engines being of the horizontal four-stroke cycle type, built in ngle and multi-cylinder sizes. The range of powers is from 17 to 340 b.h.p. Fig. 3 shows ne of these engines in conjunction with a Ruston gas-producer. The engines supplied to the l-fields are capable of working either on gas or on oil, so that the natural gas found when well-nking can be used, and, when the supply of this diminishes, the engine can be changed over to l fuel.

The bed-plate is in one piece, carrying the main bearings and cylinder liner, and the thrust of ne connecting rod is taken by the bed-plate, as the cylinder is not overhung. The crankshaft carried by three bearings, the outer bearing being provided to support the weight of the flywheel. egular running is ensured by having a balanced crank, and by using high compression which allows a weak charge being fired.

A special automatic device is used for starting the engine on compressed air, and this is also ade use of for charging the air-receiver, by means of the engine piston acting as an air-pump

Fig. 3.—Ruston Gas Engine with Suction Producer.

or the time being. Efficient lubrication is provided for all of the bearings, the piston, and the xhaust valves. Governing is effected by the Ruston patent throttle gear which varies the open-ig of the gas and air inlet-valves to suit the load. This gear consists of a roller forming a movable ulcrum between a lever having a constant angular movement and the upper surface of the inter-alve plunger, the lift of the valve varying directly as the distance of the roller from the lever ulcrum. The roller and the pressing surfaces are of hardened steel, and the movements are rranged so as to avoid slip.

Campbell Gas Engines.

The Campbell Gas Engine Co. Ltd., Halifax, are builders of horizontal and vertical gas ngines in the single-cylinder type from 15 to 160 b.h.p. and with two and four cylinders up to 40 b.h.p. The engines are of the four-stroke cycle type, and can be arranged for working on as or adapted for oil.

The single-cylinder horizontal design has the cylinder well supported by the bed-plate, which xtends beneath the cylinder as far back as the combustion chamber, and the cylinder liner is emovable. Horizontal engines are also made with two cylinders and four cylinders: these ngines have the bed-plate and crankshaft housing in one casting, to which the cylinders are bolted. The cylinders are also supported on a sole plate resting on the foundation, and the combustion hambers are detachable.

A throttle governor is fitted giving variable-quality governing, in which the piston receives a impulse at every cycle and the compression pressure is the same at all loads. The weights the horizontal as well as of the vertical engines are about 2½ to 3 cwts. per horse-power.

Cylinders and pistons are fitted with forced lubrication, crankshaft and camshaft bearing with ring lubrication, and the big-end and small-end connecting-rod bearings with sight-fee automatic lubricators.

The Campbell vertical gas engines are of the enclosed crank-chamber type, and are bui with two, three, or four cylinders from 75 to 585 b.h.p. Forced lubrication is fitted to t cylinders and all enclosed bearings. Ignition is by low-tension magneto with separate machi and operating gear to each cylinder. Governing is on the throttle, the governor being drive direct from the crankshaft by its own independent gearing. The vertical engines run at a high speed than the horizontals, and are well adapted for direct coupling to dynamos owing to the good balance and low coefficient of speed fluctuation. The rotation is so uniform that it claimed even alternators may be operated in parallel.

National Gas Engines.

Horizontal and vertical four-stroke cycle gas engines are made by the National Gas Engi Co., Ltd., of Ashton-under-Lyne, the power ranging from 2 to 2,500 b.h.p. Up to 10 b.h.p. t engines are of the horizontal overhung cylinder design; for greater powers a special design girder bed and supported cylinder is adopted.

The horizontal engines are built in various sizes up to 100 b.h.p. per cylinder. Ignition is l low-tension magneto, a sparking-plug being fitted in the combustion chamber. Governing the smaller sizes is on the hit-and-miss principle, but throttle governing can be supplied if desire and the larger sizes of engines are fitted with a patent variable admission governing gear.

The National Gas Engine Co.'s vertical engines are of the (*a*) single cylinder per crank desig and (*b*) of the tandem single-acting design. The single cylinder per crank engines are made three sizes, viz. 14 ins., 18 ins., and 24 ins. stroke, and the powers vary from 90 to 900 b.h.p. Th tandem engines are built with 18-in. stroke and 24-in. stroke, and the powers range from 300 2,500 b.h.p. The engines are suitable for working on town, producer, blast-furnace, and coke-ov gases, and the cyclic variation is such that there is no difficulty in running electric alternators parallel.

A recent test of an engine of this type furnished the following results:

Engine.—A 750 b.h.p. National Vertical Tandem Single-Acting engine having three cran and six cylinders, the three upper cylinders being each of 23 ins. bore, and the three lower ea of 22 ins. bore. Piston sleeve 6 ins. diameter, stroke 24 ins.

Details.	At Over-load.	At Full Load.	At ¾ Load.	At ½ Load.	At ¼ Load.	At No loa
Duration of trial; minutes	60	60	45	30	15	18
Revolutions per minute	203	204	204	206	206	206
B.H.P. developed	903	748	571	380	208	0
Cu. ft. gas per B.H.P. hour	68·4	66·4	72·3	85	124	—
B.Th.U. per cu. ft. of gas (lower)	151	149	139	150	150	—
B.Th.U. per B.H.P. hour	10,328	9,894	10,050	12,750	18,600	—
Brake thermal efficiency, per cent.	24·64	25·72	25·32	20·0	13·7	—

The engine was driven by Mond gas. At full load 6·55 gallons of cooling water were rais 42° F. in temperature per b.h.p. hour, being 27·8 per cent. of the heat evolved by the gas us

The pistons are unwatered. Forced lubrication is supplied to all parts, the oil pressure bei about 20 lbs.

Vickers Gas Engines.

Large gas engines of the horizontal four-stroke cycle type are constructed by Vickers Lt Barrow-in-Furness. The engines are double acting, and range from 800 b.h.p. in single 1 tandem cylinders to 5,000 b.h.p. in twin tandem engines.

A number of these engines have been supplied for driving dynamos, alternators, etc. Eight of ese engines for the Appleby Iron Co., of Appleby and Frodingham, have cylinders 800 mm. dia. 1,200 mm. stroke, and develop 1,200 kw. when running at 100 r.p.m.

Separate cylinder liners are fitted. The inlet valves are located on top, and the exhaust valve the bottom of the cylinder; they are operated by shaped rolling levers driven by eccentric the half-speed shaft. The crankshaft is forged in one piece and balance weights are fitted. ie main bearings are in four parts, lined with white metal, and have self-aligning wedge ljustment. The main bearings of the 1,500 b.h.p. engine are 21 ins. diam. and the piston rod ·75 ins. diam.; the latter is hollow to convey the cooling water to the pistons.

Governing is on the 'quantity and quality' system, and it is possible to run direct-driven ternators in parallel. Hand adjustment is provided for regulating the speed while running. parate hand control for gas and air for each end of both cylinders is provided.

Ignition is effected by means of two low-tension 'make-and-break' ignition plugs in each end each cylinder. A motor generator delivers current at 70 volts, which is distributed by a rotary per, fitted at the rear end of the side shaft.

The 1,500 b.h.p. blowing engine runs at 80 r.p.m. and delivers 27,000 cub. ft. of free air per inute against 12·5 lbs. per sq. in. The total weight of this engine is approximately 305 tons.

Hindley Gas Engines.

Messrs. E. S. Hindley & Sons manufacture vertical single-acting four-stroke cycle gas engines sizes from 40 to 700 b.h.p. of the fast revolution type designed for direct coupling to high-eed machinery as dynamos, centrifugal pumps, fans, etc.

The engines are light and compact; special care has been given to the balancing, and the eight of pistons and connecting-rods has been reduced as much as possible to enable the engines run freely and quietly at high speeds; being multi-cylindered, and having adequate flywheel ertia, the cyclic variation is small.

Governing is effected by varying the quality of the mixture of gas and air; ignition is by gh-tension magneto, with variable timing; frequently high-tension coil ignition is also fitted a stand-by.

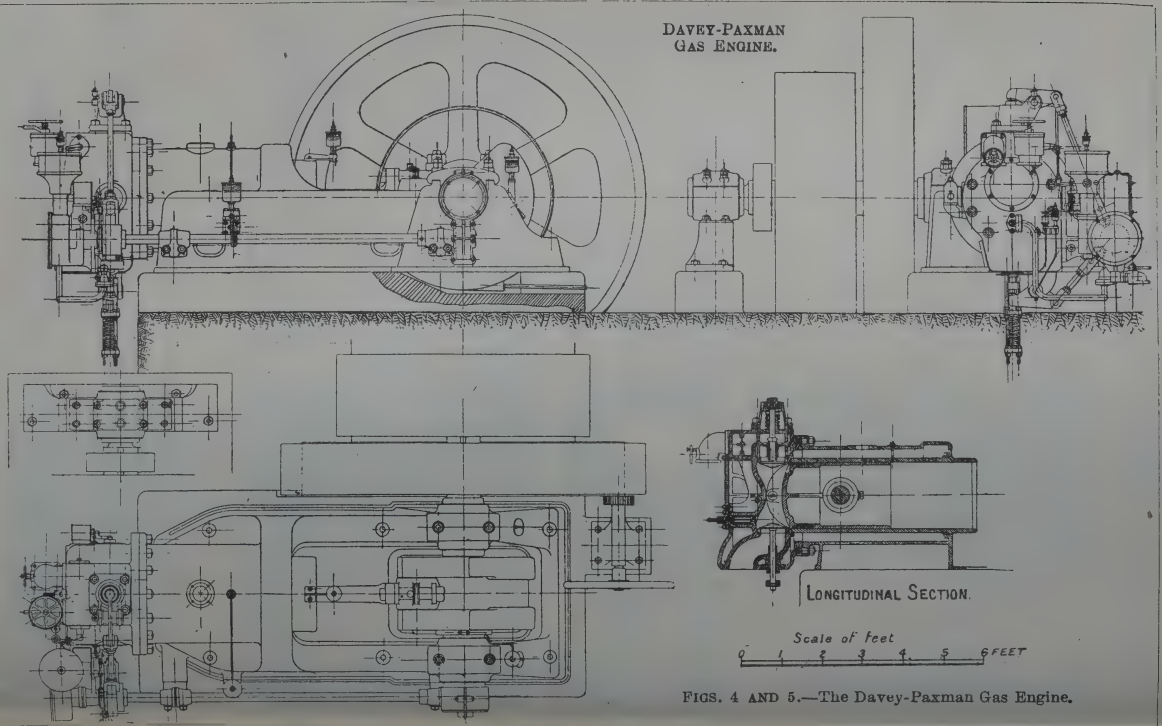
The cylinders are cast in one with the valve-boxes, the construction of the water-jacket being ie subject of a patent. The outer water-jacket, the cylinder, and the valve-box form one casting, that there is no joint to cause trouble. At the same time the special corrugated form of ater-jacket permits of unequal expansion between the cylinder walls and the jacket. All joints the cylinder which are subject to the pressure of the power-stroke are ground-in metal-to-etal joints, no packing being used either in the case of the top cylinder cover, valve cover, or nition plugs. The connecting-rods are of forged steel, and are so arranged that, together ith the pistons, they can be withdrawn through the top cover, which can be easily removed ithout disconnecting any gear. The crankshaft is of special quality steel, machined from a lid forging, and is not bent or subjected to strain in manufacture. The governor controls the lmission of gas, so that compression is practically constant at all loads.

The camshaft runs in three or more bearings, and is driven from the crankshaft by means gearing, the whole being enclosed in the crankcase. The crankcase is of box section, rongly webbed, and carrying the crankshaft bearings; it is provided with large inspection ors, which give easy access to all the working parts. The lubrication is forced under pressure all bearings by a valveless oil pump; this system of lubrication ensures economy in oil consump-on, which is in some cases as low as ·0002 of a gallon per b.h.p. per hour.

Davey Paxman & Co.'s Gas Engines.

The Paxman gas engine of the horizontal type, in sizes from 23 to 270 b.h.p., operates on the ur-stroke cycle. For large powers two engines are coupled with a single crankshaft, having ie flywheel between the cylinders. The engine is illustrated in figs. 4 and 5. Producers, suitable r anthracite and coke, are also made by Davey, Paxman & Co., Colchester.

Special features of the engines are the shape of the combustion chamber, which gives an excel-nt combustion of the fuel together with freedom from fracture, and the patented timing arrange-ient for the spark to facilitate starting, the general design following accepted practice and aving supported cylinder with removable liner.



FIGS. 4 AND 5.—The Davey-Paxman Gas Engine.

Gas engines of the vertical design are also made in various sizes from 25 b.h.p. to 900 b.h.p. in single and multi-cylinder types, and are most suitable for driving factories, electric generators, etc. They occupy little floor space and have a small cyclic variation.

A large number of Davey, Paxman & Co.'s gas engines are in operation, working on a variety of fuels. The utmost attention has been given to securing reliability, and their design of combustion chamber makes the engines very economical.

Fielding & Platt's Gas Engines.

Gas engines of the horizontal four-stroke cycle type are manufactured by Fielding & Platt Ltd., Gloucester, in various sizes from 6 to 150 b.h.p. For larger powers, two engines are coupled together, having a flywheel between the cylinders mounted on the two-throw crankshaft, these engines being made in sizes up to 300 b.h.p. Four-cylinder engines are also made.

The cylinder has a separate liner supported throughout its whole length in the water-jacketed extension of the bed. The variable-admission governor controls the opening of the gas-and-air-mixing valve, thereby varying the volume of charge admitted to the cylinder. The stroke of the mixing-valve is directly under the control of the governor, and, although the volume of charge is varied, the ratio of gas and air in the mixture remains practically constant. By this means an explosion takes place every cycle, and it is claimed that, when working with a suction plant, this steady method of drawing the gas ensures a better quality of gas, and avoids the possibility of trouble through insufficient gas under variable loads.

The cylinder jacket and combustion chamber have separate water circulation, and specia care has been taken to reduce the number of parts. Ignition is by means of a low-tension magneto, and the ignition plug can be readily removed from the cylinder for examination. The engines are suitable for running on gas produced from a large variety of fuels, and the 'Fielding' suction gas plants have several important features, enabling the plant to be quickly started up and to respond instantly to all varying loads.

The Fielding gas engine installations are extremely simple to operate, and the makers state that any man of ordinary intelligence can be entrusted to work it, as they have made a special study of simplicity.

Premier Gas Engines.

The Premier Gas Engine Co., Ltd. (*Crossley Brothers, Ltd.*), of Sandiacre, specialise in multi-cylinder gas engines of the horizontal type, ranging in powers from 100 to 1,000 b.h.p. Large numbers of these engines have been installed for all classes of work, including the driving of alternating current generators in parallel. The speeds of the engines are suitable for coupling to electric generators, and the engines have but a small cyclic irregularity.

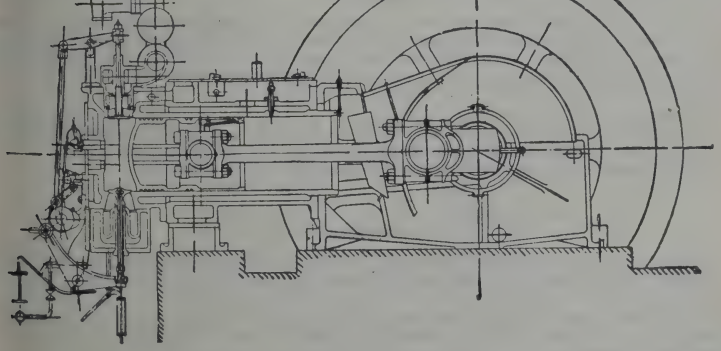


Fig. 6.—Premier Gas Engine.

From the sectional view, fig. 6, the arrangement of the cylinder, combustion chamber, valves, and cam operating gear can be seen. It will be noticed that the breech end and cylinder form one casting, and the usual joint in the combustion space is avoided. This removes any risk of water leaking into the cylinder.

These engines work on the four-stroke cycle and are made in two, three, and four cylinders, bolted to massive beds which support the crankshafts. The cranks are completely covered by oil splash guards, and the main bearings are supplied with oil by a pump, which is of the valveless oscillating type, operated by the side shaft. The cylinders, piston pin, crank pin, and exhaust valve spindles are also lubricated under pressure automatically.

The valves open directly into the cylinders, the inlet valve being directly over the exhaust valve, a design introduced by the Premier Co. as far back as 1893. A large throttle valve is fitted to control the air supplied to all the cylinders, and can be readily adjusted by hand; in addition, separate throttle valves are fitted on each cylinder. All the valves are operated by a shaft running in self-oiling bearings behind the cylinder, so arranged that the jacket inspection cover can be removed without disturbing it.

Governing is effected by controlling a throttle valve in the gas supply, and the governor is of the high-speed type, powerful and sensitive, driven direct from the crankshaft.

Starting is automatic by means of compressed air, which makes the engines easy to start.

Except in cases where engines are driving alternators in parallel, an isolating valve is fitted in the gas manifold by which the gas supply to one or more cylinders may be shut off when working on light loads with a consequent saving in fuel consumption.

These engines have the advantages of even turning moment, good balancing, forced lubrication, and they occupy little floor space for their power. Very high economy, both in fuel and lubricating oil, is claimed.

As will be seen from the illustration, the Premier gas engine is very accessible, both for cleaning and overhauling, as all of the working parts can be inspected and reached from floor level. This allows of good supervision, and as the piston and connecting-rod can be removed from the crankshaft end of cylinder, this operation can be carried out without disturbing any part of the valve gear or cylinder covers.

The Premier Gas Engine Co., Ltd., also manufacture a special type of cross-head vertical gas-engine, which differs from the usual type in many ways and possesses special features. It is made with 2, 3, or 4 cylinders for moderate powers at moderate speeds. The lower ends of the cylinders are shut off from the crank case by light covers, through which piston rods pass. Cross-heads and guides are therefore used, and the design corresponds in many respects to that of a steam-engine.

The Premier Company were the first to introduce this cross-head type of gas engine, and it is now generally adopted by Diesel engine makers in this country and on the Continent of Europe.

For powers of 1,000 b.h.p. to 5,000 b.h.p., the Premier Company manufacture a special type of double-acting vertical engine. This engine is of the four-stroke type, and therefore with four cylinders there are four impulses per revolution. As there is a compression on every stroke smooth running is obtained as a result of this and also because of the forced lubrication system which supplies oil at a pressure to all motion joints.

The design is suitable for powers of 1,000–2,250 b.h.p. continuous load with four cylinders and one crank, and for twice these loads, 2,000–4,500, with two-crank and eight-cylinder design, the speeds being from 125 r.p.m. for the smallest to 94 r.p.m. for the largest. A single crank for every four cylinders is one of the greatest innovations of the engine, and the small space required for this type of engine is a valuable characteristic.

It is specially adapted for the generation of electricity at steelworks and blast furnaces, especially where gases are available as a bye-product, and not produced artificially, and the rough usage of a steelworks is more readily resisted by this moderate speed engine. Fig. 7, p. 1923, shows, in plan and sectional elevation, the D.A.V. type of engine.

Tangye Gas Engines.

Horizontal gas engines of the four-stroke cycle type are made by Tangyes, Ltd., Birmingham, in sizes from 3½ to 490 b.h.p. Two designs, AA and T, are supplied, and a large number of engines have been sold.

The smaller sizes of engines have horizontal cylinders bolted to the beds, and the liners are removable. Governing is on the hit-and-miss principle; the AA design have highly sensitive inertia governors.

Engines of the HT type have the cylinders well supported by the bed, which extends up to the combustion chamber and forms the water-jacket. The cylinder liners are separate and are made of a special hard mixture of cast iron. Governing is on the variable-admission system with Tangye's patent operating gear, which controls the quantity of the charge admitted to the cylinder and an impulse is obtained every cycle.

THE PREMIER GAS ENGINE.
(D.A.V. type.)

Plan and Sectional Elevation.

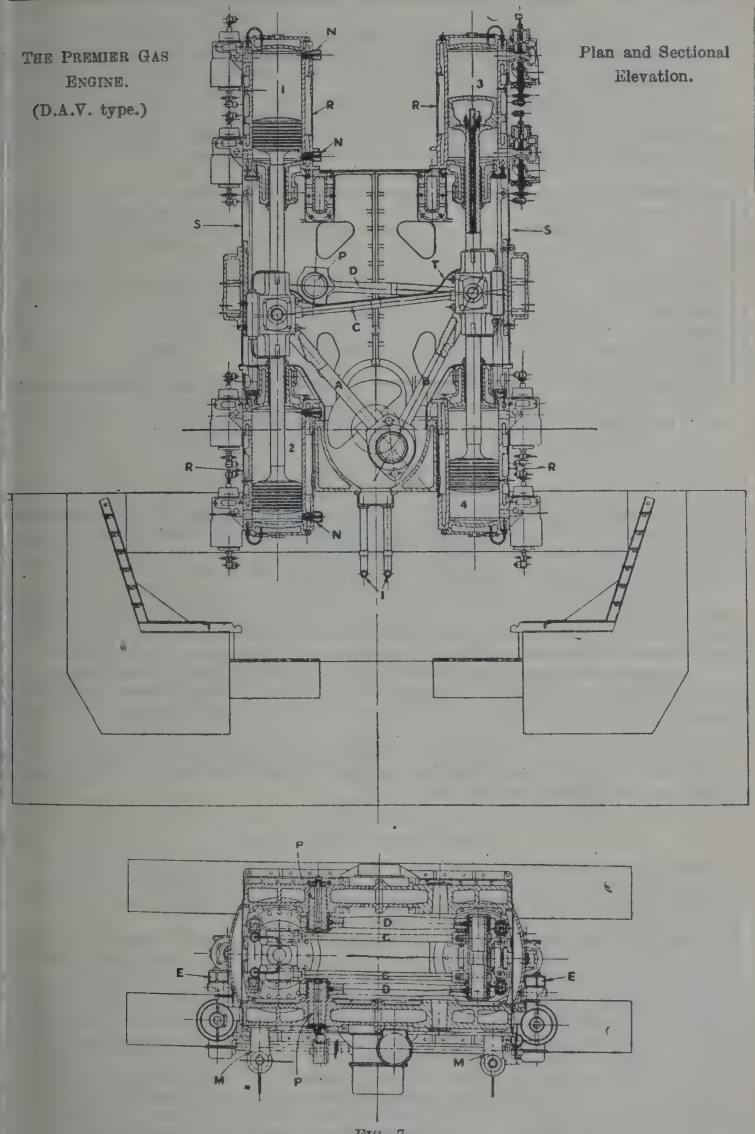


FIG. 7.

Ignition is by means of low-tension magneto, the spark being produced in the combustion chamber by means of a mechanically operated make-and-break arrangement, with variable timing device. On the larger sizes the sparking-plug is arranged so that the internal sparking points can be cleaned while the engine is at work. The engines are designed so that they can make long continuous runs; they are very simple to operate and are easily started, compressed-air apparatus being supplied with the larger sizes.

Tangyes were among the first firms to call attention to the fuel economy to be obtained from the use of gas engines with suitable suction gas producers, especially as engines would work on such inferior fuels as wood refuse, etc. The economy may be gathered from the following table which gives the approximate cost of fuel in a plant developing continuously 50 b.h.p. for sixty hours:

Nature of Fuel.	Rate of Fuel Cost.	Consumption per b.h.p. per hour.	Cost of 50 b.h.p. for 60 hours per week.
'Town' gas	2/- per 1,000 cubic ft.	15 cubic ft.	£4 10 0
Anthracite	40/- per ton	·75 lb.	2 0 0
Gas coke	30/- "	1 lb.	2 0 0
Charcoal	40/- "	1¼ lbs.	3 7 0
Bituminous non-caking coal	24/- "	1¼ lbs.	2 0 0
Wood refuse	Nil	2½ lbs.	Nil

The figures given above are an average, but the cost of running will depend, of course, upon the size of the engine and the relative prices and qualities of the different fuels.

Gardner Gas Engines.

The Gardner engines are made of both vertical and horizontal design and operate on the four-stroke cycle. The range of sizes is from 1½ to 180 b.h.p. Horizontal engines up to 14 b.h.p. can be supplied to work on either town gas, paraffin, or spirit.

The engines are of very neat design and substantially constructed. They give particularly smooth running, and a large number have been supplied.

The small sizes have been specially designed for gaseous and liquid fuels and are substantially constructed in order to make them suitable for heavy commercial duties and long continuous runs, such as for electric-lighting, etc. The workmanship and design of even the smallest size are exceptionally high class, as the engines are intended for production in large quantities.

The larger horizontal engines are fitted with single fly-wheel and outer pedestal bearings. The special features are the sensitive centrifugal throttle governor, giving low-speed variation, and the silent-running that is obtained. They are easy to start, economical to work, and have a high efficiency.

In addition, a range of Gardner engines made in twelve sizes, from 10 to 180 b.h.p., have been designed for marine and stationary work. They are supplied for running on town and producer gas, paraffin, spirit, and heavy oils, and are most suitable for marine work, driving electric generators, and for industrial purposes.

Peter Brotherhood Gas Engines.

Horizontal engines of the single-cylinder, four-stroke cycle type, developing 10 to 150 b.h.p., are manufactured by Messrs. Peter Brotherhood, Ltd., Peterborough. The engines are made with two cylinders in sizes from 172 to 300 b.h.p. Producer gas plants capable of working on a wide range of fuels are also made by this firm.

The engines are very simple and neat in appearance, being well proportioned. They are easily operated, and there are no parts liable to get out of order. Several patented features are embodied in the design, which make for efficiency and reliability.

The governor is on the variable-admission principle; the charge of gas and air admitted to the cylinder is varied in quantity to suit the load, but there are no cut-outs and the engine receives an impulse every cycle. Special attention has been given to all the working parts of the valve gear, etc., the cams are of hardened steel and the valves are made from nickel steel, alloy steel being used for the exhaust valve lever.

The bed of the engine is formed with the cylinder jacket and supports the cylinder liner throughout its length. The combustion chamber has specially large water-jacket spaces, which are quite accessible for cleaning, it only being necessary to remove a cover.

Ignition is by means of a low-tension magneto, having powerful double magnets; special timing gear is fitted so that the engine can be easily started. The ignition plug is arranged to

prevent any possibility of the striking spindle bearings becoming coated with rust or deposit, and patented terminals are used on the plug and magneto.

Positive lubrication has been provided, so that when running the engine requires very little attention. A low-pressure self-starter can be fitted for engines of moderate powers, but, for engines of 100 h.p. and over, air starting is recommended, as with this it is claimed that even the largest engines start up as easily as a steam engine.

A number of improved features have been embodied in the producer, making it very simple to operate and capable of working with all grades of anthracite, coke, charcoal, and other inferior fuels.

Lilleshall Gas Engines.

Gas engines ranging in power from 500 to 4,000 b.h.p. are manufactured by the Lilleshall Co. Ltd., of Oakengates, Shropshire. The engines are of the tandem, horizontal, double-acting, four-stroke cycle type, and a working impulse on every stroke is obtained. A section is shown in fig. 8 of the 2,500 b.h.p. engine, from which the general disposition of parts can be clearly seen.

The Lilleshall Co. have recently introduced a number of important improvements, making for additional strength and reliability. The pistons and rods are, of course, water-cooled, the water supply being of a pressure of from 45 to 65 lbs. per square inch on account of the reciprocating motion of these parts; this is supplied by a pump worked from the crankshaft. For the jackets of the cylinders and covers the water is supplied at a pressure of about 15 lbs. per square inch. Each cylinder is provided with an open tank into which all exit water-pipes deliver, the discharge from each being thus always in view; each exit-pipe is fitted with a thermometer and regulating valve by which the temperature of the cooling water can be maintained at the desired degree.

These engines are installed to a very large extent in iron and steel works and collieries, as well as in electrical power stations.

An output up to 1,500 b.h.p. can be developed in one cylinder, the consumption of heat per b.h.p. hour amounting—at normal output—to about 9,900 B.Th.U.

The engines are very strongly constructed, and simple in general arrangement as well as in each individual part. The surface pressures on the moving parts are small, and their lubrication is effected automatically. The frame, cylinder, connecting piece, and rear slide are centrically connected with one another, so that the engine axis is accurately fixed.

The cast-iron cylinders are symmetrically formed, in order to avoid undue strains caused by the heat, and are amply cooled. The cooling-water jackets are easily accessible for purposes of cleaning. In addition to the cylinders, the exhaust-valve seats, the hollow piston rod, and the pistons, are cooled.

The cooling-water consumption amounts per b.h.p. hour to 7·7 gallons at an inlet temperature of 60° F.

The weight of the pistons and piston rod is not carried in the stuffing boxes, but by special crossheads, in the frame, the connecting piece, and the rear slide.

The inlet valve gear consists of a positive action which opens the air valve and gas inlet valve. By means of the governor the valve lift, and consequently the quantity of mixture, is changed according to the engine output. The ignition is effected electrically by a small accumulator battery. The time of ignition can be easily regulated during operation.

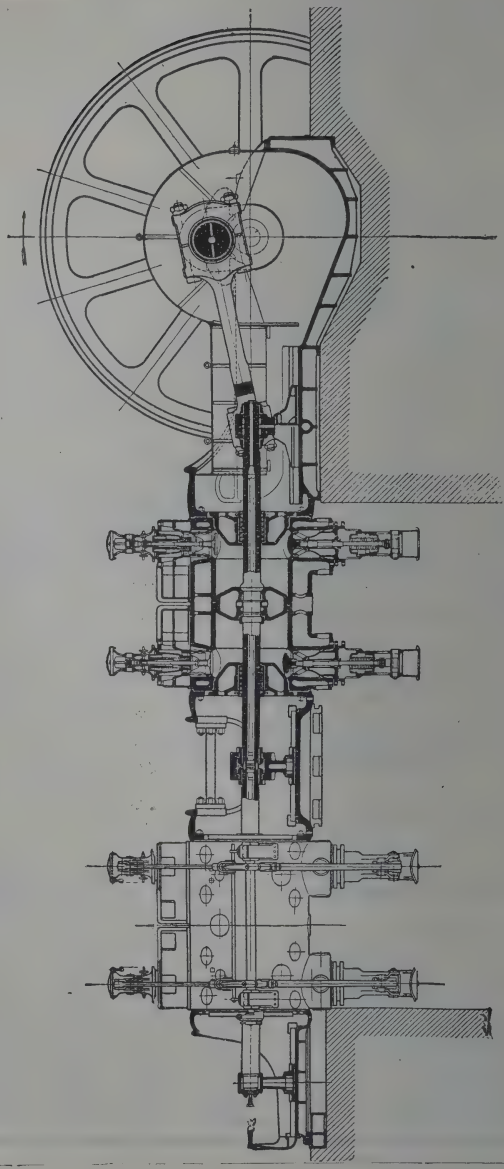
By means of compressed air the engines are very easily started.

Alternate-current dynamos driven by these gas engines can be connected in parallel without any trouble.

From tests of a tandem double-acting horizontal four-stroke engine of this type, developing 1,200 b.h.p. on blast-furnace gas, and having cylinders of 33·46 ins. bore with 43·3 ins. stroke, the following results were obtained :—

Test Results from a 1,200 h.p. Engine using Blast-Furnace Gas.

Item.	Quarter Load.	Half Load.	Three-Quarter Load.	Seven-Eighths Load.	Full Load.
Duration in minutes	33	28	29	26·8	25·33
Revs. per minute	106	105·8	106·3	106·5	105·6
I.H.P.	—	807	1,146	1,312	1,427
B.H.P.	280	557	871·5	1,037	1,186
Mechanical efficiency per cent.	48·5	69	76·2	79	83·1
M.E.P. in lbs. per square inch	—	42·5	60·0	68·7	75·3
Cu. ft. gas per b.h.p. hour	213	145·6	120·5	109·5	101·8
B.Th.U. per cu. ft. of gas	88·5	88·5	89·4	89·6	87·9
B.Th.U. per b.h.p. hour	18,532	12,262	10,794	9,921	8,976
Per cent. brake thermal efficiency	13·8	20·9	23·7	25·8	28·5



Lilleshall Gas Engine.

Fig. 8.—Longitudinal Section of Lilleshall Gas Engine.

Galloway Gas Engines.

Messrs. Galloways, Ltd., Manchester, took up in 1909 the manufacture of the large gas engines of the Ehrhardt and Sehmer type and have since introduced many improvements. The range of powers is given in the following table :—

Electric Generating Engine.

Cylinder Diameter.		Stroke.		R.P.M.	Normal continuous B.H.P.	Max. continuous B.H.P.	Max. Momentary B.H.P.	Blowing Engines.	
Mm.	Ins.	Mm.	Ins.					Max. R.P.M.	Normal B.H.P. at Max. R.P.M.
950	37·4	1,100	43·3	107	1,200	1,300	1,440	95	1,060
1,050	41·4	1,200	47·3	94	1,400	1,540	1,680	85	1,270
1,150	45·3	1,300	51·2	94	1,850	2,000	2,200	85	1,650
1,250	49·2	1,400	55·1	94	2,320	2,550	2,780	80	1,970

The standard Galloway engine is tandem double-acting four-stroke cycle with horizontal cylinders. For sizes over 3,000 h.p. a twin tandem engine is adopted, i.e. two lines of cylinders working on two cranks on a common crankshaft. The engines are designed to run on blast-furnace gas, coke-oven gas, and producer gas.

The special features of the engine are : (*a*) Patented built-up cylinder. The barrel is in two main parts, and the water-jacket is formed by a steel plate casing. Both casting and expansion stresses are eliminated. (*b*) Patent piston with internal diagonal ribs to prevent bending stresses. (*c*) Patented method of fixing piston on rod, allowing of longitudinal adjustment. (*d*) Improved piston rod packing. (*e*) Patented water-cooled exhaust valve box and seat, the exhaust valve itself not being water-cooled. (*f*) Simplified valve gear. (*g*) Powerful servo-motor governor.

The piston and rod are water-cooled and all water discharges are open for inspection purposes. The engine is of simple and strong construction, arranged for ease of accurate alignment, and free to expand when working without distortion or stress. All water-jackets and internal parts are easily accessible for inspection and cleaning.

Experience with a recent installation of these engines showed that the period between overhauls could be safely extended to two years, and even after that lengthy period of running the cylinders and piston rings were found to be in excellent condition, and all the main working parts free from appreciable wear.

Browett-Lindley Gas Engines.

Messrs. Browett-Lindley & Co. Ltd., Patricroft, have developed a vertical gas engine of the ordinary four-stroke cycle type for direct coupling to electric generators and other purposes.

The engines are made with two, three, four, and six cylinders ranging in power from 60 to 1,200 b.h.p. A number of these engines have been supplied for such industrial work as driving mills, etc., and are very satisfactory in operation.

The sectional view of a four-cylinder engine given in fig. 9 shows the accessibility of these vertical engines. The design allows the piston to be easily removed and the cylinder covers are quite free from valves or other gear. The valve gear is quite simple, hardened steel cams are used to operate the valves and the cam roller guides are of the piston type. Both the inlet and exhaust valves can be readily removed for inspection when desired, and the latter are provided with renewable seats.

The governor fitted to these engines is very powerful and the working parts are lubricated by oil under pressure, so that reliable operation can always be expected. Forced lubrication is provided for all of the principal bearings on the engine, the oil being supplied under pressure from a valveless pump.

Features of the Browett-Lindley engines are the simple design, the absolute freedom from back firing, and the equal distribution of power to each cylinder at all loads. A large number of installations are at work on town and producer gas, and very economical running is obtained.

The lowest heat consumption recorded with these engines is 9,540 B.Th.U. per b.h.p., and the highest 10,260. The mechanical efficiency of the engines is about 85 per cent. A cyclical regularity suitable for driving alternators in parallel can be obtained without the need of excessively heavy flywheels. The weights of the standard engines vary from about 2 to 2½ cwt. per horse-power.

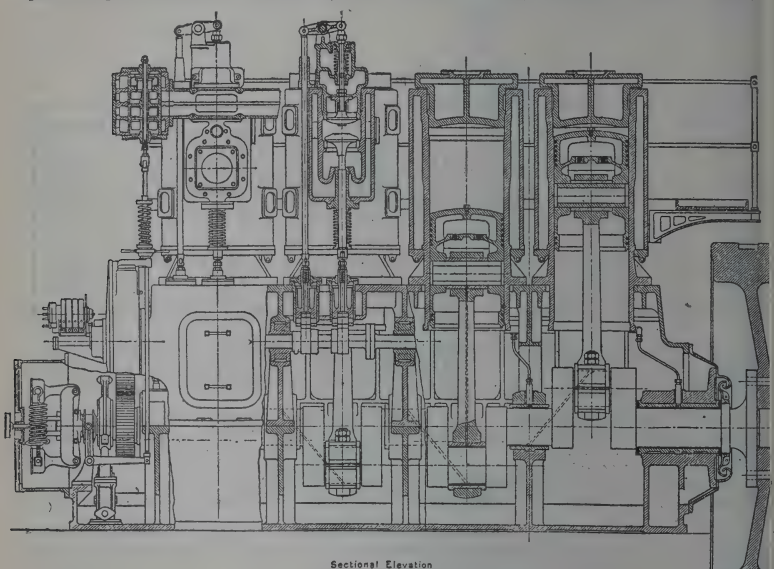


FIG. 9.—Browett-Lindley Gas Engine—Elevation.

FULLAGAR GAS ENGINES.

An important development of the opposed piston type of engine appears in the recent two stroke design of the late Mr. H. F. Fullagar (fig. 10), and a few of these gas engines are now at work.

Each 'unit' comprises *two* open-ended cylinders placed side by side; each cylinder contains two pistons as in the Oechelhauser design, but in the Fullagar design opposite pistons of each cylinder are connected by diagonal rods as indicated, thus dispensing altogether with return connecting rods, while a *two*-throw crankshaft suffices for the four pistons of the unit.

The obliquity of the tie-rods is small, and the side thrusts due to this obliquity are taken by the crossheads and guides shown above A and C; it will be seen that pistons A and D are connected, as also are B and C, by long diagonal rods. An explosion between A and B drives B downwards, thus actuating the left-hand crank, and simultaneously drives A upwards, thus actuating the right-hand crank through the tie-rod connecting A and D; the crankshaft accordingly receives as the result of each explosion a practically pure turning couple, or 'torque.' It will also be observed that as the cylinders are open-ended there are no vertical stresses set up in the framing of the engine when running; hence the Fullagar engine may be expected to be light in relation to its power output.

The engine works on the two-stroke cycle, and thus each cylinder furnishes one working impulse per revolution. As a unit includes two cylinders, each *unit* furnishes *two* working impulses per revolution. Stationary engines for land installation usually comprise two or three units, furnishing four or six working impulses per revolution. In the case of great power, or where height is limited and the speed must be high, as e.g. in submarines, engines would consist of even four units. The usual inlet and exhaust ports are indicated in fig. 10; the charge is supplied at a pressure of between 2 and 3 lbs. per sq. in. by gas and air pumps, which may be driven by the engine.

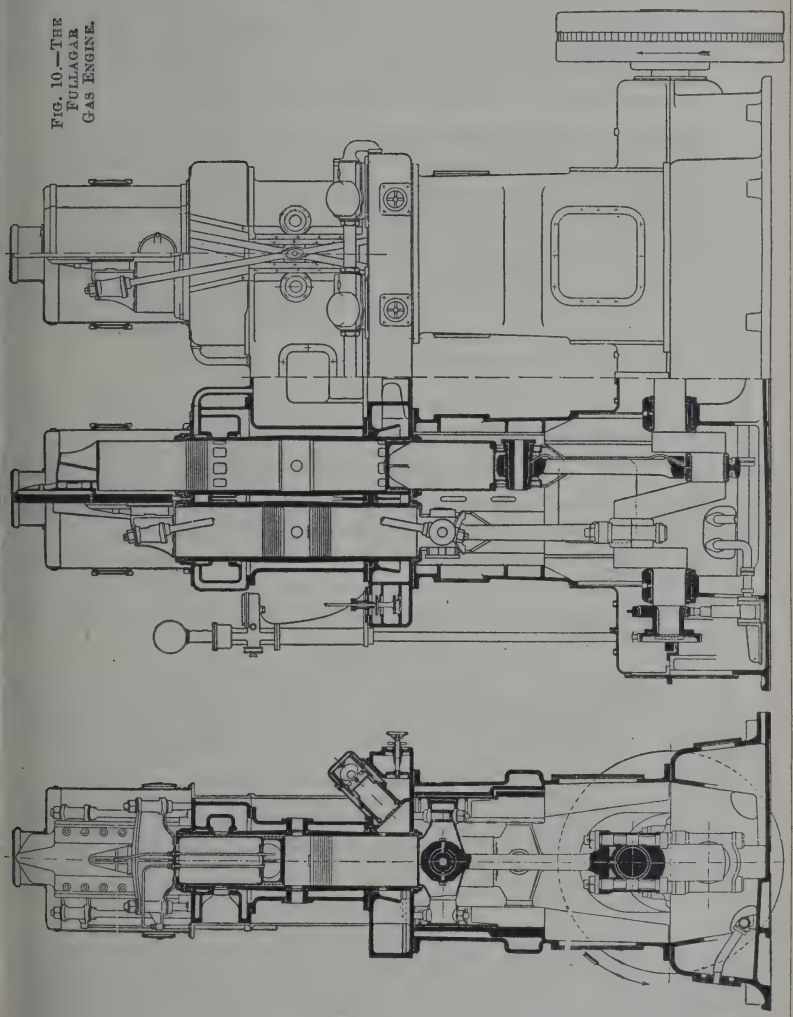


FIG. 10.—THE FULLAGAR GAS ENGINE.

The upper guides are modified to act as scavenge air pumps, the upper crosshead being fitted to operate as pistons, unless separately driven blowers or pumps are required.

The Fullagar engine may be arranged to run in either direction; it is only necessary to alter the timing of the fuel admission valve and the ignition.

An experimental gas engine of 550 b.h.p., constructed by Messrs. W. H. Allen, of Bedford, to the designs of the Fullagar Engine Ltd., has been installed at the Newcastle Electricity Supply Company's station at Gateshead-on-Tyne; this engine consists of *two* units, the cylinders being of 12 ins. bore, while each piston has a stroke of 18 ins. The normal speed is 250 revolutions per minute, corresponding to a piston speed of $\frac{250 \times 18}{6} = 750$ ft. per minute.

Sectional views of this engine are given in fig. 10.

If p denote the mean effective pressure in lbs. per sq. in. within a cylinder during the working stroke, then the work done upon *each* piston in foot-lbs. is $p \times \frac{\pi}{4} d^2 \times \frac{s}{12}$. Where d and s are respectively the bore and piston stroke, in inches.

As each cylinder contains two pistons, the work done by each cylinder per working stroke is $2 \times p \times \frac{\pi}{4} d^2 \times \frac{s}{12}$ foot-lbs., and this is the work done per cylinder per revolution of the crankshaft. Now a unit comprises two cylinders, and hence the work done by a unit per crankshaft revolution is $2 \times 2 \times p \times \frac{\pi}{4} d^2 \times \frac{s}{12}$ foot-lbs., that is $\frac{\pi}{12} . pd^2s$ foot-lbs. Accordingly if the crankshaft makes n revs. per minute, the indicated horse power is given by :—

$$\text{I.H.P.} = \frac{1}{33{,}000} . \frac{\pi}{12} . pd^2sn \text{ per unit} \quad . \quad . \quad . \quad (19).$$

As the Gateshead engine includes two units, its i.h.p. will be twice this, or:—

$$\text{I.H.P.} = \frac{\pi}{33{,}000 \times 6} . p.d^2sn \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

Though the mechanical and thermal efficiency of this type of engine is high, the ratio $\frac{\text{B.H.P.}}{\text{I.H.P.}}$ on the experimental engine was only about 0·8, as for experimental purposes the air blower and gas pumps were of a somewhat temporary character; hence 550 b.h.p. corresponds to $\frac{550}{0{\cdot}8} = 690$ i.h.p. roundly.

Putting 690 for i.h.p., 250 for n, 12 for d, and 18 for s, in Eq. 20 we get as the value of the mean effective pressure :—

$$p = 67 \text{ lbs. per sq. in.}$$

A 30-hour test by Prof. Hopkinson showed that this engine has an overall thermal efficiency from heat supplied to b.h.p., of 30 per cent., while the indicated thermal efficiency attains the value 37·6 per cent., the difference being due to the somewhat inefficient pumps.

The weight of the engine, including flywheel, is roundly 21½ tons; this corresponds to only about 87½ lbs. per b.h.p., which is much lighter than other stationary gas engines of the same power.

A 2,000 h.p. engine, constructed by Mssrs. Belliss & Morcom, Ltd., of Birmingham, to the designs of the Fullagar Engine Ltd., of Gateshead, was started during 1918 in a Waste Heat Station on the North-East Coast, using coke-oven gas of a calorific value of about 440 B.Th.U. per cubic foot (net value). This engine has six cylinders, i.e. three Fullagar engine units with 12 pistons. The cylinders are 18-inch bore and 27-inch stroke, the speed being 171·4 r.p.m. The engine is of the totally enclosed forced lubrication type, the overall dimensions over engine and alternator being :—

Length, 38 ft. 7½ ins. Breadth, 15 ft. 3½ ins. Height, 21 ft.

The approximate weight of the engine, including all auxiliaries but without alternator, is 110 tons. The piston heads are oil-cooled and scavenge air is supplied by a separate electrically driven blower, the gas-charging pumps being coupled directly to the crankshaft of the engine. The preliminary full load trials have shown a gas consumption of under 30 cubic feet per kilowatt hour, with an electrical output of 1,250 k.w. net at the generator terminals (i.e. after deducting the amount of power required by all auxiliaries). The direct-coupled alternator supplies electricity to the Newcastle Electricity Supply Company's system.

The Fullagar system is being developed for use with liquid fuel by Messrs. Cammell, Laird & Co. Ltd., of Birkenhead, John Brown & Co. Ltd., David Rowan & Co. Ltd., Palmer's Shipbuilding and Iron Co. Ltd., and The English Electric Company. (*Merz & McLellan.*)

(See also p. 2427.)

Prices and Weights of Gas Engines.

The prices and weights of gas engines vary considerably, depending on the type and design, but may be taken as from about 7*l.* to over 10*l.* per horse-power at the makers' works. The weight is largely affected by the type and design, engines being single or multi-cylindered, slow speed or high speed, horizontal or vertical, the different designs being necessary to suit the various requirements.

Thermal Efficiency of Gas Engines.

The brake thermal efficiency of four-stroke gas engines has risen from 14 per cent. in 1882 to 32 per cent. in 1908; the following table from Sir Dugald Clerk ('The Gas, Petrol, and Oil Engine,' p. 243) illustrates the rise in efficiency :—

INDICATED AND BRAKE THERMAL EFFICIENCIES OF FOUR-STROKE GAS ENGINES FROM 1882 TO 1908.

(*Sir Dugald Clerk, F.R.S.*)

Year.	Experimenter.	Engine.	Bore & Stroke, inches.	Efficiencies per Cent.		
				Mech.	Indic. Thermal.	Brake Thermal.
1882	Slaby	Deutz	6·75 × 13·7	87·6	16	14
1884	Thurston	Crossley	8·5 × 14	84·2	17	14·3
1888	Soc. Arts	Crossley	9·5 × 18	86·1	22	18·9
1888	Soc. Arts	Griffin (6 cycle)	9·02 × 14	80·9	21	17
1888	Kennedy	Beck (6 cycle)	7·5 × 15	87·3	21	18·3
1892	Capper	Crossley	8·5 × 18	82·0	22·8	17·4
1898	Robinson	National	10 × 18	87·0	28·7	25
1900	Humphrey	Crossley	26 × 36	83·0	31	25·7
1900	Witz	Cockerill	51·2 × 55·1	81·7	28	22·9
1905	Inst. C. E.	National	14 × 22	85·5	35	29·9
1907	Burstall	Premier	16 × 24	77·1	41·5	32
1908	Hopkinson	Crossley	11·5 × 21	87·5	36·8	32·2

In tests made on a Crossley-Otto engine in 1882, 1 i.h.p. hour was obtained with an expenditure of 23·7 cubic feet of London gas, while at the Society of Arts trials, held in 1888, a Crossley engine consumed 20·55 cubic feet per i.h.p. hour. Sir Dugald Clerk found, in 1894, when testing a Crossley engine, that the consumption of gas (Openshaw) per i.h.p. hour was as low as 14·5 cubic feet.

At the present time it may be taken that the consumption of town gas per b.h.p. hour at full load varies from 15 cubic feet to 25 cubic feet per hour, according to the size of the engine, and also according to the heating value of the gas.

The increased efficiency that has been obtained in the best known forms of engines is probably due to greater compression of the gas, and to some lesser extent to improved means of displacing the burned gases from the cylinders.

Large stationary gas engines are commonly of the horizontal tandem double-acting four-stroke type, as with this arrangement a working impulse is obtained at every stroke. Pistons and piston-rods are of course always water-cooled in such engines.

Piston speed in large gas engines has reached 800 to 900 feet per minute. Mean pressures of 85 to 95 lbs. per sq. in. can be obtained in the cylinder with gas of 110 B.Th.U., though engines are usually rated on an assumed 70 lbs. only.

Generation of Electricity by Gas and Oil Engines.

The Electricity Commissioners have published reports * on the output and fuel consumption of electric power stations in Great Britain. The stations are classified in thirteen groups, of which six groups have producer gas engines and six groups oil engines, according to output.

* *Generation of Electricity in Great Britain, year ending March* 31, 1926. Electricity Commission. H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.

For four of these groups, representing the largest, the smallest, and two intermediate sizes o station, the following figures are abstracted from the report for the year ending on March 31 1926 :

GAS-PRODUCER STATIONS.

Output of Station Units in Year.	Between 1,000,000 and 2,500,000.	Between 250,000 and 500,000.	Between 100,000 and 250,000.	Under 50,000.
Number of stations in group	3	11	19	4
Total units generated by gas-producer plant	5,563,222	3,828,839	3,130,916	114,744
Total fuel consumed (actual) tons	6,101	3,850	3,679	226
Average fuel consumption per unit generated (converted to basis of coal) lbs.	3·01	2·25	2·64	4·41
	Total units generated.		Total fuel consumed.	
Total output of all gas-producer stations (57) for year ending March 31, 1926	20,485,985		Tons. 22,498	
Figures for year ending March 31, 1925	14,976,846		17,394	

GENERATION OF ELECTRICITY BY GAS-ENGINE STATIONS USING TOWN'S GAS.

The total units generated by gas-engine stations using town's gas, during the year ending March 31, 1926, was 3,069,174 (from 17 stations).

For the year ending March 31, 1925, the total units were 3,478,315 (from 16 stations).

OIL ENGINE STATIONS.

Output of Station Units in Year.	Between 1,000,000 and 2,500,000.	Between 250,000 and 500,000.	Between 100,000 and 250,000.	Under 50,000.
Number of stations in group	13	18	18	16
Total units generated by oil engines	18,013,960	5,704,943	2,658,435	351,930
Total fuel consumed (actual) tons	1,816	6,679	1,657	228
Average fuel consumption per unit generated (converted to basis of oil) lbs.	1·08	1·24	1·23	1·40
	Total units generated.		Total fuel consumed.	
Total output of all oil engine stations (101) for year ending March 31, 1926	45,686,479		Tons. 26,196	
Figures for year ending March 31, 1925	42,539,281		23,161	

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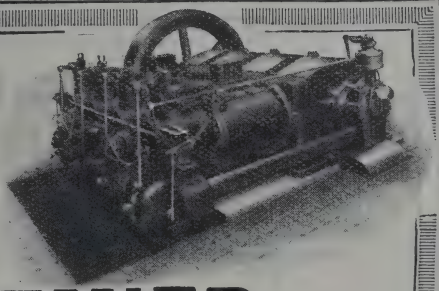
from 275 to 1000 B.H.P.
VERTICAL GAS ENGS.
from 1000 B.H.P. UP.



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CONVEYING, ELEVATING & SCREENING PLANTS.

F. 1933

Gas Engine Starters.

Large gas engines are very usually started by means of compressed air pumped by the engine, when running, into a reservoir. They may be started by means of a small gas engine, after the fashion of the barring engine for steam-engines. This small engine must be able to compress the charge of the large cylinder or one of them sufficiently to ignite; or gas and air may be pumped into the cylinder by a small engine and ignited just as the engine is turned off its dead point.

The Wells Starter.—The Wells Bros. starter consists of a small hand-pump fitted at the rear end of the combustion chamber. The action of this pump is to force gas into the cylinder, the crank of the engine being already fixed in the forward position; the action of a valve then permits the pumping of air into the cylinder, and upon the proper mixture being obtained the charge is ignited by ordinary means.

The Fielding and Platt Starter.—Arranged in close proximity to the engine is an air receiver, into which air is pumped under pressure. After gas has been admitted into the engine cylinder, indicated by a flame at a junction pipe, compressed air is admitted into the cylinder from the receiver, and the mixture is ignited at the moment of combination.

The air pressure self-starter was introduced by Fielding & Platt, Ltd., in 1895, and standardised by practically all other makers, and is in common use to-day. On four-stroke cycle engines it has been brought up to date by an automatic control worked by cam on the countershaft, so arranged that the air impulse is only permitted during the power stroke, and is cut off automatically on the other three strokes of the engine, thus avoiding the risk of attendant leaving the air pressure to oppose the piston on the return stroke. No explosive mixture is used. The air tank is automatically charged by the engine itself.

Cooling Water for Internal Combustion Engines.

With stationary engines a cooling water tank or reservoir is usually provided, and in such cases the loss by evaporation varies from 0·2 to 0·4 gallon per b.h.p. hour; with large gas engines it is usual to employ cooling towers. The water is pumped from a well through the engine jackets, etc., and passes thence to the top of the tower; falling to the bottom, it returns to the well at but little above the atmospheric temperature. With a cooling tower the loss by evaporation is greater than with a cooling tank, and commonly amounts to from 0·4 to 0·5 gallon per b.h.p. hour. From 30 to 35 gallons of cooling tank capacity is required per b.h.p.

The 'Heenan' Water Cooler (p. 1296) is particularly suitable for these installations, and in addition to occupying small space has the advantage that it consumes only approximately 0·1 to 0·2 gallon of water per b.h.p. hour.

The ordinary standard sizes of these machines vary in capacity from 625 gallons of water per hour up to 55,000 gallons per hour, which the machines are capable of cooling from 120° down to 90° F. under temperate climatic conditions.

As an example, a *medium* size cooler of the type in question is capable of dealing with the following problems and providing the corresponding water temperatures:

Application.	Quantity g.p.h.	Water Temperatures.	Heat extracted per Hour.
1. Petrol engines and dynamometers	10,000	170°/100° F.	7 million B.Th.U.
2. Gas, oil, and Diesel engines	,,	120°/90° F.	3 ,, ,,
3. Steam-engine condensers	,,	105°/85° F.	2 ,, ,,
4. Air compressors	,,	85°/75° F.	1 ,, ,,
5. Refrigerating plant	,,	72°/67° F.	500,000 B.Th.U.

DATA RELATING TO COOLING WATER USED IN INTERNAL COMBUSTION ENGINES.

Type of Engine.	Bore and Stroke. Ins.	B.H.P.	Cooling Water Temperatures.			Gallons circulated through Jackets, etc., per B.H.P. hour.	B.Th.U. removed by cooling Water per B.H.P. hour.
			Inlet. °F.	Outlet. °F.	Rise of Temp. °F.		
Normal petrol car engines	—	15 to 75	160	200	40	7·5	3,000
Diesel, 3-cyl.	17·75 × 27	360	54	103	49	5·62	2,750
Diesel, 1-cyl.	11·8×18·1	40	60	100	40	6·25	2,500
Oechelhauser	26·5×37·5	500	72	108	36	5·9	2,125
Nuremberg double-acting tandem	33·5×43·3	1,200	60	100	40	7·5	3,000
National single-cyl. horizontal	22·5×30	140	60	140	80	3·5	2,800
National 6-cyl. tandem vertical	22×24	750	58	100	42	6·5	2,730

The water necessary for cooling the pistons and valves is also included in this table in the cases of engines so provided.

Rosseline.

This medium (*Boilerine, Ltd.*) is for the purpose of obviating the incrustation which takes place in water-jackets when salts are present in the cooling water. There are no acids in the preparation, so that joints or attachments cannot sustain any injury. Where scale is already in existence, the action of Rosseline is to cause it to flake and crumble. An average of a quarter pound of Rosseline per brake h.p. per week should be used, the proportion being one pound per 1,000 gallons of water, the approximate quantity of water used to keep a cylinder cool being four gallons per b.h.p. per hour.

Parts of Gas Engines.

In the following formulæ (mainly from Gyldner), a maximum explosion pressure of 350 lbs. per square inch is implied.

1. *Cylinders* are of hard, close-grained cast iron; for the inner wall (*i.e.* working barrel) the working stress may be taken in design at 1,500 lbs. per sq. in. to reduce wall thickness and distortion under heat. If d be the cylinder bore, in inches, and t the wall thickness, then :—

$$t = \cdot 047\, d + \cdot 375 \qquad (21)$$

the ·375 being added as an allowance for reboring, etc. Cylinders up to about 8 ins. bore may have cylinder walls not less than $\frac{1}{4}$ in. thick if cast in one, or $\frac{5}{8}$ in. if with separate working barrels. For bores of 24 ins. and above, the wall thickness may be diminished gradually, or by steps, until at the open end it becomes :—

$$t = \cdot 02\, d = 0 \cdot 5 \qquad (22)$$

2. *Pistons* are of close-grained cast iron; in large engines cast steel is sometimes used. Piston rings are of medium hard, but not very brittle, cast iron. The rings are usually parallel and are of the Ramsbottom type.

3. *Gudgeon, or wrist pins* are usually of steel with a hardened outer surface; the diameter δ may be estimated from the formula :—

$$\delta = 0 \cdot 35 \sqrt[3]{d^2 l_0} \text{ ins.} \qquad (23)$$

where l^0 is the distance from centre to centre of the gudgeon pin lugs, in inches. The intensity of bearing pressure at the moment of explosion should not exceed about 1,800 lbs. per sq. in. of projected area of bearing; this leads to the formula for the length, l, of gudgeon bearing :—

$$l = 0 \cdot 15 \frac{d^2}{\delta} \text{ ins.} \qquad (24)$$

The gudgeon bush is of phosphor bronze; sometimes white-metal lined in larger sizes.

4. *Connecting Rods* in small engines are usually drop-forgings of mild steel; in large engines steel forgings machined all over are used. Connecting rods are treated in calculations as long

columns supported at the ends; a factor of safety of 12 is usual; Euler's formula then leads to the result that the full diameter, $\triangle$, of a rod of circular section may be :—

$$\triangle = 0{\cdot}128\ \sqrt{d\ L}\ \text{ins.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

where L is the length of the rod in inches. Towards the gudgeon end, the diameter may be diminished to ·9 or ·8 $\triangle$. The big end of the connecting rod is very commonly of marine type; when of more than about 5 ins. diameter this bearing is usually of cast iron or cast steel, white-metal lined; for smaller sizes bronze is general.

5. *Crankshafts.*—For large engines high-grade steel forgings with an u.t.s. of at least 70,000 lbs. per sq. in. and 20 per cent. ductility in 8 ins.; or open-hearth steel of u.t.s. at least 65,000 lbs. per sq. in. and 18–20 per cent. elongation in 8 ins. may be used. Recently, in special cases, nickel steel has been adopted with an u.t.s. of about 98,000 lbs. per sq. in. and 21 per cent. elongation in 8 ins.

For ordinary steels the allowable working stress is about 12,000 lbs. per sq. in. If s be the stroke, in inches, then H. Allen gives for the crankshaft diameter, D :—

$$D = 0{\cdot}42\ \sqrt[3]{d^2\ s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

With the higher pressures occurring in engines of the Diesel type (see p. 1939) the constant 0·42 must be increased to 0·52 in this equation.

Crank-pin diameter may be about 1·1 times the crankshaft diameter; the length should be about $0{\cdot}18\ \frac{d^2}{D}$ ins. The bearing pressure in crankshaft bearings should be about 400 lbs. per sq. in. of projected area of bearing.

The crank web may have a depth of 1·33 to 1·66 D and a thickness of 0·85 to 0·55 D.

Valves of Internal Combustion Engines.

The valves of present-day internal combustion engines of all kinds are practically all of the 'Poppet' or 'Mushroom' type. In small sizes the valves and stems are in one piece, and usually either of medium carbon steel or nickel steel. Large valves, especially when water-cooled, have cast-iron discs and medium carbon steel stems; such valves in some cases attain large dimensions, the Siegener Co., for example, having built Koërting type engines with valves 19·68 ins. in diameter and a lift of 3·14 ins. Valve cages and seats are of hard close-grained cast iron. Inlet valves are sometimes automatic; exhausts must be mechanically operated. It is preferable to place valves with their axes vertical whenever possible. The mean velocity of gas through the valves is 5,000 to 6,000 ft. per minute in good practice.

Packings for Heavy Gas Engines.

See 'Britimp' Brand Metallic Packings, p. 1949.

Flywheels.

6. *Flywheels* when of cast iron in one piece should not have a rim velocity exceeding 100 ft. per second. If b be the breadth, and R and r the outer and inner radii of the rim, all in feet, and if n denote the number of revolutions per minute, then the kinetic energy, or stored work in the rim, is :—

$$\text{Kinetic energy} = 0{\cdot}1205\ (R^4 - r^4)\ b\ n^2. \quad \text{Foot-lbs.} \quad . \quad . \quad . \quad . \quad . \quad (27)$$

The 'Cyclic Irregularity' or 'Coefficient of Fluctuation of Speed' is the ratio borne by the difference between the maximum and minimum angular velocity of the crankshaft in any one complete cycle, to its mean angular velocity.

The Cyclic Irregularity is often denoted by $\frac{1}{m}$; its permissible value varies with the nature of the work to be done by the engine; the following are a few typical cases :—

Nature of Work.	m
Ordinary workshops; wood-working, pumping, etc.	30–40
Belt-driven continuous-current dynamos in series	80
,, ,, in parallel	120
Belt-driven alternators in parallel	180
Cotton-spinning machinery	200
Direct-coupled alternators in parallel	250

Mathot has proposed the following formula for rapidly calculating flywheel sizes :—

$$W = C \cdot \frac{m\ P}{R^2 n^3} \cdot 10^6 \text{ tons} \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

where,

W = weight of flywheel rim in tons.
R = mean radius of rim, in feet.
P = b.h.p. of engine.
n = normal speed, in revs. per min.
C = a numerical coefficient.

The following are suitable values for C :—		C
1.	For single-cylinder, single-acting engines	265
2.	For two single-acting cylinders side by side; cranks at 180°	167
3.	" " opposed; cranks at 180°	125
4.	" " side by side; cranks at 0°	125
5.	" " opposed; cranks at 0°	167
6.	" " tandem; cranks at 0°	125
7.	For four single-acting cylinders opposed two and two; cranks at 0°	42
8.	For single-cylinder, double-acting engines	167
9.	For two double-acting cylinders side by side; cranks at 0°	42
10.	" " tandem, on same crank-pin	42

The total weight of the flywheel is about 1·4 W tons.

Flywheels are frequently more massive than the above calculation indicates, especially in cases where the speed fluctuation must be kept small even although one or more explosions be missed due to governor action.

Breakages in Internal Combustion Engines.

The following table is compiled from a wide induction of cases from the records of Insurance Companies, and indicates the relative frequency of failure of the several organs of internal combustion engines :—

Analysis of Failures of Parts of Internal Combustion Engines.

Description of parts which are believed to have given way first.	Average before 1904.	1904-1908.	1909.	1910.
	Per cent.	Per cent.	Per cent.	Per cent.
Valves and valve-gear	30·1	33·3	29·6	42·8
Cylinders and cylinder ends	19·3	16·1	15·4	8·5
Pistons	9·7	5·0	2·7	5·1
Connecting-rods and their bolts	11·9	10·3	9·4	9·1
Main shafts	5·1	11·2	13·4	7·9
Governors and governor-gear	5·1	7·0	5·4	3·4
Silencing-boxes and exhaust-pipes	2·8	3·6	1·3	2·8
Flywheels and driving-drums	5·1	5·4	0·7	2·8
Clutches and couplings	1·7	0·0	0·0	0·6
Frames and pedestals	3·4	1·8	1·3	1·7
Bolts *	4·6	1·5	2·0	1·7
Total wrecks, cause not ascertained	0·6	0·4	0·0	0·6
Main driving-ropes and belts	0·6	0·6	0·0	0·0
Miscellaneous	—	2·2	7·4	4·5
Gas-producer plants	—	1·6	11·4	8·5
	100·0	100·0	100·0	100·0

* These do not include bolts in connecting-rods, valve-gear, or other moving parts, the bolts in these parts being tabulated with the parts themselves.

Notes on Fixing a Gas Engine.*

(*F. R. Parsons.*)

Foundations.

The outline of the foundation of an engine will be determined by the over-all dimensions of its bed or framing. Races for the flywheels must be allowed for if their diameter is such that clearance cannot be obtained otherwise. In a general way a margin of from 3 ins. to 6 ins. all round on engines of from 5 to 25 b.h.p. will meet the case. Above this and up to 100 b.h.p. a margin of from 9 ins. to 12 ins., according to needs and the formation of the bed, will be required. The depth of the concrete foundation depends a great deal upon the character of the subsoil. An engine standing on a good gravel bed would require much less concrete depth than one standing on a clay soil, or made-up ground. Engines up to 10 b.h.p. should in a general way have a bed at least 2 ft. to 2 ft. 6 ins. thick; up to 100 b.h.p. this should be increased to from 3 ft. 6 ins. to

* *Mechanical World*, July 18, 1919.

4 ft. Modern-type horizontal gas engines which have a box-section framing and little cylinder overhang are much less susceptible to vibratory troubles, hence the depth of the bed need not be so excessive.

Opinions vary considerably as to the composition of concrete for engine beds. Always, however, it is much more profitable in the long run to have a fairly strong mixture, thereby diminishing considerably the setting period, and ensuring a good firm job. The following mixture has been found to be a highly satisfactory one for any class of high-speed machinery or engines of any power: broken rubble (stones or bricks), 4; clean river sand, limestone, or granite chippings, 4; cement, 1. Dirt or loose soil adhering to the material detracts from its homogeneity and delays setting. It is a good plan to wash well the stones and larger material from a hosepipe before mixing. Each layer of concrete should be well rammed as it is laid, so as to force the material to the outer extremities of the bed. If the latter cannot be completed right out of hand, the old surface should be well wetted before proceeding with the new material.

Holding-down Bolts.

Always leave ample bolt freedom in the concrete bed so that there shall be no difficulty of getting the engine into position, and also permitting it within certain limits to be moved in either direction if so desired. Use square-necked bolts and washer-plates with square holes, the plates being of ample area in order to resist the pull enforced by the nuts. Grout the bolts in with a mixture of clean fine sand and cement in equal parts when the exact position of the engine has been found, and it has been levelled and set. Holding-down bolts are better not arranged below the concrete foundation, but embedded therein; say, allowing from 6 ins. to 18 ins. of concrete, according to the size and thickness of the bed, below them. Set the bolts and plates on this, then proceed with the filling in. Bolts need not be tied together with a single long plate unless one happens to come so close to the outside of any part of the bed as to have insufficient hold. Always set the bolts in a wood-frame templet having holes in it similarly placed to those in the engine bed.

Size of Gas Meter.

Given the brake horse-power of the engine, the size of a meter required to pass a sufficient quantity of gas per hour can be ascertained by the following rule: Multiply the b.h.p. of the engine by the constant 3·4, then add the constant 5, the result being the size of the meter in 'lights.' For example, suppose the engine we are erecting is 60 b.h.p., then $3{\cdot}4 \times 60 + 5 = 209$. As this rule allows ample margin, we should therefore decide upon a 200-light meter.

Size of Gas Service.

To find the correct size of gas pipe to connect between the meter and the engine, the following rule may be applied: Multiply the meter size, in lights, by the constant 0·008, then add the constant 0·75, the result being the bore of the service pipe in inches. Thus, using the previous example, we have $200 \times 0{\cdot}008 + 0{\cdot}75 = 2{\cdot}35$ ins. In this case, if the connection between the meter and the engine was fairly straight, and not over-long or containing many curves, a pipe 2½ ins. bore would be ample. But if a considerable distance divided the two points indicated, or many bends were introduced, it would be better to use a 2½ in. bore pipe.

Exhaust Pipes.

Generally, engines from 1 to 5 b.h.p. may have an exhaust pipe from 1 in. to 1¼ ins. diameter; 5 to 30 b.h.p., from 1¼ ins. to 2½ ins.; above this and up to 100 b.h.p., from 2½ ins. to 5 ins. in the bore.

Circulating Water.

Almost all gas engines require on an average about 4½ gals. of water per indicated horse-power hour, in order effectively to reduce cylinder temperature, this assuming the temperature of the return water not to exceed 150° F. To effect this by means of circulating tanks would be equivalent to an amount of from 25 to 30 gals. of water per b.h.p. as the contents of the tanks. The effective height of a tank should not be less than 2½ to 3 times its diameter. The higher the tank is situated above the cylinder jacket the more brisk becomes circulation. To keep the bottom of a tank at or about cylinder level causes circulation to be sluggish, and promotes the accumulation of sediment and deposit. For this reason it is generally best to keep the tank bottom at least a foot above the centre of the engine cylinder. A ball tap should be provided to supply cold water to the coldest tank, and if the engine is heavily worked it may also be necessary to arrange for an overflow from the hottest tank. Engines up to 25 b.h.p. can be served from 2 ins. diameter pipes; above this to 50 b.h.p., 2½ ins.; up to 100 b.h.p., 3 ins. to 3½ ins. diameter pipes should be used. The return pipe should be sloped all the way to the tank.

General.

In setting a gas engine on its concrete bed it is advisable to keep the cylinder end slightly the highest, an amount of about ¼ in. in every 3 ft. being ample. This assists in draining the waste oil from the cylinder and other parts of the engine to a point where it may be drawn off and collected.

The exhaust box should not be built solid into the ground or in a pit. It is advisable to mount it on iron rollers placed upon a flat stone or on an iron plate. This provides the necessary means for expansion, without which the joints and connections might suffer.

The gas-inlet pipe to the meter, or from the meter to the engine, should on no account be placed close alongside the hot exhaust pipe. This tends to raise the temperature of the gas, thus making it more rarefied and of less heating value per cubic foot. The cooler the gas admitted the more dense is the charge and the more powerful the explosion.

SECTION XXXI

PART III

OIL ENGINES.

DIESEL ENGINES.

A Diesel engine is a prime mover actuated by the gases resulting from the combustion of a liquid or pulverised fuel injected in a fine state of subdivision into the engine cylinder at or about the conclusion of the compression stroke. The heat generated by the compression of air within the cylinder is the sole means of igniting the charge. The combustion of the charge proceeds at, or approximately at, constant pressure.

The Diesel engine, fig. 11, was patented by Dr. Diesel in 1892, and was brought to a commercial success during the next four or five years by certain engineering firms, with whom he was associated. It differs from the gas engine, or petrol-paraffin engine, where the combustible charge is drawn into the cylinder during suction stroke, and therefore the degree of compression is limited to avoid pre-ignition, the charge being usually ignited electrically. In the case of the Diesel engine, only air is drawn into the cylinder and compressed to about 480 lbs. per sq. inch, and the oil is injected in a fine spray into this compressed air and burns gradually as long as the injection is maintained. During this whole period the pressure in the cylinder does not rise above the compression pressure which therefore is the maximum pressure that the working parts of the engine have normally to withstand.

Diesel engines are made either of the four or two-stroke cycle type, and according to requirements run at various speeds. In the four-stroke cycle type, air at atmospheric pressure is drawn into the cylinder during the first stroke, and compressed during the second stroke to a pressure of about 480 lbs. per sq. in.; this compression of the air causes its temperature to rise to about 950° F., which is more than amply sufficient to ignite the spray of oil injected during part of the third or working stroke. When the injection stops the gases expand and the exhaust valve opens shortly before the piston reaches the end of the third stroke. The products of combustion are expelled during the fourth stroke of the piston.

In engines of the two-stroke cycle type the air, instead of being drawn into the cylinder by the engine piston, is delivered thereto under low pressure and is also used partly to expel the exhaust gases. After the air-inlet ports or valves have closed, this charge of air is compressed to the same pressure (480 lbs. per sq. in.) as in the case of the four-stroke engine. The fuel is injected in the same manner as in the four-stroke engine. The gases expand as soon as combustion is completed, and the exhaust ports are uncovered by the piston shortly before reaching the bottom dead centre, the gases being expelled by the entering charge of air.

The thermal efficiency at full load reckoned on the b.h.p. is about 36 per cent. and the fuel consumption at this load about 0·4 lb. per b.h.p. hour. The products of combustion are invisible and odourless.

Nearly all four-stroke engines are built of the vertical type, with a strong cast-iron 'A' frame, the upper part of which forms the outer cylinder of the water jacket; into this upper part is fitted a liner of special close-grained cast-iron, which is water-jacketed for almost its entire length.

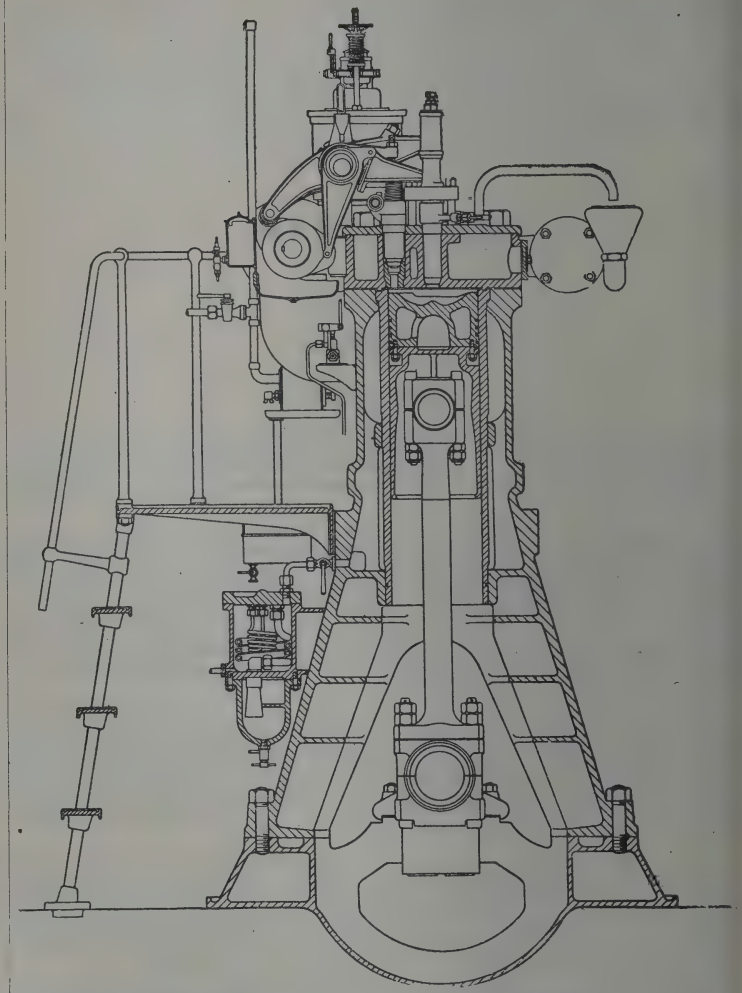

FIG. 11.—The Diesel Engine.

'MIRRLEES DIESEL' OIL ENGINES

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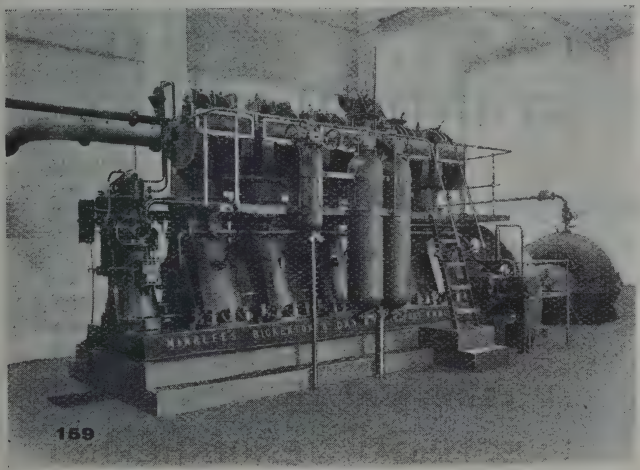

MIRRLEES DIESEL ENGINE DRIVING CENTRIFUGAL PUMP.

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7 Stationers' Hall Court, Ludgate Hill, London, E.C.4.

F. 1941

The cylinder cover contains four valves, the two large ones being the exhaust and air-inlet valves. The central valve is a needle valve which gradually admits fuel to the cylinder about 1° or 2° before the completion of the compression stroke, to 15° to 20° of the working stroke. The fourth valve controls the admission of the compressed air which is used in starting the engine. The cover is thoroughly water-jacketed to prevent the valves from overheating.

The exhaust and air-inlet valves are of the mushroom type and are self-contained in cast-iron casings which bed on cone seatings in the cover, so that should it be necessary to replace a valve with the minimum loss of time a complete valve and casing can be substituted.

The starting valve, like the suction and exhaust valves, opens into the cylinder. The fuel admission valve opens outwards, except in the Burmeister & Wain engine, in which it opens inwards. The fuel valve of most Diesel engines works through a packing gland to prevent leakage of injection air, remote cases of valves sticking in this packing are occasionally recorded. To prevent even this possibility, Mirrlees, Bickerton & Day, Ltd., and also Tosi, use fuel valves which require no packing.

All valves are closed by springs and opened by rocking levers actuated from the horizontal camshaft, which is supported by ring-lubricated bearings, bolted to the cylinder frame. The camshaft derives a half-speed motion through spiral gearing from a vertical shaft, which in turn is driven by spiral gearing from the crankshaft. In some engines there is a direct gear drive from the crankshaft to the camshaft. This vertical shaft drives a centrifugal governor acting directly on the suction valve of the fuel pump.

A cast-iron trunk piston is adopted, made sufficiently long to be a guide in the cylinder and to take the side thrust due to the angularity of the connecting rod, and is provided with three to six 'Ramsbottom' rings to maintain a gas-tight cylinder; in recent large engines the crosshead type is, however, becoming usual.

The fuel pump of the engine operates as follows:—

The plunger draws a full stroke of oil from a reservoir into the pump chamber past the suction valve. This quantity of oil is in excess of that required for combustion. The excess is returned past the suction valve on the delivery stroke by the action of the governor, which holds open the suction valve for a sufficient length of time to allow the excess fuel drawn in to escape back into the reservoir. In this way the amount of fuel delivered to the engine is precisely the amount required to do the work taken from the engine at that instant, and steady running is ensured, as there is never any actual cut-out.

A feature of the Diesel engine is the facility and certainty with which it starts, it being quite possible to start the engine within 45 seconds. It was the first type of internal combustion engine to be started from cold on crude oil.

The engine is able to burn any class of oil, from refined to the cheap petroleum residue, as well as tar oil, and provided the calorific value is not less than 18,000 B.Th.U.'s per lb., the makers guarantee the consumption at full load not to exceed 0·4 lb. per b.h.p. hour in the larger sizes and 0·45 lb. per b.h.p. hour in the smaller sizes.

The following information taken from the published figures of The Diesel Engine Users' Association relates to the running costs of a 335 b.h.p. 'Mirrlees-Diesel' engine at the Buxton Electricity Works, Derbyshire, for a period of one year, 1925–26:—

Load factor	33 per cent.
Fuel cost	0·344*d.* per unit
Lubricating oil	0·019*d.* ,,
Wages	0·104*d.* ,,
Water	0·004*d.* ,,
Stores	0·004*d.* ,,
Repairs and maintenance	0·047*d.* ,,
	0·522*d.* per unit generated.

The fuel consumption of Diesel engines increases per b.h.p. hour as the load decreases, but the increase is not so marked as in the case of steam engines. The following figures (p. 1942) relating to a test carried out by the writer on a 300 h.p. high-speed Sulzer-Diesel engine are representative and indicate approximately the average extent of the increase in specific consumption with a decrease of load. It will be noticed also that at the maximum overload of 30 per cent.

the fuel consumption per b.h.p. hour is also increased. High-speed engines are always slight less economical than those of the low-speed type. The amount of cooling water usually requir in ordinary Diesel engines is in the neighbourhood of four to six gallons per b.h.p. hour, the ou let temperature being generally 150 to 120 degrees.

TEST ON 300-H.P. FOUR-CYLINDER HIGH-SPEED DIESEL ENGINE.

B.H.P.	Load.	Lbs. per b.h.p. Hour.
75	Quarter	·635
150	Half	·465
225	Three-quarters	·435
300	Full load	·42
330	10 per cent. Overload	·425

'MIRRLEES-DIESEL' ENGINES.

'Mirrlees-Diesel' engines (figs. 12 & 13) are constructed by Messrs. Mirrlees, Bickerton & Da Ltd., of Hazel Grove, Stockport, whose works are specially equipped for the sole manufactu of heavy oil engines.

The first Diesel engine made in Great Britain was a 'Mirrlees-Diesel' of 20 b.h.p., whi was made so far back as 1897, and it is interesting evidence of the life of a Diesel engine th this engine is still working daily. 'Mirrlees-Diesel' engines are thus the outcome of thirty-o years' experience, and the total power supplied aggregates over 200,000 b.h.p.

All 'Mirrlees' engines are of the vertical type, and various sizes of cylinders have be standardised as briefly shown below.

Cylinder Output (b.h.p.)	R.P.M.	No. of Cylinders per Engine.	Range of Engine Power (b.h.p.)
Four-stroke Cycle 'Mirrlees' Engines.			
25	450	3 to 6	75 to 150
55	300	1 to 6	55 to 330
100	250	3 to 6	300 to 600
125	200	3 to 6	375 to 750
150	200	3 to 6	450 to 900
Two-stroke Cycle 'Mirrlees' Engines.			
375	187	3 to 6	1125 to 2250

Engines of 1,125 b.h.p. and upwards are of the two-stroke cycle type, and of 'Mirrlees-Nobe design. The engines are single acting, and have one piston per cylinder, and a low speed rotation.

The fuel valves of 'Mirrlees' engines are of a patent 'packingless' type, thus removing t necessity for any packing, and thereby eliminating any possibility of sticking. The pistons us in 'Mirrlees' engines are of a greatly improved design; they incorporate a 'floating' piston pi and special design of top-end bearing, giving larger bearing surfaces than is possible with ordina practice. Formerly all piston pins have been a driving fit in the piston. The 'Mirrlees' pist

pin is free to rotate both in the piston and connecting rod, thus obviating any piston distortion due to expansion or 'driving in' of the pin, also giving easier dismantling, greater life and reliability.

The fuel consumptions of 'Mirrlees-Diesel' engines are remarkably low, as shown by the following results, and are obtained in regular working over long periods, even with engines of small powers.

At full load	. . . .	0·4 lbs. per b.h.p. per hour	
,, three-quarters	. . .	0·42	,, ,, ,,
,, half	. . . . .	0·47	,, ,, ,,

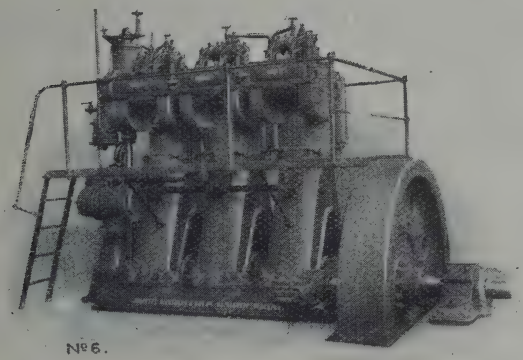


FIG. 12.—165 b.h.p. 'Mirrlees-Diesel' Engine.

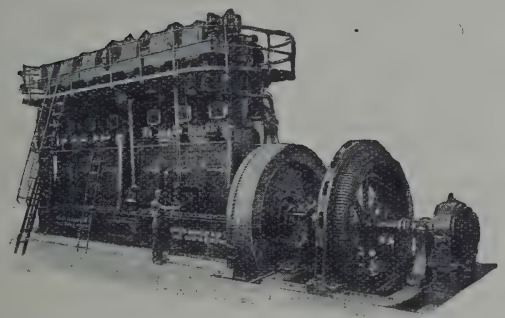


FIG. 13.—1,000 b.h.p. 'Mirrlees-Diesel' Two-Stroke Engine.

Messrs. Mirrlees, Bickerton & Day also specialise in enclosed type Diesel engines which have been largely adopted on board ship for lighting and power purposes. Over eighty engines of this type, aggregating over 18,000 h.p., have been supplied to the British Admiralty alone, mainly for use on capital ships of the 'Dreadnought' and later classes. This type of engine has also been adopted by several foreign navies and many of the principal steamship companies.

Another development which has proved a great success is the use of tar oil or creosote a fuel for Diesel engines, and a special device has been introduced by the above firm for this pur pose. The modified arrangement of fuel pump, etc., required is shown in fig. 29, p. 2144.

Belliss & Morcom Diesel Engines.

Diesel engines of 60 and 100 b.h.p. per cylinder are standardised by Belliss & Morcom, Ltd Birmingham, in three, four, five, and six-cylinder units. They are of the vertical design and ru at 330 and 350 r.p.m.

The rated powers vary from 185 b.h.p. three-cylinder to 600 b.h.p. six-cylinder, in eight size and the design has been developed from their extensive experience in the building of submarin engines and conversion of ex-German submarine engines for central station work.

Forced lubrication is applied throughout; the overhead camshaft is also lubricated und pressure, and oil escaping from the bearings is led back to a tank under the bedplate for re-u after filtering.

The cylinders are separate castings with liners and detachable heads, water cooled, and eac head has one inlet, one exhaust and one fuel valve. The pistons are oil cooled on the high ratings.

A vertical three-stage air compressor is driven from the crankshaft, and the second stage below the first to avoid oil-laden air being drawn in from the crankcase. Starting air is admitte to three cylinders, the valves being grouped at the end of the camshaft.

The adoption of the higher speeds and the complete system of forced lubrication and coolin result in a very efficient engine, which runs smoothly, and the freedom from vibration is ver noticeable. The loss of power due to altitude is given as 4 per cent. for each 1,000 ft. above se level, and the loss of power due to air temperature is 2 per cent. for each 10° F. above 80° F.

English Electric Co.'s Diesel Engines.

The Willans-Diesel oil engines are manufactured at the Rugby Works of the English Electr Company Limited, and have been made since 1906. These engines are in use in all parts of th world, driving all kinds of machines, centrifugal pumps, electric generators, etc., both dire coupled and by means of belts or ropes. They are made in standard sizes from 250 to 500 b.h.

The engines are of the vertical type, the crank chamber is enclosed and forced lubrication use The air-compressor for supplying air for fuel injection and starting purposes is fitted on th end of the engine bedplate and driven from the crankshaft. The speed is controlled by a centr fugal governor acting upon the inlet valve of the fuel pump, thus regulating the quantity fuel exactly to the load. The consumption of residue oil is guaranteed not to exceed 0·41 0·45 lb. per b.h.p. hour at full load, depending on the size of the engine, while at half load th consumption per b.h.p. hour is but 15 per cent. higher.

The engines are made to jigs and limit gauges, thus ensuring interchangeability of spare part which is of the utmost importance in cases where engines are installed in remote countries. Larg engines in powers from 750 to 3,000 b.h.p. are made to the Fullager designs.

Beardmore-Tosi Diesel Engines.

These engines are made in various sizes up to 2,400 b.h.p. and are of the four-stroke cyc enclosed type. The range of horse-power developed per cylinder is 15 to 400 b.h.p., the dimensio ranging from 180 mm. to 630 mm. Crossheads have been adopted in both the land and mari types. The Tosi design gives the greatest freedom from trouble for the piston and gudge pin.

Great attention has been paid to the design of the details of these engines, especially to t lubrication and water circulating systems. The consumption of fuel oil is between ·42 and ·45 per b.h.p. hour. The engines are also very economical in lubricating oil, as only about ·0045 per h.p. is required for the slow-speed engines.

A feature of the Tosi engines is that they will fire regularly at speeds as slow as 40 r.p.m., at which speed compression pressure is 450 lbs., as against 485 lbs. per square inch at normal speed. One reason for the capacity to run at such a reduced speed is the fact that the phase and duration of the fuel injection period can be regulated according to the speed of the engine. At low speeds the quantity of fuel injection air is reduced and the cooling effect of the excessive quantity that would enter the cylinder, were no means of regulation provided, is entirely absent.

Messrs. William Beardmore & Co., Ltd., also make a range of quick-running oil engines with cylinders 8½ ins. by 12 ins., in four, six, and eight-cylinder units, developing 200 to 400 b.h.p. at 750 r.p.m. Also they make engines with cylinders 12 ins. diameter by 12 ins. stroke in four, six, eight and twelve-cylinder units, developing 420 to 1,260 b.h.p. at 750 r.p.m.

These engines are of the four-cycle high compression airless injection type, with steel monobloc crankcase fitted with steel cylinder liners. The lower part of the crankcase consists of a light tray with an oil sump. The main bearings are phosphor-bronze lined with white metal, forced lubricated, and the crankshaft is of high-grade steel with ground pins and journals.

The pistons are made from forgings of a special aluminium alloy fitted with six cast iron piston rings and a floating piston pin of case-hardened nickel steel.

These engines are used for the Diesel electric cars of the Canadian Railways, and are being taken up by the L.M. & S. Railway because of their extremely light weight, high economy, and reliability.

Allen Diesel Engines.

The Allen Diesel engines are made in various sizes from 50 b.h.p. upwards, and are of the Burmeister & Wain design, which has proved very successful. The engines are of the vertical four-stroke cycle type, totally enclosed, and fitted with forced lubrication.

The construction of these engines has received very careful consideration to enable them to make long, continuous runs, such as are required for work on ships. A low fuel consumption is obtained, and the engines are also economical in lubricating oil.

The Allen Diesel engine is constructed mainly for auxiliary work, such as lighting, etc., on board ship. Further particulars of the engines designed by Burmeister & Wain are given on pp. 2411–15.

Schneider Diesel Engines.

Schneider & Co., Le Creusot, have had an extensive experience in the manufacture of large Diesel engines for land and marine purposes. One of the firm's experimental engines, a single cylinder two-stroke cycle type, has developed 1,200 h.p. at 150 r.p.m.

Two-stroke cycle Diesel engines of various powers up to 2,400 h.p. have been made and a number of these have been in regular work for over seven years. Four-stroke cycle engines have also been made and give very satisfactory service.

The Schneider engines are of the vertical type, of both the open and enclosed design, and all of them are fitted with crossheads. The makers have also completed some double-acting stationary Diesel engines of the four-cycle type developing up to 2,600 h.p.

Sulzer Diesel Engines.

Sulzer Bros. of Winterthur, Switzerland, make stationary engines of the four-cycle type from 50 to 1,000 b.h.p. For higher powers they have adopted the two-stroke cycle principle, and all of their marine engines are of this type. A large number of these engines are in operation, and the design of their stationary engines follows that of the marine type shown on p. 2418.

In the larger engines the reciprocating scavenge pumps are replaced by rotary turbo blowers, supplying scavenging air to the cylinder at a pressure of 1½ to 2 lbs. per sq. in. This simplifies the engine, and enables a greater shaft horse-power to be obtained from a given size of engine using the same mean indicated pressure in the cylinder.

Sulzer Bros. now make a new type of airless injection Diesel engine, shown by fig. 14, to meet the demand for oil engines of small powers. The engine operates on the two-stroke cycle, and ignition is obtained by the heat of compression only; the fuel being injected by the fuel pump into a water-cooled space called the pre-ignition chamber, situated in the cylinder head and in communication with the working cylinder. Exhaust ports are arranged in the lower

part of the cylinder liner on the opposite side of which are the scavenge ports, which admi compressed air from the crankcase when the piston is at the bottom of its stroke.

The fuel consumption on a 50 h.p. engine of this type is 0·47 lb. per b.h.p. hour when runnin on ordinary Diesel fuel oil. The engines start immediately from cold, and are able to run a

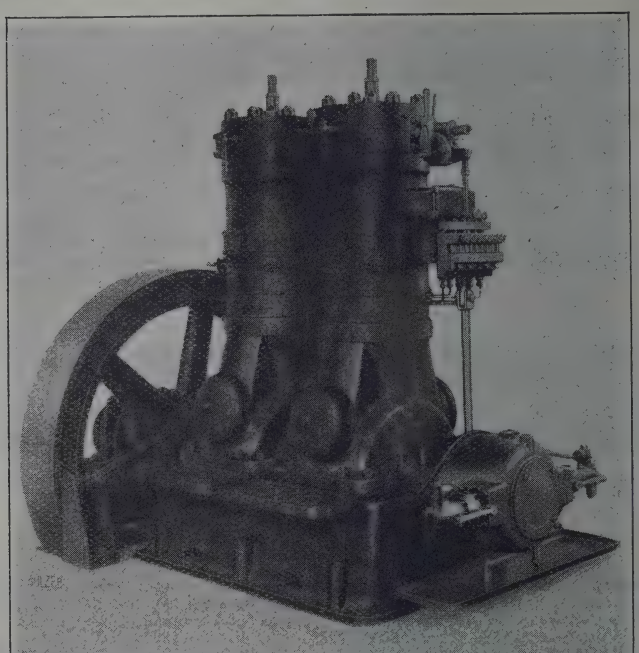


FIG. 14.—Sulzer Airless Injection Diesel Engine.

all loads, even quite light, with regularity. The only valve in regular operation on the cylinde is the fuel injection valve, which is automatic, also the air admission valve on the crankcase i automatic, which greatly simplify the engine, and the robustness of its construction will b apparent from the illustration.

CARELS DIESEL ENGINE.

The Carels Diesel engines are constructed by Messrs. Carels Frrèes, Ghent, Belgium, in size from 50 to 3,000 b.h.p. The first engine was made in 1894, and their standard four-cylinde 600 b.h.p. engine is illustrated by fig. 15.

In 1905 Carels exhibited at Liége a three-cylinder 500 b.h.p. engine; in 1908 they constructe their first 1,000 b.h.p. two-stroke cycle reversible marine engine, and in 1910 they built an engin developing 1,000 b.h.p. in a single cylinder.

Messrs. Carels Diesel & Steam Engines (London), Ltd., which is the British organisation o this firm, have given the following particulars regarding two 320 b.h.p. generating sets installe in 1906 for the Wakefield & District Tramways. The engines are direct coupled to 200 kw generators at 174 r.p.m., and the average run per day during the sixteen years they have bee installed is approximately seventeen hours. Only a small staff is required to run the engines and the guaranteed fuel oil consumptions which were obtained are: full load, 0·42 lb. per b.h.p hour; three-quarter load, 0·45 lb.; and half load, 0·476 lb. One class of lubricating oil

CAREL'S DIESEL ENGINE.

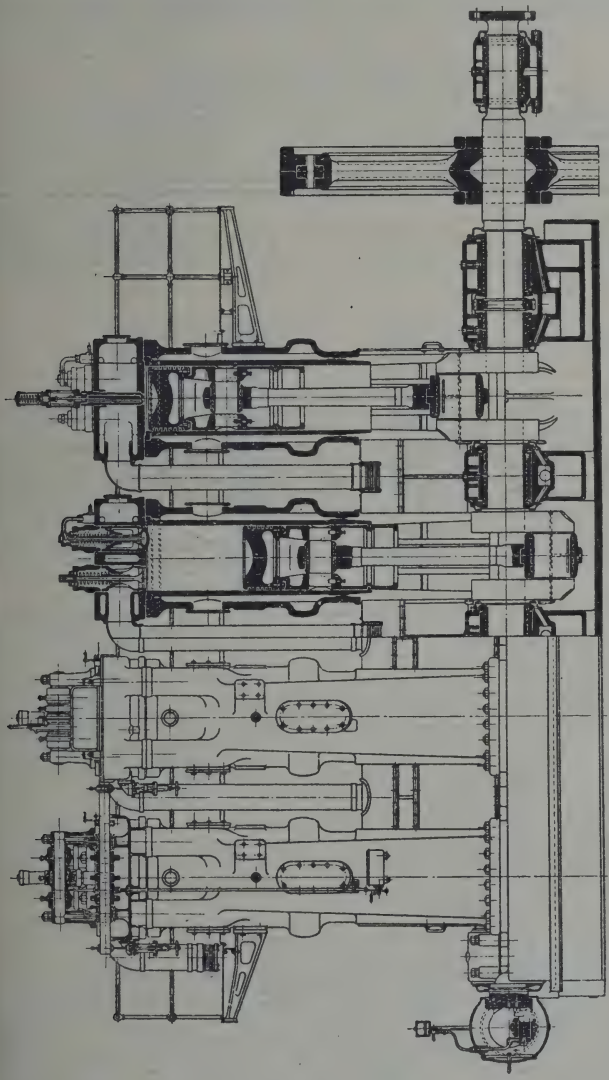


FIG. 15.—Carels 600 h.p. Four-stroke Cycle Diesel Engine.

suitable for all parts of the engine, and the consumption is 4·16 grammes per kw. hour. Th average cost for repairs and maintenance over the sixteen hours is approximately 5*s.* per b.h. per annum.

These two engines are interesting, as they were among the first Diesel engines to be installe to deal solely with a fluctuating traction load, and their performance has been satisfactory also the engines are running well at the present time.

Other Makers of Diesel Engines.

Geo. Ansaldo & Co., Rome, manufacture Diesel engines of large powers, and a number a in regular use. One of their 1,100 b.h.p. two-stroke cycle engines running at 100 r.p.m. w recently subjected to severe tests to determine the flexibility and overload capacity. It w found possible to run the engine at as low a speed as 35 r.p.m., and the following are particula of the overload trials :—

Overload Trial on 1,100 B.H.P. Ansaldo Diesel Motor.

Overload.	Duration of Trial in hours.	R.P.M.	B.H.P.	Fuel Oil consumption, lbs. per b.h.p. hour.	Lubricating Oil consumption, lbs. per b.h.p. hour.
47 per cent.	1	127·7	1,622·5	0·445	—
30 ,,	30	116	1,433	0·440	0·006
12 ,,	5	104·7	1,232·5	0·425	—

These figures dispose of any doubt as to whether the Diesel engine as now constructed c be overloaded for a long period without damage.

Diesel engines are also manufactured by Svenska Aktiebolaget Nobel Diesel, Nynasham Sweden, in various sizes up to 3,000 h.p., and are made in both the four-stroke and two-stro cycles. These engines are of the open vertical type and a large number have been supplie The Nobel engine is one of the best-known Continental designs, for he first commenced its man facture in Petrograd in 1897, and it is noteworthy that the Swedish company now intend specialise on the two-stroke cycle engines.

The Atlas Diesel Co., Ltd., also make these engines in various sizes up to 1,000 b.h.p.

(For further information on Marine types of the Diesel engine, see p. 2409 *et seq.*)

English Electric Co. Fullagar Oil Engines.

The Fullagar oil engine is similar in design to the gas engine described on p. 1928, and made by the *English Electric Co.*, Rugby, in five sizes, from 750 b.h.p. four-cylinder at 250 r.p. to 3,000 b.h.p. The engine is of the vertical enclosed opposed piston type, built up in units two cylinders placed close together, each cylinder having two opposed pistons, there being o crank and one connecting rod per cylinder. The upper piston of one cylinder is connected the lower piston of the second cylinder by diagonal rods.

The pistons move in opposite directions in one cylinder : one piston first uncovers the exha ports which extend all round the cylinder bore, then the other piston uncovers the scaven ports, which also extend round the bore, at the other end of the cylinder, and fresh air at a l pressure is supplied by a pump formed in the upper crosshead, flowing from one end of the cylind to the other, sweeping out the burnt gases and leaving the cylinder filled with fresh air.

The engine works on the Diesel principle, and on the two-stroke cycle, the air in the worki cylinders being compressed until the temperature is raised to about 1,000° F., in order to ign the fuel which is atomised and blown in by compressed air. A three-stage direct-driven compress supplies the air for starting purposes and fuel injection. Fuel is directed horizontally betwe the pistons, so that the fuel does not impinge directly against the pistons. Scavenging air, also that for the compressor, is supplied from chambers in which the upper crossheads wo The crossheads thus act as displacers, the automatic air inlet and delivery valves being arrang behind the chambers in question.

A number of engines are in satisfactory operation driving electric generators in this count and various parts of the world, while several engines of various powers up to 1,500 are now course of construction at Rugby.

The only mechanically operated valves in regular operation are the fuel admission valv there being one per cylinder ; there are no cylinder covers, which is a very desirable simplificati Starting valves, opened by compressed air, are fitted on two cylinders, the valves being operation during the first few revolutions only.

All main bearings, connecting rod bearings, and lower crossheads are forced lubricat whilst the main pistons, upper crossheads, air compressor, and other parts are lubricated mechanically operated lubricators operated from the cam shaft.

The balance of the engine is excellent, owing to the fact that the centre of gravity of t reciprocating masses working side by side nearly coincide ; whilst, owing to its construction a

balance, the engine is suitable for working at higher rotative speeds than the ordinary reciprocating engine. The length of a 6-crank 1,125 b.h.p. engine is no greater than that of an ordinary 500-b.h.p. four-cycle engine; whilst the weight per b.h.p. is about 30 per cent. less than that of the four-cycle engine of equal power, the explanation of this being that the engine is in effect a double acting two-stroke cycle engine without cylinder covers. Also the height to crane hook for removing pistons is less than that necessary to withdraw a piston and connectiong-rod of a four-cycle engine of equal power.

Packings for Diesel Engines.

'BRITIMP' BRAND METALLIC PACKINGS.*

(*British Metallic Packings Co., Ltd., 7 Princes Street, Westminster, S.W.1.*)

Each complete packing (which is equally suitable for heavy gas engines) is made up of two types of rings—viz. the fire rings shown by 'E' (fig. 15A), and the packing rings indicated by 'C.' The fire rings are to protect the packing rings from the heat of the burning gases and are placed next to the cylinder. Each fire ring unit consists of two inner rings, 'E,' in segments, surrounded by an outer ring 'F.'

Each packing unit is made up of two complete rings of cast iron. Each ring is in three sections, with staggered joints. The outer surfaces of the rings are coned in opposite directions, and the coned surfaces are shrouded by a cast-iron ring in three sections (see 'D,'), and the whole is kept together by a spiral spring. Fig. 15A shows a complete packing unit.

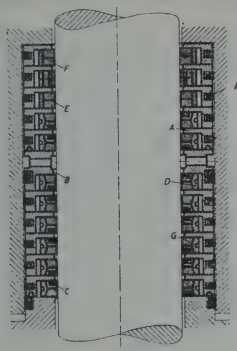


FIG. 15A.

The coned surfaces produce radial and axial surface pressure components which form the gas-pressure seals between the radial and axial surfaces of the packing.

Each fire ring unit and packing unit is enclosed in a chamber ring 'A,' and the pressure seal between these rings and the stuffing box is obtained by the rings 'H.' Lubrication is provided by way of the lantern ring 'B.'

This is a typical example of a Diesel engine packing, and similar arrangements are used for heavy gas engines. The designs, however, are varied to suit any special conditions which may exist.

Weight of Diesel Engines.

For land installations, considerations of economical production have resulted in cast iron being extensively used in the Diesel engine; due to this, and to the high pressures employed, the weight per b.h.p. is somewhat high; thus, including fly-wheels, Guldner gives as the weight per b.h.p.:

A.	In single-cylinder engines:			600 lbs.
B.	,, two-	,,	,,	520 lbs.
C.	,, three-	,,	,,	350 lbs.

In recent practice, and particularly in cases where weight reduction is of importance, as *e.g.* in Diesel engines for submarines, these figures have been largely reduced; this is effected by using materials of considerably greater tensile strength in place of cast iron, and weights as low as 300, 250, and 200 lbs. per b.h.p. for cases A, B, and C respectively, may be found. In high-speed engines the weight has even been reduced to as little as 60 lbs. per b.h.p. with four-stroke engines, and 45 lbs. with two-stroke designs.

The Diesel engine is more economical in fuel consumption than any other type of internal combustion engine, but in construction it is necessarily a somewhat costly type.

* See also pp. 1263, 1805, and 1844.

Care of Diesel Engines.

The causes of perhaps 90 per cent. of all the troubles that occur with Diesel engines ar either insufficient cooling, improper lubrication, or poor combustion. Good results cannot b expected from the engine unless adequate cooling and lubricating systems are provided and fue oil of a certain quality used. The owner should not expect his operator to show good results i he has failed to furnish the needed apparatus and materials. The owner should further under stand that a Diesel engine requires periodical minor adjustments and repairs, and the enginee should be given an opportunity to do this work.

Following out a schedule of inspection, such as one gives any high-grade machine, will resul in a reliability and economy of operation that will justify the slight additional labour involved There can be no justification for the neglect that the engine so often experiences. (*Power.*

Cost of Diesel Engines.

The price of Diesel engines varies considerably, depending upon the design and speed, an may be taken as being from about 9*l.* to over 12*l.* per h.p. at the maker's works.

Diesel Engine Crankshafts.*

All shaft failures investigated owe their origin to lack of alignment of the main bearings This is usually the result of unequal rates of wear of the several bearings supporting the shaft though in some cases it can be traced to negligence during erection, or, in older engines, t defective foundations.

The following system of assuring perfect alignment of the shaft is recommended, especially t those engineers who have no reserve plant and who have to get repairs done during the week-en

If the engine is a 4-cylinder, take out bearing C first and micrometer it. Look up the log book and ascertain how much it has worn since the shaft was last realigned. Then take ou bearing A, micrometer it, and ascertain the extent of wear in the same period. If it has worn dow $\frac{8}{1000}$ in., and bearing C has worn down $\frac{12}{1000}$ in., then scrape down bearing A $\frac{4}{1000}$ in. more, re-bed i to the shaft, or, preferably, to a special dummy journal, and then replace it. Treat all the bearing in like manner. If the engine is a 2-cylinder, or a single-cylinder unit, then probably the bearin adjacent to the flywheel is most worn. It therefore should be taken out first, measured up, an replaced, scraping only if found 'high' at one end. Then take out the other bearings and scrap them in accordance with the data obtained. In the case of a 3-cylinder engine, the probability i largely in favour of bearing B being the lowest, and this, therefore, should be taken out first.

Thus, where plant is not in excess, the engineer can readjust a bearing each week-end until th whole set is completely put in order, and he runs very little risk of heated bearings if he is carefu The system has its limits. It would not do to apply it in this manner if rate of wear were ver variable.

It is necessary to dismantle the whole engine to make a good start with the system. If th engine has been very carefully erected, and is not more than a year or two old, then one ma exercise his discretion and assume that any large differences in the thickness of the main bearin shells is due to difference in rate of wear.

As regards the subsequent adjustment, running clearance of main bearings, it is not usuall feasible to measure this with feelers. Where possible it is preferable to feel the lift in eac bearing, and let the cap closer and closer until the bearing either heats (in which case scrape ou the cap) or until the lift just disappears.

Recourse may be had to leads so long as they are considered only as a means of obtaining th *relative* and not the absolute clearance in a bearing. In the ordinary way, if one uses 20 or 2 gauge lead wire, running clearance will be right if the lead squeezes out to $\frac{8}{1000}$ in. or $\frac{9}{1000}$ i thick. If one uses 16 gauge, then this may squeeze to about $\frac{10}{1000}$ in. or $\frac{12}{1000}$ in. thick. Th actual clearance is probably only $\frac{4}{1000}$ in. to $\frac{6}{1000}$ in. The difference between real and apparen clearance depends upon a number of factors. It should be borne in mind that leads do not sho the true clearance in a white-metal bearing.

Best Proportion of Shafts.

Tensile strength, not less than 34 tons.
Ductility not less than 25 per cent. in 2 ins.
Diameter of pins and journals, 0·525 to 0·54D.
Length of main bearings, 0·75 to 0·8D.
Length of big end pin, 0·525 to 0·54D.
Thickness of webs not less than 0·32D, but centre to centre of cylinder made minimum possibl and any excess over the proposed length of pin and journal to be put into the webs.
Fillets to be not less than one-tenth the diameter of the shaft.

For details of Diesel engine parts see 'Marine Diesel Engines,' Section XXXVI., p. 2409.

* Paper by F. H. Smith read before the Diesel Engine Users' Association, July 12, 1916.

Alignment of Crankshafts and Engine Parts.*

(Geo. E. Windeler, M.I.Mech.E.)

Where small units are built up with separate bedplates and columns or crank cases, it is imperative to check the parallelism of the crankshaft journal from the planed surfaces of the bedplate. The other details which require alignment checking are the connecting rod and the piston, it being essential that the top and bottom bearings of the connecting rod are perfectly parallel and free from twist.

The following is a simple and efficient method for measuring the inaccuracies :

Place into the bottom end of the connecting rod (fig. 16) an accurately ground mandril, say $\frac{5}{1000}$ in. or $\frac{6}{1000}$ in. less in diameter than the bore of the bearing. A similar mandril is placed in the top end bearing. Generally speaking, this mandril is five to six times the length of the bearing. The whole is then placed vertically in two V-blocks, and a scribing block fitted with a micrometer screw is then used to measure the height of the mandril at each end which projects through the rod. The difference between the two dimensions is the exaggerated amount of inaccuracy, and, assuming that the bar is five times the length of the bearing, then the actual amount of error on the connecting-rod bearing itself would be one-fifth of the total error

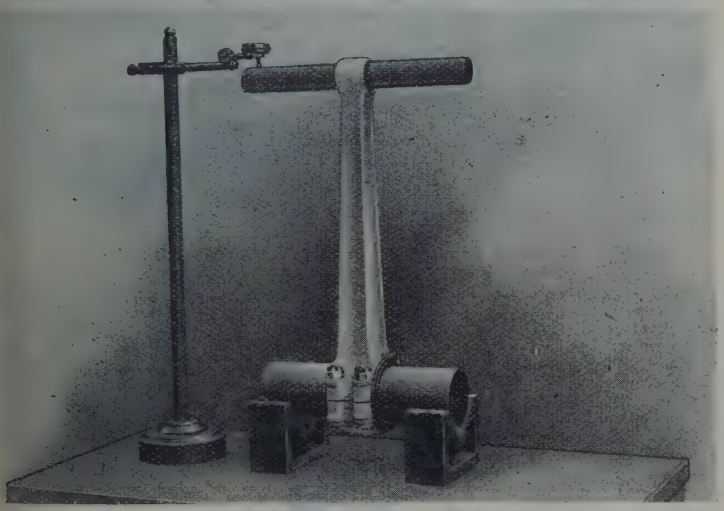


FIG. 16.—Testing the top and bottom bearings of the connecting rod.

shown ; so that if the test-bar showed an out of parallel from one end to the other of $\frac{5}{1000}$ in., then the top end bearing of the connecting rod would be out of parallel with its bottom end bearing to the extent of $\frac{1}{1000}$ in. This is an instance of measuring, by exaggeration, very fine inaccuracies.

It is also desirable to test the rod to ensure that the holes lie perfectly parallel with each other in the vertical plane, that is to say, to ensure that the holes are not twisted with each other. To carry this into effect the rod is lowered down into a horizontal position (fig. 17) and a packing piece is placed under the rod immediately below the centre of the bearing. A scribing block with a micrometer screw is then used to test the height from one side to the other, in the same way as the vertical test was carried out. If any twist occurs with small rods, this can be corrected by twisting the rod, but in large rods other means have to be adopted to remove the error.

The same method is adopted for testing whether the piston pinhole is at right angles to the piston (fig. 18).

---

* Abstract of paper on 'Alignment of Machinery' read before the Manchester Association of Engineers, December 8, 1917.

In moderate-sized units the alignment of the cylinders and parts is often carried out by mean of dummy parts which are accurately made, and may be regarded as a form of jig for testin the parts during the course of erection. With larger sized units this is not always practicabl and other means have had to be resorted to to obtain the same degree of accuracy.

In large units such as are in general use to-day, and in which the rate of revolution i high and the running clearances very close—as, for instance, in a large vertical engine, sa 20 ft. above the crankshaft, with the piston clearance $\frac{14}{1000}$ in. diameter when cold—it i imperative that the cylinder and guide should be at right angles to the shaft, and that th

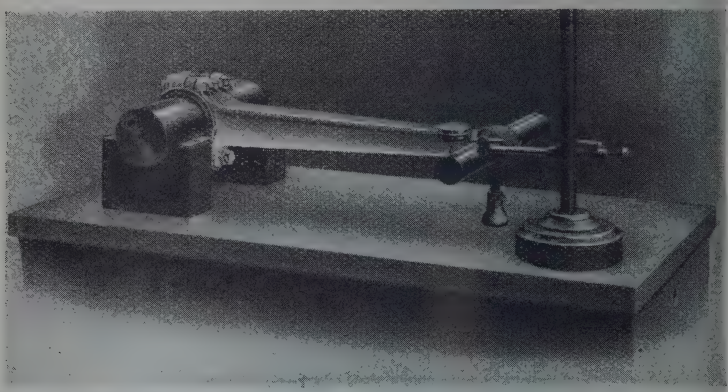


FIG. 17.—Testing the alignment of the holes with the vertical plane.

readings of the alignment should be accurately taken for tabulation. A fine wire is generall used for the alignment of the vertical components, but as it is a flexible member and give to slightest pressure of contact, really reliable data are not obtained from its use in th ordinary way.

The following describes a simple audible electrical device used in conjunction with the fin wire system for accurately checking the alignment of engine parts.

It is assumed that the engine bedplate is machined on the under side and parallel with th top side of the bedplate. The bedplate is then accurately levelled on parallel strips, bot

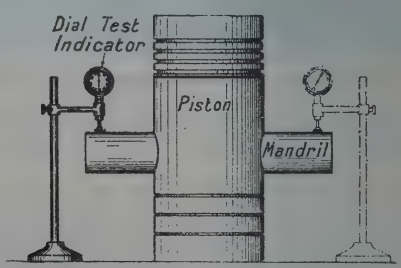


FIG. 18.—Diagram showing method of testing alignment of hole in piston for gudgeon pin.

longitudinally and transversely, and supported by such strips at defined points. The cranksha is then placed in its bearings and tested for parallelism with the planed surface of the bed, an at the same time the shaft journals are tested for concentricity with each other by similar mea to that described under small engines. Assuming this to be satisfactory, the columns a placed accurately in position and the cylinders placed on top of the columns. A fine wire

then stretched over the whole length of engine, the ends passing over uprights secured to the engine bed and adjacent to the ends of the crankshaft. Suspended at each end is a non-magnetic 'plumb-bob' of sufficient weight to keep the wire taut. The wire is then set so as to intersect the centre lines marked on the end of the crankshaft.

The cylinders are then lined true longitudinally to this wire and correctly pitched one with another. Long wires are then passed through each cylinder, of sufficient length to pass between the crank webs, and a heavy 'plumb-bob' is secured to each wire and immersed in viscous oil contained in a small vessel, to prevent oscillations of the 'plumb-bob' and the wires. These wires are set accurately to the centre of the top end of the cylinders by means of the audible device, and readings are then taken at the top and bottom of cylinders and between the crank webs. The wire is suspended over a rounded knife-edge metal bar at the top end of the cylinder, in such a way as to prevent kinking and cutting of the wire, and this metal bar is supported on hard wood blocks from the top face of the cylinder. The use of wood blocks is necessary to

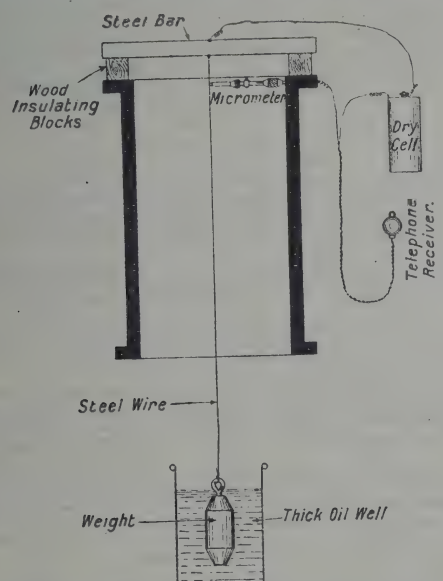


FIG. 19.—Diagram showing method of aligning cylinder using audible warning device.

insulate the metal bar from the engine parts. Connected to the metal bar by one of its terminals is a dry battery (fig. 19), the other terminal of which is earthed to the engine frame with a telephone receiver in circuit; then contact between the suspended wire and the cylinder will cause the electrical circuit to be closed.

The micrometer gauge is then set to half the diameter of the cylinder, less half the diameter of the wire, plus, say, $\frac{1}{2}$/1,000 of an inch. This setting allows $\frac{1}{2}$/1,000 in. pressure against the wire when the wire is set dead central at the top of the cylinder. The micrometer gauge is then inserted between the wire at the points named above, and if the gauge touches the wire the electrical circuit becomes closed by this contact and a distinct noise is transmitted through the telephone receiver. To enable the operator to have the use of both hands, the receiver may be held to his ear by means of an elastic band passed round his head. The micrometer gauge being adjustable, any 'plus' or 'minus' readings can be taken at will with a definite known amount of contact pressure on the wire. The readings obtained are entered on a chart. By reference to this chart the foreman decides what action should be taken to rectify the error shown, and the preliminary and final records are filed for reference.

With this device it is possible to obtain the same readings consistently, and it has the advantage that it is portable and adjustable to any engine, either horizontal or vertical. It

can be sent out to inspectors to check the alignment of engines which have been some tim at work. Also the wear of the bore of the liners can be accurately recorded with the exac position at which the wear has taken place.

In multi-cylinder engines it is important that the crankshaft should be properly supported e each journal, otherwise springing of the shaft takes place at each compression and power stroke which may ultimately result in fracture of the shaft. It is therefore important that the shaf and bearings should be periodically examined. One of the insurance companies has adopted simple means of measuring the amount, and proceeds in the following manner:

The engine is barred round with each crank on its respective top centre, and the distanc between the crank webs is measured with a micrometer gauge at a definite point and recorded Each crank is then barred down to its bottom centre, the distance between the crank webs agai taken, and the difference between the two readings noted. A simple calculation gives a clos approximation of the amount that the shaft is clear from its bearings, and a new bearing can b fitted by gauging the thickness of the existing shell from outside diameter to inside diamete and then making the new bearing thickness plus the amount calculated from the figures take between the crank webs. This method can also be used to detect any want of alignment o outboard bearings of gas and oil engines, and is invaluable for this particular difficulty. I is a very accurate and reliable method, and has saved many cranks from ultimate fracture.

Cyclic Variation Recorders.

A number of arrangements have been made for the purpose of accurately recording the cyclic variations of the rotational speed of an engine; the first attempts were mainly with tuning forks, and this form of apparatus was well developed by Manlove, Alliott & Co. A variation o this was first used by the writer to test the cyclic regularity of steam engines built by Davey Paxman & Co. in 1907.

In this apparatus the tuning-fork was replaced by an electric motor running at a constant speed and the records were taken on the peripheries of the flywheels, the flywheels having been suitably prepared.

Mirrlees, Bickerton & Day have taken tests of the cyclic variation of their Diesel engines in a similar manner, and the arrangement of the apparatus is as follows:—

On a base is formed a V, so that an ordinary lathe compound tool rest can be fitted to same, which tool rest is operated across the face of the wheel by a quick-pitch, square-thread screw, actuated by a heavy handwheel, so as to obtain as near as possible uniform movement across the space to be traversed, though this is not essential to the accuracy of the results.

Mounted on the compound rest is a small electric motor arranged in such a manner that it can be worked towards or away from the surface of the wheel by the compound rest. Secured on the end of the motor spindle is mounted a carefully balanced disc into which is inserted a hardened steel, accurately-ground pointer. Immediately below this is fixed a small bracket which holds another adjustable pointer vertically below the point of the rotating pointer on the disc when touching the face of the flywheel of the prime mover.

The object of the fixed pointer is to scribe a line in the form of a helix circumferentially on wax on the rim of the flywheel, whilst the duty of the rotating pointer is to cut short intersecting marks across these lines at constant intervals of time. These objects are obtained by moving the slide rest parallel to the surface of the wheel whilst the prime mover is running at normal revolutions and the electric motor at uniform speed.

The fixed pointer marks a helical line in the wax deposited on the periphery of the flywheel and the pointer marks off distances on this line at equal intervals of time. These distances are a record of the average speed of the flywheel during small intervals of time and from them a speed curve can be plotted.

It is essential that the points are in line vertically, so that the mark cut by the revolving pointer is bisected fairly accurately by the helical line. The electric motor, which is run at a high speed of revolutions, is supplied with current from an ordinary 12-volt motor-car lighting battery, which forms part of the equipment.

Generally speaking, the length of the record should be not less than 4 or 5 revolutions, though the number is only limited by the width of the flywheel surface and the pitch of helical line, which is usually about $\frac{1}{2}$ in. The motor is arranged at such a speed as to give a suitable number of readings on the periphery of the wheel, so that slight variations in the velocity of the rim can be detected. The distances between the marks are then carefully measured off with a steel tape and

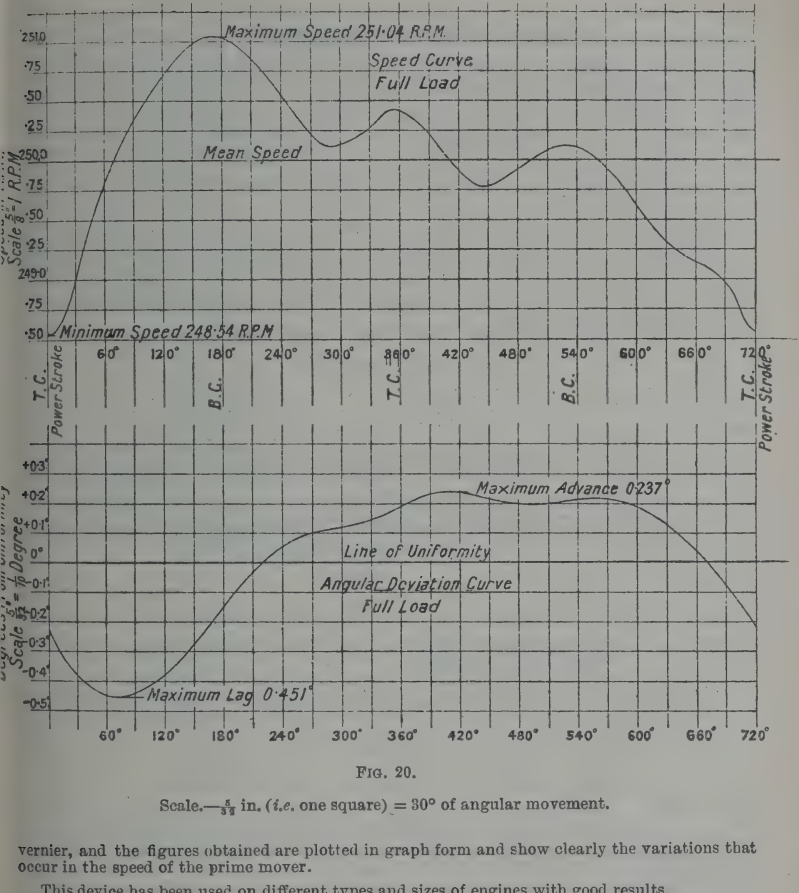


FIG. 20.

Scale.—$\frac{5}{8}$ in. (*i.e.* one square) = 30° of angular movement.

vernier, and the figures obtained are plotted in graph form and show clearly the variations that occur in the speed of the prime mover.

This device has been used on different types and sizes of engines with good results.

The theoretical figures and graphs were based on information obtained from diagrams from actual engines several years before the results were taken by the instrument. The graphs shown on fig. 20 indicate these theoretical figures, and the graphs shown on fig. 21 are those produced by the information obtained with the Mirrlees, Bickerton & Day Cyclic Variation Recorder.

The novelty of the device lies in the use of the periphery of the flywheel of the prime mover as the recording drum, and the application to the flywheel of a delicate recording substance such as wax.

Having plotted a correct speed curve from data given by the trial, the angular deviation from true uniformity of rotation is obtained either (1) fairly accurately by direct calculation from the speed curve, or (2) very accurately by plotting another graph from the speed curve showing the changes in angular position of the flywheel relative to an imaginary wheel rotating uniformly.

The apparatus is inexpensive and of such a character that it can be readily manufactured and easily operated by any careful person with engineering experience. The data obtained can readily be transposed into scaled graphs by a skilled draughtsman

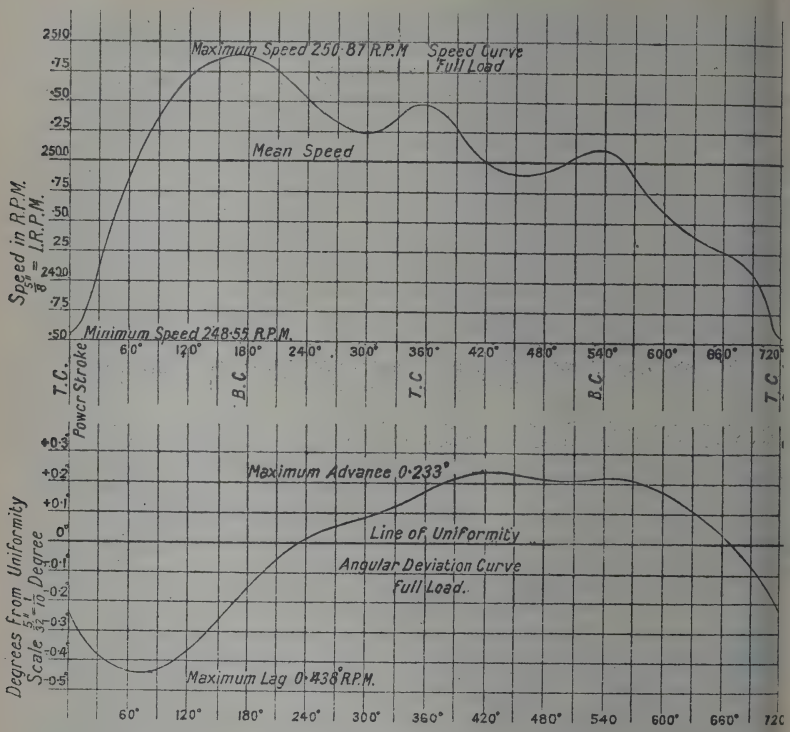


FIG. 21.

Scale.— $\frac{5}{32}$ in. (*i.e.* one square) = 30° of angular movement.

The amount of current used for operating the electric motor is very small, as its duty is to merely maintain at a constant speed the disc carrying the pointer, and to overcome the slight resistance offered by the pointer scratching the marks (one per revolution of the motor) on the surface of the wax.

The method adopted for securing the wax to the wheel is as follows :—The wheel is thoroughly polished and carefully rubbed down, whilst running, with turpentine ; the wax, which is pure beeswax, is carefully heated to a liquid state in a glue kettle and then plastered on to the surface of the wheel. The use of the glue kettle was found necessary, as if the wax were overheated during the process of warming it would not adhere to the surface, the overheating apparently reducing its resilience and causing it to become ' short.'

The thickness of wax deposited on the wheel should be about $\frac{3}{16}$ in. and turned down till it is about $\frac{1}{16}$ in. thick. It can be readily removed afterwards with a scraper, but it was found undesirable to use the same wax over and over again, as a certain amount of greasy matter (probably oil vapour condensed on the wax) mingled with it and destroyed its nature ; so that in carrying out experiments it is desirable to use fresh wax each time.

SEMI-DIESEL ENGINES.

A semi-Diesel engine is a prime mover actuated by the gases resulting from the combustion of a hydrocarbon oil. A charge of oil is injected in the form of a spray into a combustion space open to the cylinder of the engine at or about the time of maximum compression in the cylinder. The heat derived from an uncooled portion of the combustion chamber, together with the heat generated by the compression of air to a moderate temperature, ignites the charge. The combustion of the charge takes place at, or approximately at, constant volume.

The semi-Diesel engine is the simplest form of oil engine, especially if of the two-stroke cycle type, and can be arranged to work satisfactorily with practically the same range of fuel oil as the Diesel engine.

Moderate compression pressures of 150 to 200 lbs. per sq. in. are adopted, consequently the working pressures are low and a comparatively light and inexpensive engine is obtained. The majority of engines operate on the two-stroke cycle and have solid injection of the fuel.

The weight of the engines varies from about 1½ to 2¼ cwts. per h.p., and the price at the makers' works is from about 7½*l.* to 9*l.* per b.h.p., depending on the size.

Crossley Crude Oil Engines.

The Crossley semi-Diesel engine of the two-stroke vertical type, built in four sizes from 6 to 20 b.h.p., and has a separate scavenging pump. Crankcase compression is eliminated, and this enables forced lubrication to be used for the bearings.

The engines will work on paraffin, gas oil, and the heavier crude and residual fuel oils with good economy, and because of the forced lubrication system the lubricating oil consumption is only about 1 per cent. of the fuel consumption.

The scavenge pump is attached to the side of the engine and delivers the air to the cylinder through water-cooled ports uncovered by the piston. The fuel pump is operated from the crankshaft by a cam, and governing is by allowing the excess oil to pass back to the suction side of the pump, through the control valve in the pump.

Petter Medium Compression Heavy-Oil Engines.

The Petter heavy oil engine has recently been modified to dispense with the usual hot bulb, and is built in sizes from 25 b.h.p. in one cylinder to 600 b.h.p. in six cylinders.

The vaporiser is entirely water-cooled and ignition is effected spontaneously by the internal heat of the compressed air, after the initial heat at starting. The piston and under-side of the cylinder head are entirely symmetrical, so that they are free for expansion. The atomiser is a simple automatic spraying device arranged to be adjustable to suit different grades of fuel oil. The improved design enables a very low fuel consumption to be obtained, this being only 0·43 lb. per b.h.p. per hour in the larger sizes.

The engine is illustrated by figs. 22, 23. Crankcase compression is adopted and is maintained dry from lubricating oil, with the result that the consumption is extremely low. This, together with the improved efficiency, renders the exhaust practically invisible at all loads.

Smaller engines of the semi-Diesel type from 5 to 42 b.h.p. are manufactured at the Yeovil works of Messrs. Petter.

Petter marine engines are made in units of one, two, three, four, and six cylinders, ranging in power from 5 to 600 b.h.p.

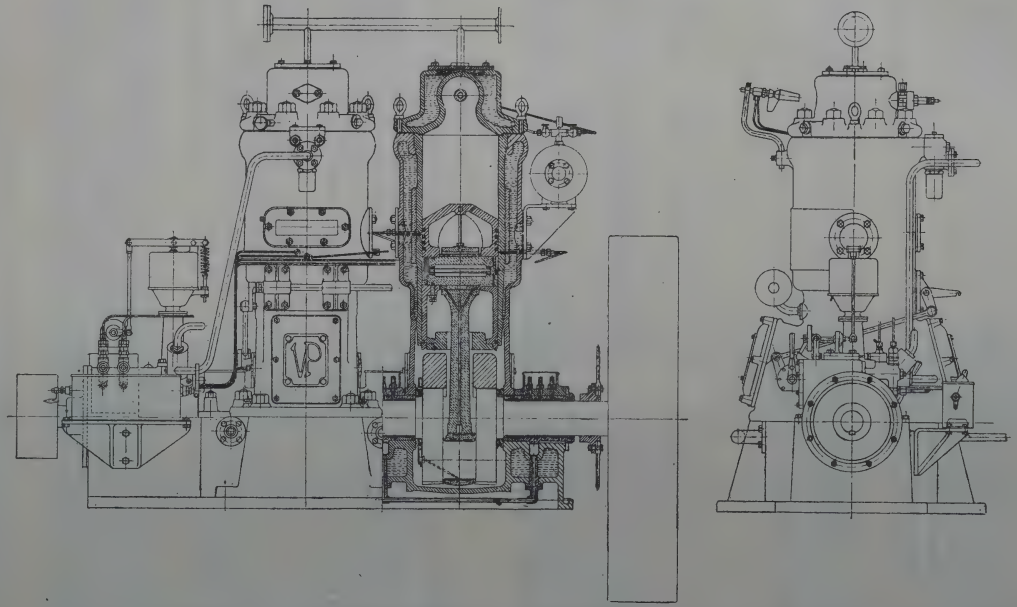
The single and two-cylinder engines are fitted with a clutch and reverse gear; the three, four, and six-cylinder engines are directly reversible by compressed air, and these engines do not require a clutch, but are supplied with an independent air compressor and electric generator oil engine driven set. Also these engines have a thrust block of the Michell type.

All of the engines are fitted with bilge and circulating pumps, and the main bearings are water-cooled, and the marine engines comply with Lloyd's, Bureau Véritas, and Board of Trade requirements.

Clayton-Babcock Crude Oil Engines.

These engines are made in sizes 6 to 150 b.h.p. They work on the two-stroke cycle principle, with an impulse at every revolution, securing a very even turning movement, rendering the engine especially suitable for electric lighting and other purposes where very steady running is essential.

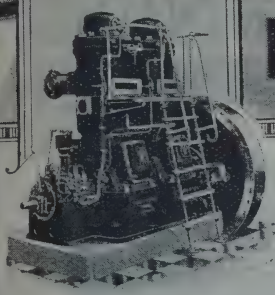
PETTER MEDIUM COMPRESSION HEAVY-OIL ENGINE.



FIGS. 22-23.—Petter Medium Compression Heavy-Oil Engine. Sectional Arrangement.

PETTER

OIL ENGINES



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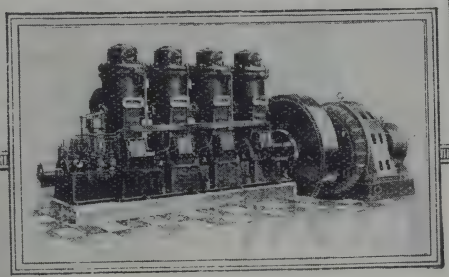

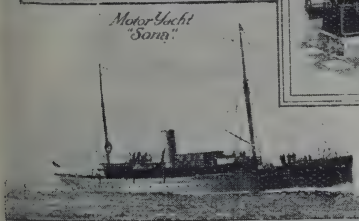

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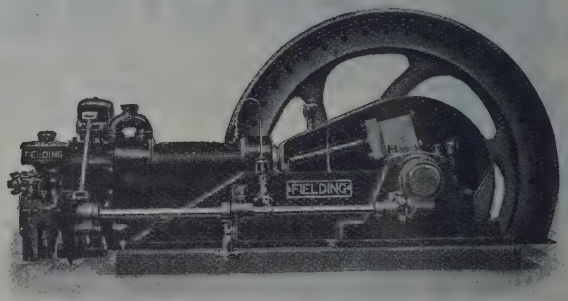

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They are of the simplest possible construction, there being no exhaust or inlet valves, side shafts, cams, skew gears, and rocking levers, and the absence of these complications ensures long life and low cost of upkeep.

The engines work on all kinds of fuel oil, the consumption being very low, and the working cost ½*d.* per b.h.p. per hour, based on the present price of fuel oil in this country.

A special feature of these engines is that while the crankcase is totally enclosed, protecting all working parts from dust and dirt, complete accessibility is secured by the patent removable crank-case cover, which can be easily and quickly lifted off, thus rendering the engine as accessible as the open type four-cycle engine.

Marshall Crude Oil Engines.

Messrs. Marshall, Sons & Co., Ltd., Gainsborough, were one of the earliest makers of the semi-Diesel engine, having commenced their manufacture in 1911, and they make horizontal engines from 8 to 25 b.h.p., and vertical engines from 30 to 450 b.h.p. The horizontal typeis largely supplied on portable carriages for agricultural and other work.

The engines operate on the two-stroke cycle, and have an impulse every revolution. The governor is mounted on the crankshaft and controls the stroke of the fuel pump plunger automatically at all loads, so that the amount of fuel injected into the cylinder is proportional to the load and no hand regulation whatever is required. A noteworthy feature of the governor and fuel pump gear is that they are totally enclosed and work in an oil bath.

Marshall engines have a wide range of speed variation and do not cool down when running quite light. Also they will take overloads without trouble and no water injection is required in the cylinder. Separate cylinder liners are fitted on all sizes, and the engines are extremely economical in fuel and lubricating oil. Numbers of these engines have been supplied for Town and other Councils, for lighting, pumping, and sewage disposal. Among the many installations of Marshall engines may be mentioned one of three 200 b.h.p. engines which supply power continuously day and night in a chemical works.

Campbell Crude Oil Engines.

Vertical engines of the two-stroke cycle are made by the Campbell Gas Engine Co., Halifax, in sizes from 23 to 270 b.h.p. for land and marine purposes. They are supplied with single, two, and four cylinders.

The engines are of the usual valveless type, and have ports in the cylinder so that the air inlet and exhaust periods are controlled by the piston. All of the parts are substantially constructed and the engines are easily started; all sizes being arranged to start by means of compressed air at 120 to 150 lbs. pressure.

Lubrication, as well as other important details, has received careful attention on the engines, and the large number in use indicate the success of the engines. They work on gas oil, solar oil, kerosene, and the lighter crude and residual oils.

Beardmore Oil Engines.

Engines in powers from 10 to 600 b.h.p. are made by William Beardmore & Co. Ltd., Coatbridge. The engines are of the vertical design working on the two-stroke cycle and are supplied in from one to six cylinders for both land and marine purposes.

The crank-case of the engine is used as a pump, the air drawn in through the covers is compressed during the downward stroke of the piston and admitted to the cylinder when the piston is nearly at the bottom of its stroke. The exhaust ports are already uncovered and the shape of the piston top deflects the air to assist in scavenging the cylinder. The air in the cylinder is compressed during the upward stroke of the piston and fuel is injected by means of a pump through an atomiser into the combustion chamber when the piston is nearly at the top of its stroke.

A number of these engines are in use for electric lighting and power purposes and for driving various kinds of industrial machinery, but the majority have been installed in yachts, barges and coasting vessels of all descriptions.

The weight of the engines varies from about 1¾ to 2¼ cwts. per horse-power for land work and from about 1½ to 2 cwts. per horse-power for marine propulsion.

Allen Oil Engines.

Crude oil engines are made by W. H. Allen, Sons & Co. Ltd., Bedford, in single, two and four cylinder sizes ranging in power from 10 to 320 b.h.p. Particulars of the engines, giving cylinder dimensions, are given on p. 1960. The rating and speeds are moderate and the engines are capable of running continuously at full power.

The engines work on the two-stroke cycle and have an impulse every revolution, the governor being arranged to control the amount of fuel oil injected in proportion to the load. They can be started in a few minutes by preliminary heating of the vaporiser with a blow lamp, which is used at starting only. They will run at any load for an indefinite period without the starting lamp or any other additional device; also no adjustment is required for light running, and the engine will run under no-load without misfiring.

A noteworthy feature is that the engines will work satisfactorily when running at reduced speeds, down to as low as half the normal speed. Regular running is obtained and the exceptional economy of these engines is still maintained.

The engines will work on almost any good quality crude or residual oil of specific gravity up to ·95, and the fuel consumption is only ·5 pint per b.h.p. per hour at full load. At ¾-load the consumption per b.h.p. is slightly increased and at ½-load the increase is not more than 20 per cent. Thus each engine has a large economical range of power.

B.H.P.	Revs. per minute.	Number of Cylinders.	Bore and Stroke (Inches).	Size of Flywheel (Inches).		Overall Dimensions of Engines (Inches).			Approximate Weight of Engine complete (Cwts.).	
				Dia.	Width.	Height.	Width.	Length.	Nett.	Gross.
25	375	1	9½ × 11	42	8	59	42	74	48	57
35	325	1	11½ × 13	51	10	70	51	88	72	83
50	275	1	13¾ × 15	60	12	81	60	98	103	117
50	375	2	9½ × 11	42	8	59	42	101	73	85
70	325	2	11½ × 13	51	10	70	51	130	108	123
80	250	1	16¾ × 17½	66	14	95	66	121	165	183
100	275	2	13¾ × 15	60	12	81	60	146	155	173
100	375	4	9½ × 11	42	8	59	42	151	122	138
140	325	4	11½ × 13	51	10	70	51	152	184	204
160	250	2	16¾ × 17½	66	14	95	66	167	248	279
200	275	4	13¾ × 15	60	12	81	60	175	258	290
320	250	4	16¾ × 17½	66	14	95	66	232	415	460

Brotherhood Oil Engines.

Single and twin cylinder horizontal crude oil engines from 16 to 130 h.p. per cylinder are manufactured by Peter Brotherhood, Ltd., of Peterborough.

An illustration of an engine of 130 h.p. is shown in fig. 24.

These engines use compressed air for starting only, the injection of the fuel being performed by a pump the stroke of which is varied according to the load by a centrifugal type governor.

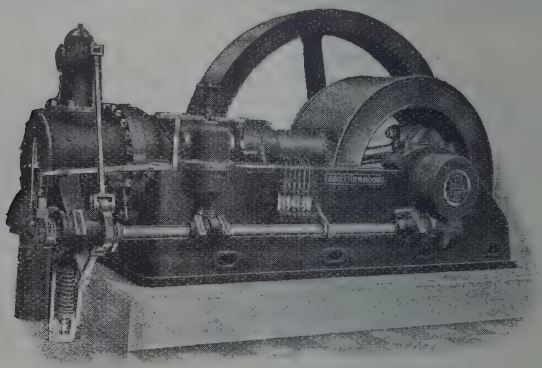


Fig. 24.—Peter Brotherhood Oil Engine.

They start without any preliminary heating when using all kinds of petroleum and its derivatives, such as crude oil, mazout, and tar oil.

The compressor for providing the air for starting is an independent unit, arranged to be driven by belt or separate motor, and, in case of need, by hand.

The consumption of crude oil with a calorific value of about 18,000 B.T.U. per lb. varies from 0·42 to 0·55 lb. per b.h.p. hour at full load, according to size.

Robey Oil Engines.

Semi-Diesel engines for land and marine work are made by Robey & Co., Ltd., Lincoln, in various sizes from 12 to 280 b.h.p. They are of the vertical two-stroke cycle type and are extremely simple.

The fuel is injected into the combustion chamber through a special form of sprayer, which gives good atomisation. The governor is of the centrifugal type mounted direct on the crankshaft and controls the amount of fuel injected in proportion to the load.

Robey engines will run on the usual kinds of refined, crude, or residual oil, and they have worked satisfactorily on tar oil.

Bolinder Engines.

The Bolinder engine (fig. 25), although essentially of the hot-bulb type, contains several features which distinguish it from other motors of this class. It is a high standardised production, and is now made in sizes up to 500 b.h.p. in four cylinders. As in most other motors of this design, the air is drawn in the crank chamber on the compression stroke of the piston, this air being compressed to a relatively low pressure in the crank chamber by the piston on its outward stroke. Just before the piston reaches the end of its stroke the exhaust ports are uncovered in the cylinder, allowing the exit of the exhaust gases, which are finally completely driven out through the exhaust pipe by the admission of the compressed air from the crank chamber through further ports in the cylinder wall uncovered by the piston as it continues on its downward stroke. On the upward stroke the piston compresses the air thus taken into the cylinder, and on reaching the top of its stroke the fuel is sprayed into the hot-bulb, thus causing combustion, vaporisation, and expansion within the cylinder. The bulb is kept hot by the heat due to the combustion, and the compression is usually about 125 to 150 lbs. per square inch. It is, of course, necessary to heat up the bulb by a blow-lamp before starting, but once the engine is running it is not necessary to keep the lamp burning, even when operating on light load.

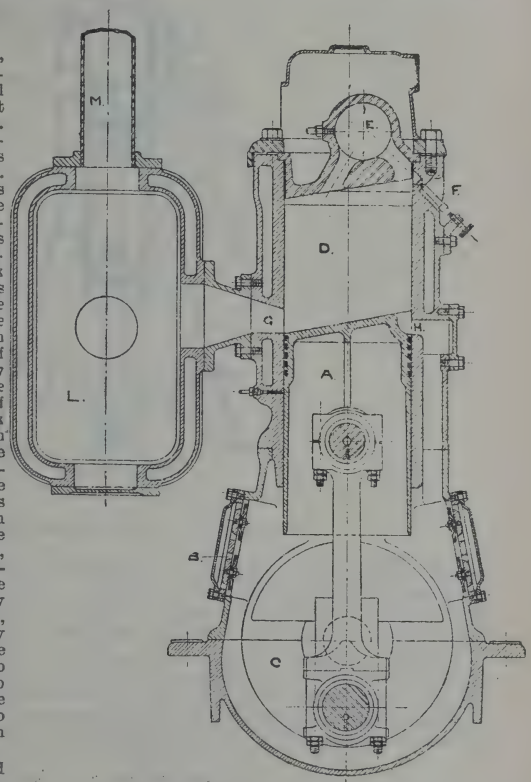


Fig. 25.—The Bolinder Engine.

Engines of 90 b.h.p. and above dispense with water injection into the cylinder, and are fitted with small two-stage air compressors driven from the main crankshaft. Compressed air is forced into the bulb at the same time as the fuel. If required the engine can be run at about three-quarters power with the air compressor disconnected and without overheating. On the smaller sizes, water injection is retained, as it is possible to obtain a higher power for given cylinder dimensions.

For marine work, the Bolinder engine is made directly reversible, the principle being, broadly, the injection of fuel to cause an explosion after the engine has slowed down nearly to the point of stopping, and whilst the piston is on the upward stroke, so that reversal of motion follows. This is carried out by a special device regulating the action of the fuel pump.

The Bolinder motor is manufactured in Stockholm, but is handled in Great Britain by Messrs. James Pollock, Sons & Co. Ltd.

'MIRRLEES-SIMPLEX' OIL ENGINES.

Messrs. Mirrlees, Bickerton & Day Ltd., of Stockport, are now manufacturing a semi-Dies type of oil engine known as the 'Mirrlees-Simplex' engine. This series of engines is an additio to the firm's extensive range of 'Mirrlees-Diesel' engines, for which they have a world-wic reputation, and the powers are from 35 b.h.p. to 240 b.h.p.

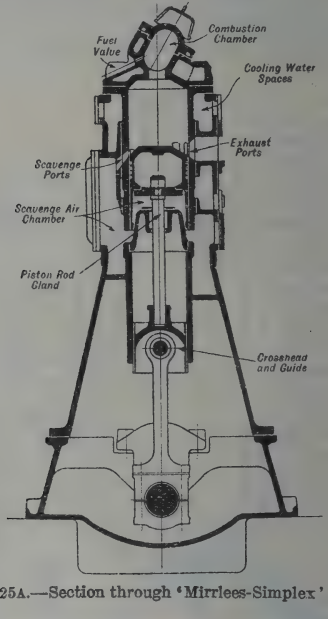


FIG. 25A.—Section through 'Mirrlees-Simplex' Engine.

The 'Mirrlees-Simplex' engine is a low-compression two-cycle engine employing mechanica fuel injection and forced lubrication for the bearings. The outstanding feature of this engine i the elimination of the use of crankcase compression. This important departure from the commo practice has been attained by employing the crosshead type of construction and compressing th scavenging air in the chamber formed between the piston and a gland plate through which th piston rod passes (see fig. 25A).

This design completely isolates the crankcase from the cylinder, so a copious supply of lubri cating oil can be used for all working parts within the crank-chamber without oil being carrie over with the scavenging air into the cylinder, and the consumption is reduced. Also the crank chamber oil is unaffected by piston and cylinder temperature, no grit is drawn into the crank chamber with the scavenging air, the crosshead pin is not affected by the piston temperatures and the side thrust on cylinder walls and piston is eliminated.

FIELDING AND PLATT OIL ENGINES.

The well-known 'Fielding' Horizontal Four-stroke Semi-Diesel Oil Engines, of which ther are many hundreds in operation, have special features, and are of the low compression hot bull type. They are made in sizes from 12½ b.h.p. to 400 b.h.p., and the compression is 250 lbs. pe sq. in. In practice this compression enables engines to be started with 150 lbs. air pressure and it is important to note that for factory work, if ever the air receiver becomes exhauste these engines can easily be started by hand with the half compression cam in action.

The engines will run without attention from the time they are started, and, being fitted with the 'Fielding' patent pump and governor control, work with exceptional smoothness. Al patterns are of the single flywheel and third bearing type with separate water chamber at bac end, and the cylinder is fully supported with oil tray round bed. Up to 100 b.h.p. single-cylinde engines are standardised, and above this power twin cylinder. The consumption of fuel varie from 0·45 lb. per b.h.p. per hour on the larger sizes down to 0·55 lb. per b.h.p. per hour on th smaller engines.

THE STILL (I.C. + STEAM) ENGINE.

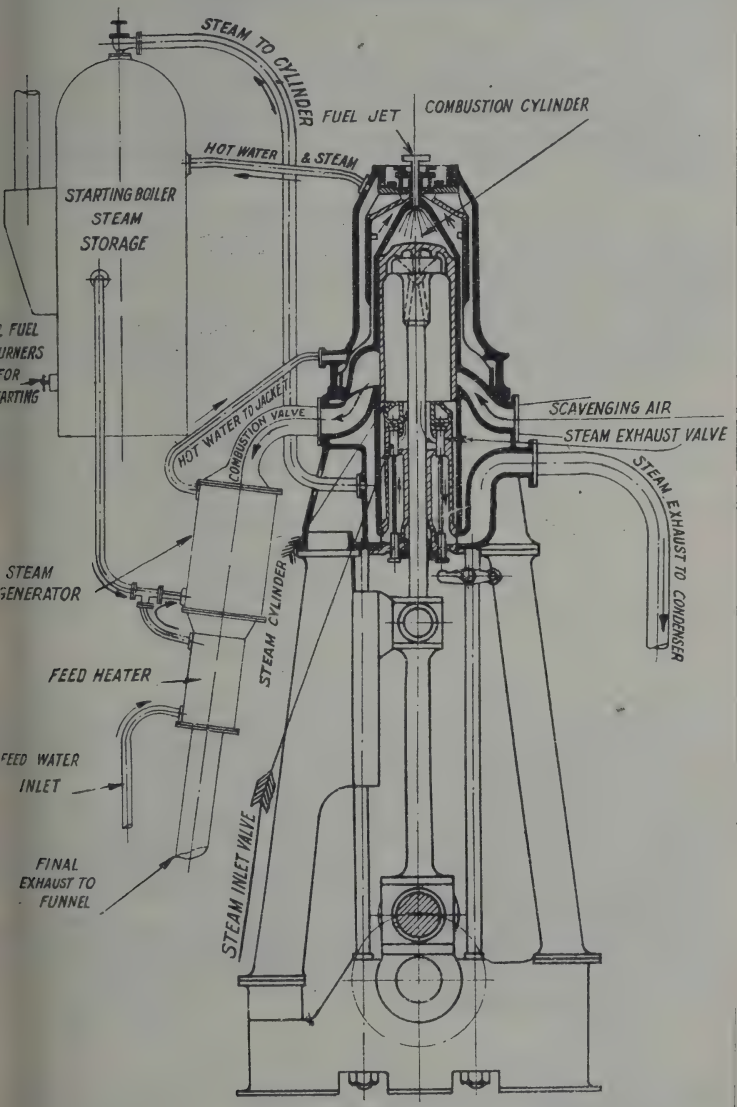


FIG. 26.

The fuel-injection system consists of a plunger pump fitted with a sleeve valve which is un control of the governor, and acts as a cut-off valve. The injection pump works very smooth and without noise.

Other Makes of Semi-Diesel Engines.

Semi-Diesel engines of the horizontal four-stroke cycle type are manufactured by Tangy Ltd., Birmingham, and Bates & Scholes, Ltd., Denton, Manchester.

Engines of the vertical design operating on the two-stroke cycle are also made by Plenty Son, Newbury; the Aster Engineering Co., Wembley; John Kirkaldy, Ltd., Burnt Mill; Nor Henty & Gardners Ltd.; the Keighley Gas & Oil Engine Co., Keighley; Widdop & Co., Keighl Clayton & Shuttleworth, Lincoln; Babcock & Wilcox; and the Hamworthy Engineering Ltd., Poole.

Still (I.C. + Steam) Engines.

An engine of high thermal efficiency has been developed by the Still Engine Co. and is ma factured by several licensees. The main working cylinder uses liquid or gaseous fuel, and in same cylinder, on the opposite side of the piston, steam is employed. The steam is produced the recoverable heat from the internal combustion side, which passes through the walls of cylinder as well as into the exhaust gases.

Heat, wasted in other internal combustion engines, is usefully employed in the Still eng to increase the power of the engine and reduce the consumption of fuel per horse-power develo

As will be seen from fig. 26, the jacket and cooling water form part of the circulating sys of a steam generator, which may be an integral part of the engine. The cylinder liner is speci

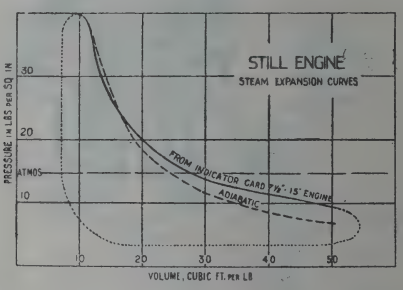


Fig. 27.

constructed and is about one-third of the usual thickness; it is ribbed externally to add t conducting surface. The quantity of steam capable of being generated from the rejected h of an internal combustion engine depends upon the efficiency of the combustion cycle and on load. At full load the quantity may be about 7 lbs. per b.h.p. of the engine.

In the indicator diagram (fig. 27) taken from the under, or steam, side of the piston, adiabatic expansion line as plotted shows there is no loss from condensation. Heat is ta from the piston and cylinder walls and the steam exhausts at a slight superheat.

An experimental engine tested by Professor Vernon Boys generated 3·28 lbs. of steam f the jacket alone, and from the jacket and exhaust together 6 lbs. of steam per b.h.p. hour. average m.e.p. from the combustion stroke was 90 lbs. per sq. in. The steam evaporated by heat rejected gave 14 lbs. m.e.p. per sq. in. on every return stroke of the piston. Thus, the f stroke cycle engine had a total m.e.p. of 118 lbs. per cycle.

The possibilities of this design are very great; by admitting additional steam generated fuel under the boiler, the total m.e.p. can be increased considerably. This enables the en to take big overloads, and by the use of steam easy starting and manœuvring are obtained.

The thermal efficiency of the Still engine compared with other prime movers is shown in ollowing table:

Marine steam engine, superheated	16% to 17%
Parsons steam turbines	15 ,, 20
Gas engines	22 ,, 30
Petrol engines	23 ,, 27
Semi-Diesel engines	27 ,, 30
Still gas engine	31
Still petrol engine	33
Diesel engines	30 ,, 36
Still oil engines	38 ,, 44

HIGH-COMPRESSION OIL ENGINES.

The high-compression oil engine is the outcome of experiments to simplify and reduce the cost of Diesel engines. Many attempts have been made to produce engines capable of burning cheap heavy oils with an economy approaching that of the Diesel, but in which the high-pressure air blast is avoided without sacrificing the capability of the engines to start immediately from cold.

Among the first of the successful engines was the Vickers, which has been largely developed for propelling submarines. Several other makes of high-compression engines are now on the market, and the elimination of the air compressor has produced a marked improvement as regards simplicity compared with Diesel engines.

What is known as 'solid injection' is adopted for spraying the fuel into the cylinder, the oil being raised to a high pressure by the fuel pump momentarily at the period of injection, or permanently in a small receiver and admitted to the cylinder by timing the opening of the fuel admission valve.

The weight and price per horse-power are lower on these engines than Diesel engines, but up to the present the economy is not quite so good.

Vickers Oil Engines.

High-compression oil engines for land or marine purposes are manufactured by Vickers. Ltd., Barrow-in-Furness, in sizes from 500 b.h.p. upwards. The engines are of the vertical, multi-cylinder, four-stroke cycle type.

The mechanical fuel injection system on these engines has been used for the last eleven years and no air blast is required for the fuel. The engines will start from cold without preliminary heating of any part. A sufficiently fine spray into the cylinder is obtained by forcing the oil at a high pressure through minute holes in a special nozzle below the fuel-injection needle valve.

A fuel pump may be fitted for each cylinder, or two pumps can be used for all the cylinders, and delivering the oil at a pressure of from 2,000 to 4,000 lbs. per sq. in. into a pulsator tube from which it passes through a special strainer to the needle valve in the cylinder head. The pressure depends upon the speed and power at which the engine is running. Control of the power is obtained by varying the time and the amount of opening of the fuel valve, and by adjusting the pump to the desired pressure.

Engines of a total horse-power of nearly 500,000 have been built, and the makers claim the following advantages over Diesel engines :

High-pressure air for fuel injection eliminated.

Increased safety in working and lower compression pressure.

Reduction of space, weight, and cost.

Elimination of cooling effect of air blast on p ston and cylinder head.

The six-cylinder 1,250 b.h.p. engine has cylinders 24·5-in. diam. by 39-in. stroke, and the normal speed is 118 r.p.m. The fuel consumption is stated to be as low as 0·38 lb. per b.h.p. per hour.

Crossley Oil Engines.

Crossley Bros., of Openshaw, Manchester, make high-compression oil engines in sizes from 20 to 300 b.h.p. single cylinder, and up to 260 b.h.p. double cylinder. The engines are of the horizontal four-stroke cycle type.

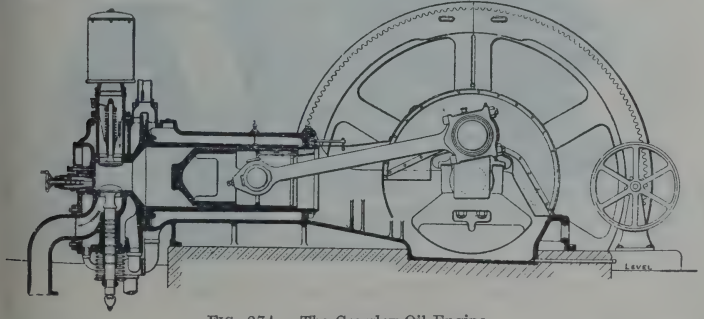


Fig. 27A.—The Crossley Oil Engine.

All of the engines start up from cold without preheating, and will work on crude, refined, or residual and vegetable oils. The patent fuel pump and governor gear are particularly interesting, as the commencement of the fuel injection is constant at all loads. Governing is effected by

reducing the amount of the charge delivered by the fuel oil pump at reduced engine loads; t full consumption is thus, as far as possible, proportioned to the power output. Messrs. Cross state that in a recent test the consumption of (crude) oil for b.h.p. hour at full load was 0·39 l and at about half load rose to only 0·44 lb. with their governing arrangement. They point that this performance compares favourably with that of the more costly Diesel type of engine

These engines can be supplied as convertible engines to work with either fuel oil or produ gas, whichever may be the cheaper fuel at the time.

Crossley Premier Oil Engines.

The Premier Gas Engine Co., Ltd., of Nottingham, in combination with Messrs. Crossley Bro Ltd., now build cold-starting multi-cylinder horizontal heavy-oil engines with solid injection fuel. The engine is made in units up to 1,200 b.h.p. and is specially adapted for direct coupling electric generators.

Up to 500 b.h.p. there are three and four cylinders mounted on one bedplate, above 500 b.h there are two bedplates, each having mounted thereon three or four cylinders, with central dri

The engine has the advantage of low head room and accessibility to all working parts. It very economical in fuel and lubricating oil, and is specially suitable for working on heavy residu fuel oils; also will start from cold without preheating.

Ruston-Hornsby Oil Engines.

This engine of Messrs. Ruston & Hornsby, Ltd., fig. 28, is of the solid injection type. T makers have succeeded in dispensing with the high-pressure air blast for fuel injecti altogether, a quick-acting fuel force-pump being employed to inject the fuel oil through a specia designed mechanical atomiser.

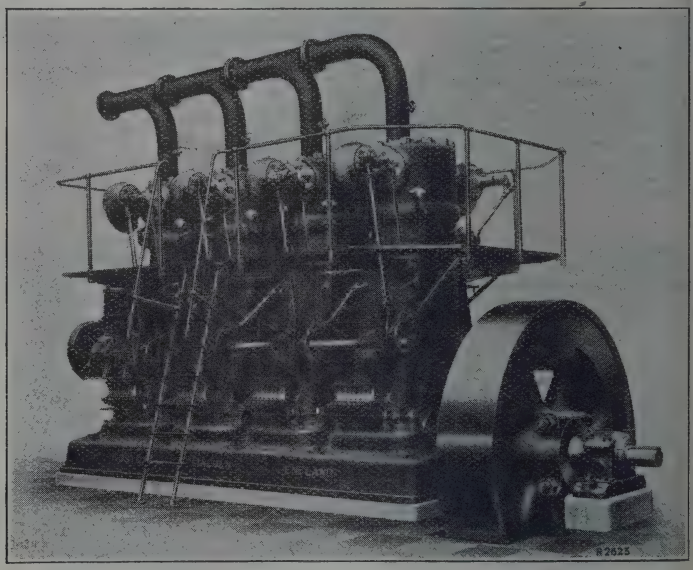


Fig. 28.—Ruston Four-cylinder Vertical Engine.

Starting is effected with certainty from cold under all conditions without any prelimina heating or any special starting device being employed.

The engines are built in single and multi-cylinder units, and range from 16 b.h.p. to 340 b.h. in the horizontal form, and from 55 b.h.p. to 825 b.h.p. in the vertical type.

Fig. 28 shows a 440 b.h.p. engine of the vertical type.

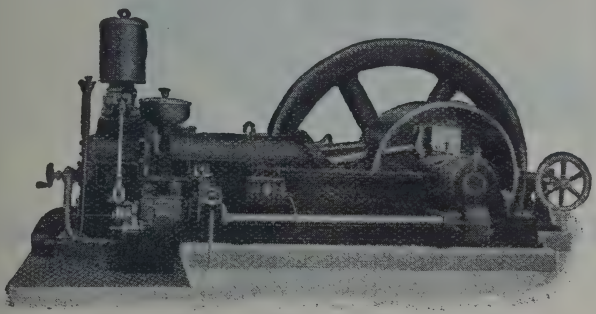
CROSSLEY

COLD-STARTING—AIRLESS INJECTION

OIL ENGINES

from 6 to 1,000 B.H.P.

combine Simplicity and Reliability with remarkable Economy in Fuel Oil and Lubricating Oil Consumption.



ALTERNATIVE FUELS

These engines can be supplied as convertible engines to work either with **FUEL OIL OR WITH PRODUCER OR OTHER GAS.** This is very useful in many trades and in many countries, especially where, periodically, refuse fuels for making producer gas are available for little or no cost to the user.

THE MOST HIGHLY DEVELOPED HEAVY-OIL ENGINE.

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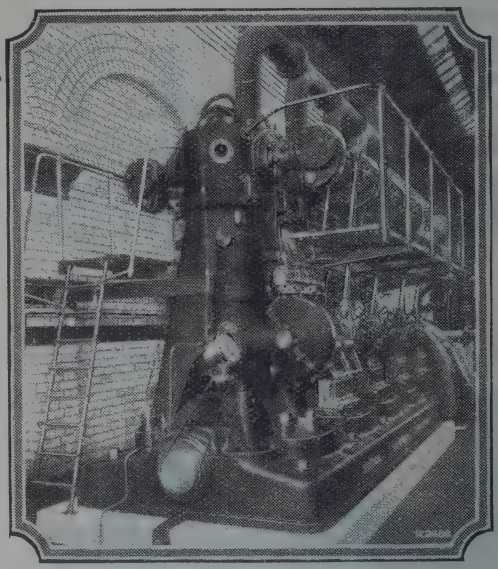


Ruston Economy Maintained!

Experience Counts

"Averaged over the whole 8.029 hours' run by the engine, the fuel consumption has been 0.698 lb. per kw.-hour, with a running plant load factor of 46.5 per cent. The question has been raised as to whether the fuel economy would be maintained with this type of engine. In connection with this it will be useful to state that during the last 1,120 hours' run by the engine the consumption has been 0.693 lb. per unit generated with a running plant load factor of 50 per cent. Therefore there was no sign of falling off in economy after 7,000 hours' running.

"The engine has now run 8,000 hours and experience of it has justified the installation of a further engine of the same type."

Extract from paper read July 9th, 1925, before the Diesel Engine Users' Association by the Municipal Engineer in charge of the above 4 Cylinder Ruston Engine.

Ruston & Hornsby, Ltd., Lincoln

A special feature is the valve gear, which is actuated by means of an eccentric gear and one slide shaft, thus reducing the number of working parts to a minimum, and giving a compact and silent running engine.

The action of the engine is as follows:—The piston on its outstroke takes in air, which, on the return stroke, is compressed in the combustion chamber, and nearly at the point of greatest compression, the oil fuel is injected by a pump, which forces the oil through a mechanical atomiser. The compression temperature is sufficient to ignite the charge. The power stroke follows, then the exhaust, after which the cycle is repeated. By adopting this cycle, on the one hand a high compression can be used with its attendant economy, without incurring pre-ignition, whilst, on the other hand, an air compressor and air receiver are avoided.

The oil-fuel pump is driven through a lever by a quick-acting cam on the layshaft, which is completely enclosed and runs in oil. A lever is provided by which each pump can be worked by hand, or thrown out of action altogether to stop the engine. The fuel pumps and side shafts of the horizontal engines are carried by the bedplate, thus relieving the cylinder head.

The mechanical atomiser, which is fixed in the combustion head, consists of a duplex valve loaded by a powerful spring, which is lifted at each stroke of the oil-fuel pump. The valve has two seats of different diameters, the smaller of which closes the opening of the combustion chamber, and the larger a leak pipe to the oil tank. When the smaller valve lifts, the oil is forced through channels converging to a central outlet, which so split up the stream that it emerges on either side of the nozzle in a cone-shaped cloud of oil particles. The movement of the valve is about $\frac{1}{70}$th inch, and is entirely automatic in action. There is no packing or oil-tight diaphragm, or any complication liable to get out of order, and the action, though delicate, is found in practice to be absolutely reliable.

The regulation of the speed is effected by the opening of a by-pass valve by the governor, the toe of the valve resting upon a lever carried upon a cam. The fulcrum of the lever is adjustable by a screw, so that although the lift of the valve is minute, there is always a means at hand for easily keeping it in perfect adjustment. The consumption of oil, even the lowest grade of crude, residue, or fuel oils, is complete, while the economy is remarkable.

Tests which have been made show that a high thermal efficiency is obtained with the cheapest fuel oils on the market, the consumption ranging from 0·40 to 0·47 lb. per b.h.p. hour according to the size of the engine.

National High-Compression Oil Engines.

The National Gas Engine Co., Ltd., Ashton-under-Lyne, make high-compression oil engines in sizes from 18 to 100 h.p. single-cylinder type, and up to 200 h.p. in double-cylinder engines. The engines are of the horizontal four-stroke cycle type. These engines start up from cold without pre-heating, and will work from crude and residual oils.

A special fuel pump and governor gear are fitted, which give efficient and silent running, and the engines fire at all loads. The fuel consumption of these engines is as low as 0·42 lb., and does not rise above 0·5 lb. at half load.

Campbell Cold Starting Heavy Oil Engines.

The 'heavy-oil' engines made by the Campbell Gas Engine Co. Ltd., of Halifax, Yorks, work on the four-stroke cycle with a compression pressure of about 300 lbs. per sq. in.

Air only is taken into the cylinder and compressed by the piston. The fuel is injected at about the end of the compression stroke, so that pre-ignition is rendered practically impossible. The fuel is injected by a cam-operated ram pump through a mechanical atomiser which delivers the fuel into the combustion chamber in the form of an extremely fine spray or mist. The speed of the engine is governed by increasing or diminishing the stroke of the fuel pump and thus the quantity of fuel injected in each cycle; there is no by-pass on the fuel pump. This system provides a working impulse in every cycle at all loads, thus ensuring minimum speed fluctuation and approximate equalisation of the working stresses in consecutive cycles.

By a recent improvement the heating lamp can be dispensed with entirely and the engine started up immediately from cold. The cold-starting system is now the standard for all except small engines, but it can be applied to the latter if required.

In the Campbell heavy-oil engine water drip or injection to the cylinder is not required under any conditions, and no provision is made on the engine for using it.

It is claimed that any kind of crude or residual petroleum may be used, even if it contains asphalt or bitumen. Tar oil (distilled from coal, specific gravity 1·05) can also be used.

The Campbell Co. state that the consumption varies with the size of engine and heat value of the fuel. When using residual petroleum of about 18,000 B.Th.U. per lb., the consumption varies from 0·55 lb. per b.h.p. per hour in an engine of 9 b.h.p. to about 0·43 lb. in one of 100 b.h.p. A test was recently conducted on an engine of 35 maximum b.h.p. extending over a fortnight,

running not less than 12 hours per day, including runs of 24 and of 30 consecutive hours, an finishing with a non-stop run for seven days and nights. This last run consisted of 72 hour consecutively at full load, 24 hours each at $\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ load with a two hours' interval each da at loads varying from zero to maximum, and concluding with 24 hours at full load.

The fuel used during this trial was Mexican fuel oil of 0·96 sp. gr. containing about 3·2 pe cent. of asphalt and having a viscosity of 1,500 sec. as tested in a No. 1 Redwood viscomete The whole of the fuel used was weighed, and the consumption was found to be :—

At full load	. . . . .	0·49 lb. per b.h.p. per hour	
,, $\frac{3}{4}$,,	. . . . .	0·485 ,,	,,
,, $\frac{1}{2}$,,	. . . . .	0·515 ,,	,,
,, $\frac{1}{4}$,,	. . . . .	0·656 ,,	,,

The test was carried out by independent engineers, and during the whole of the time r adjustment of any kind was made to any part of the engine.

The Campbell heavy-oil engine is built in a range of standard sizes from 3½ to 100 max. b.h.p single cylinder, 120 to 340 b.h.p. in two cylinders, and 240 to 680 b.h.p. in four cylinders. It also built in the vertical type with three or four cylinders, from 48 to 630 b.h.p., the larger siz being fitted with crossheads and slipper guides. The makers claim that this engine possess all the advantages of the Diesel engine, while it is simpler in construction, easier to handle, ar lower both in first cost and in running and maintenance.

Blackstone Oil Engines.

Messrs. Blackstone & Co., Ltd., of Stamford, make cold-starting heavy fuel oil engines in siz from 6 to 900 b.h.p., and their patent system of spring injection enables the engines to start fro cold without preheating and work with great economy.

Fig. 29 shows a sectional view of the combustion chamber and the spring injection system. T fuel is injected at the same point at all loads and the combustion period is prolonged so that the is no great rise in initial pressure at the moment of injection. The fuel consumption on the larg engines is only 0·4 lb. per b.h.p. per hour.

The fuel-injection arrangement consists of a low-pressure fuel pump, a moderate-pressure fu injector, consisting of two members with a spiral spring between, and a spring-loaded fuel injecti

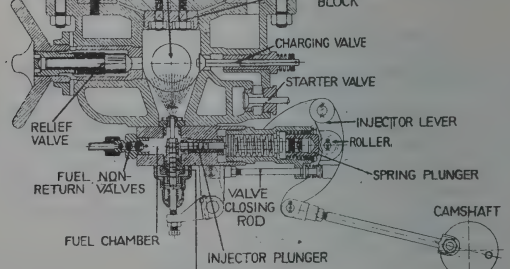


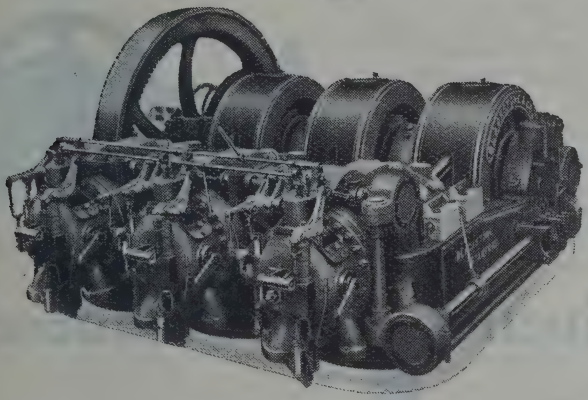
Fig. 29.

valve. The correct quantity of fuel is delivered by the pump and displaces the injector plung outwards, there being no pressure on this at the moment. The injector lever next compresses t spring, and the injector plunger is held by abutting upon the fuel retained by the injector val which is held on its seating by the compression of an auxiliary spring. This spring is released the timed operation of the injector lever, so allowing the fuel which is under pressure of 1,000 l per sq. in. to open the injector valve. The injector plunger is then forced inwards and injects t fuel through the valve jet orifice into the combustion chamber.

"BLACKSTONE"

SPRING - INJECTION

Oil Engines



These engines are to be found in all parts of the world supplying power for varying requirements — driving pumps for water supplies, drainage, sanitation — operating aerial ropeways—producing electricity for supply companies—providing power direct or electric power and light for large or small workshops, factories, mills, farms, estates, plantations, etc. The fuel consumption per B.H.P. hour is the lowest recorded in this type of engine. This is due to more perfect combustion, and results in a maximum power output, thus providing the power user with

The Most Economical Power

obtainable commercially.

STATIONARY UNITS	PORTABLE UNITS
6 B.H.P. to 900 B.H.P.	6 B.H.P. to 45 B.H.P.

For further particulars write for Catalogue Y.B. 406.

Blackstone & Co., Ltd., Stamford

ENGLAND.

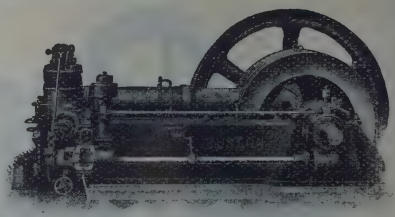
F. 1968

RUSTON

Horizontal Oil Engines

The Best by Test.

Starts from cold under all conditions, has low guaranteed fuel consumption, and works on lowest grade fuel oils.
Made in sizes up to 340 B.H.P.



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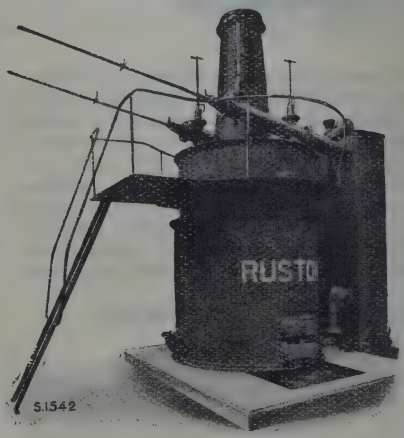


Will produce power, light and heat from waste such as wood chippings, sawdust, plumstones, bark, coconut shells, cotton seeds and any combustible refuse.

Write for Booklet.

Ruston & Hornsby Ltd.,
Engineers - - Lincoln

Paxman Oil Engines.

Cold-starting high-compression heavy fuel oil engines are made by Messrs. Davey-Paxman & Co., Ltd., Colchester, in single, two, three, four, five and six cylinder units, ranging from 25 to 900 b.h.p. at speeds of 360 to 250 r.p.m.

The engines work on the four-stroke cycle with 380 lbs. compression and a maximum pressure in the cylinder of about 550 lbs. Each cylinder stand is a separate casting bolted to the bed, and has a removable liner. The cylinder head is fitted with inlet valve, exhaust valve, and spring injection fuel valve. The crankshaft bearings are ring lubricated, and a mechanically operated lubricator is fitted for the piston and connecting-rod bearings.

The valve gear is their patented eccentric-driven type, which gives a very smooth action to the valves and in a large measure is responsible for the absence of shock and the quiet running of the Paxman engine.

LOW-COMPRESSION OIL ENGINES.

The early oil engines were all low-compression engines, and the desire to use the heavier grades of petroleum, which are cheaper than the more refined grades, caused the development of higher pressures, so that the increased temperature could completely vaporise the heavier fuels.

The low-compression oil engines still have, and will always continue to have, a wide application, owing to the low working pressures and small cost.

In the normal 'oil engine' a heavy kerosene is usually employed as fuel; Russian oil is, in general, rather preferred, though the ordinary American brands are also used with quite satisfactory results. A standardised oil described as R.V.O. (Russian vaporising oil) of specific gravity 0·825 and flash point 86° F. (close test) is regarded as the normal fuel for these engines; other descriptions commonly used, however, include Rocklight, Russolene, Homelight, Gladiator, Phœbus, Silver Spray, Crown Diamond, Royal Daylight, White Rose, Tea Rose, and Bear Greek. Among the heavier fuels used are refined shale-oils as Broxburn and Scotch Lighthouse, and also the refined heavy oils of Burma, Assam, Roumania, etc.

The average composition of the petroleum oils used is 85½ per cent. carbon, 13½ per cent. hydrogen, and 1 per cent. oxygen, and the mean calorific value, by Berthelot calorimeter, is roundly 19,600 B.Th.U. per lb. When arranged to use either petrol, kerosene, or heavier oils, engines usually develop powers in the proportion of about 100 : 90 : 80, respectively.

It should be carefully noted that the nominal power of internal combustion engines in general is for location at sea-level; when required to work at an altitude a deduction from the nominal power should be made of 3 per cent. for each 1,000 ft. of height, due to the diminished density of the air (see table, p. 2024).

In the ordinary oil engine the heavy kerosene fuel is vaporised in a heated chamber maintained at the necessary temperature either by heat derived from the successive explosions (hot-bulb vaporisers), or from the exhaust of the engine; or, lastly, in a few cases, by means of a separate blow-lamp. In most cases a preliminary heating of the vaporiser by a blow-lamp is necessary for 10 to 15 minutes before the engine can be started. These engines are practically all of the single-acting four-stroke type, and compress a mixture of kerosene vapour and air into the combustion chamber.

Ignition of the charge is sometimes automatic; high and low tension magneto ignition is also used, while in cases where lamp-heated vaporisers are adopted tube ignition is general. On account of the care and attention necessary where lamps are used, and also in some cases due to increased fire risks, makers are in general favouring one or other of the methods of lampless ignition.

Ruston-Hornsby Oil Engines.

This widely known engine, invented by Mr. Akroyd Stuart, 1886-1890, first successfully adopted the now largely used 'hot-bulb' in order to vaporise the oil fuel and automatically explode the charge at the proper instant. A sectional view is given in fig. 30 of a present design by Messrs. Ruston & Hornsby, Ltd.; the hot-bulb is seen as an unjacketed, or partly jacketed extension of the combustion chamber, the connection being by a narrow passage as shown; this hot-bulb receives a preliminary heating by a blow-lamp for 10 to 15 minutes and the engine is then turned by hand. On the suction stroke the piston draws a charge of air only into the combustion chamber and cylinder while at the same time a few drops of air are injected by the fuel pump into the hot-bulb and there vaporised; on the compression stroke the air is packed into the combustion chamber and hot-bulb and mingles therein with the heavy petroleum vapour; the mixture is at first too rich to explode, but as the compression proceeds it becomes more and more dilute, and the capacities are so adjusted that just as the piston reaches the end of its stroke the heat of the walls of the hot-bulb automatically explodes the charge. The working stroke next follows and is succeeded by the exhaust; the cycle then recurs.

The temperature of the hot-bulb is maintained by the heat derived from the successi explosions and the ignition is entirely automatic. The engine is thus of the single-acting fou stroke type.

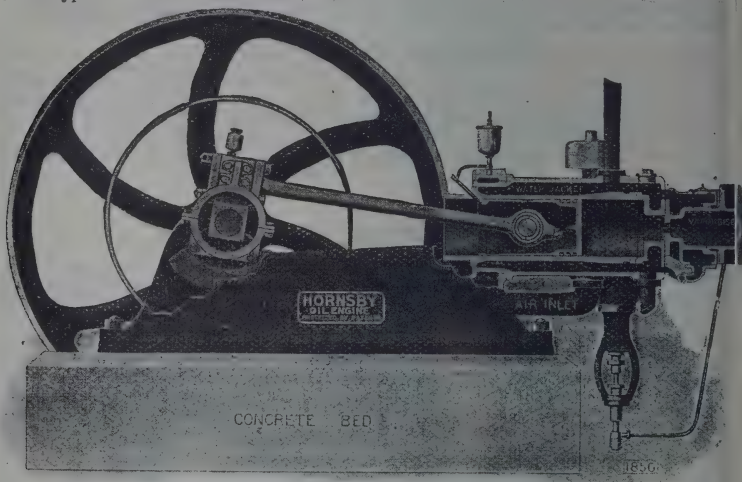


FIG. 30.—The Ruston-Hornsby Oil Engine.

A test by Professor W. Robinson in 1908, of a single-cylinder 32 b.h.p. Hornsby engine, usi 'Russolene' as fuel, furnished the following results:

Duration of trial	1 hour	Brake horse-power	32
Compression pressure, lbs. per sq. in.	85	Total oil burned, lbs.	19·6
Explosion pressure, lbs. per sq. in.	260	Lbs. oil per b.h.p. hour	0·6
Revolutions per minute, mean	230·2	Brake thermal efficiency, per cent.	22·6

BLACKSTONE OIL ENGINES.

When starting these engines the vaporiser and the igniter are heated by a lamp in from four six minutes. The flywheel is then turned forward by hand (unless a self-starter is used) to obta the first explosion, after which the engine works automatically, the necessary heat for the vaporis and for ignition being maintained by the successive explosions; a continuous burning lamp therefore dispensed with. A timing or ignition valve is used to regulate the period of ignitio During compression this valve cuts off all heated parts, and the utmost regularity of the explosio under all loads is secured. A patented water drip valve is fitted to enable a small quantity of wat to be admitted to the vaporiser to regulate its heat on long, continuous, heavy loads. As long there is oil in the tank the engine continues to work.

The engine is governed by means of our patent direct-acting shaft governor, which contr the vapour valve—this system having been found to give the most economical and efficient resul It regulates the oil consumption to the power given off. The speed may easily and instantly regulated whilst the engine is running.

Any ordinary lamp oil may be used, but the efficiency of the engine depends upon the qualit

BLACKSTONE 'COLD-STARTING' KEROSENE ENGINE.

This engine (which has magneto ignition) is specially suitable for small electric-lighting uni It works on the following cycle: On the suction or forward stroke, the cylinder is filled with pu air, which is drawn in through the air valve and compressed during the return stroke into the co bustion chamber; during the last quarter of return stroke a charge of oil is forced by the fuel pun through the oil jets and broken up into fine mist by a blast of compressed air which blows it throu the bunsen port directly into the centre of combustion space. This air blast also induces a flo of air from the combustion chamber through circulating ports, thus forming a rich combustib mixture surrounded by excess air, which is fired by an electric spark from the sparking pl

situated so as to ignite the tail end of the mixture. The working or expansion stroke is thus produced, at the end of which the exhaust valve opens and allows exhaust products to be driven out of the cylinder on return stroke of piston, after which the whole cycle is repeated. As each charge of fuel is measured directly from the sensitive graduating governor great economy and low speed, variation is assured, and speed can be instantly regulated by hand whilst the engine is running. The engine can be started instantly from cold, on paraffin without petrol, lamp, or other external heat for the A size and upwards, but the V to O are hand-started and require an egg-cup full of petrol to give the first few impulses.

National Oil Engines.

Oil engines of the horizontal four-stroke cycle type are made by the National Gas Engine Co., Ltd., Ashton-under-Lyne, in sizes from 2½ to 47½ b.h.p. These engines are made in two types: (*a*) the petrol-paraffin engines, which start on petrol and then run on paraffin, and are fitted with electric ignition, and (*b*) the hot-bulb engines, a special feature of which is the vaporiser and ignition timing device, which secures effective vaporisation of the oil and the proper timing of the ignition at all loads. A lamp must be used for starting on the hot-bulb engines, and the vaporiser needs to be heated for about ten minutes to make it hot enough to start the engine.

The engines are supplied both stationary and portable, and are suitable for agricultural and industrial work.

Hamworthy Oil Engines.

Hamworthy oil engines are made in eight sizes—2½, 3½, 6, 9, 11, 15, 20, and 25 b.h.p.—and are manufactured on strictly repetition lines by the Hamworthy Engineering Co., Poole.

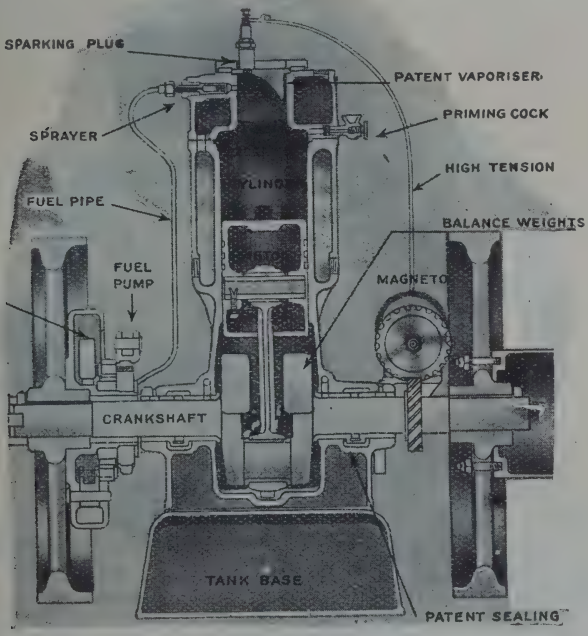


Fig. 31.—The Hamworthy Oil Engine.

These engines are supplied stationary, semi-portable, or portable. They are exceptionally reliable, and are suitable for any purpose requiring power.

Fig. 31 shows the extreme simplicity of these engines; they are stated to be most economical, the full load fuel consumption being only 0·44 pint per b.h.p. hour in the larger sizes.

Magneto ignition is fitted on sizes 2½ to 9 b.h.p., and the engines can be started up immediately by one turn of the crankshaft on petrol, then changed over to paraffin fuel. The larger sizes work on any residual fuel oils up to 0·95 sp. gr. and are now made in multi-cylinder sizes up to 150 b.h.p.

Robson Oil Engines.

Horizontal oil engines of the four-stroke cycle type from 9 to 75 b.h.p. are manufactured by John Robson Ltd., Shipley.

The engines are suitable for using paraffin and light crude oils. A separate cylinder liner is fitted and the bed is well supported on the foundation, the bed and cylinder jacket being in one casting.

The combustion chamber is a separate casting bolted to the bed, and the valves are arranged vertically, so that they are easily accessible. The governor is of the centrifugal type and regulates the amount of fuel injected into the combustion chamber.

Petter Oil Engines.

Engines of the two-stroke vertical type have been manufactured by Messrs. Petters, Ltd., of Yeovil, for many years, and the company have supplied over 25,000 oil engines. The small sizes are the well-known Petter 'M' type engines, suitable for farm, estate, and factory machinery, electric lighting, pumping, and other purposes.

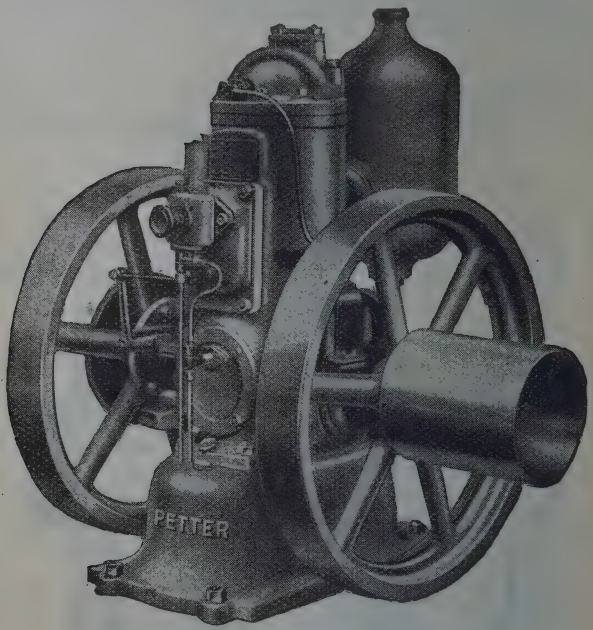


Fig. 32.—The Petter 'M' type Oil Engine.

The Petter 'M' type engines are made in three sizes: 1½, 3, and 5 b.h.p.; and in three patterns: stationary, for fixing on concrete (as illustrated), semi-portable on wood skids, and portable on four-wheeled carriage.

These engines work on paraffin and have magneto ignition. They are started on a small quantity of petrol, and change over automatically to paraffin after working for a few minutes. By means of the patent fuel injector, the paraffin is vaporised and burnt with the same completeness as in a petrol engine, and at half the cost of fuel.

A STATEMENT OF FACT

PROMISES v. REALITY

Electricity for power can rarely be bought for less than **1d.** a unit.

Generated by a

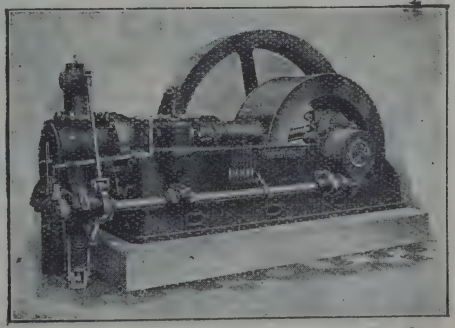
BROTHERHOOD HEAVY OIL ENGINE

of 130 H.P., working at $\frac{3}{4}$ full load 3,000 hours a year and making full allowance for fuel, interest, depreciation, wages and stores, the cost is $\frac{5}{8}$d. a unit—

Saving £280 a year, or 37½%

Will the advent of the Super Power Station achieve this?

PETER BROTHERHOOD Ltd.
PETERBOROUGH



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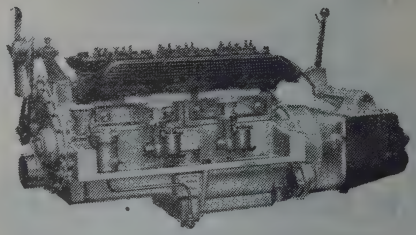

6 J.U.L. SIX-CYLIDER ENGINE, 37/80 B.H.P., WITH GEARBOX.

SPECIFY "DORMAN"
and Solve your Engine Problem.

W. H. DORMAN & CO. LTD.

Internal Combustion Engine Specialists,
STAFFORD.

Telephone: 121 STAFFORD. *Code:* BENTLEY'S. *Telegrams:* DORMAN, STAFFORD.

The Dorman Engine.

Messrs. W. H. Dorman & Co., Ltd., Stafford, manufacture two, four, and six-cylinder engines in various sizes developing 8 to 100 b.h.p. at 1,000 r.p.m., as shown in the following table:

No. of Cylinders.	Bore m/m.	Stroke m/m.	Volume c.c.	B.H.P. 1000 r.p.m.	Treasury Rating.
4	66	100	1368	8	10·5
4	69	100	1496	10	11·8
4	80	130	2613	19	15·9
2	120	140	3166	20	17·8
4	95	140	3970	25	22·4
4	100	140	4398	30	24·8
6	95	140	5954	44	33·6
6	100	140	6597	48	37·2
4	120	140	6333	45	35·7
4	120	185	8369	72	35·7
6	120	185	12553	100	53·6

The cylinders are monobloc except on the 100 h.p. six-cylinder engine, where they are cast in two pairs of three each, and on the 45 h.p. engine, where the cylinders are cast in two pairs. The larger sizes are fitted with detachable heads of the Ricardo patent turbulent type. Side-by-side valves have been adopted, owing to their silence in operation, and the inlet valves are 3 per cent. nickel steel, while the exhaust valves are of stainless steel.

These engines are specially designed to meet the demand for increased passenger and weight carrying capacities of vehicles, and the increasing use of internal combustion engines for locomotives and rail cars.

Other Makers of Oil Engines.

Engines of the horizontal four-stroke type are also made by Crossley Bros., Ltd., Manchester; Fielding & Platt, Gloucester; and Tangyes Ltd., Birmingham.

Vertical engines are made by Gardner & Sons, Patricroft; the Parsons Engine Co., Southampton; J. I. Thornycroft & Co., Basingstoke; the New Pelapone Co., Leeds; and Lister & Co., Dursley.

INTERNAL COMBUSTION TURBINES.*

(Contributed by T. B. Morley, D.Sc., M.I.Mech.E.)

The heat engine which has the highest thermal efficiency is an internal combustion engine; the one which can be made in units of maximum power and which, moreover, has many attractive features, such as almost perfect balance due to its purely rotary motion, and small bulk in relation to output, is the steam turbine. It is not to be wondered at, therefore, that engineers have reflected upon the desirability of a prime mover which should combine the merits of both these types. The internal combustion turbine has been the dream of many speculative and inventive minds, but, though many hundreds of patents have been taken out for internal combustion turbines, few have yet been constructed, and none has so far passed the experimental stage.

It is evident, therefore, that there are serious difficulties to be overcome in order to produce a successful internal combustion turbine.

Speaking generally, in all internal combustion turbines, fuel, gaseous or liquid, is burned, and the products of combustion, issuing from the combustion chamber through nozzles at high velocity, impinge upon the blades of a turbine rotor. In comparison with the cycle of a reciprocating engine, the chief difference is that, whereas in that engine the expanding gases do work upon a piston, in the turbine the energy of the gases takes the form of kinetic energy, which is represented in the acquisition of velocity by the jets of gases which are led to the turbine blading.

The combustion, as in the case of the reciprocating engine, may be at constant pressure or at constant volume, or at a combination of the two conditions. If it is at constant pressure, in order to obtain a cycle of reasonable ideal efficiency, the working substance must be compressed before

* See also 'The Internal Combustion Turbine,' by T. B. Morley, *Proc. Manchester Association of Engineers*, February 1925.

ignition or else the products of combustion must be expanded below atmospheric pressure by a exhauster. In either case, a pump or an exhauster is necessary, and it is the large amount o work necessarily absorbed in this stage of the cycle—relatively much greater than in the corre sponding stage of a steam turbine cycle, *viz.* the compression in the air pump and feed pump— which is one of the serious obstacles to the success of this type of internal combustion turbine.

If, as is desirable for a large unit, the compression or exhauster is of the turbo type, its rela tively low efficiency compared with a piston compressor greatly accentuates this drawback.

This particular difficulty may be almost entirely avoided by the adoption of a cycle in whic the combustion is at constant volume. In this case, however, it is not possible to produce steady continuous jet; the action of each combustion chamber must necessarily be intermittent the jets of gas issue at varying velocity, and the blading angles and blade speeds cannot satisf the conditions for maximum efficiency as they cannot vary in accordance with the varying je velocities. The loss of efficiency due to this is not, however, of very great magnitude.

The most serious difficulty in the production of a reliable internal combustion turbine is practical one. In all cases the temperature of the jet of gas striking the blading must be very hig in order that the cycle may be efficient; the blading and the rotor must, therefore, be made o materials capable of withstanding temperatures say up to 800° C., at least, without scaling or los of form, and without undue reduction of strength, as the blades and rotor must run at high spee and are, therefore, subject to considerable centrifugal stresses as well as to the tangential drivin effort.

The combustion chamber and nozzles are exposed to still higher temperatures, but as they ar stationary and not so severely stressed, nor so delicate in form, the problem of suitable materia for them is not so acute.

In order to reduce the temperature of the jet the gases resulting from the combustion of th fuel may be diluted, with steam for example, before they enter the expansion nozzles leadin them to the blading. Interesting types of mixed-fluid internal combustion turbines, *i.e.* turbine in which the working substance is a mixture of gas and steam, are described in Davey's 'The Ga Turbine' (*Constable & Co.*, 1914), but though certain of the turbines proposed, in which the steam is generated partly from the heat of the turbine exhaust and partly from the heat passing throug the walls of the combustion chamber, and in which the cycle is carried out at pressures belo atmospheric, offer good prospects of success, no actual turbine on these principles has been mad

For a description of experimental machines made before 1914, Davey's book may be referred t

The type of internal combustion turbine which has most nearly approached practical succes is that designed by Herr Holzwarth, and constructed by Messrs. Thyssen, in Germany. Th turbine is of the constant volume type. A series of combustion chambers are arranged sym metrically round the shaft, which in the later constructions is horizontal. Gas (or oil) and air a about 20 lbs. per sq. inch abs. pressure are admitted through separate inlet valves; the passag leading from the combustion chamber to the nozzle is closed during the charging operation by nozzle valve. After the introduction of the charge, all valves are closed, and the charge is ignite When the pressure has in consequence reached a certain amount it overcomes the spring whic holds the nozzle valve shut, the nozzle valve opens and is then held open. The gases pass to th nozzle, expand, and acquire velocity in the nozzle and impinge on the blades. When the pressu in the chamber has fallen sufficiently, scavenging air is passed through it, and then the cycle repeated. Similar cycles take place in the other combustion chambers. Several Holzwart turbines have been built and run on gas or on oil fuel, and test results on units in sizes up t 1,000 h.p. have been published: machines up to 5,000 k.w. capacity have been built. Unfo tunately the earlier published results were incomplete and open to severe criticism. Tests mad in 1923 on a 1,700 k.w. unit showed an overall thermal efficiency (based on output at switchboar of 14·2 per cent. Though Holzwarth turbines have been built from 1908 onwards, and orde were placed in 1919 by the Prussian State Railways, none seems as yet to have been in regul service.

Several other forms of internal combustion turbines are being experimented upon in German U.S.A., and England.

Combinations of reciprocating engine and turbine, the turbine being driven by the exhau gases from the reciprocating engine, offer good prospects of success. The Rateau exhaust turbi for supercharging aero-engines is one example of this combination.

As regards the internal combustion turbine, considered as a prime mover by itself and not a an adjunct to a reciprocating engine, the prospects of success in the near future are very doubtfu unless the metallurgist can provide a material which will withstand the very high temperatur called for in the blading.

Lloyd's Rules for Marine Internal-Combustion Engines.

The following rules for the survey of internal combustion engines for marine purposes have en drawn up by Lloyd's Register of British and Foreign Shipping :—

General.

Section 1.—In vessels propelled by internal combustion engines the rules as regards machinery ll be the same as those relating to steam-engines so far as regards the testing of material used their construction and the fitting of sea connections, discharge pipes, shafting, stern tubes, d propellers.

Construction.

Section 2.—1. The following points should be observed in connection with the design of the gines :—

2. The shaft bearings, connecting-rod brasses, the valve gear, the inlet and exhaust valves ust be easily accessible.

3. The reversing gear and clutch must be strongly constructed, and easily accessible for amination and adjustment.

4. In engines of above 60 b.h.p. which are not reversible, and which are manœuvred by clutch, a governor or other arrangement must be fitted to prevent racing of the engine when clutched.

5. In vessels intended for open sea service and fitted with engines in which the lubricating oil circulated under pressure, a spare oil pump is to be supplied with all connections ready for mediate use, and two independent means are to be arranged for circulating water through the l cooler, where this is fitted.

6. When the engines are of the closed-in type they must be so fitted that the contained lubricat- g oil can be drained when necessary, and in wood vessels an easily drained metal or metal- ed tray must be fitted to prevent leakage of either fuel oil or of lubricating oil from saturating e woodwork.

7. Carburettors, where petrol is used, and vaporisers, where paraffin is used, should be so signed that when the engine is stopped the fuel supply is automatically shut off. If an over- w is provided in the carburettor or vaporiser, a gauze-covered tray with means of draining must be fitted to prevent the fuel from flowing into the bilges.

Strong metallic gauze diaphragms should be fitted either between the carburettor (or vapor- r) and cylinders or at the air inlets.

8. If the ignition is electric, either by magneto or by coil and accumulator, all electric leads ust be well insulated and suitably protected from mechanical injury. The leads should be pt remote from petrol pipes, and should not be placed where they may be brought into ntact with oil.

The commutator must be enclosed, and the sparking coils must not be placed where they n be exposed to explosive vapour.

9. In paraffin and heavy-oil engines, where lamps are used for ignition or for vaporising, ese lamps should be fixed by some suitable bracket, and the flame enclosed when in use.

10. The circulating pump sea suction is to have a cock or valve on the vessel's skin placed on e turn of the bilge in an easily accessible position, and the circulating pipe is to be provided with efficient strainer which can be cleared inside the vessel. The discharge overboard is to be ted with a cock or valve on the vessel's skin if it is situated under or near the load line of the ssel.

11. The pumping arrangements are to be the same as would be required in the case of a steam ssel of the same size and power, with the exception that no bilge suction need be fitted to the culating pump. In the cases of vessels fitted with water ballast, the water ballast pump must ve, in addition, one direct suction from the engine-room bilges.

In open launches, and in small sailing vessels in which the engines are auxiliary only, a suitable ditional hand pump, fitted to draw from the engine-room bilges, may be accepted in lieu of a wer-driven pump.

12. Where the cylinder liners are made of hard, close-grained cast iron of plain cylindrical form, curately turned on the outside as well as bored on the inside, so that their soundness can be certained by inspection, they need not be hydraulically tested by internal pressure. If, however, ey are made of complicated form, the question of testing must be submitted.

13. The water jackets of the cylinders, and the water passages of the cylinder covers and stons must be tested by hydraulic pressure to 30 lbs. per sq. in. and must be perfectly tight at at pressure.

14. The exhaust pipes and silencer are to be efficiently water-cooled or lagged to prevent mage by heat, and if the exhaust is led overboard near the water-line, means must be arranged prevent water from being syphoned back to the engine.

15. The machinery must be tried under full working conditions, the report stating the approxi- ate speed of vessel, the number of revolutions of the engines at full power, both ahead and tern, and the lowest number of revolutions of the engines which can be maintained for anœuvring purposes.

Rules for Determining Sizes of Shafts.

Section 3.—1. The diameter of the crank shaft must not be less than that given by the following formula :—

$$\text{Diameter of crank shaft} = \sqrt[3]{D^2 \times (A\,S + B\,L)}$$

where D = diameter of cylinder in inches or millimetres,
S = length of stroke in inches or millimetres,
L = span of bearing adjacent to a crank measured from centre t centre in inches or millimetres.

The values of A S + B L are as given in the following tables :—

TABLE I.—FOR PETROL OR PARAFFIN OIL ENGINES.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	For Smooth Water Service Values of A S + B L	For Open Sea Service Values of A S + B L
1, 2, 3, or 4 Cylinders	1 or 2 Cylinders	0·0308 S + 0·0143 L	0·0342 S + 0·0159 L
6 ,,	3 ,,	0·0310 S + 0·0143 L	0·0344 S + 0·0159 L
8 ,,	4 ,,	0·0351 S + 0·0136 L	0·0389 S + 0·0151 L
12 ,,	6 ,,	0·0474 S + 0·0120 L	0·0526 S + 0·0133 L

The above table applies to engines in which there are bearings adjacent to each side of eac crank. If there are two cranks between consecutive bearings the same rules will apply, but L wi be the span between the centres of the bearings adjacent to the two cranks.

TABLE II.—FOR HEAVY OIL ENGINES IN WHICH THE MAXIMUM PRESSURE IN THE CYLINDERS IS 200 LBS. PER SQUARE INCH.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of A S + B L
1 up to 8 Cylinders	1 up to 4 Cylinders	0·0298 S + 0·0144 L
12 ,,	6 ,,	0·0376 S + 0·0118 L

TABLE III.—FOR HEAVY OIL ENGINES IN WHICH THE MAXIMUM PRESSURE IN THE CYLINDERS IS 550 LBS. PER SQUARE INCH.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of A S + B L
1, 2, 3, or 4 Cylinders	1 or 2 Cylinders	0·0643 S + 0·0340 L
6 ,,	3 ,,	0·0673 S + 0·0347 L
8 ,,	4 ,,	0·0643 S + 0·0340 L
12 ,,	6 ,,	0·0673 S + 0·0347 L

2. For heavy oil engines in which the maximum pressure in the cylinders is intermedia between 200 and 300 lbs. per sq. in., or between 300 and 450 lbs. per sq. in., or between 450 an 550 lbs. per sq. in., the coefficients A S + B L are to be interpolated between those given in th above tables.

3. For auxiliary engines of the above-mentioned types the diameters of the crank shafts ma be 5 per cent. less than given by the foregoing formulæ applying to main engines for open se service.

4. In solid forged shafts the breadth of the webs should be not less than 1·33, and the thick ness not less than 0·56 times the diameter of the shaft as found above, or if these proportions a departed from, the webs must be of equivalent strength.

5. The diameter of the intermediate shaft must not be less than that given by the followi formula :—

$$\text{Diameter of intermediate shaft} = C \times \sqrt[3]{D^2 \times S}$$

where D = diameter of cylinder ;
S = stroke of piston;

the values of C being those given in the tables, p. 1977.

TABLE VI.—FOR PETROL OR PARAFFIN OIL ENGINES.

FOR SMOOTH WATER SERVICE.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of the Coefficient C where A = 0·0025.	A = 0·0050.	A = 0·0100.
2 Cylinders	1 Cylinder	0·240	0·250	0·256
3 ,,	—	0·255	0·264	0·270
4 ,,	2 ,,	0·272	0·277	0·282
6 ,,	3 ,,	0·298	0·301	0·304
8 ,,	4 ,,	0·322	0·324	0·325
12 ,,	6 ,,	0·363	0·364	0·365

FOR OPEN SEA SERVICE.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of the Coefficient C where A = 0·0025	A = 0·0050	A = 0·0100
2 Cylinders	1 Cylinder	0·252	0·262	0·269
3 ,,	—	0·269	0·276	0·283
4 ,,	2 ,,	0·286	0·291	0·296
6 ,,	3 ,,	0·313	0·316	0·319
8 ,,	4 ,,	0·338	0·340	0·341
12 ,,	6 ,,	0·382	0·382	0·383

TABLE VII.—FOR HEAVY OIL ENGINES IN WHICH THE MAXIMUM PRESSURE IS 200 LBS. PER SQUARE INCH.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of the Coefficient C where A = 0·0025.	A = 0·0050.	A = 0·0100.
2 Cylinders	1 Cylinder	0·210	0·220	0·240
3 ,,	—	0·225	0·234	0·252
4 ,,	2 ,,	0·239	0·248	0·263
6 ,,	3 ,,	0·268	0·272	0·284
8 ,,	4 ,,	0·289	0·290	0·298
12 ,,	6 ,,	0·334	0·335	0·338

TABLE X.—FOR HEAVY OIL ENGINES IN WHICH THE MAXIMUM PRESSURE IS 550 LBS. PER SQUARE INCH.

4-Cycle Single-Acting Engines.	2-Cycle Single-Acting Engines.	Values of the Coefficient C where A = 0·0025	A = 0·0050	A = 0·0100
2 Cylinders	1 Cylinder	0·230	0·255	0·305
3 ,,	—	0·245	0·268	0·309
4 ,,	2 ,,	0·260	0·280	0·312
6 ,,	3 ,,	0·283	0·296	0·318
8 ,,	4 ,,	0·310	0·316	0·323
12 ,,	6 ,,	0·360	0·364	0·368

In using the foregoing tables the appropriate value of A is found from

$$A \times W \times d^3 \times R^2 = D^2 \times S$$

where D = diameter of cylinder in inches;
S = stroke of piston in inches;
d = diameter of flywheel in feet;
R = revolutions of engines per minute;
W = total weight of flywheel in tons.

6. If a separate flywheel shaft is fitted its diameter must be at least equal to that of the crank shaft.

7. Where ordinary deep collars are used the diameter of the thrust shaft measured under the collars must be at least $\frac{2}{3}\frac{1}{0}$ths of that of the intermediate shaft. The diameter may be tapered off at each end to the same size as that of the intermediate shaft.

8. The diameter of the screw shaft must not be less than the diameter of the intermediate shaft (found as above) multiplied by $\left(0{\cdot}63 + \frac{0{\cdot}03\ P}{T}\right)$, but in no case must it be less than 1·07 T

where

P = the diameter of the propeller in inches or millimetres,
T = the diameter of the intermediate shaft in inches or millimetres.

This size of screw shaft is intended to apply to shafts fitted with continuous liners the whole length of the stern tube, as provided for in Section 11, Clause 3 (Rules for Engines and Boilers of Steam Vessels). If no liners are used, or if two separate liners are used, the diameter of the shaft should be $\frac{2}{3}\frac{1}{0}$ths that given above.

The diameter of the screw shaft is to be tapered off at the forward end to the size of the thrust shaft.

Fuel Tanks and Connections.

Section 4.—1. All fuel tanks and their fittings are to be in accordance with Section 49 (rules for steel ships).

2. Strong and readily removable metallic gauze diaphragms should be fitted at all openings on petrol tanks.

3. No glass gauges are to be fitted to fuel tanks containing either petrol or paraffin oil.

4. Filling pipes are to be carried through the deck so that the gas displaced from the tanks has free escape to the atmosphere.

5. Separate fuel tanks should be provided with metal-lined trays to prevent any possible leakage from them flowing into the bilges or saturating woodwork. Arrangements are to be provided for emptying the tanks and draining the trays beneath them. For petrol tanks the trays must have drains leading overboard where possible, or they should be gauze-covered trays with means for draining them.

6. All petrol or paraffin oil pipes are to be of annealed seamless copper with flexible bends. Their joints are to be conical, metal to metal. A cock or valve is to be fitted at each end of the pipe conveying the fuel from the tank to the carburettor or vaporiser. The fuel pipes should be led in positions where they are protected from mechanical injury and can be exposed to view throughout their whole length.

7. The engine-room and the compartment in which the fuel tanks are situated are to be efficiently ventilated.

8. An approved fire-extinguishing apparatus must be supplied.

Periodical Surveys.

Section 5.—1. The machinery is to be submitted to survey annually. At these surveys the cylinders, pistons, connecting-rods, crank and other shafts, inlet and exhaust valves and gear, clutches, reversing gear, propeller, sea connections, and pumps are to be examined. The electric ignition is to be examined and the electric leads tested. The fuel tanks and all connections are to be examined and, if deemed necessary by the surveyor, to be tested to the same pressure as required when new. If practicable, the engines should be tested under working conditions.

2. The screw shaft is to be examined annually and drawn at intervals of not more than three years in the cases of shafts fitted with continuous liners, and of shafts fitted with approved glands, or other approved appliances, at their after ends to permit of them being efficiently lubricated. In the cases of other shafts, they should be drawn at intervals of not more than two years. (On the application of owners the Committee will be prepared to give consideration to the circumstances of any special case.)

High Compression Oil Engines.

Rules for the Construction and Survey of Diesel engines and their auxiliaries have been adopted by the General Committee of Lloyd's Register, and can be obtained on application to Registrary, 71 Fenchurch Street, London, E.C. 3.

SECTION XXXI

PART IV

HOT-AIR ENGINES.

In these the working air receives its heat from an external furnace by conduction through the walls of a metal containing vessel; such engines may thus be described as 'External Combustion Engines' to distinguish them from 'Internal Combustion Engines' wherein the air is heated by chemical combustion occurring throughout its mass. In the Stirling engine the diagram consists of two isotherms and two constant volume lines (fig. 33). The contained air is (1) compressed isothermally at (abs.) temperature T_1 from v_1 to v_2; (2) heated at constant volume v_2 to pressure p_3 and temperature T_3; (3) expanded isothermally at temperature T_3 behind the working piston from pressure p_3 and volume v_3 to pressure p_4 and volume v_1; and (4) cooled at constant volume v_1 from temperature T_3 to temperature T_1, the pressure correspondingly falling from p_4 to p_1. The useful work done is represented by the area 1, 2, 3, 4. If r denote the expansion ratio v_1/v_3 we have :—

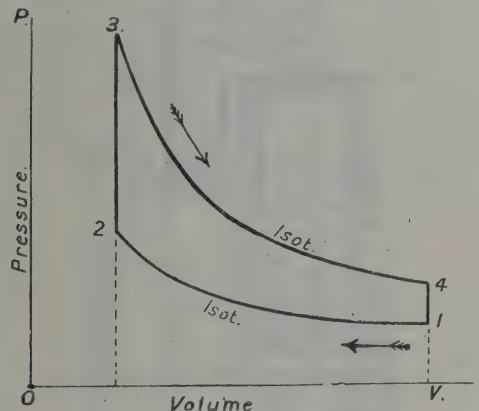

FIG. 33.

$$\text{Heat supplied} = k_v (T_3 - T_1) + c\, T_3 . \text{Log}_e\, r.$$
$$\text{Heat rejected} = k_v (T_3 - T_1) + c\, T_1 . \text{Log}_e\, r.$$

The useful work is the difference of these, viz. :—

$$(T_3 - T_1) . c . \text{Log}_e\, r .$$

And the thermal efficiency is accordingly :—

$$\frac{(T_3 - T_1) . c . \text{Log}_e\, r .}{k_v (T_3 - T_1) + c\, T_3 \text{Log}_e\, r} .$$

This has a value much less than that of the Carnot engine working between T_1 and T_3, viz. $\frac{T_3 - T_1}{T_3}$, on account of the term $k_v (T_3 - T_1)$ in the denominator. The Rev. R. Stirling, in 1827, introduced the regenerator or 'heat-filter' for storing the heat $k_v (T_3 - T_1)$ given out during the period

4, 1, fig. 33, and restoring it to the air during the period 2, 3; by this device the term $k_v (T_3 - T_$ disappears from the denominator and, if perfectly realised, the efficiency would then become equ to that of the perfect Carnot engine, viz. $\frac{T_3 - T_1}{T_3}$. The first Stirling engine (made in 1830) shown diagrammatically in fig. 34. A is a light, bulky displacer filled with brickdust, an fitting easily in its cylinder. The lower portion of the air chamber, B, is situated immediatel over the furnace C, the upper portion being kept always cool by a system of cold-wate circulating pipes W. In the annular space EE, surrounding the cylinder within which works, is a series of very thin metal plates separated by spaces of about ·02 in. width only this is the regenerator. Its upper end is constantly at about the temperature T_1, and lowe end at the temperature T_3; H is the working cylinder, and K its piston.

In the configuration shown, the displacer is at the top of its stroke, while K is at the bottor of its stroke; the contained air is thus at minimum volume and maximum temperature, and th

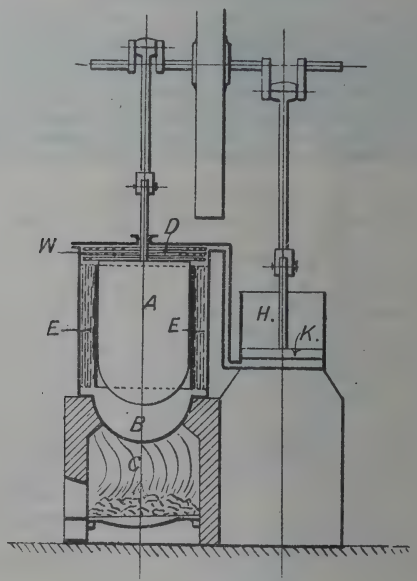

FIG. 34.—The Stirling Engine.

corresponding point on the diagram fig. 33 is 3. The piston next moves out on its working stroke, the pressure falling with expansion and heat being supplied to the working air from the furnace. At the end of the out-stroke of K, A is at the bottom of its stroke and has thus passed the working air from B, through the regenerator EE to the cooled end W of the air chamber; its temperature is now T_1, and pressure accordingly low. The air in passing from B to W through EE gives up to the plates the heat $k_v (T_3 - T_1)$ in the ideal case, and this heat is restored again to the air on its return passage through EE from W to B; by this device the economy was much improved.

It will be noted that there are no valves; the working piston is always in communication with the air chamber, and the air in the working cylinder is always at low temperature. By closing the working cylinder H at the top, and connecting it to a second air chamber and displacer the engine becomes double acting. Though theoretically interesting, the hot-air engine proved so impracticable in any but the smallest powers that it is now quite obsolete. The practical difficulties of rapidly heating a large volume of air; failure of the bottom of the air vessel B; and the great weight and bulk of these engines have combined to effect their disuse. The actual thermal efficiency realised in practice is only from 7 per cent. to 10 per cent.; the mechanical

efficiency is also, in general, low. In the following short table some trial results are given for reference :—

Air Engine.	Date.	Cyl. Bore. Ins.	Stroke. Ins.	Revs. per Min.	Horse Power.		Mechl. Eff. Per Cent.	Lbs. Fuel per Hour.	
					Indic.	Brake.		per I.H.P.	per B.H.P.
Buckett	1883	24·0	16·0	61	20·2	14·4	71	1·8	2·5
Benier	1887	13·4	13·8	117	5·8	4·0	69	3·1	3·6
Bailey	1883	14·6	6·9	106	2·4	1·3	55	4·2	7·6
Rider	1898	6·7	9·5	128	0·66	0·23	35	—	—
Ericsson	1898	8·0	3·9	101	0·23	0·06	27	—	—

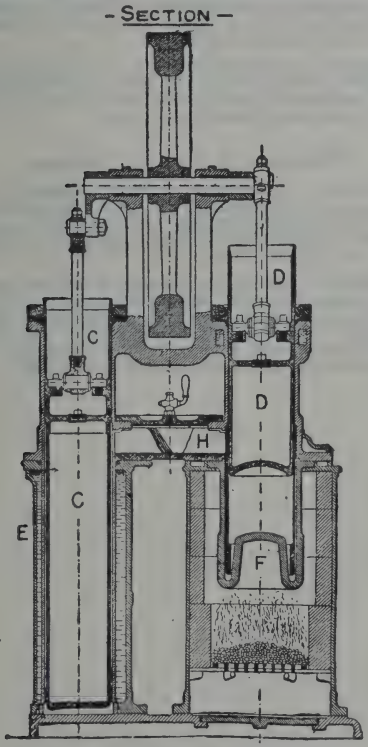

FIG. 35.—The Rider Hot-Air Engine.

Owing to their ease in working and absolute safety, small hot-air engines are still usefully employed in certain situations as, e.g., for driving fog signals on lightships and lighthouses, and for domestic purposes, as pumping, sawing, driving small tools, etc., in cases where only small power is needed.

A pattern of hot-air engine which has been much used is the 'Rider'; it includes all the features of the early Stirling engine except that the working cylinder is in communication with the hot end of the air chamber, and not the cold end as in all Stirling's designs.

In this engine (fig. 35) there are two vertical cylinders, each of which contains a piston
plunger, their strokes and diameters, however, not being equal, that in the power cylinder,
which the air is heated, being the larger. One of these (that to the left hand), lettered C,
the displacer, while that on the right, D, is the power piston. The crankshaft carries a flywhe
in the middle of its length and cranks at each end attached to C and D by connecting-rods,
shown.

The cranks are so placed that when C is at the bottom, D is slightly above the middle of i
stroke. A fire, F, is maintained below the power cylinder, while the displacer cylinder is coole
by a water jacket. The cylinders C and D are constantly in communication through the passage E
in which is contained a regenerator consisting of a number of thin wrought-iron plates place
very close together, whose function has already been explained (*supra*).

The bottom of the power cylinder is maintained at a high temperature by the fire below it
when the power piston D is at the bottom of its stroke the air beneath it, being highly heated,
at pressure and the piston accordingly moves upwards as D is of larger diameter than C. Th
accompanying descent of C transfers air from the cool displacer cylinder through the regenerat
in H—where it becomes warmed up—and delivers it by way of a pendent liner in the pow
cylinder below the rising working piston D when it becomes heated, thus increasing in pressur
and assists in driving D to the top of its stroke.

When this point is reached, the displacer plunger C is at half-stroke upwards, and the subs
quent descent of D transfers air from the power cylinder, via the regenerator, to the cooled dis
placer cylinder, the temperature and pressure consequently falling, and heat being stored up i
the regenerator to be absorbed during the next power stroke.

Efficiency of Hot-Air Engines.

In the best hot-air engines a consumption of 1·8 lb. of gas coke has yielded 1 indicate
horse-power, or 2·54 lbs. of coke per b.h.p., the h.p. being calculated after deducting the wor
required to compress the air. The absolute efficiency is therefore only about 7·9 per cent. referred t
b.h.p. In the smaller sizes of hot-air engine the consumption of fuel is usually very much highe
than this, and is often 20 lbs. or more per b.h.p. hour.

It is practically impossible to construct an air-engine of any great power, as air, like all othe
gases, expands but one volume for each 493° of temperature through which it is raised ; and, i
order to double its volume, we must raise it 493° more, that is, to 986° F., which is much to
high for practical purposes. Even if air could be worked at this temperature, it would b
necessary to have a feed-pump of nearly the capacity of the engine, and the engine itself woul
have to be more than twice the size of a steam-engine of the same power.

SECTION XXXII

AUTOMOBILES

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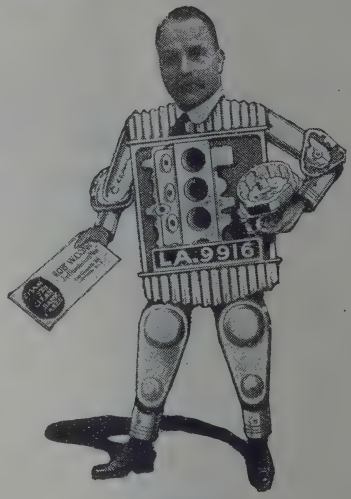

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SECTION XXXII

AUTOMOBILES.

(Contributed by Ernest W. Birch, A.M.I.A.E.)

ENGINES.

The four-stroke, single-acting, inverted type of engine is in general use.

A few years ago the average power output was 7 b.h.p. per litre of swept piston volume per 1,000 engine r.p.m.; to-day this has been raised to 9 b.h.p. and 10 b.h.p. for racing engines.

There are many factors contributing to this increased output, such as (*a*) carefully designed combustion-chambers without pockets, which allow of the cylinders being machined all-over, thus giving equal capacity and equality of explosion pressure, (*b*) improved design of induction system whereby each cylinder is correctly fed with its right proportion of properly atomised fuel, (*c*) reduction of reciprocating weights due to the use of aluminium alloys.

Other important developments are super-charging, air cooling by blower, evaporative cooling, thermostatic control of cooling system, air cleaners, special alloys for valves, pistons, etc.

The following examples of engines indicate current practice in this country and abroad.

THE MORRIS ENGINE.

(Oxford and Cowley Models.)

This make represents one of the best examples of 'continuous flow' production in this country. Details of 1928 models are as follows (fig. 1.):

THE MORRIS ENGINE.

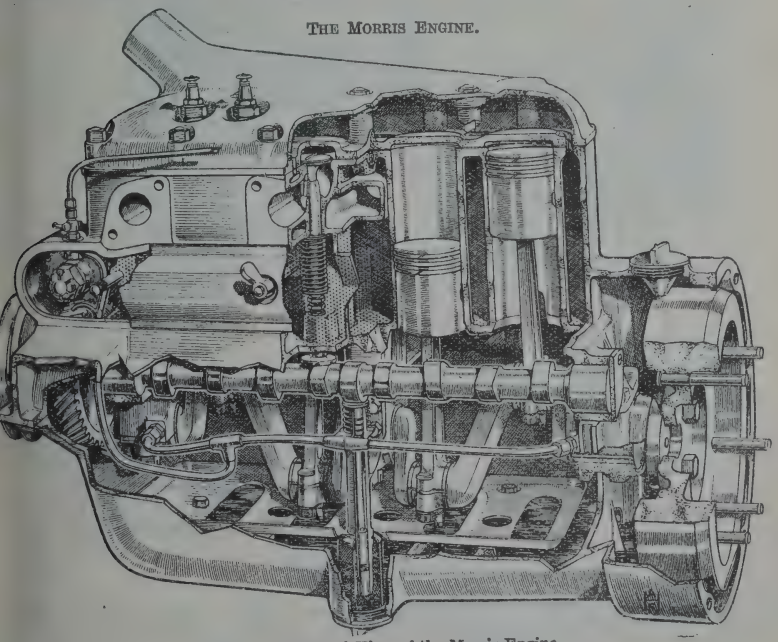


FIG. 1.—Sectional View of the Morris Engine.

Four cylinders cast in one with the upper half of the crankcase, and fitted with detachable cylinder head. The crankshaft has three white-metal bearings carried upon special bearing blocks attached to the cylinder block.

'*Cowley*' connecting rods 'I' section steel with split small end in which gudgeon pin is clamped by set screw, the gudgeon pin taking its bearing in the piston bosses. '*Oxford*' connecting rods of Duralumin, gudgeon pin fitting the same as for '*Cowley*' model. Piston in both models of aluminium with three rings, the upper one being fitted with special spring centering-ring behind it to reduce liability of piston slap. Side by side valves are used. Camshaft and magneto driven by skew-gears at forward end of crankshaft. Thermo-syphon cooling assisted by belt-driven fan. Lubrication is by plunger type oil pump driven from an eccentric in the centre of camshaft.

The '*Cowley*' engine develops 22·3 h.p. at 2,800 r.p.m. and the '*Oxford*' 30 h.p. at 2,250 r.p.m.

A new six-cylinder has been introduced rated at 17·7 h.p. with a bore of 69 mm. and stroke of 110 mm.

The engine is fitted with an overhead camshaft which operates the overhead valves. The crankshaft is carried in four main bearings, and special attention has been directed in the design of the engine to accessibility.

The Lanchester Engine.

The engine illustrated is the 21 h.p. model (fig. 2).

Six cylinders 3·1 ins. bore by 4·5 ins. stroke. Treasury rating 23·1 h.p. Swept volume 203·8 cub. ins. (3,340 c.c.). Power developed at 2,800 r.p.m. is 57 h.p., the brake m.e.p. being 79 lbs. sq. in.

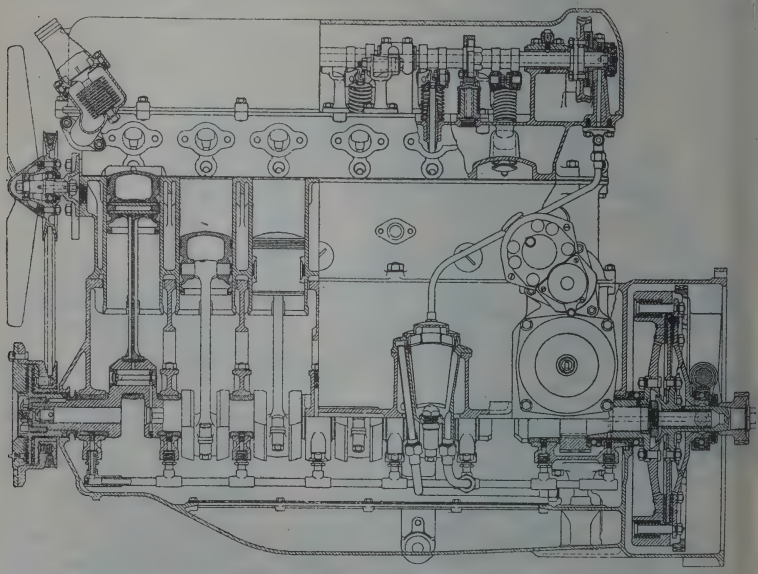


Fig. 2.—Lanchester Engine.

Cylinders cast *en bloc* with detachable head carrying the valves. *Domed* aluminium piston fitted with three light pressure rings and a scraper ring. Hollow floating gudgeon pins with end buttons to prevent scoring of cylinder.

Connecting rods 'I' section with bronze small end bushes and white metal liners for big ends. Crank pin bearings $1\frac{7}{8}$ in. diam. by $1\frac{1}{16}$ in. long. Overhead hollow central camshaft with inclined valves. Camshaft carried on five plain bearings. Damping device provided for damping torsional irregularities. Hollow crankshaft $1\frac{7}{8}$ in. diam. (except for end bearing, which is $2\frac{1}{4}$ in.) carried on seven main bearings of die-cast white metal. Front, middle, and rear bearings $1\frac{7}{8}$ in. long, intermediate journals, $1\frac{3}{8}$ in. long.

Beyond the crankcase proper there is an extension enclosing a vertical shaft and a cross shaft with the gears for driving the overhead camshaft and auxiliaries. An eighth bearing $2\frac{1}{4}$ ins. diam. by $1\frac{3}{8}$ in. long, with white-metal-lined bronze shell, takes the weight of the flywheel.

Daimler Double Sleeve Valve Engine.

This engine operates on the four-stroke, single-acting cycle, but the poppet valves are replaced by cylindrical sliding valves. The piston is enveloped by two open-ended shells which are in turn

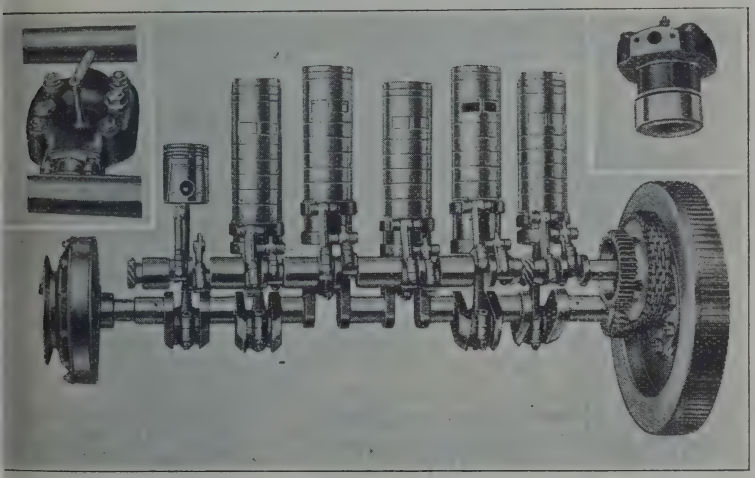


FIG. 3.—Daimler Engine. Sleeve-valve assembly.

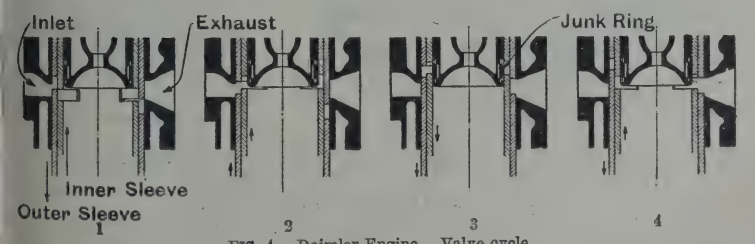


FIG. 4.—Daimler Engine. Valve cycle.

contained within the cylinder casting. These shells are reciprocated in a vertical direction by short links or connecting rods mounted on an independent shaft (fig. 3).

Cycle of Operations.

(Fig. 4, p. 1987.)

Diagram 1 shows the inlet port opening and the exhaust port closing at the beginning of t suction stroke. The inner sleeve is rising and the outer sleeve is descending.

Diagram 2 shows the exhaust closed and the inlet closing at the beginning of the compressi stroke. The ports in the inner sleeve are passing up into the cylinder head, where they are seal by the junk ring during the period of maximum pressure and temperature at the beginning the firing stroke (*see diagram* 3).

Diagram 4 shows the exhaust already well opened at the beginning of the exhaust stroke. T sleeves are now again moving to the position shown in *diagram* 1.

The complete cycle of operations—suction, compression, firing, and exhaust—occupies t revolutions of the crankshaft.

The latest development is the use of steel sleeves made of seamless drawn tubing in place cast iron, which, owing to their lightness and great port area, enable the engine to sustain hi power with perfect balance at high speeds.

The Vauxhall Single Sleeve Valve Engine.

This engine has six cylinders 81·5 mm. bore by 124 mm. stroke. Treasury rating 24·7 h. swept volume 3,880 c.c.

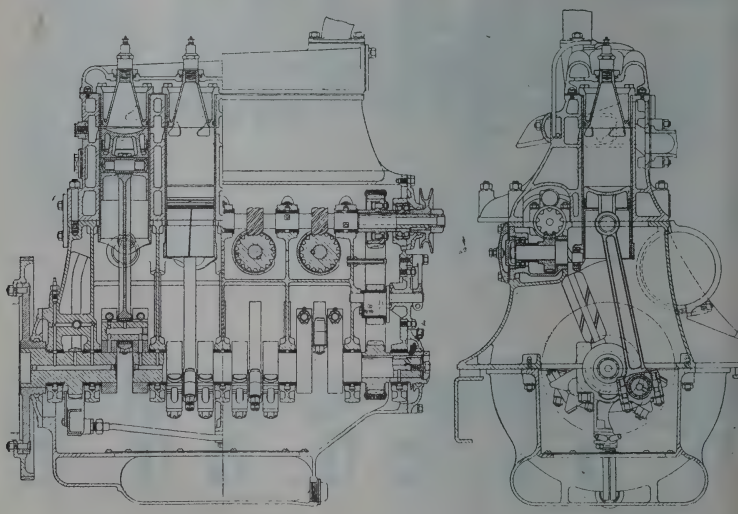


FIG. 5.—Vauxhall Single Sleeve Valve Engine.

There are several special features, such as the built-up crankshaft which is case-hardened, t sleeve driving gear with the spherical bearing in the sleeve, to give the necessary universal moti required by this type, and the shape of the combustion chamber. The sleeve gears are lubricat by troughs, and the sleeves and piston by splash.

Franklin 26 H.P. Air-cooled Engine.

(American.)

Six cylinders 3¼ in. bore by 4¾-in. stroke. A special feature of this engine is the system of air cooling. A Sirocco fan directly connected to the front end of the crankshaft supplies air through a duct over the top of the cylinders, thence through self-enclosing jackets surrounding the cylinders. Deflectors are used to direct the air current in order to secure uniform cooling. At a car speed of 20 m.p.h. the fan absorbs 0·32 h.p. and delivers 1350 cubic feet of air.

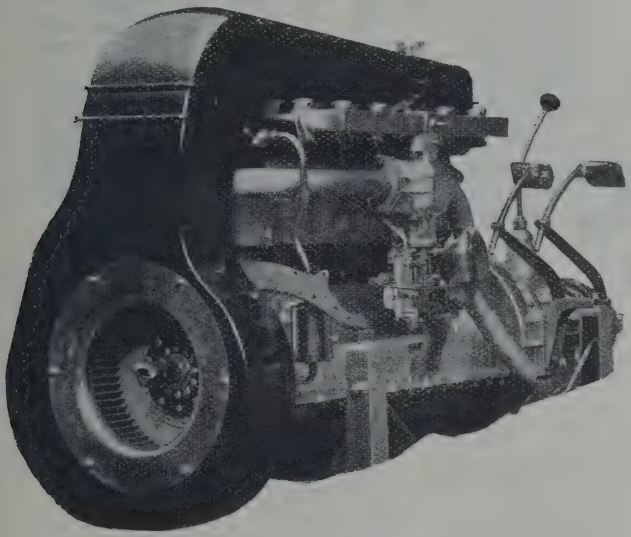


Fig. 6.—Franklin Air-cooled Engine.

Crankshaft case-hardened at the seven main bearings. Camshaft has four plain bearings, with cams forged integral with shaft. Timing gear, oil pumps, and ignition driven off camshaft by helical gears. Connecting rods 'I' section of Duralumin, drilled for lubrication of cylinder walls and piston. Aluminum alloy piston with four rings. Gudgeon pin clamped in small end of rod and chromium plated. Cylinders, unit castings of nickel cast iron with copper cooling flanges cast into cylinder walls.

Packard Engine.

(American.)

Eight cylinders cast *en bloc* with detachable head, 3⅜-in. bore by 5-in. stroke, swept volume 357·8 cub. ins. or 5,865 c.c. 84 b.h.p. at 3,000 r.p.m. (*normal speed*), brake m.e.p. 62 lbs. sq. in. Compression ratio, 4·5 : 1.

Side valves of tungsten steel. Cast-iron pistons with three rings, weight 24 ozs. Gudgeon pins, hand push fit-in piston boss. Connecting rods of 'I' section, bronze bushed at small end, white-metalled at big end (2⅛ in. diam. by 1½ in. long). Firing order: 1, 3, 2, 5, 8, 6, 7, 4, from forward end of engine, main crank bearings 2⅜ in. diam. by 1⅝ in. long. Rear bearing 2½ in. long to support flywheel. Forward end of crankshaft fitted with torsional vibration damper. Hollow camshaft with eight plain bearings, 1⅜ in. diam. Vertical oil pump driven off camshaft by spiral gears. Camshaft and dynamo driven by silent chain.

Water pump mounted on end of cylinder block in which suction passages are cored. Pump impeller fixed by screw to spindle, the other end of which is splined to take fan boss.

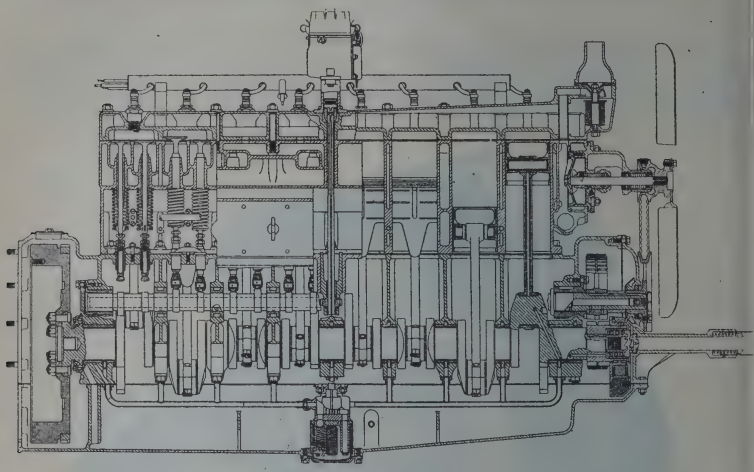


FIG. 7.—Packard Engine.

Thermostatic control is fitted to cooling system. Ignition by coil, the timer being driven by a vertical extension of oil-pump shaft.

THE CITROËN 11·4 H.P. ENGINE.

(French.)

The engine is a four-cylinder monobloc and is in unit with the gear-box. Bore 60 mm. by 100 mm. stroke, giving a swept volume for the four cylinders of 1,453 c.c.

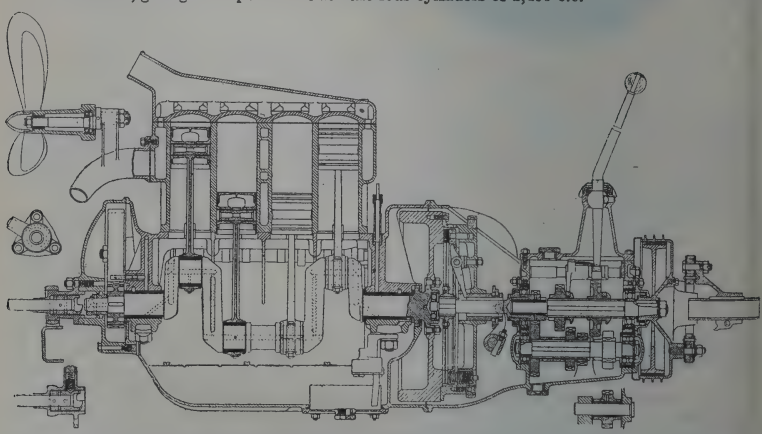


FIG. 8.—Citroën Engine.

The cylinders are bolted to the top in the usual way, the crank case being of aluminium and embodying at the rear the flywheel housing, on which are cast two arms for the engine suspension.

At the front of the crankcase are the helical timing gears, the dynamo being positively driven. The crankshaft is of the two-bearing type, and the camshaft has also only two bearings.

Cast-iron pistons of usual design are fitted with two pressure rings and an oil scraper ring, being fitted in the skirt.

The exhaust manifold is partly formed in the cylinder block, the two middle valves exhausting through a common port and the end ones through single ports. Endwise location of the crankshaft is at the rear bearing, there being a small flange on the rear web. Both crankshaft bearings are split.

The cooling fan is driven by a flat belt from a pulley carried on an extension of the magneto drive spindle.

Bianchi 10–15 h.p. Engine.

(Italian.)

Four-cylinder engine with overhead valves, 64 mm. bore by 100 mm. stroke. Swept volume 1,287 c.c. At 2,750 r.p.m. 27 b.h.p. is developed, and at 3,250 r.p.m. 32 b.h.p. which gives a brake m.e.p. of 99·3 lbs. sq. in.

Cast in one with the upper portion of the crank case, the cylinder barrels have ample jacket spaces, although the outer pair of cylinders are joined. Between the inner pair of cylinders an induction passage is cored through the water space. The crankshaft, which is 40 mm. in diameter throughout, is carried in three white-metal lined bronze bearings. Axial location of the crankshaft is effected by the forward main bearing, hardened thrust washers being interposed between the

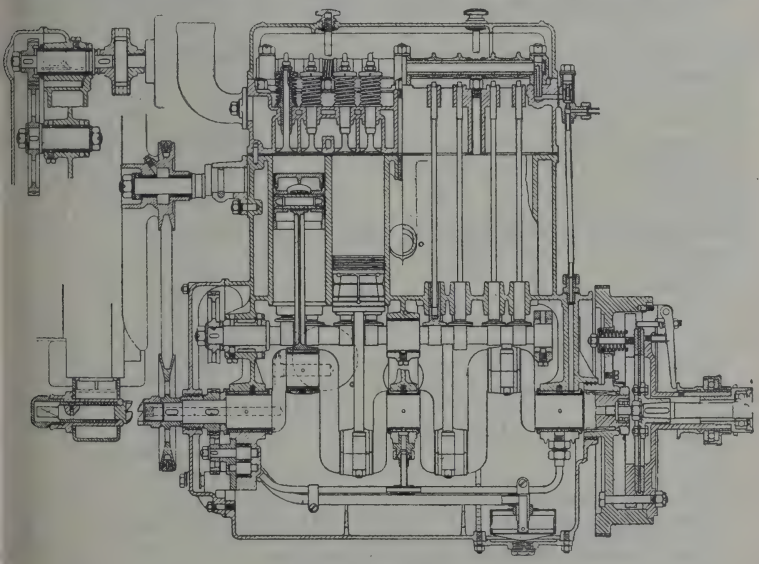


Fig. 9.—Bianchi Engine.

shell and the crank web and timing pinion. Connecting rods are of high tensile steel and have brasses lined with white-metal, and bushes in their small ends. The die-cast aluminium alloy pistons have two-joint rings and a double scraper-ring. The piston skirts are split and relieved.

The ends of the hollow gudgeon pins which work directly in the piston bosses are fitted with buttons. The cylinder bores are ground to a uniform diameter, there being no relief above the working level of the top piston ring. Long studs secure the detachable cylinder head, in which the valves are carried in bronze guides. Plain bronze bushes are used for the three camshaft bearings.

Forced lubrication of the main bearings and big-ends is effected by means of a horizontal gear pump.

Analysis of English, American, and Continental Passenger Automobile Practice, 1927.

The figures are the result of an analysis of 300 English cars, 120 American, and 304 Continental. (Figures are in percentages unless otherwise mentioned.)

Number of Cylinders	2	4	6	8
English	1	49	42	8
American	—	6	65	29
Continental	3	70	25	2

Position of Valves :	Side by side.	Overhead.	Sleeve
English	41	48	11
American	81	14	5
Continental	32	61	7

Stroke Bore Ratio (actual.)

English—Max. : 1·88 (5⅛ ins. stroke by 2¾ ins. bore). Min. : 1·25 (5 ins. stroke by 4 ins. bore). Average 1·55.

American—Max. : 1·74 (5 ins. stroke by 2⅞ ins. bore). Min. : 1·05 (4¾ ins. stroke by 4½ ins. bore). Average 1·408.

Continental—Average 1·47

Stroke (actual.)

English—Max. : 5·9 ins. Min. : 3 ins.
American—Max. : 6·0 ins. Min. : 4 ins.
Continental—Max. : 5·9 ins. Min. : 2·91 ins.

Bore (actual).

English—Max. : 4·25 ins. Min. : 2·12 ins.
American—Max. : 4·$\frac{7}{16}$ ins. Min. : 2$\frac{13}{16}$ ins.
Continental—Max. : 4·92 ins. Min. : 2·2 ins.

Type of Clutch :	Multi Disc.	Single Plate.	Cone
English	12	78	10
American	19	80	1
Continental	39	41	20

Fuel Supply :	Gravity.	Pressure.	Vacuum.
English	48	2	50
American	1	6	93
Continental	32	6	62

Final Drive :	Bevel.	Spiral Bevel.	Worm.
English	2	91	7
American	—	96	4
Continental	9	90	1

Rear Springs :	¼ Elliptic.	½ Elliptic.	¾ Elliptic.	Cantilever.	Transverse.
English	8	76	2	12	2
American	—	92	2	4	2
Continental	11	65	1	19	4

Cooling System :	Thermo-Syphon.	Pump.	Air-cooled.
English	37	62	1
American	5	94*	1
Continental	51	48	1

The following data refer to American engines and cars.

Engine.—Shape of cylinders :

'L'	77
'T'	3
'I'	14
'F'	1
Sleeve	5

Camshaft Drive.—

Helical gear	23
Chain	74
Spiral bevel	3

Oiling System.—

Force feed	59
Splash	1
Pressure	22
Force feed and splash	18

Width of Piston Ring Groove : Max. $\frac{1}{32}$ in., $\frac{1}{8}$ in., ; aveage, $\frac{3}{16}$ in.

Diameter of inlet valve (*clear*) : Max. 2$\frac{1}{4}$ ins., ; min, 1$\frac{1}{4}$ in., ; average, 1·495 in.
Lift of valve : Max., $\frac{7}{16}$ in. ; min., $\frac{7}{32}$ in.
R.p.m. at maximum horse-power : Max., 3,600 ; min., 1,500.

Gear-Box.—Combined with engine (*unit power plant*), 87. Separate, 13.

Rear Axle.—

Full floating	7
¾-floating	9
Semi-floating ...	84

Torque taken by springs ... 80
,, ,, torque tube ... 10
,, ,, arm 10

Rear Axle Gear Ratio.—Max., 5·6 ; min., 3·44 ; average, 4·65.

* 48 per cent. fitted with thermostatic control.

Main Features of Representative British and Foreign Cars.

Abbreviations used: O.H. = overhead. S.S. = side by side. S.B. = spiral bevel. W. = worm. S.P. = single plate. M.P. = multi-plate. C. = cone. I.C. = inverted cone. D. = disc.

Make.	Makers Rating.	Treasury Rating.	No. of Cylinders.	Bore and Stroke, mm.	Cubic Capacity, c.c.	Position of Valves.	Type of Ignition.	Clutch.	No. of Speeds (Forward).	Final Drive.	Wheel Base. Ft.	Wheel Base. Ins.	Track. Ft.	Track. Ins.	Weight of Complete Chassis. Cwt.
BRITISH															
Alvis	12/50	11·8	4	69 × 110	1,645	O.H.	Mag.	S.P.	4	S.B.	9	4½	4	1	16½
Armstrong Siddeley	30	29·5	6	88·9×133·4	4,964	O.H.	Mag.	M.P.	3	S.B.	11	4½	4	8	—
Austin	20	22·4	4	95 × 127	3,610	S.S.	Mag.	S.P.	4	S.B.	10	10	4	8	33
Austin	7	7·8	4	56 × 76	748	S.S.	Mag.	S.P.	3	S.B.	6	3	3	4	8
Bently	3 litre	15·9	4	80 × 149	2,996	O.H.	Mag.	I.C.	4	S.B.	9	9½	4	8	32
Clyno	12/35	11·9	4	69·5 × 105	1,592	S.S.	Mag.	I.C.	3	S.B.	8	9	4	0	16
Crossley	18/35	17·7	6	69 × 120	2,692	O.H.	Mag.	S.P.	4	S.B.	10	5	4	8	31
Daimler	—	50·0	12	81·5 × 114	7,136	Sleeve.	Dual.	S.P.	4	W.	13	7	5	0	50
Ford	20	22·4	4	95 × 102	2,900	S.S.	Ford.	M.D.	2	B.	8	4	4	8	16
Humber	15/40	15·9	4	80 × 140	2,815	*	Mag.	C.	4	S.B.	10	6	4	9	31
Lanchester	40	38·4	6	101·6×127	6,178	O.H.	Dual	S.P.	3	W.	11	9	4	10	37
Morris-Cowley	11·9	11·9	4	69·5 × 102	1,550	S.S.	Mag.	M.P.	3	S.B.	8	9	4	0	11½
Morris-Oxford	14/28	13·9	4	75 × 102	1,805	S.S.	Mag.	M.P.	3	B.	8	10½	4	0	12½
Rolls-Royce	40/50	43·3	6	108 × 140	7,700	O.H.	Dual	S.P.	4	S.B.	12	0	4	9	—
Rolls-Royce	20	21·6	6	76·2 × 114·3	3,130	O.H.	Dual	S.P.	4	S.B.	10	9	4	8	—
Standard	14/28	13·9	6	75 × 110	1,944	O.H.	Mag.	D.	3	W.	9	8	4	8	—
Sunbeam	30/90	35·9	8	85 × 120	5,448	O.H.	Mag.	M.P.	4	S.B.	12	3	4	11	—
Vauxhall	25/70	24·7	6	81·5 × 124	3,882	Sleeve	Mag.	M.P.	4	S.B.	11	4	4	10¼	39
Wolseley	16/35	15·6	4	80 × 130	2,614	O.H.	Mag.	S.P.	4	W.	9	10	4	4	28

* *Side exhaust and overhead inlet.*

Make.	Makers Rating	Treasury Rating.	No of Cylinders.	Bore and Stoke, mm.	Cubic Capacity, c.c.	Position of Valves.	Type of Ignition.	Clutch.	No. of Speeds (Forward).	Final Drive.	Wheel Base. Ft. Ins.	Track. Ft. Ins.	Weight of Complete Chassis. Cwt.
FRENCH													
Ballot	13/45	13·0	4	70 × 130	1,995	O.H.	Coil	C.	4	S.P.	10 2	4 5	29
Berliet	23/70	22·4	4	95 × 140	3,969	O.H.	Mag.	M.P.	4	S.B.	12 3	4 9	30
Citroën	11·4	12	4	68 × 100	1,453	S.S.	Mag.	S.P.	3	S.B.	9 5	3 11½	—
Darracq	15/40	13·9	4	78 × 110	2,102	O.H.	Mag.	S.P.	4	S.B.	9 10	4 5½	—
Delage	34	33·8	6	95 × 140	5,950	O.H.	Mag.	S.P.	4	S.B.	12 7	4 10	33
Hispano-Suiza	37·2	38·0	6	100 × 140	6,597	O.H.	Coil	S.P.	3	S.B.	12 0	4 9	—
Voisin	18/75	22·4	4	95 × 140	3,969	Sleeve	Mag.	M.P.	4	S.B.	12 0	4 7½	25
GERMAN													
Benz	16/40	15·9	4	80 × 130	2,620	O.H.	Batt.	C.	4	S.B.	10 5	4 8	—
Mercedes	33/140	32·9	6	94 × 150	6,245	O.H.	Mag.	M.P.	4	S.B.	12 4	4 8	30
ITALIAN													
Alfa-Romeo	22/90	21·5	6	76 × 110	2,994	O.H.	Mag.	M.P.	4	S.B.	10 3½	4 9½	23¾
Bianchi	15/50	15·0	4	78 × 120	2,294	O.H.	Mag.	S.P.	4	S.B.	10 4	4 6	23
Fiat	10/15	10·5	4	65 × 110	1,460	S.S.	Mag.	M.P.	4	S.B.	8 8½	4 1½	20
Fiat	40	26·8	6	85 × 140	4,766	O.H.	Mag.	M.P.	4	S.B.	10 10	4 10	38
AMERICAN													
Cadillac	31·25	31·25	8	79 × 130	5,152	S.S.	Coil	M.P.	3	S.B.	11 6	4 8	40
Kissel	32·6	32·6	8	81 × 114·3	4,711	S.S.	Coil and Dis.	M.P.	3	S.B.	11 5	4 8½	40
Marmon	34	34	6	95 × 130	5,565	O.H.	Coil and Batt.	M.P.	3	S.B.	11 4	4 9	33¾
Moon	20	20	6	73 × 121	3,031	S.S.	Coil and Batt.	S.P.	3	S.B.	9 8	4 8	21
Packard	39·2	40·0	8	88·9 × 127	6,304	S.S.	Batt.	S.P.	3	S.B.	11 11	4 10	39
Studebaker	27·3	27·3	6	86 × 114	3,958	S.S.	Coil	S.P.	3	S.B.	9 5	4 8½	23¾
Willys-Knight	25/35	25·6	6	82 × 120	3,802	Sleeve	Coil	M.P.	3	S.B.	10 6	4 8	33

Supercharging.

The object of supercharging is to inject a greater quantity of fuel mixture in the period allotted y the timing diagram, thus maintaining the volumetric efficiency at higher engine speeds and ncreasing the power output.

To supply the required quantity of mixture at the necessary pressure, a pump is provided. There are four types in use : (*a*) Roots blower, (*b*) piston pump, (*c*) vane pump, (*d*) turbo-compressor.

The various methods of supercharging can be classified as (*a*) forced induction, (*b*) supplemented nduction, (*c*) scavenging and use of two-stroke cycle.

In system (*a*) the whole of the charge is supplied to the cylinder at a pressure higher than tmospheric, the normal suction of the engine not being utilised.

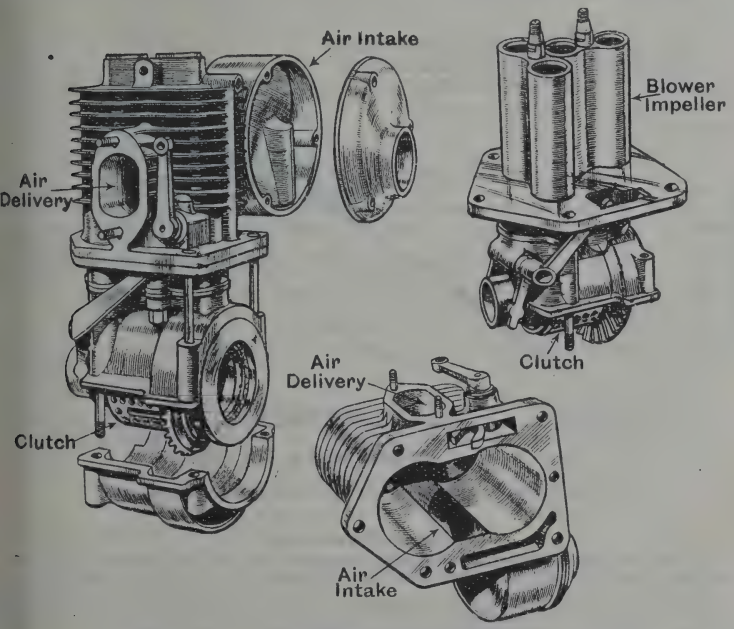


FIG. 10.—Mercedes Supercharger.

(*b*) The normal suction of the engine is utilised to furnish the greater quantity of the mixture, he charge being supplemented by special means.

(*c*) A pump is used that will furnish a volume of air slightly above atmospheric, which is used o free the cylinder and combustion chamber of residual exhaust gases.

Fig. 10 gives details of a Root's blower type supercharger used on the Mercedes engine. It nly becomes operative when the accelerator pedal is depressed past the full open throttle position. This brings into operation a multi-disc clutch that engages a set of bevel gears, and automatically connects the supercharger and closes the normal carburettor intake.

Curve C (fig. 11) represents the power required to propel the car at constant speed, and wher it intersects the horse-power curves A and B indicates the maximum possible speed, which i 75 m.p.h. without, and 87 m.p.h. with supercharger.

Curve A = power output without supercharger.

B = power output with supercharger.

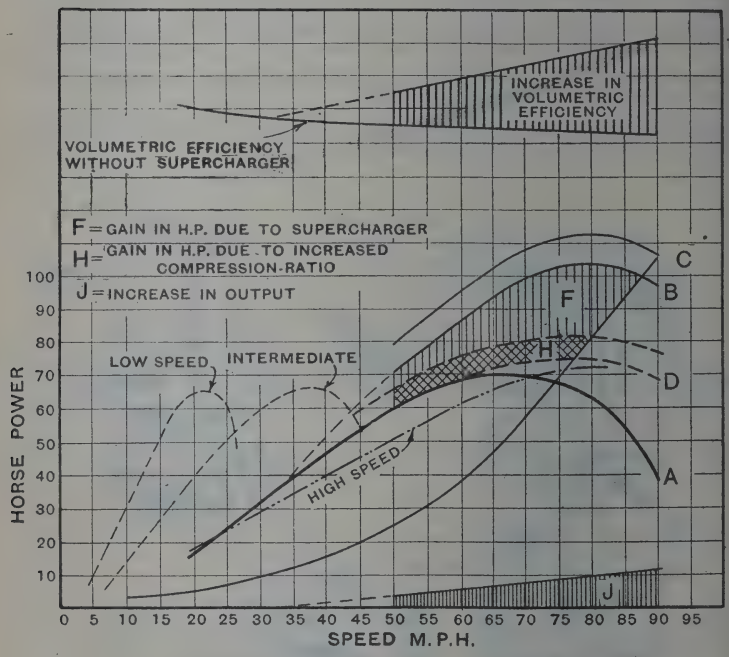


FIG. 11.—Performance Curves* 24–100 h.p. Mercedes Engine.

Engine Governors.

Engine governors as applied to commercial vehicles are used to secure uniform and econom working. There are three main types in use—(*a*) centrifugal, (*b*) velocity, (*c*) vacuum.

Type (*a*) gives close regulation and assurance of full power up to governed speed. Drivi medium must be gears, as other means are unsatisfactory. It requires lubricating and some sk to properly install. Generally placed between carburettor and intake-manifold, and usua connected with the camshaft, the governor controlling a valve in the gas passage.

Type (*b*), installed between carburettor and intake manifold, and as the engine speed increas the speed of the gas going through the manifold is increased. By using a valve in the path of t gas, work can be done on it, due to the force of the impact or gas velocity. By using a valve definite area and adding a spring tension, the speed can be calibrated to any predetermined eng speed. Methods of control—(1) cam to vary spring tension (2) tapered venturi in path of valve

This type is easy to install, compact, and requires little lubrication.

Type (*c*), actuated by alteration in manifold depression. Installed between carburettor a intake manifold and is adaptable to all engines. Full power of engine is given up to point cut-off. Provides close regulation and governs accurately at full or part throttle opening.

* C. W. Iscler, *Proc. S.A.E.*, May 1926.

Characteristics of a Good Governor.

(1) Compactness and sturdiness of construction; (2) dependability; (3) ease of installation nd adjustment; (4) capable of being sealed to prevent tampering; (5) ability to prevent over-peeding; (6) open within 100 r.p.m. of the governed speed to provide quick acceleration; (7) ot increase the engine speed at part throttle opening; (8) not overrun, but cut off sharply t governed speed; (9) not cause engine to surge; (10) not damaged by back-fire.

Fuel Distribution to Cylinders.

Tests made on a standard four cylinder 22·5 h.p. car. showed the following values, the latter eing determined from gas analysis.

Cylinder No.		CO_2 in Exhaust. Per Cent.	Air Fuel Ratio.	Distribution. Per Cent.	Excess or Deficiency. Per Cent.
A.	1	8·1	10·9	28·5	+ 14·0
	2	8·4	11·1	27·4	+ 9·6
	3	12·0	13·5	21·8	— 12·8
	4	11·6	13·3	22·3	— 10·8
B.	1	9·0	11·5	27·2	+ 8·8
	2	9·5	11·9	26·6	+ 6·4
	3	11·4	13·1	23·2	— 7·2
	4	11·9	13·4	23·0	— 8·0

A = tested at 15 m.p.h. up a 4 per cent. gradient. B = tested at 30 m.p.h. up a 4 per cent. gradient.

The tests show that the two front cylinders (Nos. 1 and 2) are subject to 'loading-up,' particularly at the lower speed.

Air Filters.

Measurements of engine wear of two identical 6-cylinder engines after running under similar conditions:—

		With Air-filter.	Without Air-filter.
Cylinder walls		0·0011 in.	0·0090 in.
Pistons		0·0005 ,,	0·0036 ,,
Ring groove clearance	Upper	0·0110 ,,	0·0650 ,,
	Middle	0·0040 ,,	0·0660 ,,
	Lower	0·0014 ,,	0·0230 ,,
Percentage of incombustible matter in carbon		6·5	31·0

Carburation.

Specific Gravity of various fuels at 15° C.:

Bowleys Special	0·684	Shell 'Borneo'	0·753
Carless	0·704	Refined Peruvian	0·729
Express	0·707	Benzol	0·846
Pratt	0·719	Rocklight Paraffin	0·825
Carburine	0·720	White Rose Paraffin	0·800
Shell	0·721		

Carburettors.

The function of a carburettor is to provide constant proportions of fuel and air under varying conditions of load, speed and throttle movements.

The jet has two main functions—(*a*) spraying the fuel into the mixture chamber, (*b*) controlling the amount of fuel. There are various types of jets, circular orifice, annulus or slit, the most generally used being the circular orifice. With slow running the air velocities are low, causing erratic behaviour of the jet. It is therefore necessary to (*a*) provide a separate jet for slow running or (*b*) arrange to concentrate the air flow round the jet.

A single jet carburettor cannot meet all the varying demands, hence the majority of carburettors are provided with several jets and choke tubes of different sizes, so that for different engine demands one or other of the jets, or a combination of jets, comes into operation. There are three general types of throttle : (*a*) Butterfly, (*b*) Sleeve or Barrel, (*c*) Valve.

The duty of the float chamber is to maintain a constant fuel level in the carburettor itself, and should be so proportioned that it has sufficient capacity under all conditions. The float, which operates in the float chamber, functions on the same principle as the ball valve in a water cistern. The floats are generally hollow, and the top and bottom should be dished, or serrated, to allow for any 'breathing action' that may take place due to a difference of pressure between the inside and outside of the float. Cork floats are also used, but these should be made up of laminations properly impregnated, and baked.

The float actuates the needle valve, which controls the supply of fuel to the carburetter. It may act direct, lifting the valve on to its seat, or may operate through toggle levers, or in some cases be spring controlled. A filter should be incorporated to prevent the entry of dust and dirt.

In general a carburettor should meet the following conditions :—

(1) Provide constant proportions of fuel and air under varying conditions of load, speed and throttle movement.

(2) Be provided with a means of altering the mean spraying velocity so as to be adaptable to various engine characteristics.

(3) Be provided with a means of maintaining correct mixture strength and fuel disintegration at sudden throttle openings.

(4) Should be able to provide an over-rich mixture for starting purposes and until the engine is sufficiently warm to handle the normal adjustment.

(5) It should be easy to adjust, accessible and non-derangeable.

Sections of typical carburetters are shown in fig. 12.

Paraffin Carburettors.

Paraffin carburettors which have been used on marine motors for a number of years past are now being adopted to a certain extent on motor cars, and particularly on commercial motor vehicles. Although there are many types that have been employed, the general principle is practically the same in every case, namely, heating the mixture on its passage to the cylinder by means of the exhaust gases. The arrangement adopted is to pass the mixture through a vaporiser, around which the exhaust gases have to flow on their way to the silencer. In any case, however, the motor must always be started on petrol. Up to the present time paraffin carburettors have not been entirely successful for automobiles.

Location of Carburettor Intake.

As the result of road tests, the best position appears to be (*a*) on the side of the engine on which the fan blades have a descending motion ; (*b*) about mid-way between the radiator and the dash ; (*c*) about mid-way between the side of the bonnet and the centre line of engine ; (*d*) about one-third of the distance down from the top of the bonnet towards the top of the cylinder head.

Engine Starting.

Within certain limits the richness of the fuel determines the number of revolutions the engine must make before an explosion is obtained. Richness of mixture in the cylinder rather than that of the mixture leaving the carburettor determines whether or not an explosion will occur, and it is suggested that this is a function of delayed vaporisation of fuel left in liquid form in the manifold and cylinder during previous cycles. (*T. O. Eisinger.*)

Detonation and Anti-Knock Substances.*

The phenomenon of detonation appears to be substantially as follows :—When a mixture of hydrocarbon vapour and air is compressed to a high pressure and to a temperature approaching that of its self-ignition temperature, and is then ignited from any one point, the flame at first spreads by the normal process of combustion, compressing before it the unburnt portion of the charge. When the rise in temperature of the unburnt portion due to compression by the burning gases exceeds the rate of heat dissipation by a certain margin, spontaneous ignition of the former takes place, and an explosion wave is set up which strikes the cylinder walls with a hammer-like blow, thus causing the metallic ring, known as 'pinking' on detonating.

* Report of the Empire Motor Fuel Committee, *Proc. I.A.E.*, vol. xviii.

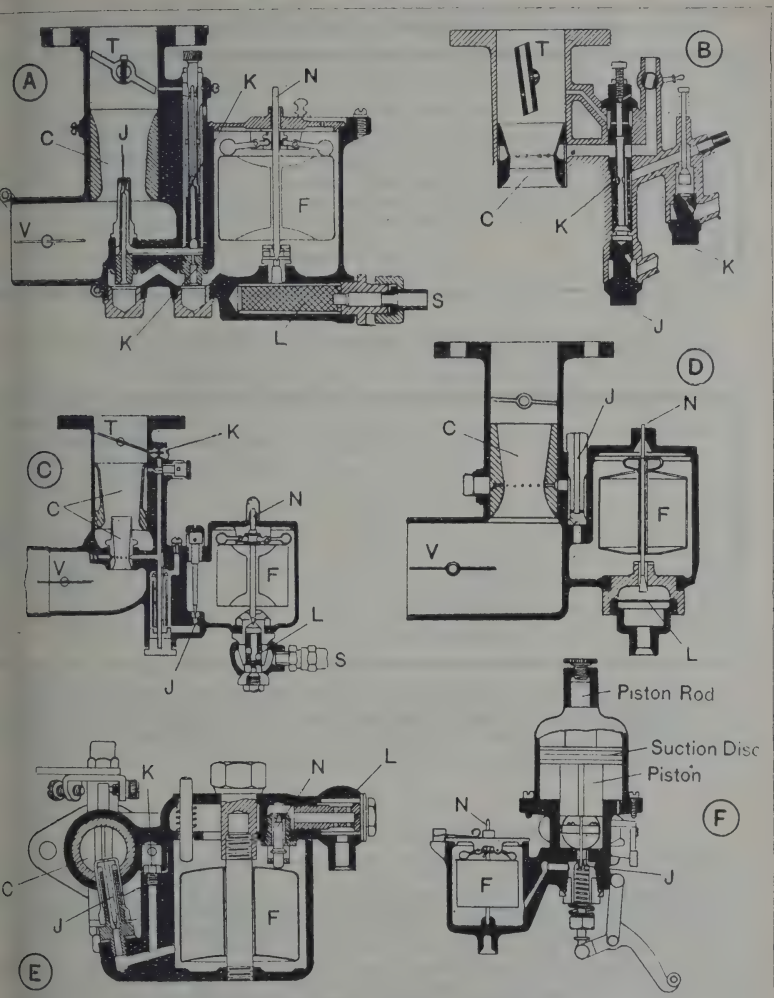


FIG. 12.—Sections of Typical Carburettors.

A. Zenith (Vertical Type).
B. Claudel-Hobson (Power Jet Model). (Float chamber not shown.)
C. Stromberg (Model M).
D. Brown & Barlow. (Auxiliary jets not shown.)
E. Solex (Horizontal Type MH).
F. H.V. Type. Controllable-Jet S.U. Carburettor.

C = Choke Tube. F = Float. J = Main Jet. K = Auxiliary Jet.
L = Filter. N = Needle. S = Fuel supply. T = Throttle Valve.

A number substances will suppress detonation (*anti-knock*), whilst others will induce it.

Element.	Form in which Used.	Effect on Detonation.
Iodine	Element.	Suppresses.
Bromine	Element.	Induces.
Oxygen	Element.	Induces.
Oxygen	Ethyl nitrite or nitrate	Induces.
Nitrogen	Aniline.	Suppresses.
Selenium Tellurium	Di-ethyl compounds	Suppresses.
Tin Lead	Tetra-ethyl compounds.	Suppresses.

'*Anti-knock*' substances are efficient when present in minute proportions, and in the cas of lead-tetra-ethyl, one molecule in 200,000 molecules of air-fuel mixture is sufficient.

Element.	Compound.	Corresponding Per Cent. by Volume.	Corresponding Number of Molecules of Theoretical Air-Fuel Mixture to one Molecule of Anti-Knock.
—	Benzene	25·0	150
Iodine	Ethyl-iodide	1·6	2,150
Nitrogen	Xylidine	2·0	2,600
Tin	Tin-tetra-ethyl.	1·2	7,100
Selenium	Di-ethyl-selenide.	0·4	11,750
Tellurium	Di-ethyl-telluride	0·1	50,000
Lead	Lead-tetra-ethyl.	0·04	215,000

In using lead-tetra-ethyl it is necessary to add some halogen-containing compound to counte act the harmful action on the sparkling plug electrodes. Carbon tetra-chloride, or ethyline d bromide can be used, the function of these compounds being to convert the lead into lead halid immediately after combustion. Lead-tetra-ethyl is a colourless liquid. S.G. 1·62, boiling poi 152° C., miscible with petrol in all proportions and poisonous.

Mechanical Losses in Engines.*

The mechanical losses remain practically constant, irrespective of the torque, for though th friction increases slightly with an increase of load, the work done in filling the cylinder increas as the throttle is closed, and the two practically balance. An 80 per cent. mechanical efficienc at full load becomes only 55 per cent. at 30 per cent. of full torque, while a 90 per cent. efficienc becomes 73 per cent., so that the difference that has to be taken into account is not that betwee 80 per cent. and 90 per cent., but between 55 per cent. and 73 per cent.

Of the gross mechanical losses, piston friction in a well-designed engine accounts for abou 60 per cent. of the total. Pumping losses account for about 25 per cent., while the friction of th bearings and all the auxiliary gear amounts to about 15 per cent. Piston friction can best b reduced by keeping both the weight and bearing surface of the piston down to the minimun Pumping losses are not susceptible of much reduction. A little can be done by the use of larg valves and the most suitable timing, but on reduced loads the losses are mainly due to the r striction through partially closed throttle. These losses are therefore more or less inevitab unless means can be found to work with a weakened instead of a throttling mixture. Unles means be adopted to augment turbulence during the compression the valves must be kept fair

* H. R. Ricardo, *Proc. I.A.E.*

mall and the velocity through them high, or slow and incomplete combustion, with loss of power, fficiency, and excessive heat flow will result. The friction of the bearings is relatively small.

It is almost impossible to assess the losses due to general vibration. However, an engine annot vibrate without absorbing a considerable amount of energy. Every effort should be made o ensure the best possible balance.

Excessive turbulence gives rise to excessive heat losses and a narrowing of the mixture ange.

It gives rise also to excessive roughness of running. The optimum degree of turbulence from he point of view of efficiency corresponds to a rate of pressure rise of 30 to 40 lbs. per sq. in. per legree of crankshaft travel. It is the rate of pressure rise, and not the maximum pressure which ives rise to harshness. A high compression engine, so long as it is not detonating, will be as sweet unning as a low compression one, provided its rate of pressure rise is the same or less.

Heat Losses in Engines.

Heat Flow through Cylinder Walls.

Average Heat Flow. B.Th.U.'s per sq. in. per minute.

Water-Jacketed Engines.	6 Cylinder Passenger Car.	6 Cylinder Motor Coach.	12 Cylinder Aircraft.
Valve position	In head.	L-head.	In head.
Brake horse-power	51	92	415
Heat loss. B.Th.U.'s per min.	2,500	7,400	10,700
Surface, sq. ins.	540	1,150	2,520
Average heat flow B.Th.U.'s per sq. in. per min.	4·6	6·4	4·3

Heat Losses to the Cylinder Jackets.

Type of Cylinder.	Heat Loss. B.Th.U.'s./min/B.H.P.	Water evaporated. Lbs./min./B.H.P.
Aviation	30	0·03
Valve in head	50	0·05
L-Head	70	0·07
T-Head	80	0·08

To guarantee that the cylinder block will always be full of water, it is necessary to pump more water than can ever be evaporated. In practice it has been found desirable to pump 2½ times the maximum evaporative requirements. The water pipes should be large enough to carry this quantity of water without undue pressure drop, or at a velocity exceeding 6 ft. per sec.

Minimum inside diameter, $d'' = \sqrt{\frac{1}{(4 \times 28{\cdot}8 W_p) \div (60 \times 60. \times 12\pi)}} = \sqrt{0{\cdot}0085\ W_p}$.

W_p = weight of water pumped in pounds per min.;

28·8 = volume in cubic inches of 1 lb. of water at 212° F.

For average conditions in a cylinder jacket, the temperature drop through the water film is approximately 20–25° F. The temperature of cylinder walls will increase approximately with an increase in water temperature until it has reached 185–190° F., when no further rise in the cylinder wall temperature will occur so long as the heated surface is wet with water or foam. The effect of a carbon or lime deposit $\frac{1}{32}$ in. thick may cause an increase of inner wall temperature of some 200° F.

Analysis of Heat Losses.

(H. R. Ricardo.)

In the case of a well-designed engine, with a compression ratio of 5 : 1, about 32 per cent. the total heat of the fuel is converted into useful work on the piston, 28 per cent. is carried aw by the cooling water, and the remaining 40 per cent. is lost to radiation, exhaust, etc. Of the to heat carried away by the cooling water, approximately 6 per cent. will be lost to cylinder wa during the combustion period, 7 per cent. will be yielded up during expansion, and 15 per ce during exhaust stroke.

Of the 6 per cent. lost during the combustion period about 40 per cent. appears as useful wo or 2·4 per cent. of the total heat of the fuel. Of the 7 per cent. lost during expansion, abo 20 per cent. will be utilised, or 1·4 per cent. of the total heat of the fuel. Of the 15 per ce lost during exhaust stroke, no part could be utilised.

Although 28 per cent. of the total heat of the fuel is carried away by the cooling water, o 3·8 per cent. could be converted directly into useful work on the piston, and the efficiency of t engine would be increased from 30 per cent. to 35·8 per cent., a gain of barely 12 per cent.

If all the loss of heat to the cylinder walls be suppressed, the temperature of the working flu would be corespondingly higher, with a result that the losses due to the increase of specific h and of dissociation at the higher temperature would be substantially increased, and a net g from 32 per cent. to about 34·5 per cent.

These figures indicate the relatively small part the loss of heat to the cylinder walls plays an internal combustion engine, and how misleading it may be to assess that loss of heat, by t heat carried away by the cooling water. As a first approximation it is fairly correct to assu that, of all the heat carried away by the cooling water of a cylinder, little more than 10 per ce would actually be converted directly into useful work.

Water Pump.

(Gear Type.)

Capacity of gear pumps can be calculated from the volume of the space between the teeth the gears. This space can be assumed to be equal to one-half the volume between the outs cylinder and the root cylinder of the gears. As two gears are working, the theoretical deliv per revolution will be equal to the difference in area between the outside and the root circle one gear times its width. Tests of pumps running at 1500–2000 r.p.m. with boiling water sh that the actual delivery is 20–30 per cent. of this amount.

$$W_p = 0{\cdot}25 \times 0{\cdot}0346 \frac{\pi}{4}(D^2 - d^2)FN = 0{\cdot}0068\ (D^2 - d^2)FN$$

or,

$$\frac{147W_p}{N} = (D^2 - d^2)F$$

where,
d = root diam. of gear-ins.; D = outside diam. of gear-ins.; F = width of gear-ins.; N r.p.m. of pump gears; W_p = weight of water pumped; lbs. per min.; 0·0346 = weight 1 cu. in. of water at 212° F.

(A. G. Herreshoff, 'Proc. S.A.E.' 1926.

Boilerine Radiator Tablets.

These tablets, invented and manufactured only by Boilerine Limited, are for the purpose obviating the fur which forms in radiators and water-jackets. There is nothing in the prepa tion detrimental to the joints or metal parts. Where scale is already in existence 25 tab per gallon of water take the lime into solution, dissolving the particles, thus leaving the w of the cylinder-jackets and radiator tubes perfectly clean.

Following this cleaning process all water put in the radiator should be 'Boilerined' to extent of 2 tablets per gallon, up to 14 degrees of hardness, and one extra tablet for every 7 degr beyond; one tablet per gallon for rain water to prevent rust.

When water is poured into the radiator, it amounts to putting in a quantity of lime or ch or if soft water, a means of producing rust.

If this is done without 'Boilerine' tablets, the lime adheres to the walls of the cylinders radiator tubes until efficiency is choked out of the cooling system.

Boilerine Limited have proved from tests that thirty hours heating of water at 190° F. gi nearly the same amount of deposit as half an hour's boiling, thus, surely, though unseen, the mo is, at the working temperatures, storing up in its cooling system this cause of trouble, consequen the flow of water is reduced, producing overheating, or allowing the impurities in the wate cause rust and corrosion, hence leakages.

These claims are confirmed by the reports given on tests of twelve and six months' durat respectively, made by Messrs. Thomas Tilling, Ltd., and Messrs. W. H. Dorman & Co., L Stafford.

Crankcase Corrosion.

The presence of water in the crankcase is responsible for the corrosion. The quantity of ter present in the products of combustion is dependent upon the hydrogen content of the fuel, e mixture ratio, and the humidity of the air that enters the engine. The amount of water at may be condensed on the cylinder walls or in the crankcase depends upon the effectiveness the piston and piston rings in preventing gas leakage, the temperature of the cylinder walls d crankcase, and the extent of the breather action. Condensation of water from the gases combustion will start at approximately 130° F. when petrol is used, and at 123° F. when 0 per cent. mixture of petrol and benzol is used. The relative freedom of some engines from ter accumulation is due to their higher operating temperatures, or to the better interchange air by breather action, which results in dilution of the gases in the crankcase and consequent luction of the saturation temperature of the gases.

Water alone will cause corrosion, but the action may be accelerated by the formation of weak phurous or sulphuric acid.

In order to reduce water accumulation, pistons must reduce blow-by, and in addition means ould be provided to reduce the warming-up period and ventilate the crankcase. Either air- or am-cooling, with provision for controlled heating of the crankcase, is favourable for the solution the problem.

(*M. A. Thorne*, ' *Proc. S.A.E.*,' 1926.)

Chromium plating of the crankcase has proved an effective measure against corrosion.

Engine Efficiency Constants.*

The following equation for efficiency is recommended by Tizard and Pye, and is based upon 0 per cent. weak mixture, which corresponds very closely to the conditions under which the ximum observed efficiencies are now obtained.

$$E = 1 - \left(\frac{1}{r}\right)^{0.296}.$$

r.	E.	r.	E.	r.	E.	r.	E.	r.	E.	r.	E.
·8	0·3261	4·4	0·3552	5·0	0·3790	5·6	0·3995	6·2	0·4175	6·8	0·4329
·9	0·3316	4·5	0·3595	5·1	0·3826	5·7	0·4026	6·3	0·4200	6·9	0·4354
·0	0·3366	4·6	0·3637	5·2	0·3861	5·8	0·4057	6·4	0·4229	7·0	0·4376
·1	0·3410	4·7	0·3674	5·3	0·3896	5·9	0·4087	6·5	0·4251	7·5	0·4495
·2	0·3461	4·8	0·3717	5·4	0·3930	6·0	0·4116	6·6	0·4280	8·0	0·4596
·3	0·3506	4·9	0·3753	5·5	0·3963	6·1	0·4145	6·7	0·4307	—	—

Firing Order.

From considerations of balance it is necessary to get as uniform a turning-moment as possible. ur-cylinder engines are so arranged that there is a power impulse every stroke or two power pulses every revolution, the one beginning as the other ends. The crank throws are placed in one plane, the two centre throws being together and at 180° to the two outer throws. ith this arrangement two orders of firing are possible, viz. 1–2–4–3 and 1–3–4–2; both are used, t the latter is the more general.

With a six-cylinder engine the throws are divided into three positions or 120° apart. 1 and 6 always in line, 3 and 4 are always in line, and 2 and 5 are always in line. For a right-hand nk the firing order is 1–5–3–6–2–4 or 1–2–4–6–5–3, and for a left-hand crank 1–4–2–6–3–5 1–3–5–6–4–2.

For an eight-cylinder ' V ' engine :

$$\left.\begin{matrix}8\text{–}7\text{–}5\text{–}2\\1\text{–}4\text{–}6\text{–}3\end{matrix}\right\} \text{ or } \left\{\begin{matrix}1\text{–}3\text{–}4\text{–}2\\8\text{–}6\text{–}5\text{–}7\end{matrix}\right.$$

For an eight-cylinder ' in-line ' :

(*a*) 1–5–3–7–4–8–2–6
(*b*) 1–7–3–5–4–2–6–8
(*c*) 1–3–2–5–8–6–7–4
(*d*) 1–5–2–6–4–8–3–7

* I.A.E. Data Sheet No. 205.

Effect of Changes in the Compression Ratio upon Engine Performance.*

With an increase in the compression ratio there is usually an increase in b.h.p. and a decre in consumption up to a ratio of 14 : 1, provided there is no serious pre-ignition or detonati The changes in indicated thermal efficiency with changes in compression ratio are in close agr ment with those based on the air-cycle efficiencies at the various ratios.

Change in the compression ratio does not produce a consistent change in the friction h volumetric efficiency, or in the range of fuel-air ratios over which the engine can operate. T ratio between the heat loss to the jacket-water and the heat converted into b.h.p. or i.h decreases with an increase in the compression-ratio.

Piston Clearance and Compression Ratio.

Analysis of 100 different makes of engines show the average clearance for cast-iron pistons be 0·013 in. at the top and 0·003 in. at the bottom.

The extreme values were :—Top, max. 0·026 in., min. 0·002 in. Bottom, max. 0·005 i min. 0·001 in.

Average compression ratio 4·42 ; max. value 5·76 ; min. value 3·33. (Compression ratio Ratio of total cylinder volume to combustion chamber volume). In general 4·5 may be c sidered as high compression, 4·0 as medium, and 3·5, or below, as low.

COMPRESSION PRESSURE FOR VARIOUS PERCENTAGES OF COMBUSTION SPACE VOLUME.

Combustion chamber, percentage of piston displacement.	Compression Pressure. lbs. per sq. in. gauge.			Combustion chamber, percentage of piston displacement.	Compression Pressure lbs. per sq. in. gauge		
	High value.	Average value.	Low value.		High value.	Average value.	Lo val
25	125	112	97	33	89	80	68
26	118	107	92	34	86	77	66
27	113	102	88	35	83	74	64
28	108	97	84	36	80	72	62
29	103	93	80	37	77	70	60
30	99	89	77	38	74	68	58
31	95	86	74	39	72	66	56
32	92	83	71	40	70	64	55

COMPRESSION RATIO, $r = \dfrac{\text{Combustion space + swept volume}}{\text{combustion space}}$.

AIR STANDARD EFFICIENCY, $\text{E} = 1 - \left(\frac{1}{r}\right)^{1\cdot4} - 1.$

BRAKE M.E.P.

d = diameter of piston. ; s = stroke ; n = r.p.m. of crankshaft ; P = total m.e.p. piston, lbs. per sq. in. ; p = brake m.e.p., lbs. per sq. in.; c = power strokes per revolut of crank.

If d and s are in inches,

$$\text{B.h.p.} = \frac{s.d.^2p.n.c.}{504300}\ ;\ \text{P} = \frac{396000\ \text{b.h.p.}}{s \times c \times n}\ ;\ p = \frac{504300\ \text{b.h.p.}}{s.d.^2n.c.}.$$

If d and s are in millimetres,

$$\text{B.h.p.} = \frac{s.d.^2p.n.c.}{8262 \times 10^6}\ ;\ \text{P} = \frac{\text{b.p.h.} \times 1006 \times 10^6}{s.n.c.}\ ;\ p = \frac{\text{b.h.p.} \times 8262 \times 10^6}{s.d.^2n.c.}.$$

* Report No. 205, National Advisory Committee for Aeronautics, U.S.A.

Pistons.

The material most generally used at present is Cast Iron, but great advances have been made n the use of non-ferrous alloys, and the following, which is an extract from a paper by L. Aitchison, ndicates their advantages.

Light alloy pistons are in general use for aero engines and racing car engines. The main advantages in their use are :—

(*a*) Owing to their light weight, friction is reduced, and also the loading on the connecting-od bearings, due to the reduction of inertia of the reciprocating parts.

(*b*) Owing to the lower temperature of the crown (due to the greater thermal conductivity) ittle or no carbonisation of the lubricating oil takes place on the under-side.

(*c*) Owing to the lower mean temperature of the oil film between the piston and cylinder walls, ess oil may be used without risk of piston seizure.

A disadvantage in their use is due to larger coefficient of expansion, which necessitates ncreased clearance and is the cause of piston-slap.

The Ricardo Piston.

This piston, fig. 13, is a 'slipper' type and aims at securing increased power by the reduction of friction and weight. The contamination of the lubricating oil due to gas leaking past the rings, which takes place in the ordinary form of piston, is reduced by allowing the leaking gas to escape before reaching the piston skirt. Also the lower ring groove is bevelled and drilled to enable the ring to act as a scraper.

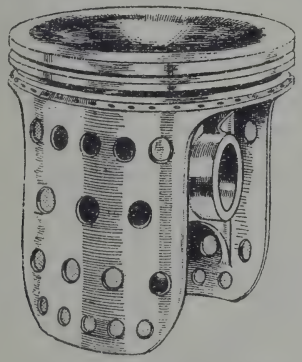


Fig. 13.—Ricardo Slipper Piston.

Features of this piston are: (*a*) Gas pressure is transmitted direct from the crown of the piston to the centre of the gudgeon-pin bosses; (*b*) thrust from the connecting rod is transmitted directly to the bearing surfaces; (*c*) bearing surface is provided only where it is needed: (*d*) gases that pass the piston-rings may escape freely into the crank case; (*e*) no wad is transmitted through the side-walls, or past the piston-ring grooves; (*f*) the lower piston-ring acts as a scraper, so that oil that has worked up past the slippers can be returned through the small holes beneath. Tests made with this piston showed a reduction in oil consumption from 0·06 lbs. per h.p. hour, to 0·035 lbs. At the same time fuel consumption dropped 4 per cent. with about 4 per cent. increase in b.h.p. For cylinder bores ranging from 3½ ins. to 5 ins. the weight of the piston, complete with gudgeon pin and piston rings, can be reduced to 0·1 lb. per sq. in. of piston area.

Cast-Iron Cylinder Liners and Piston Pots.

The advantages in the use of cylinder liners are :—

(*a*) Cylinder blocks can be made of a cheaper and more fluid iron; (*b*) expensive jigs for cylinder grinding unnecessary; (*c*) can be replaced if necessary; (*d*) reduces the rejection of blocks due to flaws discovered during boring.

Liners may be of steel or centrifugally cast iron, and are essential where light alloy cylind blocks are used. Piston pots are generally made of centrifugally cast iron.

The features of centrifugally cast iron are :—

(*a*) Close grain and dense structure, combined with a diminutive formation of the graphi plates ; (*b*) uniform physical properties ; (*c*) superior grinding finish to sand castings.

The dense structure increases resistance to percolation, and since the material receives chilling effect from the dies in which it is cast, it is tougher and harder than sand-cast metal.

It can be machined readily at about 30 ft. per min. Brinell 200–240. The tensile streng based on the B.E.S.A. ring formula is 19–22 tons per sq. in., and owing to the size and dist bution of the graphite plates, grain growth and distortion are reduced.

Design of Piston Rings.

The practice of making eccentric piston rings with the idea of obtaining equal distributi of radial pressure is now being replaced by the use of concentric rings which have been subject to hammering or peening. The effect of peening is to reduce the nominal modulus of elasticit E_n, by about 10–15 per cent. (There is no definite elastic modulus for cast iron, as no part of t stress-strain diagram is straight.) The minimum value for the modulus is given in B.E.S.A. spe fication, No. 5003/1927, as $13 \cdot 5 \times 10^6$ lbs. per sq. in., and the maximum value as $15 \cdot 5 \times 10^6$ l per sq. in. According to the British Piston Ring Co., Ltd., the value of E_n for good pist ring iron varies from approximately 15–17 $\times 10^6$ lbs. per sq. in., but the effect of hammering is reduce this by about $1 \cdot 5 \times 10^6$, so that the value of E_n for the finished rings should be betwe $13 \cdot 5$–$15 \cdot 5 \times 10^6$ lbs. per sq. in.

If

d = diameter of cylinder bore, ins. ;

t = radial thickness of ring, ins. ;

b = width of ring measured parallel to cylinder axis, ins. ;

δ = Free gap in ins. (measured in a straight line tangential to the circumference of ring and parallel to the plane of the ring) ;

p = pressure between ring and cylinder wall per sq. in. of contact area ;

f = calculated maximum stress in tons per sq. in., assuming the material to be truly elastic, and of modulus E_n ;

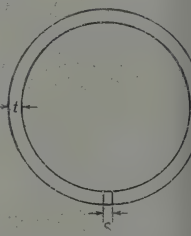


FIG. 14.

E_n = nominal Young's Modulus ;

Q = diametral load in lbs. applied along diameter of ring corresponding to a change gap of δ_1 ins. ;

Then

$$E_n = \frac{5 \cdot 37 \left(\frac{d}{t} - 1\right)^3 Q_1}{b \cdot \delta_1}$$

Minimum thickness of ring $= \frac{d}{30}$

Maximum thickness of ring $= \frac{d}{30} + 0 \cdot 008$ in.

Width of ring varies in steps from $\frac{d}{16}$ for 2-in. size to $\frac{d}{24}$ for the 6-in. s

Tolerance $\frac{-0 \cdot 001 \text{ in.}}{+0 \cdot 000 \text{ in.}}$

Maximum free gap $= \frac{d}{7 \cdot 5}$. Such a gap produces approximately the same stress in the r

during the operation of placing it over the piston as it has when in its closed position in the cylinder, but since the ring is continuously closed in the cylinder it is desirable to use a smaller free gap so as to reduce the stress in the ring under working conditions. A free gap of $3\frac{1}{2}$ times the minimum thickness is more satisfactory in practice.

A ring with a free gap of $3{\cdot}5 \times \frac{d}{30}$ gives a minimum pressure of 9·15 lbs. per sq. in. (taking $E_n = 13{\cdot}5 \times 10^6$ lbs. per sq. in.).

$$\text{Cylinder wall pressure } p = \frac{\left(\frac{\delta_1}{t}\right) E_n}{7{\cdot}08 \left(\frac{d}{t}\right) \left(\frac{d}{t} - 1\right)^3}$$

where δ_1 is the difference in inches between the free gap and the gap when in the cylinder measured in the same manner as δ.

$$\text{Maximum stress } f = \frac{\left(\frac{\delta_1}{t}\right) E_n}{5280 \left(\frac{d}{t} - 1\right)^2} \text{ tons per sq. in.}$$

In a ring having a free gap of $3\frac{1}{2} \times t$, the change of gap (δ_1) is approximately equal to $4\frac{1}{2} \times t$ when putting the ring over the piston, and $3\frac{1}{2} \times t$ when putting it into the cylinder.

The load Q is calculated from $Q = \left(\frac{3\pi}{\pi + 4}\right) p.\, b.\, d.$

where b and d are in inch units, p is expressed in lbs. per sq. in., and Q in lbs.

Horse Power, Treasury Rating (T_R).

$$(a)\ T_R = \frac{d^2N}{2{\cdot}5},$$

where

d = bore in ins.; N = number of cylinders.

$$(b)\ T_R = \frac{d^2N}{1613},$$

where

d = bore in mm.; N = number of cylinders.

The Society of Automotive Engineers (S.A.E.), America, standardised the following formula, based on a piston speed of 1000 ft. per minute:

$$\text{S.A.E., horse-power} = \frac{(\text{Diam. in inches})^2 \times \text{No. of cylinders.}}{2{\cdot}5}$$

Horse Power from Given Working Volume and M.E.P.

$$\text{Horse-power} = \frac{P_m \times Q \times N}{396000},$$

where,

P_m = m.e.p. lbs. per sq. in.; Q = working volume in cu. ins.; N = r.p.m.

Valve Area for Given Volume, Revolutions and Gas Velocity.

$$V_g = \frac{VcN}{360\ \Delta},$$

where,

V_g = gas velocity, ft. per sec.; Vc = volume swept out per cylinder; cu. ins.
Δ = valve area in sq. ins.; N = r.p.m.

Inlet Pipe Diameter.

$$Vg = \frac{QN}{180\pi D_1^2},$$

where

Vg = gas velocity, feet per sec.;
D_1 = diameter of inlet pipe; ins.
Q = working volume per rev.; cub. ins.
N = r.p.m.

Compression Pressure.

$$\left(\frac{V_2}{V_1}\right)^n = R^n = \frac{P_2}{P_1},$$

where

V_1 = volume of clearance space; cub. ins.
P_1 = atmospheric pressure; lbs. per sq. inch.
$n = 1{\cdot}3$;
R = compression ratio.
V_2 = volume of piston displacement + V_1 cub. ins.
P_2 = compression pressure in lbs. per sq. in (absolute).

Calculating Lift of Poppet Valves.

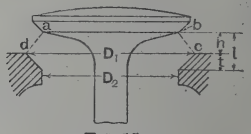


FIG. 15.

The gas passage is the area of the curved surface of the frustrum of the cone *abcd*. V = volume of gas to be discharged in cubic feet, and V_g = mean gas velocity in feet per secon through valve opening, and A = area of valve opening, then,

$$A = \frac{144V}{Vg} \text{ (sq. ins.).}$$

The lift l must be such as to produce this area for the gas to pass through.

$$h^2 = \frac{4A^2}{\pi^2 (d_1 + d_2)^2} - \frac{(d_1 - d_2)^2}{4}.$$

Knowing the value of d_1, d_2, A and t, the lift $l = h + t$ (Fig. 15).

DIMENSIONS OF POPPET VALVES.
(S.A.E. Standard.)

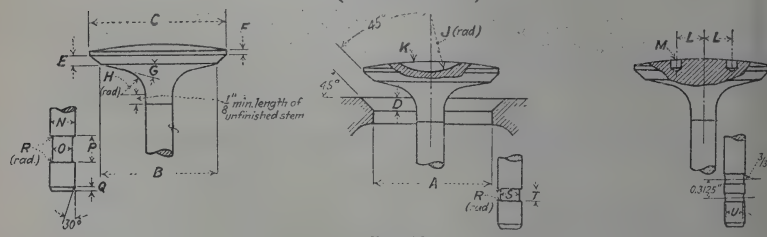


FIG. 16.

Dimensions of Poppet Valves.

Heads and Seats.

Nom. Size. A.	Dimensions (ins.). Fig. 16. B.	C.	D.	E.	F.	G. Deg.	H.	J.	K. Width.	K. Depth.	L.	M. Diam.	M. Depth.
1	31/32	1 6/16	1/16	3/32	1/32	7	1/4	3/4	1/16	3/32	1/4	1/8	1/8
1 1/8	1 3/8	1 9/32	1/16	3/32	1/32	7	1/4	3/4	1/16	3/32	1/4	1/8	1/8
1 1/4	1 7/32	1 13/32	1/16	3/32	1/32	7	1/4	1	1/16	3/32	1/4	1/8	1/8
1 3/8	1 11/32	1 17/32	1/16	3/32	1/32	7	1/4	1	1/16	3/32	1/4	1/8	1/8
1 1/2	1 15/32	1 2	3/32	3/32	1/32	7	1/4	1 1/4	1/16	3/32	1/4	1/8	1/8
1 5/8	1 19/32	1 7/8	3/32	3/32	1/32	7	1/4	1 1/2	1/16	3/32	1/4	1/8	1/8
1 3/4	1 23/32	2	3/32	6/64	3/64	7	1/4	1 1/2	3/32	3/32	1/4	1/8	1/8
1 7/8	1 27/32	2 1/8	3/32	6/64	3/64	7	1/4	1 1/4	3/32	5/32	1/4	1/8	1/8
2	1 31/32	2 5/16	1/8	6/64	1/16	12	7/16	1 1/4	3/32	3/32	1/4	1/8	1/8
2 1/8	2 1/32	2 7/16	1/8	6/64	1/16	12	7/16	1 1/2	3/32	3/32	1/4	3/32	3/32
2 1/4	2 3/32	2 9/16	1/8	6/64	1/16	12	7/16	1 1/2	3/32	7/64	1/4	3/32	3/32
2 3/8	2 11/32	2 11/16	1/8	6/64	1/16	12	7/16	1 1/2	3/32	7/64	1/4	3/32	3/32
2 1/2	2 15/32	2 13/16	1/8	6/64	1/16	12	7/16	1 1/2	3/32	7/64	1/4	3/32	3/32
2 5/8	2 19/32	2 15/16	5/32	7/64	1/16	12	9/16	1 1/2	3/32	1/8	1/4	3/32	3/32
2 3/4	2 23/32	3 1/2	5/32	7/64	1/16	12	9/16	1 1/2	3/32	1/8	1/4	3/32	3/32
2 7/8	2 27/32	3 5/16	5/32	7/64	1/16	12	9/16	1 1/2	3/32	5/32	1/4	3/32	3/32
3	2 31/32	3 7/16	5/32	7/64	1/16	12	9/16	1 1/2	3/32	5/32	1/4	3/32	3/32

Radii for Curvature of Crown of Valve-Head.

Nominal size	1–1⅛	1⅛–1¼	2–2¼	2⅜–2⅝	2¾–3
Radius, ins.	5	6	7	8	9

Valve Stems and Grooves.

(Fig. 16.)

Nom. Size. A.	Dimensions (ins.). N. Max.	O. Max.	P. Max.	Q.	R. Max.	S. Max.	T. Max.	U. Max.
1 –1⅛	0·3100	0·250	0·328	1/32	0·012	0·235	0·144	0·250
1⅛–1¼	0·3725	0·309	0·391	1/32	0·012	0·253	0·144	0·309
2 –2⅜	0·4345	0·312	0·516	1/32	0·015	0·312	0·175	0·372
2½–3	0·5595	0·437	0·578	1/16	0·020	0·405	0·206	0·495

The above dimensions are for steel valves; they are considered equally applicable for cast-iron valves, except that it may be desirable to have slightly more metal in the latter under the heads.

Valve stem tips shall be hardened to give a scleroscope reading of 55–65 after finishing. Recommended that length of tips from end of stems to stem-grooves be not less than finished diameter of stem to prevent undue breakage after hardening.

Tolerance on fractional dimensions ± 0·010 in.

Valve Timing.

Analysis of one hundred automobile engines (1927) showed the following average timing:

Inlet opens, 10° A.	Exhaust opens, 47° 50′ B.
Inlet closes, 40° A.	Exhaust closes, 7° 30′ A.
A = after T.D.C.	B = before T.D.C.

In 95 per cent. of the engines the inlet and exhaust valves were of the same diameter.

$$\frac{\text{Diameter of inlet valve } (clear)}{\text{Valve lift}} = 4{\cdot}75. \qquad \frac{\text{Cylinder Bore}}{\text{Valve diameter}} = 2{\cdot}2.$$

Material for Valves.

Valves operate under a tension-impact load, the temperature varying from practically atm spheric at the tappet end to about 1600° F. at the head. The temperature gradient is a functi of the guides in which the valve reciprocates, and for any particular design is affected by t material in the guide, the degree in which it shrouds the stem, and the inner surface of the gui The temperature of the head is affected by the width of valve seat and cross-sectional area stem. The head and upper part of stem are subjected not only to high temperatures, but also the corroding action of the mixture, and the corroding and eroding action of the hot gases passi through the valve at a velocity of 150–200 ft./sec.

The scaling of a valve not only reduces the cross-sectional area, but the loose scale may a become attached to the valve seat.

The strength of the valve material at ordinary temperature is important only in so far as it a function of the hardness. For highly stressed valves the strength at high temperatures important, and it is necessary to select a material which does not show a decrease in the origi strength sufficient to cause distortion or failure.

Bearings.

Crankshaft and big-end bearings are usually white-metal lined ; gudgeon bushes of bron

Corresponding to a maximum explosion pressure of 300 lbs. per sq. in., the bearing pressure lbs. per sq. in. of projected area is as follows :—

For ' big-end ' bearings : 800–1,100 lbs. per sq. in. ; more usually the latter.

For ' gudgeon ' bearings : 1,500–2,700 lbs. per sq. in. ; average about 2,000 lbs. per sq. in.

Gear-Box Gears.

As the result of over ten years' experience in the testing of gear-box gears, H. F. L. Orc summarises his observations as follows :—

(*a*) Gears which are hardened after finishing are always noisy.

(*b*) Gears with teeth accurately finished after hardening are quiet.

(*c*) Gears with teeth finished as accurately as possible may be noisy in the best-finished ge boxes.

(*d*) Gears with teeth roughly finished may be under some conditions comparatively quiet

(*e*) An accurately finished gear is just as essential to cheap and uniform production as accurately finished cylindrical shaft or bearing.

(*f*) In a quiet-running pair of gears the limits of accuracy on the teeth are the finest possi much finer than those which are required in any other conjugate surfaces in the gear-box.

(*g*) In the ordinary gear-box the gear teeth are usually the least accurate of any of the work surfaces.

(*h*) Some ratios run more quietly than others, tooth load and quality of finish being equal

(*i*) The stub gear to run quietly must have extreme accuracy of tooth form, especially pitch spacing. Consequently this gear is more difficult to finish to a degree of quiet running th the full-depth tooth gear.

Strength of Splined Shafts.

From tests carried out on actual shafts, the elastic limit for a splined shaft is substantially l than for a plain round shaft of a diameter equal to the base diameter of the spline. On the ot hand, the ultimate strength of the splined shaft is materially greater than that of the round sh It would appear that the reason the elastic limit is lower in the splined shaft is that the mate in the splines adds very little to the torsional strength, but the strain on the fibres at the outs of the splines will be about the same as if the shaft were of solid round section and equal in diame to the outside diameter of the splines. With fairly elastic material, if the distortion is contin beyond the elastic limit, the splines assume a helical form and gradually come into tension, there adding to the resistance of the shaft to further deformation. If the splines are supported, as in t case of the permanent fitting so that they are in more nearly direct shear from the beginning the load application, their shearing strength is added to that of the body of the shaft.

Analysis of Breakdowns, 1924–1925–1926.

(Royal Automobile Club.)

Cause of Breakdown.

(A) Engine.

	1924.	1925.	1926.		1924.	1925.	1926.
	Per Cent.				Per Cent.		
(1) Cylinders and piston	5·8	6·9	8·0	(5) Crankshaft	0·7	0·8	0·5
(2) Lubrication	3·7	3·1	2·3	(6) Starting	0·8	0·5	0·6
(3) Water circulation	0·9	1·4	1·7	(7) Valves	0·7	0·5	0·9
(4) Valve mechanism (including camshaft, layshaft, secondary and timing gears)	1·0	1·0	0·9	(8) Not stated	5·9	7·2	6·6

(B) Transmission and Brakes.

(1) Couplings, universal joints and propeller shafts	4·3	5·0	4·6	(3) Gear Box	3·7	3·6	2·8
(2) Clutch	4·1	4·1	4·4	(4) Brakes	0·5	0·4	0·3

(C) Back Axle.

(1) Axle shafts	12·8	12·4	12·6	(3) Bevels and Worms	1·6	1·1	1·2
(2) Differential	1·6	1·3	1·2				
(D) *Ignition*	20·7	22·7	22·5	(H) *Lighting failures*	2·2	2·3	2·1
(E) *Carburation*	4·1	3·0	2·5	(J) *Accidents*	12·2	13·1	14·1
(F) *Front axle and steering*	6·3	4·1	4·3				
(G) *Road Wheels and Suspension*	6·4	6·1	5·9				

Steering Wheel Position.

The following formulæ (*W. Ferrier Brown*) are for the calculation of the steering-wheel position, a, b, and d, being known factors.

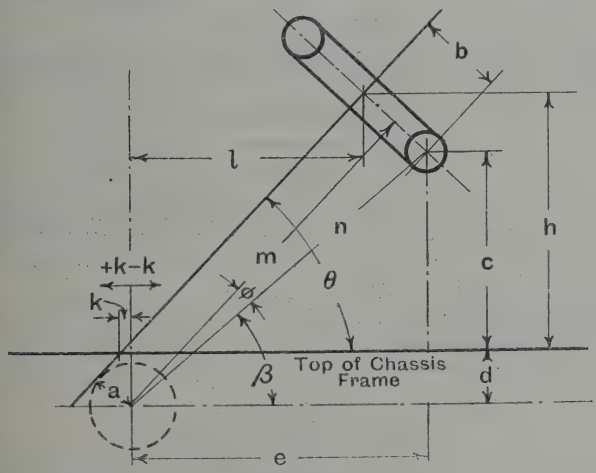


FIG. 17.—Steering Wheel Position.

Given m and θ—to find c and e.

$\phi = \tan^{-1}\frac{b-a}{m}$; $n = \frac{m}{\cos\phi} = m \sec\phi$;

$\beta = \theta - \phi = \sin^{-1}\frac{c+d}{n}$; $e = n\cos\beta$;

$c = n\sin\beta - d$.

Given c and e—to find m and θ.

$\beta = \tan^{-1}\frac{c+d}{e}$; $n = \frac{e}{\cos\beta} = e \sec\beta$;

$\phi = \sin^{-1}\frac{b-a}{n}$; $m = n\cos\phi$;

$\theta = \phi + \beta$ = rake of column.

To find h and l.

$h = m \sin\theta + a\cos\theta - d$; $l = \cos\theta\,(m - a\tan\theta)$.

To find h and l.

$h = c + b\cos\theta$; $l = e - b\sin\theta$.

To find k (which may be + or −

$$k = \frac{a}{\sin\theta} - \frac{d}{\tan\theta}.$$

Lubrication.*

Carbon Formation.—The tendency towards carbon formation is due to an excess of oil worki past the piston rings into the combustion chamber. Special means are used to limit the amou of oil reaching the combustion chamber, such as (*a*) baffle plates between the crank case a cylinder casting, (*b*) scraper ring on the piston, (*c*) effective oil relief groove on the piston or relief holes, (*d*) adequate control of the oil supply to meet the engine's requirements.

Sealing the Piston Rings.—The clearance between the piston and the cylinder wall controls t lubricant to seal the piston rings. When this is small, a light or medium bodied oil is sufficie Larger clearances require a heavier-bodied oil.

Piston clearance must be considered in conjunction with the cylinder bore. A clearance 0·005 in. on a small-diameter piston is relatively large compared with the same clearance on piston of double the size.

Piston material affects the clearance allowed; thus heavier-bodied oils are necessary for al minium pistons compared to cast iron. Other factors are: the number of piston rings and th position on the piston, the presence of oil grooves on the piston to assist in oil distribution, meth of finishing cylinder bore.

Lubrication of Transmission and Differential.

The following characteristics of the lubricant are necessary :—

(*a*) Must be of a character and consistency to coat, follow, cushion, and adequately lubrica the gear mesh.

(*b*) Must be capable of thorough distribution to any ball, roller, or plain bearing, and mu have no corroding effect on the balls, rollers, or raceways.

(*c*) Should be of a body and character to minimise resistance and power loss due to the churni action of the gears. In the case of transmission, it should offer the minimum of resistan to the manual act of gear changing.

(*d*) Should be capable of carrying off the greatest amount of heat, and of exerting a washi action on the gear teeth and bearing surfaces.

(*e*) Should be a body to prevent leakage from the gear-box or back axle under all norm operating conditions.

Chassis Lubrication.

Advantages of Oil for Lubrication.

(C. T. Myers.)

(1) Sustains as heavy a bearing load as grease with less friction.

(2) Fed to one properly located point in a bearing will quickly spread over the entire surfa

(3) Will flow through a very small hole, and can be conducted a considerable distance capillary attraction and surface tension.

(4) Carries much less dust than grease, can be filtered, and not so much exposed to dirt grease, when in bulk or when being applied.

(5) Contains no inert matter to clog holes or channels.

(6) Engine oil can be used.

(7) Easier to apply automatically than grease.

(8) A flow of clean oil tends to clean a bearing, and bearings arranged for oil lubrication c be cleaned with petrol or paraffin.

(9) When oil is used on spring bolts, the seepage works down into the spring leaves, preventi rust.

Weight of Passenger Cars.

(*W. Ferrier Brown, 'Proc. I.A.E.'*)

The total weight of an average car is made up as follows :—

Chassis complete, 65 per. cent; body complete, 30 per cent.; wings, valances, and ste boards, 5 per cent.

For the complete body in detail, the proportionate weights are :—

Body frame (steel), 14 per cent.; body framing complete with head-fittings, 42 per cen panels (steel), 10 per cent.; paint, glass and inside mouldings, 12 per cent.; Trimmi including two extra seats complete, etc., 22 per cent.

* See also Handbook published by the Vacuum Oil Co., Ltd.

COEFFICIENT OF FRICTION BETWEEN TYRE TREADS AND VARIOUS SURFACES AT SLOW SPEEDS.

(H. Chase.)

Tyre.	Surface.	Coefficient of Friction.			
		Ahead.		Crossways.	
		Start.	Slide.	Start.	Slide.
Average of 14 tyres with various treads	Dry concrete road	0·72	0·80	0·72	0·80
	Flooded concrete road	0·81	0·94	0·78	0·94
Non-skid tread	Rough concrete (dry)	0·90	1·00	—	—
	Dry concrete road	0·66	0·66	—	—
	Flat rubber	0·76	0·76	—	—
	Water on concrete	0·76	0·98	—	—
	Water on clean asphalt	0·80	0·90	—	—
	Dry clean asphalt	0·82	0·86	—	—
	Dry clean concrete	0·80	0·84	—	—
	Moist sandy clay	0·70	0·84	—	—
	Fine loose macadam	0·70	0·70	—	—
	Oiled asphalt	0·60	0·64	—	—
	Wet oiled asphalt	0·54	0·60	—	—
Ribbed tread	Flooded concrete road	0·76	0·94	0·72	0·96
	Dry concrete road	0·72	0·80	0·72	0·76
	Fine loose macadam	0·60	0·64	—	—

Automobile Brakes.

A common misapprehension is that which assumes that there is no slipping between tyre and road until wheels are locked. Actually slippage occurs immediately upon the sudden application of the brakes, and continues until the car is brought to rest whether the wheels are locked or not. Although the wheels continue to roll, their peripheral speed begins to decrease immediately and is therefore always less than that at which the road surface passes under the car.

The effectiveness of brakes can be determined directly by measuring the breaking force per unit of car weight *i.e.* per lb. per 1000 lbs. or per ton of car weight. The relation between the distance S in feet required to stop, the initial car speed V in m.p.h., and (1) the rate of slowing down in feet per sec.$^2 = a$; (2) the retarding force in lbs. per lb. $= f_1$, (3) the retarding force in lbs. per 1000 lbs. of car weight $= f_2$, is given by

$$(1)\ S = 1{\cdot}08\frac{V^2}{a}; \qquad (2)\ S = 0{\cdot}0336\frac{V^2}{f_1}; \qquad (3)\ S = 33{\cdot}6\frac{V^2}{f_2}.$$

STOPPING DISTANCES FOR DIFFERENT TYPES OF BRAKE APPLICATION.

	Type of Brake.		
	Rear External Band Brake.	Four Brakes Internal Shoes.	Four Brakes, External Bands.
Total weight of car lbs.	6,000	6,000	6,000
Total surface of brake lining, sq. ins.	332·4	308·6	600
Weight per sq. in. of lining, lbs.	18·1	19·4	10
Stopping distance in feet at			
20 m.p.h.	35	23	15
30 ,,	70	45	35
40 ,,	113	74	60
50 ,,	175	114	90

Stopping Tests of Car Fitted with Hydraulic Brakes.

Total weight of car with driver = 4,400 lbs.; Weight on front wheels = 2,000 lbs.; Weigh on rear wheels = 2,400 lbs.
Tyres, cord, size 35 × 5, pressure 65 lbs. per sq. in.;
Road surface—dry concrete.
Speed, 30 m.p.h.
Stopping distance—brakes applied on rear wheels only = 89·2 feet.
" " " front " " = 67·6 "
" " " rear and front wheels = 36·8 feet.

Noisy Brakes.

Tests show that scratching of the brake drum by brass wire in the brake lining, high rive heads, particles of steel from the drum or grit from the road, sets up vibrations in the drum, an that the note given out by these vibrations is of the same tone as the ringing note produced b striking the undamped drum with a hammer. The sound can be damped or muffled by applyin slight pressure at a point diametrically opposite the initial point of vibration. Other recom mendations are :—(a) *drums should be of high carbon steel*; (b) *rivet heads should be sunk* ⅛ in *below the surface of the lining*; (c) *the use of moulded lining containing no wire*; (d) *the bands mu be truly circular.* (*Proc. S.A.E.*, Feb., 1926.)

Laminated Springs.

Size and Number of Plates.

$$\text{Total load on spring W in cwts.} = \frac{sbt^2n}{L},$$

where,

s = maximum stress in plates = 460 cwts. per sq. in.; t = thickness of plates in ins. = breadth of plates in ins.; L = length of spring between eyes in ins.; n = number of plate

Given W and L, and assuming n, values for b and t can be calculated. These must be checke against the rate of deflection, which is determined by :

$$\text{Deflection per ton of load} = \frac{L^3}{40{,}000bnt^3}.$$

From experimental data it appears desirable to so design leaf springs that the plate lengths a proportional to the second moment of area (moment of inertia) of the plate sections, except f strengthening near the eyes to take care of rebound.

Friction in Laminated Springs.

Friction tests show that the friction is a minimum with a lubricant consisting of equal volum of cylinder oil and powdered graphite. The close proximity of the curve for static and slidi friction with this lubricant are of special note. An important conclusion drawn from the tests that with graphite μ is substantially constant.

Values of μ under similar loading conditions.

	Light Oil.	Excess Oil wiped off.	Graphite.
Static	0·24	0·34	0·08
Sliding	0·10	0·18	0·06

Effect of End Taper.

Fig. 18 is a diagram showing the relative liability to fracture of various plates in springs deduced from more than 500 fractures.

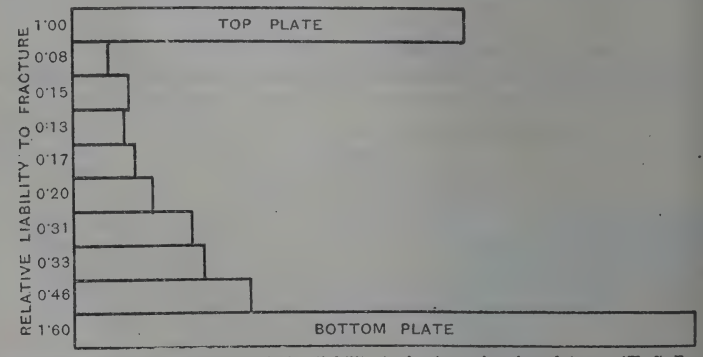


Fig. 18. Diagram showing the relative liability to fracture of spring plates. (*H. S. Rowe*

Plates which are reduced in width only are not appreciably different from square-ended plates, such tapering having no practical effect on the strengths, reactions, stresses, or flexibilities of the spring. On the other hand, taper in the thickness has an enormous effect. A combination of the two tapers—in the width and in the thickness—is sometimes of much importance, but generally the effect of tapering the width is very much less than of a taper in the thickness.

The life or fatigue of a spring is to a considerable extent governed by the stress reversal which occurs on account of nip and flick.

NOTE.—For a very complete survey of the subject, papers by Landau and Parr (*Journal Franklin Institute*, U.S.A.) and Rowell (*Proc. Institution of Automobile Engineers*) should be consulted.

Power Required by Motor Vehicles to Negotiate Gradients.

It is first necessary to determine the maximum engine torque T. If d = engine bore in ins., n = number of cylinders, s = stroke in ins., then $T = 5{\cdot}66d^2sn$ (approx.). Let S_R = total speed reduction ratio between engine and driving wheels and e = efficiency of driving mechanism, then the torque T_1 transmitted to the driving wheels is given by $T_1 = TS_Re$ (e may be taken as 0·9 for top gear and 0·75 to 0·85 for intermediate and low gears).

Total tractive force F in lbs. $= \frac{2TS_Re}{D}$, where D = diameter of driving wheels in ins.

This tractive force is available to overcome (*a*) resistance due to acceleration or gradients, (*b*) road resistance and wind resistance.

AVERAGE VALUES IN POUNDS PER TON FOR ROLLING PLUS AIR RESISTANCE FOR DIFFERENT CLASSES OF VEHICLES ON VARIOUS ROAD SURFACES.*

Road Surface.	Motor Buses and † Passenger Cars.	Commercial ‡ Vehicles.
Best paved surfaces	37	22
Paved surface in average condition	42	30
Best water-bound gravel	55	40
Ordinary gravel	65	50
Best earth roads	65	50
Fair to good earth roads	75	60

The size of tyre appears to affect the rolling resistance very little so long as the tyres conform to good practice as to size and load. Low-pressure cord tyres have somewhat higher rolling resistance than the high-pressure cords, but the difference decreases for the rougher surfaces.

If G = gradient per cent. and R = rolling plus air resistance in lbs. per ton, and W = gross weight of vehicle in lbs., then,

$$\frac{2TS_Re}{D} = \frac{W.G}{100} + \frac{W.R}{2240}; \text{ or, } \frac{4480TS_Re}{D} = W(24G + R);$$

from which the engine torque required to drive a vehicle up a given gradient can be determined; or knowing the engine torque, the maximum gradient that the vehicle can negotiate.

* Report of Committee on the Economic Theory of Highway Improvements, S.A.E. Highway Research Board, 1925.

† Speed 35 m.p.h., high-pressure cord tyres. For low-pressure cord tyres add 10 lbs. per ton.

‡ Speed 15 m.p.h., pneumatic tyres.

The following values of road resistances are given by G. W. Watson (*Proc. I.A.E.*):

Nature of Road.	Resistance, lbs. per Ton.	Nature of Road.	Resistance, lbs. per Ton.
Good asphalt	15	Soft macadam	97
Poor asphalt	29	Small cobbles	60
Good wood paving	30	Medium cobbles	130
Good granite sets	35	Large cobbles	240
Best macadam	43–46	Sand road	360
Ordinary macadam	50–60	Loose sand	560

Tyres.

Comparison of Tyre Sizes.

Range of wheel load, lbs.	675–1,120	1,000–1,500	1,400–1,900
High-pressure tyres, ins.	4	4½	5
Inflation pressure, lbs. per sq. in.	45–6	45–60	45–65
Medium-pressure Tyres, ins.	4½	5½	6
Inflation-pressure, lbs. per sq. in.	30–50	38–54	42–58
Balloon Tyres, ins.	5½	6	6½
Inflation pressure, lbs. per sq. in.	27–35	26–38	30–40

Ideal Load and Inflation Pressure.

The following formulæ are based on the Goodyear Company's tables:

If d = section diameter ins. and P = inflation pressure lbs. per sq. in.:

For cord tyres $P = 12 \cdot 5 + 10d$; For canvas tyres $P = 17 \cdot 5 + 10d$.

The ideal load (lbs.) per tyre, $W = 32 \cdot 4d^{2 \cdot 24}$.

For any given inflation pressure the variation of permissible load with diameter is given by $W = cpd^{1 \cdot 18}$, where $c = 1 \cdot 81$ for cord tyres and $1 \cdot 63$ for canvas tyres.

*Wear of Tyres.**

For high-pressure tyres, road tests show:

(1) Wear increases with speed.

(2) Increased wear with higher temperatures (high temperatures are very destructive to tyres).

(3) Relative wear of rear tyres to front varies from 200 to 118, probable average 150.

For balloon tyres:

(1) Wear is less affected by differences in road surfaces than for high-pressure tyres.

(2) Firm-surfaced roads (*i.e.* asphalt, cement) all have approximately the same effect on tread wear.

(3) Surfaces such as gravel, earth, dry and in good surface condition, cause less tread wear than firm-surfaced roads.

(4) Front tyre wear is greater than rear tyre wear on firm-surfaced roads, and is less than rear tread wear on loose-surfaced roads.

* Highway Research Board, National Research Council, Washington.

RATE OF DEFLECTION OF PNEUMATIC TYRES.*

Standard Pneumatic Tyres.	Inflation Pressure. Lbs. per sq. inch.								
	15	20	25	30	40	50	60	80	100
650 × 65	700	525	450	404	341	302	—	—	—
26 × 3	642	492	420	373	297	232	195	—	—
28 × 3½	488	410	355	315	254	207	182	—	—
815 × 105	488	374	316	275	217	177	158	—	—
880 × 120	420	340	290	248	192	154	138	—	—
895 × 135	335	278	237	207	170	147	130	110	—
36 × 6	—	—	—	—	120	103	88	78	75
38 × 7	—	—	—	—	—	—	82	66	60
40 × 8	—	—	—	—	—	—	78	61	52
Balloon Tyre sizes.									
27 × 4·40	600	464	378	332	275	—	—	—	—
28 × 4·95	584	440	370	322	265	—	—	—	—
30 × 5·25	500	390	318	270	218	—	—	—	—
32 × 6·20	464	354	298	250	192	—	—	—	—
34 × 7·30	400	316	263	228	180	—	—	—	—

The above values represent the rate of deflection when any working load is already applied. The numbers are given in millimetres per cwt. increase in load, and in each case the result has been multiplied by 100 to avoid decimal points.

RATE OF DEFLECTION OF SOLID TYRES.

Solid Tyre Sizes.	Normal Load.	Normal Load less 25 per Cent.	Normal load plus 50 per Cent.
90 × 754	31	36	23
100 × 881	25	28	20
110 × 850	23	29	17
120 × 850	19	24	15
130 × 850	15	17	13
140 × 850	18	22	12
160 × 850	13	16	10
180 × 850	11	13	9
8″ × 850	11	13	10
10″ × 850	7	9	6
12″ × 850	6	7	5

THE MACINTOSH N.A.P. UNPUNCTURABLE TYRE.

This tyre, fig. 19, is so constructed that it possesses a large hermetically sealed core containing uncompressed air. It has a broad and flat base similar to that of the ordinary solid tyre, thick, strong, and abnormally flexible walls, and a narrow tread having a central row of triangular cavities about half an inch deep, which give definite non-skidding and side-slipping properties on slippery surfaces. This form of construction is such that it is claimed to need no attention whatever during the whole life of the tyre, which is guaranteed in the United Kingdom to be a minimum of 10,000 miles or twelve months, whichever expires the sooner. Another important feature is that the walls are entirely of rubber and contain no fabric, with the result that exceptionally cool running is obtained. This tyre seems to combine in a remarkably efficient manner the advantages both of the pneumatic and the solid variety. For such vehicles as Ford one-ton trucks it is particularly well adapted.

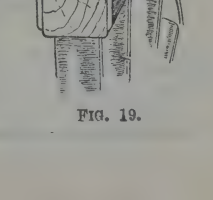


FIG. 19.

* A. Healey, *Proc. I.A.E.*, vol. xix.

Operating Costs.

Heavy Motor Vehicles.

	Initial Cost, Complete with Body.					
	4-ton 4-wheel	4½-ton 6-wheel	6-ton 4-wheel	6-ton 6-wheel	8-ton 6-wheel	10-ton 6-wheel
	£1,050	£790	£1,150	£1,150	£1,200	£1,550
Running Cost (Pence per Mile):						
Petrol (1/6 per gallon)	2·25	1·85	3·00	2·40	3·22	3·60
Lubricants	0·29	0·24	0·39	0·38	0·38	0·43
Tyres	1·25	1·30	2·20	2·00	2·10	2·50
Maintenance	1·80	1·50	2·20	1·90	1·90	2·05
Depreciation	1·82	1·36	2·15	2·24	2·24	2·90
Total	7·41	6·25	9·94	8·92	9·84	11·48
Standing Charges (Pence per Week):						
Licence	144	144	144	144	144	144
Wages	840	840	840	840	840	840
Rent and rates	138	138	144	144	144	144
Insurance	120	120	120	120	120	120
Interest on Capital	228	172	270	270	282	362
Total	1470	1414	1518	1518	1530	1610
Assuming an average of 350 miles per week, the total cost of operation per ton mile of useful load would be:						
Running cost	1·85	1·39	1·66	1·49	1·23	1·15
Standing charges	1·05	0·90	0·72	0·72	0·54	0·46
Total	2·90	2·29	2·38	2·21	1·77	1·61

(*G. W. Watson, 'Proc I.A.E.'*)

Petrol Omnibus Service Results, 1926.

Net running costs per bus mile vary from 7·58d. (Burton-on-Trent) to 15·82*d.* (Leicester).
Gross operating costs vary from 8·45*d.* per bus mile (Southport) to 16·54*d.* (Preston).
Number of buses fitted with pneumatic tyres = 40 per cent.
Receipts per bus mile vary from 8·4*d.* (South Shields) to 23·33*d.* (*Coventry*).

Comparative Cost of Petrol and Electric Vehicles.

(D. E. Batty.)

Size of lorry, 2½ tons.
Service, delivery, town and suburban, 10-15 miles radius.
Miles per day, 35.
Working days per annum, 300.
Miles per annum = 10,500.

CAPITAL COST.

	Petrol.	Electric. Iron Battery.	Electric. Lead Battery.
Chasiss	550	525	525
Body	100	100	100
Battery	—	683	202
	£650	£1,308	£827

STANDING CHARGES.

	£ s. d.	£ s. d.	£ s. d.
Interest on capital, 5 %	32 10 0	65 8 0	41 8 0
Depreciation on body and chassis, 15% petrol vehicle, 10% electric vehicle	97 10 0	62 10 0	62 10 0
Insurance, 3½% petrol vehicle, 2½% electric vehicle	22 15 0	32 14 0	20 13 0
Rent and taxes	50 0 0	50 0 0	50 0 0
Driver's wages	150 0 0	150 0 0	150 0 0
	£352 15 0	£360 12 0	£324 11 0
Standing charges, pence per mile	8·05	8·24	7·41
Tyres per mile	1·00	0·75	0·75
Petrol, 7 miles per gallon at 1s. 6d.	2·57	—	—
Oil, grease, repairs	2·20	1·00	1·00
Battery maintenance	—	2·73	2·30
Electricity at 1½d.	—	1·80	1·80
	5·77	6·28	5·85
Standing charges	8·05	8·24	7·41
	13·82	14·52	13·26
Total cost per annum	£605	£636	£580

Welding Cracked Cylinders without Preheating.

Cast-iron automobile cylinders can be successfully welded without preheating by using bronze welding rod and employing a few ordinary precautions. When the crack is in the water-jacket it is often unnecessary to remove the block from the car. Conduction of heat can be retarded by packing the block with wet asbestos fibre cement two or three inches from the crack on each side. It is not necessary to bevel the edges of the break, but the metal should be carefully cleaned, and preferably ground bright for about 0·5 in. on each side of the break.

The oxy-acetylene blowpipe is used, and the best results are obtained with a welding rod prepared especially for bronze welding on cast iron. It is necesary also to use a good flux.

The temperature at which bronze welding is conducted is quite critical. If the casting is not sufficiently heated, the bronze will not adhere firmly, and if it is raised to too high a temperature the bronze will run off like water on a hot stove. The best method is to practice on a piece of cast iron until the operator can tell from his own experience the correct temperature.

A section of the break should be brought up to this temperature, the metal being heated along both sides of the crack for about 0·25 in. The bronze welding rod should be heated, and then dipped in the flux. Next, the bronze rod should be melted and allowed to run on the heated section of the casting, a very thin layer of bronze metal being allowed to flow on the break.

This first layer should be applied as a tinning layer, and care should be taken to see that the section to be welded is entirely covered by this tinning coat.

After the tinning coat has been applied, bronze weld metal can be added fairly rapidly, usin flux as necessary, until a weld of the proper height has been built up.

Welding should start at least 0·5 in. beyond the visible ends of the crack. If the crack i long, it may be desirable to tack-weld it in one or two places, or to begin welding in the centr and weld towards both ends. It is important that overheating of the base metal or the bronz weld metal should be avoided.

Bronze welding should be done in a well-ventilated shop or in the open air, and the operato should avoid breathing the white fumes of volatilised zinc oxide produced, as otherwise som discomfort may be experienced.

When the weld is completed it can be filed or ground down, but grinding flush with the cylinde wall should be avoided, unless the crack has been bevelled previous to welding.

(*'Machinery,' Sept.* 29, 1927.)

See also Welding Section, p. 2761.

SECTION XXXIII

PART I

AIRCRAFT . . . . . pp. 2023-2053
(Contributed by Major D. H. Kennedy, F.R.Ae.S., R.A.F.)

PART II

AERO ENGINES . . . . . pp. 2055-2071
(Contributed by Ernest W. Birch, A.M.I.A.E.)

SECTION XXXIII

PART I

AEROPLANES — GENERAL DATA — THE ATMOSPHERE — WINGS OF MONOPLANES—AIR SCREWS—AEROPLANE PERFORMANCE — NOTABLE FLIGHTS — AIRSHIPS FOR COMMERCE — STANDARD DATA FOR AIRSHIP CALCULATIONS—OXYGEN APPARATUS—PARACHUTES.

(Revised and amplified by Major D. H. Kennedy, O.B.E., F.R.Aé.S.)

GENERAL DATA.

The Atmosphere.

That the temperature of the atmosphere diminishes as one ascends is obvious from the fact that the summits of high mountains are constantly snow-covered.

The rate of diminution is, naturally, somewhat variable, but for London averages about 3·5°F. per 1,000 feet of height. The mean annual temperature of London is roundly 50°F. Hence, as the average condition a temperature of 50°F. may be taken at the surface of the earth, and a fall of temperature of 3·5°F. per 1,000 feet of height.

At h feet, therefore, the average temperature is assumed as :—

$$t = 50 - 3{\cdot}5 \times \frac{h}{1000} \text{°F.}$$

Or, using absolute temperatures :—

$$T = 510 - {\cdot}0035\ h \text{°F. abs.}$$

Hence the characteristic Equation (1) becomes in this case :—

$$p\ v = c\ (510 - {\cdot}0035\ h) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53)$$

If at height h feet the pressure be p, then at height $(h+dh)$ feet the pressure must be $(p+dp)$, dp including its sign ; the (negative) increment dp is due to the weight of a layer of air 1 square foot in horizontal section and dh feet high, and is therefore numerically equal to $\frac{dh}{v}$; hence :—

$$dp = -\frac{dh}{v}.$$

From Eq. (53) this becomes :—

$$c\frac{dp}{p} = -\frac{dh}{510 - {\cdot}0035h},$$

hence

$$c\int_{p_o}^{p}\frac{dp}{p} = -\int_{o}^{h}\frac{dh}{510 - {\cdot}0035h}$$

where p_o is the pressure at the earth's surface ; performing the integration, reducing, and taking $p_o = 14{\cdot}7$, we have for determining p, the pressure in lbs. per square inch at height h feet :—

$$\text{Log. } p = 14{\cdot}654741 + 5{\cdot}36.\text{Log. } (510 - {\cdot}0035h) \quad . \quad . \quad . \quad . \quad . \quad (54)^*$$

From this equation the table on page 2024 has been prepared ; in addition, the table gives the absolute and ordinary average temperatures in °F. for heights up to 30,000 feet ; the pressures in lbs. per square inch and in inches of mercury ; the ratio of the pressure at height h to the pressure at the earth's surface, and the volume of 1 lb. of air, in cubic feet, at the several heights. It will be found useful in calculations relating to aeronautics.

* Common Logs.

PRESSURE AND TEMPERATURE OF THE AIR AT DIFFERENT HEIGHTS.

Height in Feet above Sea Level. h.	Temperature, °F.		Pressure :—		Ratio p/p_o	Volume of 1 Lb. in Cubic Ft.
	Absolute.	Ordinary.	In Lbs. per Sq. In.	In Ins. of Mercury.		
Column :—	1	2	3	4	5	6
0	510	50	14·70	30·0	1·00	12·84
1,000	506·5	46·5	14·17	28·91	0·964	13·23
2,000	503	43	13·65	27·86	0·929	13·64
3,000	499·5	39·5	13·15	26·83	0·894	14·06
4,000	496	36	12·66	25·84	0·861	14·50
5,000	492·5	32·5	12·19	24·90	0·830	14·95
6,000	489	29	11·73	23·95	0·798	15·42
7,000	485·5	25·5	11·29	23·04	0·768	15·91
8,000	482	22	10·86	22·17	0·739	16·42
9,000	478·5	18·5	10·45	21·32	0·711	16·95
10,000	475	15	10·04	20·49	0·683	17·51
11,000	471·5	11·5	9·65	19·70	0·657	18·08
12,000	468	8	9·27	18·93	0·631	18·68
13,000	464·5	4·5	8·91	18·18	0·606	19·30
14,000	461	1	8·55	17·46	0·582	19·94
15,000	457·5	−2·5	8·21	16·76	0·559	20·62
16,000	454	−6	7·88	16·08	0·536	21·32
17,000	450·5	−9·5	7·56	15·43	0·514	22·05
18,000	447	−13	7·25	14·80	0·493	22·81
19,000	443·5	−16·5	6·95	14·19	0·473	23·61
20,000	440	−20	6·66	13·60	0·453	24·44
21,000	436·5	−23·5	6·38	13·03	0·434	25·31
22,000	433	−27	6·11	12·48	0·416	26·21
23,000	429·5	−30·5	5·85	11·95	0·398	27·15
24,000	426	−34	5·60	11·43	0·381	28·14
25,000	422·5	−37·5	5·36	10·94	0·365	29·17
30,000	405	−55	4·27	8·72	0·291	35·08

The weight of 1 cubic foot of air in lbs. is of course the reciprocal of the figure in column at any given height.

The effect of the fall in temperature with height is to cause the pressure to be slightly *less* tha if the temperature were uniform throughout; thus at 9,000 feet, with uniform temperature 50°F. throughout, the pressure is 21·54 inches of mercury, while with diminishing temperatu (*vide* table) it is 21·32 inches. Actually the atmosphere is very rarely quiescent, and in th uniform condition here assumed; the results obtained are, however, useful for calculation. I particular, for a few hundreds of feet above the surface of the earth the air is usually in a con dition of more or less complex turbulence with eddies, ascending heated currents, etc., due t the nature and configuration of the country beneath.

This table should be regarded as approximate only until further actual observations a to the temperatures and pressures at altitudes are available. The observed temperature o January 2, 1919, at an altitude of 30,500 ft., was −38° F.

Flight of Heavier-than-Air Machines.

The following elementary treatment of the subject furnishes results of some practical interes and exhibits clearly the *rationale* of mechanical flight :—

Air Pressure on a Flat Plate normally to its direction of motion.

Let

A = the area of the plate in square feet;
v = the velocity of the plate, relatively to the air, in feet per second;
G = the weight of the air, in lbs. per cubic foot, or density;
$g = 32·2$;
P = the resulting pressure on the plate, in lbs.

Then in one second a mass (GAv) lbs. of air impinges on the plate and its momentum is

destroyed; the momentum is $(GAv) \times v$, and the momentum destroyed per second measures the force, in absolute units (i.e. poundals); hence we have :—

$$P = \frac{1}{g}(GAv)\, v \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (55)$$

Actually, however, owing to the air streams formed, and the action at the back of the moving plane, the case is not quite so simple, and it is found necessary to write the equation :—

$$P = f\, GA\, \frac{v^2}{g} \text{ lbs.,} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

where f is a coefficient whose value is determined by experiment.

Very numerous experiments have at various times been made to determine f, with somewhat widely differing results according as the size, shape, and material of the plane have been varied. Experimental results of M. Eiffel and Dr. T. E. Stanton suggest that f may be taken for large surfaces, at the value $\frac{5}{8}$ roundly, so that Eq. (56) becomes, putting 32·2 for g :—

$$P = \cdot 0194 \times GA\, v^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

A change in the air velocity, as well as changes in the plate itself, as referred to above, will cause variations in the coefficient f. Experimental results on a square plate are given in the table below, which shows the speed of the air in ft. per sec. and the corresponding pressure on the plate in lbs. per sq. ft.

AIR PRESSURE ON A NORMAL FLAT PLATE AT DIFFERENT AIR SPEEDS.

Air Velocity, ft. per sec.	Pressure, lbs. per sq. ft.	Air Velocity, ft. per sec.	Pressure, lbs. per sq. ft.	Air Velocity, ft. per sec.	Pressure, lbs. per sq. ft.	Air Velocity, ft. per sec.	Pressure, lbs. per sq. ft.
30	1·36	54	4·40	78	9·07	102	15·56
32	1·55	56	4·74	80	9·56	104	16·18
34	1·75	58	5·04	82	10·02	106	16·77
36	1·96	60	5·40	84	10·57	108	17·37
38	2·17	62	5·73	86	11·10	110	18·03
40	2·40	64	6·10	88	11·52	112	18·70
42	2·66	66	6·47	90	12·08	114	19·41
44	2·91	68	6·88	92	12·64	116	20·10
46	3·21	70	7·28	94	13·20	118	20·80
48	3·48	72	7·72	96	13·76	120	21·42
50	3·78	74	8·38	98	14·35		
52	4·18	76	8·60	100	14·97		

Power Required to Drive the Plate.

If E be the horse-power necessary to drive the plane at v feet per second in opposition to a resistance of P lbs., we have :—

$$E = \frac{1}{550} Pv. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (58)$$

By aid of Eq. (57) this becomes :—

$$E = \frac{35 \cdot 3}{10^6} GAv^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (59)$$

Thus the horse-power necessary varies :—

Directly as the density of the air.
Directly as the area of the plate.
Directly as the cube of the relative speed of plate and air.

Case of a Smooth Plane inclined to the Direction of Motion.

Let the smooth plane be inclined at an angle $\phi°$ to the direction of its motion (assumed a horizontal).

As the plane is smooth, the resultant pressure R upon it must be normal to its surface. may be resolved into a horizontal component H, or drag of the plane, which directly resists t progress of the plane, and a vertical component L which measures the upward thrust of the a or 'lift of the plane.'

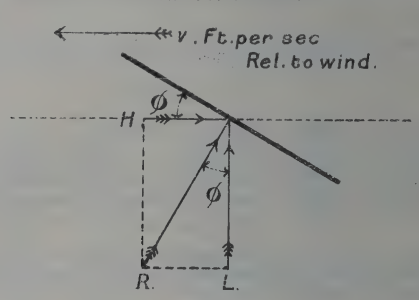


FIG. 1.

From fig. 1 it is evident that :—

$$H = R \sin \phi \quad . \quad . \quad . \quad . \quad . \quad (60) \qquad L = R \cos \phi \quad . \quad . \quad . \quad . \quad . \quad (61)$$

Experiments on the normal pressure of air on inclined planes show that the complete relatio connecting P, H, L, and ϕ is exceedingly complex. M. Eiffel finds that the value of $\frac{R}{P}$ is ind pendent of v; that it increases with the area of the plane; and that for rectangular plates wit the shorter dimension inclined, and for values of ϕ, in degrees, not exceeding 12 :—

$$\frac{R}{P} = \frac{3{\cdot}2 + 0{\cdot}5\, n}{100}\, \phi \text{ (app.)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (62)$$

where n is the proportion of span to chord of the plane, or its 'aspect ratio.'

In general the value of n is about 6; taking this value in Eq. (62) we get as an average cas

$$R = 0{\cdot}062\, \phi \text{ P. lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (63)$$

Hence from Eqs. (57), (60), and (61) :—

$$H = {\cdot}0012\, \phi \sin \phi\, GAv^2 = a\, GAv^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad (64)$$

$$L = {\cdot}0012\, \phi \cos \phi\, GAv^2 = b\, GAv^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad (65)$$

and as $E = \frac{1}{550} Hv$, we have,

$$E = \frac{2{\cdot}187}{10^6}\, \phi \sin \phi\, GAv^3 = c\, GAv^3 \quad . \quad . \quad . \quad . \quad (66)$$

whence, dividing Eq. (66) by Eq. (65) there results :—

$$E = \frac{1822{\cdot}5}{10^6} \tan \phi \times v\, L = k_0\, v\, L \quad . \quad . \quad . \quad . \quad . \quad (67)$$

which connects power, inclination, velocity, and lift.

In order to achieve horizontal flight the velocity v of the plane relatively to the air mus be just so great as to make the lift, L, equal to the weight of the plane, W.

Substitute, then, in Eq. (65), W for L, and we obtain on transposition :—

$$v_{min} = \frac{1}{\sqrt{b}} \sqrt{\frac{W}{GA}} = k_1 \sqrt{\frac{W}{GA}} \text{ feet per sec.} \quad . \quad . \quad (68)$$

Thus the speed necessary for horizontal flight varies :—

Directly as the square root of the weight of the plane.
Directly as the square root of the volume of 1 lb. of the air in cu. ft. (Table, p. 2024, col. 6).
Inversely as the square root of the area of the plane.

The horse-power necessary to just maintain horizontal flight is from Eqs. (67) and (68), putting W for L :—

$$E_{min} = k_0 k_1 \sqrt{\frac{W^3}{GA}} = k_2 \sqrt{\frac{W^3}{GA}} \quad . \quad . \quad . \quad . \quad . \quad (69)$$

Values of a, b, c, k_0, k_1 and k_2 from $\phi = 0°$ to $\phi = 12°$ are given in the following table.

ϕ in Degrees.	a. $\times 10^6$.	b.	c. $\times 10^6$.	k_0. $\times 10^6$.	k_1.	k_2. $\times 10^6$.
0	0	0	0	0	∞	0
1	21	·0012	·038	31·8	28·9	920
2	84	·0024	·1523	63·6	20·4	1,299
3	188	·0036	·3426	95·5	16·7	1,593
4	335	·0048	·6088	127·4	14·5	1,841
5	523	·0060	·9508	159·4	13·1	2,088
6	753	·0072	1·3684	191·6	11·8	2,265
7	1,024	·0083	1·8613	223·8	10·9	2,451
8	1,336	·0095	2·4291	256·1	10·3	2,627
9	1,689	·0107	3·0717	288·7	9·7	2,795
10	2,084	·0118	3·788	321·4	9·2	2,957
11	2,519	·0130	4·579	354·3	8·8	3,113
12	2,994	·0141	5·444	387·4	8·4	3,264

From Eq. (69) it is seen that the power necessary to maintain the plane in horizontal flight varies :—

Directly as the $\frac{3}{2}$ power of the weight.

Inversely as the square root of the density or directly as the square root of the bulkiness of the air as given in table, page 2024, col. 6.

Inversely as the square root of the area.

As the bulkiness of the air increases with the altitude, it appears from Eq. (68) that both the velocity necessary for horizontal flight and also the horse-power must increase as the plane ascends.

If the horse-power developed, E, exceed E_{min} the difference is expended in causing the plane to ascend. In the absence of any vertical resistance, the rate of ascent will be :—

$$\text{Rate of ascent} = \frac{550}{W}(E - E \quad) \text{ ft. per second} \quad . \quad . \quad . \quad (70)$$

When ϕ is small, sin ϕ and tan ϕ are each sensibly the same, and equal to $\frac{\phi}{57{\cdot}3}$, while cos ϕ is practically unity. Hence, as we are here considering values of ϕ not greater than 12°, we may with sufficient accuracy write :—

$$10^6 \times a = 21\ \phi^2. \qquad b = {\cdot}0012\ \phi.$$
$$10^6 \times c = {\cdot}038\ \phi^2. \qquad 10^6 \times k_0 = 31{\cdot}8\ \phi.$$

Accordingly Equations (64), (65), (66), and (67) respectively become :—

$$\text{If} = \frac{21}{10^6}\phi^2\ GAv^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (71)$$

$$L = {\cdot}0012\ \phi\ GAv^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

$$E = \frac{{\cdot}038}{10^6}\phi^2\ GAv^3 \text{ horse-power} \quad . \quad . \quad . \quad . \quad . \quad . \quad (73)$$

and

$$E = \frac{31{\cdot}8}{10^6}\phi\ v\ L \text{ horse-power} \quad . \quad . \quad . \quad . \quad . \quad . \quad (74)$$

From these equations it is seen that, within the range of inclination taken :—

The horizontal resistance, and the horse-power required, vary directly as the square of th angle of inclination of the plane, while the lift varies directly as the angle simply.

The velocity necessary for horizontal flight, v_{min}, diminishes as ϕ increases agreeably wit the values of k, as given in table, page 2027 ; but the necessary horse-power increases with increas of ϕ, as shown by the increasing values of k_2 (*vide* table, p. 2027), in consequence of th rapid increase in H.

AEROPLANES.

'Aeroplane' is the generic term for landplanes, seaplanes, and amphibians. Seaplanes ar urther subdivided into boat seaplanes and float seaplanes.

Aeroplanes may be broadly classed as follows :—

Monoplanes, having a single main plane, developed from the early Antoinette and Blériot aeroplanes.

Biplanes, having two superposed main planes, developed from the Wright and Farman design

Triplanes, having three superposed main planes, first put into practical form by Mr. A. V Roe.

There are no practical examples of more than three planes, but the development of larg aeroplanes may necessitate some such arrangement.

In general, the biplane gives the best all-round results, being stronger than a monoplan of equal lift and speed, and offering less head resistance than a monoplane of equal strength.

The very small Blériot monoplane which, on July 25, 1909, crossed the Channel from Cala to Dover, covering 31 miles in 43 minutes, had a wing span of only 25 ft. 7 ins., a total lengt of 26 ft. 3 ins., and a gross weight including pilot and in flying order, of only 650 lbs.

The superficial area of the planes was about 150 square feet ; sufficient petrol was carrie for a two hours' flight, and the engine was a 3-cylinder air-cooled 20 h.p. 'Anzani,' driving two-bladed airscrew. The wing frames were of ash covered with water-proofed linen.

The engine was placed in front, below the planes, and the pilot sat above the engine. Th seaplane was caused to ascend by depressing the after ends of the planes ; horizontal steerin was effected by a vertical rudder placed at the rear ; the planes were normally inclined about 8 to the horizontal.

It will be seen that the upward pressure amounted to $\frac{650}{150} = 4\frac{1}{3}$ lbs. per sq. foot of wing are in this case ; from 3 to 6 lbs. per sq. foot is usual, though in races, with shortened planes, th figure is said to rise sometimes as high as 10 lbs. per sq. foot.

A distance of 31 miles in 43 minutes implies an average speed, relatively to the *earth*, o $63\frac{1}{2}$ feet per second. If the Anzani engine developed just 20 b.h.p., the effective horse-powe with an airscrew efficiency of 70 per cent. was 14.

It is of interest to apply the formulæ obtained to the foregoing case. Thus we hav $W = 650$, $A = 150$; and as the flight was not at a great height, we may take $\frac{1}{G} = 13$ (table col. 6, p. 2024) ; also $\phi = 8$. Hence, Eq. (68) gives :—

$$v_{min} = 77 \text{ feet per sec.}$$

relatively to the *air*.

While, putting $L = 650$, Eq. (74) gives :—

$$E_{min} = 12\frac{3}{4} \text{ effective horse-power.}$$

Assuming the airscrew efficiency as 70 per cent., the necessary brake horse-power of the engin must accordingly be, roundly, $18\frac{1}{4}$.

Remembering that the formulæ were deduced for the simple case of a smooth true plan these figures may be regarded as giving a helpful indication. Actually the wings are neithe smooth (see table, p. 2030) nor are they true planes (see fig. 2, p. 2029) ; there is also the re sistance offered by the air to the body, rudder, stays, etc.. etc., of which no account has bee taken in the above investigation.

The velocity of the wind is, in general, least near the earth's surface, and in flying round closed circuit the effect of a wind from any quarter is, on the whole, to retard the aeroplane hence, in aerodrome speed trials (*i.e.* speed relatively to the *earth* pilots usually fly very nea the ground.

It appears from Eq. (69) that the horse-power necessary to maintain horizontal flight slowly creases with the altitude of the plane. Eqs. (68) and (69) show, in fact, that both the velocity d power for horizontal flight must increase in proportion to $\sqrt{\frac{1}{G}}$, that is, in proportion to the uare root of the bulkiness of the air. For example, at an altitude of 20,000 feet we have om table, col. 6 (p. 2024), $\frac{1}{G} = 24{\cdot}44$. Hence, in the case above taken, the necessary elocity at this height must be $77 \times \sqrt{\frac{24{\cdot}44}{13}} = 105{\cdot}5$ feet per second, while the effective orse-power must be $2\frac{3}{4} \times \sqrt{\frac{24{\cdot}44}{13}} = 17{\cdot}5$. Thus both the velocity relatively to the air, and e power, must, in this case, be increased by 37 per cent. to sustain horizontal flight at an titude of 20,000 feet, owing to the diminished density of the air.

For the first two or three thousand feet of ascent as $\frac{1}{G}$ alters but little (see table, p. 2024), ere is, in the example taken, an excess of $17\frac{1}{2} - 12\frac{3}{4} = 4\frac{3}{4}$ horse-power available for causing ascent, that, neglecting all vertical resistances, the plane would rise during the first part of its flight a maximum rate, agreeably with Eq. (70), of $\frac{4{\cdot}75 \times 550}{650} = 4{\cdot}0$ feet per second, or 1,000 feet in 15 minutes.

This, again, is a result of the right order of magnitude; for example, the winning machine the International Air Competition at Hendon on September 27, 1913, attained a height of 700 feet in 13·17 minutes, *i.e.*, at the rate of 1,000 ft. in about 4·9 minutes.

The types of aeroplanes now in general use are:—

Use.	Type.	Name.	Seats.	Engine.
Training	Biplane	Avro	2	100 h.p. rotary, air-cooled.
Reconnaissance	Biplane	Bristol Fighter	2	350 h.p. water-cooled 'V.'
Reconnaissance	Biplane	Panther	2	150 h.p. air-cooled rotary.
Scout	Biplane	Snipe	1	Radial or rotary air-cooled.
Reconnaissance	Biplane	Vimy	3	2–350 h.p. water-cooled 'V.'

Wings of Aeroplanes.

The main planes or wings of aeroplanes are commonly of rectangular form in plan, with a ansverse length, or 'span,' about 6 times the fore-and-aft length, or 'chord'; the ratio of ansverse to fore-and-aft length is termed the 'aspect ratio'; hence the 'aspect-ratio' has ually a value about 6.

The planes on either side of the fore-and-aft centre lines are set at an angle to the horizontal ane, known as the 'dihedral' or 'anhedral' angle, according to whether the planes are above or low the horizontal.

Experiments have shown that a good form of wing section is as indicated in fig. 2, and this known as the R.A.F. 14 wing section. The maximum ordinate—*i.e.* the vertical measurement om the chord—occurs at about one-third of the chord from the leading edge.

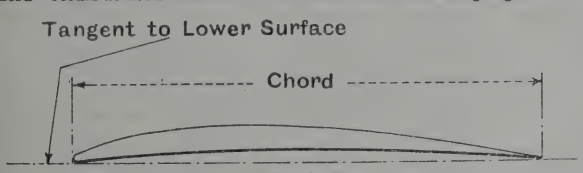


FIG. 2.

The actual shapes and characteristics of this and other wing sections are given in the tables on 2030, which represent the ordinates measured at right angles to the chord at varying distances om the leading edge of the section; the chord being taken as the tangent to the lower points the leading and trailing edges.

R.A.F. 14 WING SECTION.

Shape.			Characteristics.		
Dist. from leading edge, as fraction of chord.	Ht. above tangent, as fraction of chord.		Angle of Incidence (degrees).	Lift coeff.	Drag coeff
	Upper surface.	Lower surface.			
0	0·0068	0·0068	−4	−0·063	0·0216
0·01	0·0167	0·0015	−2	0·012	0·0126
0·02	0·0227	0·0006	0	0·084	0·0110
0·03	0·0278	0·0001	2	0·183	0·0121
0·04	0·0323	0·0000	3	0·234	0·0137
0·06	0·0400	0·0004	4	0·274	0·0158
0·08	0·0466	0·0020	6	0·348	0·0220
0·10	0·0525	0·0039	8	0·415	0·0293
0·15	0·0618	0·0094	10	0·474	0·0382
0·20	0·0663	0·0122	12	0·521	0·0514
0·30	0·0706	0·0139	14	0·542	0·0736
0·40	0·0682	0·0127	16	0·538	0·120
0·50	0·0650	0·0106	18	0·515	0·149
0·60	0·0608	0·0085	—	—	—
0·70	0·0543	0·0062	—	—	—
0·80	0·0428	0·0042	—	—	—
0·90	0·0265	0·0019	—	—	—
1·00	0·0038	0·0038	—	—	—

OTHER WING SECTIONS.

Shape.			Characteristics.		
Dist. from leading edge.	Ht. of upper surface.	Ht. of lower surface.	Angle of incidence (degrees).	Lift coeff.	Drag coeff
0	0·007	0·007	−6	−·145	0·0304
0·01	0·017	0·003	−4	−·06	0·0155
0·04	0·030	—	0	+·091	0·0083
0·08	0·041	0·001	+3	0·244	0·0119
0·22	0·057	0·010	8	0·420	0·0297
0·50	0·056	0·010	14	0·539	0·1085
0·80	0·035	0·002	20	0·490	0·180
0·98	0·010	—	—	—	—
1·00	0·003	0·003	—	—	—
0	0·012	0·012	−6	+·048	0·0448
0·01	0·034	0·003	−4	0·099	0·0389
0·04	0·076	0	0	0·362	0·0358
0·08	0·107	0·008	4	0·525	0·0418
0·22	0·150	0·054	10	0·757	0·0719
0·50	0·134	0·072	16	0·912	0·1128
0·80	0·071	0·034	20	0·536	0·188
0·98	0·015	0·002	—	—	—
1·00	0·006	0·006	—	—	—
0	0	0	−6	−·163	0·0258
0·01	0·007	−·005	−4	−·094	0·0153
0·04	0·023	−·008	0	0·063	0·0076
0·08	0·036	−·010	3	0·204	0·0108
0·22	0·056	−·013	8	0·382	0·0248
0·50	0·057	−·015	14	0·507	0·0885
0·80	0·031	−·011	20	0·455	0·167
0·98	0·007	0·005	—	—	—
1·00	0	0	—	—	—

The reduction of pressure on the *upper* surface actually contributes the larger portion of the fting force.

The value of the 'aspect-ratio' is important; if the wings be too long in a fore-and-aft rection diminished, performance results; at the Rheims aviation contest, by reducing the ore-and-aft length of the wings of his aeroplane by about one foot, M. Blériot, carrying the same eight as before, flew much faster with the same engine.

The 'Aerial Derby' of 1913 was won by G. Hamel, who, by shortening his wings prior to the ntest, averaged a speed of 76 miles per hour (relatively to the earth). It is obvious from Eq. (68) at a reduction in A causes an increase in v_{min}; the horse-power necessary must also be increased the same proportion, however, as is shown from inspection of Eq. (69). The wing area is now equently reduced for speed contests.

'Skin Friction' of the Planes.

The experiments of Dr. Zahm of Washington led him to conclude that, in proportion their densities, the frictional resistance of air is at least as great as that of water, and at this resistance is an important factor in the problem of high-speed flying. Some of r. Zahm's results are exhibited in table below. He states also that 'the frictional resistance a plane or arched surface soaring at small angles on a horizontal course is equal to the *horizontal rojection* of the surface multiplied by the average friction per square foot as given by table elow.'

Experiments were made to determine the effect of the nature of the surface of the plane upon e frictional resistance; practically no difference was found with dry varnish, sticky varnish, et surface, sheet zinc, glazed cambric, calendered or uncalendered paper, or drawing paper. ith coarse buckram having sixteen meshes to the inch, the friction at 10 ft. per second was, owever, found to be from 10 to 15 per cent. greater than with the uncovered surface.

FRICTION OF AIR PER SQUARE FOOT OF PLANE FOR VARIOUS FORE-AND-AFT LENGTHS. (*Dr. Zahm.*)

Speed of Wind. Miles per hour	Lbs. per sq. ft. Friction for fore-and-aft lengths of plane of					
	1 Ft.	2 Ft.	4 Ft.	8 Ft.	16 Ft.	32 Ft.
20	·00402	·00384	·00365	·00349	·00332	·00317
25	·00602	·00579	·00551	·00527	·00501	·00478
30	·00850	·00810	·00772	·00736	·00701	·00668
35	·01130	·0108	·0103	·0098	·00932	·00888
40	·0145	·0138	·0132	·0125	·0125	·0114
50	·0219	·0209	·0199	·0190	·0181	·0172
60	·0307	·0293	·0279	·0265	·0253	·0242
70	·0407	·0390	·0370	·0353	·0337	·0321
80	·0522	·0500	·0474	·0452	·0431	·0411
90	·0650	·0621	·0590	·0563	·0536	·0511
100	·0792	·0755	·0719	·0635	·0652	·0622

Calculation of Frictional Resistance and Horse-Power.

In using the above table, it must be remembered that a material plane exposes *two* surfaces the action of the air. For example, the frictional resistance of a material plane of 24 feet span, d with a fore-and-aft length ('chord') of 4 feet, at a speed of 80 miles per hour relatively to e air, is to be estimated as follows:—

From the table the friction per square foot for a fore-and-aft length of 4 feet at a relative eed of 80 m.p.h. is ·0474 lb.; and as there are $2 \times 24 \times 4 = 192$ square feet of total area posed to the action of the air, the total frictional resistance of the material plane is $192 \times 0474 = 9{\cdot}1$ lbs.

Eighty miles per hour $= 1{\cdot}47 \times 80 = 117{\cdot}6$ feet per second; hence the work necessary to vercome friction alone is $117{\cdot}6 \times 9{\cdot}1 = 1070{\cdot}2$ foot-lbs. per second; and thus $\frac{1070{\cdot}2}{550} = 1{\cdot}95$ orse-power must be expended to overcome this resistance. In the practical design of aeroplanes is, of course, necessary to take account not only of the frictional resistance of the wings, but lso that of the body, stays, and other parts of the machine exposed to the relative velocity f the air.

Control of Aeroplanes.

When the Aeroplane is Flying on an Even Keel.

When in flight an aeroplane has freedom of motion in three dimensions about its own cent Its motion in these dimensions is controlled by :—

The Rudder, a movable vertical surface, adjusted by the pilot's feet, controlling the directi of flight in a horizontal plane.

The Elevator, a movable horizontal surface adjusted by a lever in the pilot's hand, controlli the direction of flight in a vertical plane within the limits set by the lift of the main planes a the power developed by the engine.

The Ailerons, small movable planes attached to the outer ends of the main planes, arrang so as to increase or decrease the lift on either side of the aeroplane and adjusted by the sa lever which controls the elevator. The ailerons enable the aeroplane to be kept lateral horizontal, and to be tilted or ' banked ' as required for any manœuvre in the air.

Adjustable Tail Gear.—This gear enables the tail of an aeroplane to be adjusted in flight, a so in effect controls the aeroplane as an elevator. By setting the adjustable tail, an aeropla can be made to climb or to fly in any given attitude without having continually to exert a for upon the control column.

Wing Flaps.—Wing flaps are used to supplement the action of ailerons, but differ slight from ailerons in that the flaps are both moved in the same direction relatively to the aeroplan It is by the use of such flaps that the minimum flying speed of an aeroplane can be adjuste with the result that for a given speed the lift of the main planes can be increased. This is great advantage when an aeroplane is getting off or landing, as in the former case it is enabl to rise from the ground or water much more quickly, while in the latter the speed of contact the aeroplane is considerably reduced.

Stability.

Aeroplanes may be unstable, or inherently stable. The former require constant vigilan on the part of the pilot, or the incorporation of some mechanical device such as the Sper Gyroscopic Stabiliser, which gives them ' automatic stability.' The latter possess a tendency return to their normal flying position after any disturbance.

Inherent stability is obtained by correct proportioning of the main and auxiliary planes a their dihedral angles, and a proper balancing of the couples about the centre of the aeroplan due to the lift and resistance of the planes, the mass of the aeroplane, and the thrust of th airscrew.

Unstable aeroplanes can be manœuvred more rapidly and accurately than can highly stab aeroplanes : they are therefore more suitable as fighting machines, whilst the latter have a wid application for commercial purposes.

Airscrews.

Airscrews are now constructed either of wood or metal. In the former case, laminations hard wood, usually walnut or mahogany, are glued and pegged together and shaped to the corre pitch and blade section. In the case of metal airscrews, these are made of sheet steel, shape to the correct blade section, the details of manufacture being greatly varied. Some met airscrews are constructed with hollow steel blades which are welded at the root to a suitab metal boss.

The tips of wooden airscrews are sometimes sheathed with metal, usually brass or copp to protect the thin portions of the blade. This metal tipping is often adopted for seaplane and where airscrews are liable to be sprayed with water while running at high speed.

For the sake of efficiency, airscrews should be of large diameter, and should run at a lo speed. In large engines, a reduction gear is usually incorporated so as to allow the engine t run at a higher speed than the airscrew. With modern airscrews, an efficiency as high a 77 per cent. and over has been obtained.

Colonel Dorand has found that the diameter of the airscrew should be proportional to th weight supported per h.p. and to the square root of the total weight of the aeroplane. Also, tha the r.p.m. of the airscrew should be inversely proportional to the square of the weight supporte per h.p. and to the square root of the total weight.

The loss in the efficiency of airscrews running at a high speed is serious, and has been foun greater than any gearing loss ; therefore, for engines running at high rotational speeds, it i

ecessary to fit reduction gearing to allow the airscrew to run at about 1,200 r.p.m. Tip speeds p to 800 ft. per second have been used, but it is better for the speed not greatly to exceed 00 ft. per second.

An exhaustive treatise on aviation is that of Mons. G. Eiffel, entitled 'The Resistance of the ir and Aviation' (Eng. Trans. by J. C. Hunsaker, Constable & Co., 42*s*.); the subject is treated s completely as is at present possible, and the work may be studied with advantage by ngineers interested in the design and construction of aircraft.

Windmills.—Windmills are reversed airscrews, and are used considerably for driving secondary ower units on aeroplanes. Their aerodynamic features follow very much on the lines of air- crews, and a suitable aerofoil section is adopted for the blades. The characteristics of windmills re such that they can give a certain power at two distinct speeds, and if power be plotted against otational speed for a given forward speed, it is found that the power increases to a maximum nd then falls off. The limiting conditions of no power are when the rotational speed is zero, nd when the rotational speed is such that there is no slip of the windmill relatively to the air.

The conditions of use of windmills decide that they should be restricted in size, and conse- uently most of the windmills now used are of a comparatively small diameter with wide blades.

Resistance of Wood to Reversals of Stress.

The limiting resistance of spruce (used for aeroplane wing spars) to alternate tension and com- ression was proved by experiment to be above 1,600 lbs. per sq. inch, and below 1,970 lbs. per sq. nch. For spruce of this quality the safe range of stress under reversals of bending would be pproximately ± 1,800 lbs. per sq. inch, or one-quarter of the ultimate stress, which was found to e 6,800 lbs. per sq. inch. In this respect spruce appears to be at a slight disadvantage compared ith mild steel, in which the safe limit of stress under similar circumstances is generally about ne-third of the ultimate stress. (*The National Physical Laboratory.*)

Resistance of Tension Members of a Structure to Lateral Vibrations.

In cases in which the tension members of a structure are attached to the pin joints of the ame by means of a screw connection unaccompanied by a universal joint, it has been found hat the screws are liable to the development of fatigue cracks at the bottom of the threads, and o ultimate failure.

It has been found that if a universal joint be provided at both ends of a wire subjected to lateral ibrations, a load of one-third of the breaking load will in the case of high class material be borne or an unlimited number of vibrations, but that if only a single joint be used fracture takes place nder one-sixth of the breaking load after a few hours. (*The National Physical Laboratory.*)

Rivet for Aircraft Construction.

This rivet, the invention of Lieutenant J. W. Iseman, is for use in Duralumin construction ork in positions where it is difficult to hammer at one end and support the other, but it is also daptable for other purposes, and is a very ingenious arrangement.

The rivet is shown in fig. 3 in position both before and after riveting. A hole ending in a

Fig. 3.

onical point is drilled through the head of the rivet in the direction of the axis, as shown at **A**. The base of the cone starts at the end of the nominal grip length of the rivet, this being equal to he thickness of the riveted plates. The end of the rivet is slotted up to the grip with two slots at right angles.

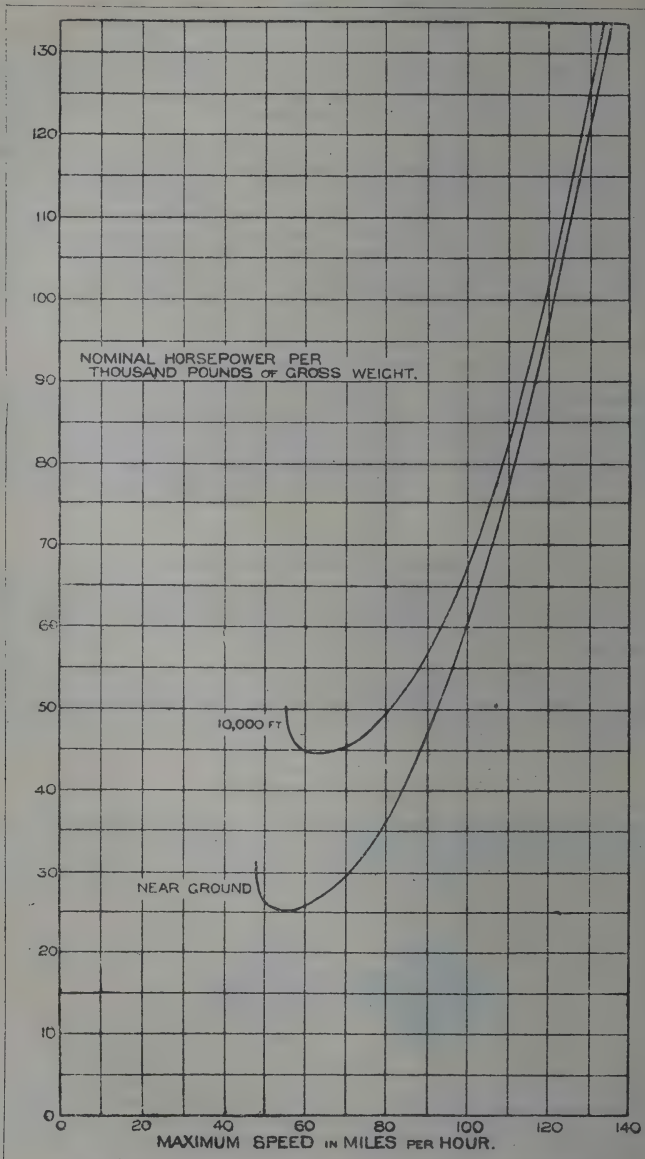


FIG. 4.—Curves showing how speed varies with ratio of H.P. to gross weight.

A pin of the same diameter as the hole and ending in a similar cone is tapped into the rivet ıtil the end is flush with the head, as shown at **B.** This pin causes the slotted end to spread ı as the straight side of the pin travels along the side of the cone. When the pin is home, the ies of the cone are parallel to the axis of the rivet as at **B.**

It is found that friction and binding between the rivet and the pin are quite sufficient to hold e latter in place.

Tests of these rivets have shown that with an outside diameter of 0·127 in. and a pin 0·053 in. diameter, a shear strength of 450 lb., of 35,500 lb. per square inch, can be developed.

Rough Prediction of Aeroplane Performance.*

The curves (fig. 4) show how the speed of flight near the ground and at 10,000 ft. depends ı the nominal power of the engine and the gross weight of the aeroplane. The ratio of horse- ıwer to weight is used. Regarded as an empirical curve, however, it is found that the rformances of the smallest and largest aeroplanes are equally well predicted. Like all general- ıtions it has its limitations, and a designer who has given special attention to one type will ; able to give a closer prediction. On the other hand, any record of performance showing riking departure from the curve may be regarded with mistrust.

The curves illustrate the aerodynamic disadvantages of high speed. It is to be noted that a oss weight of 1,000 lbs. can be carried by an aeroplane of modern type for an expenditure of ı h.p., but there is no reserve and the pilot could not climb or cope with down currents. His eed would be about 55 m.p.h. The necessary horse-power for the same load could be reduced ı providing bigger wings and flying slower, and it has been pointed out by various writers that e most economical design aerodynamically requires speeds of flight below those of commercial ility.

Using the curves of fig. 4, it can be seen that the aerodynamic quality of the aeroplanes the beginning of the war was not appreciably less than those of the present day, for all give rformances indicated by the curve. Progress has followed the development of the aero-motor hich now permits the use of one horse-power for each 8 lbs. of gross weight, whereas in 1914 e same power was yoked to a load of nearly 25 lbs. The most recent of our large aeroplanes rries nearly 20 lbs. per horse-power, and its performance on speed and ceiling is not greatly fferent from that of the 'Avro' or B.E.2C. It is now accepted as a fundamental truth that the eight-carrying aeroplane cannot be the fast aeroplane, and the rate at which the horse-power rve is rising shows that the conditions become progressively worse. It needs little imagination see that increase of top speed beyond present limits will not easily be attained, and that no eat increase such as that during the war period is within the limits of reasonable expectation. ıe table given below is instructive in the economics of aeroplane carriage.

Speed of flight, m.p.h.	Gross weight, lbs. per h.p.	Percentage of gross weight available for passengers and merchandise.
60	38	45
70	35	44
80	28	41
90	21	38
100	17	33
110	13	27
120	10	20
130	8	10

It will be seen that the choice lies between a time of six hours and a useful load of 40 per cent. the total and a time of four hours and 20 per cent. of the load useful. Only the particular need the moment can determine a final choice. (*Leonard Bairstow, F.R.S.*)

Storage of Aircraft.

To maintain good efficiency and reliability considerable attention must be given to aircraft uring the time they are not actually in flying condition, as storage in an indiscriminate manner ads to rapid deterioration of the aeroplane structure, with consequent financial loss, and the troduction of factors which may be dangerous when the aeroplane is afterwards flown.

* Extract from the Wilbur-Wright Lecture, 1919, 'Progress in Aviation in the War Period,' elivered before the Royal Aeronautical Society by Leonard Bairstow, F.R.S., C.B.E.

Many of the methods used for the storage of aeroplanes have up to the present been formulated by a process of trial and error, but by experience it is now possible to say which are the best methods.

It is necessary that care should be taken not only with the storage of the aeroplane, but also with the selection of the storage building. Such buildings should be weatherproof, ample size, and, if possible, be equipped with plant for maintaining fairly constant atmospheric condition

Given a suitable building, each complete aeroplane or its component must be stored so that no heavy parts are allowed to hang on weak points of structure. Loads thrown on the centre of an unsupported span should be avoided, as such loads may produce permanent deformation of the structure and may be sufficient to render the aeroplane or its part unserviceable. Stored aircraft should be subjected to periodical inspections in order to detect deterioration; to permit these inspections the aeroplane shed should be arranged so as to give access to all the principal components such as main planes, engines, and controls.

Methods of Storage.—There are three methods of storage which may be adopted, namely,

(*a*) Aircraft fully erected but with tanks empty. In the case of large aeroplanes, with the main planes folded.

(*b*) Aircraft dismantled into its principal parts and the parts located together.

(*c*) Aircraft dismantled into its principal parts and the parts stored separately.

Method (*a*) is adopted when the aeroplane is likely to be required for flight at short notice as it is only necessary to take the aeroplane from the storage shed and make the appropriate rigging adjustments in order to place the aeroplane in flying condition.

Method (*b*) is used where an aeroplane will not be required for immediate use, and the method is devised principally to ensure that the association of the various parts of each aeroplane may be maintained.

In method (*c*) the procedure follows much on the lines of (*b*), but in this case instead of the components of each aeroplane being kept together they are placed in common storage with similar parts of other aeroplanes.

Stored aeroplanes should be screened from strong sunlight, either by colour washes on the roof lights of shed, or by employing non-actinic glass in the roof lights, as it has been found that sunlight has a deteriorating effect on the doped fabric, causing the doped film on the latter to crack, and so allow moisture direct access to the fabric; rubber is also affected by sunlight, and cracks after prolonged exposure.

In the case of storage by methods (*a*) and (*b*) a film of oil should completely cover all the internal surfaces of the engine, and as a further safeguard this oil should be renewed at intervals of about one month. The oil used should be a high-class mineral oil, and after being injected through the sparking-plug holes the engine should be turned a few times to distribute the oil over the interior surfaces. When renewing the oil, all the old oil should first be drained from the engine.

Rigging of Aeroplanes.

Before an aeroplane is flown, it has to be erected so that its principal parts bear a definite relation to each other.

The features which are special to rigging are, principally, angle of incidence, dihedral angle, gap, chord, stagger, tail plane incidence and setting of controls.

The angle of incidence is limited to the value of the angle which the chord of the main plane makes with a horizontal or datum line when the aeroplane is in rigging position.

A typical design may be taken in the form of a single-engined tractor biplane:

Fuselage.—The fuselage is first erected and trued up, and where longerons and struts with cross bracing are used, it is necessary to adjust the bracing so that the whole structure conforms to its designed shape. The structure may be symmetrical, either in plan or elevation, or both, and when this obtains, the condition of symmetry is checked by reference to a centre line stretched along the length of the fuselage. Each bay of the fuselage is then adjusted until the members are in correct position, particular care being taken to see that the fuselage does not become twisted. After this preliminary truing up the engine, upper centre section, tail plane, fin and other such fittings may be attached to the fuselage.

With the fuselage thus erected, it is supported on suitable trestles, one being placed under the front portion and another under the tail, and adjustments made until the fuselage is in rigging position, *i.e.* until a datum line (usually fixed by the designer) is horizontal; this line is sometimes indicated by points on each of the struts of the fuselage, or alternatively, it may be obtained by stretching a line between certain fixed points at each end of the fuselage.

Undercarriage.—Taking an undercarriage of the ordinary Vee strut type, this is assembled and attached to the fittings on the fuselage. In this position it will really be slung from the fuselage so that the wheels, if fitted, will be just clear of the ground. Where Vee struts are used, longitudinal adjustments cannot be carried out, and it remains for the undercarriage to be symmetrical about the centre of the fuselage when viewed from the front. Adjustments in this direction are usually obtained from cross bracing wires which extend from near the axle end to the point of attachment of the front undercarriage struts to the fuselage; by making these bracing wires of equal length, the correct position of the undercarriage is obtained.

In this position the weight of the undercarriage may be taken by placing packing blocks under the axle ends or where the axle meets the Vee struts.

Main Planes.—The main planes are usually treated in pairs on each side of the aeroplane, and for aeroplanes with two pairs of interplane struts on each side and of span up to 30 feet, each pair of planes is assembled on the ground with the struts and bracing wires loosely attached. The whole is then lifted into position on the fuselage and the bracing wires connected up. The weight of the planes is then carried by the bracing wires, but to augment this support, trestles are placed under the lower main planes below the outer interplane struts and packed up until they meet the spars of the lower main planes. The fittings for the lower main plane spars are rigidly attached to the lower portion of the fuselage, so that the chords of these main planes will be at a definite angle to the datum line on the fuselage, this angle being the angle of incidence. Apart from 'wash in,' 'wash out,' or other refinements, this angle of the chord will be maintained throughout the span of the main plane and, in the case of planes without décalage, the chords of the upper planes will be parallel to those of the lower. The lengths of the interplane struts will determine the attitude of the upper main planes, and if struts of the proper length are used, the incidence of the upper main planes will be approximately correct. The interplane bracing wires are then adjusted to give the designed dihedral angle which is varied by raising or lowering the tips of the planes. In a similar manner, the stagger, or forward displacement of the upper plane relatively to the lower, is obtained, but, in this case, the bracing wires between the interplane struts are used for adjustment. When all the settings of the planes have been correctly adjusted, all the bracing wires are carefully tightened and locked, undue tightening being avoided as it has a tendency to bend the interplane struts. The angular settings of the planes may be checked by a measuring device such as an inclinometer, and the symmetrical arrangement of the planes by taking measurements from the top of the front outer interplane strut to the root of the front spar of the lower plane on each side and seeing that these measurements are equal.

Tail Plane.—The tail plane is set in the centre of its travel, and this position used as a basis for rigging. In this position the centre line of the tail plane will be inclined to the datum line of the fuselage at a small angle, and this setting may be obtained by altering the zero setting of the adjusting mechanism.

Controls.—The control surfaces consist of the ailerons, rudder, and elevators, and these are hinged to the main planes, stern post, and tail plane, respectively. After attachment, the cables from the pilot's controls are connected and the setting of each surface is arranged as follows:—

Ailerons.—With the pilot's control column in its central position, the trailing edges of the ailerons should droop approximately $\frac{1}{4}$ inch.

Rudder.—With the rudder bar square in the fuselage, the rudder should point directly fore and aft.

Elevators.—These are usually considered to be a continuation of the tail plane when in its normal position, and in this position the pilot's control column may be slightly out of the vertical and lean forwards or backwards according to the requirements of the design.

Autogyros.

Autogyros embody some of the features of the standard type of aeroplane coupled with certain characteristics of a helicopter. The chief features of the design consist of an aeroplane fuselage which is lifted by rotating wings that form a windmill over the fuselage. The fuselage is fitted with a power unit of the usual type and the rotation of the windmill occurs by a process known as 'auto-rotation.' A flying machine of this type has been constructed by Señor de la Cierva and successfully flown. The fuselage is that of a standard Avro type 504 biplane and the power unit consists of a 100-h.p. Le Rhône engine with a standard wooden airscrew. The fuselage has the usual type of tail unit and is supported on an Avro under-carriage. The rotating windmill, from which the lift is derived, is formed with four blades, and the central pivot for the windmill is carried on a vertical mast which is rigidly attached to the fuselage. Each blade of the windmill is set to provide a small angle of incidence, and an up-and-down movement of the blade is allowed for by a pin joint at the root end of the blade. To prevent the blade from dropping

while the windmill is stationary, the weight of each blade is carried by a length of shock absorb elastic, which has its end fixed to the top of the vertical mast, so that it can rotate with the blad The machine has the usual flying controls of the ordinary type of tail unit. Lateral control effected by two small stabilisers, one on each side of the fuselage. Each stabiliser is carried the end of a spar that projects from the side of the fuselage much in the same way as a spar the standard wing system. Before commencing a flight, the wings of the windmill are rotat by man-power, and owing to the inertia of the system, and the small bearing friction, the rotati continues for some time. The rotation is effected by first winding a cable round pegs on t lower side of the wings and then pulling on the cable to unwind it and so spin the windmill. T machine is then taken into the air in the normal manner, *i.e.* by running along the ground, a when the necessary speed of the windmill has developed, the machine lifts into the air and co tinues to fly by the forward force provided by the airscrew and the upward force derived from t rotating windmill. The maximum flying speed with the expenditure of 90-h.p. is about 1 kilometres per hour, and the slowest forward speed at which the machine has been flown is abo 54 kilometres per hour. Owing to the nature of the design, a very steep landing angle can used, and when descending at an angle of 30°, the landing speed is about 4 metres per seco horizontally and 2 metres per second vertically. The rotational speed of the windmill remai practically constant at about 130 r.p.m. throughout the range of flying conditions. The ma dimensions of the rotating wings are: span 35 ft., chord 3 ft., incidence 2°, and the weight of t complete machine is roughly 1,400 lbs.

Notable Flights.

Atlantic Flights.

The first crossing was made by the seaplane N.C.4, piloted by Commander Read, which acco plished the journey from Newfoundland to Plymouth in three stages, as follows:—

Newfoundland to Azores	1,381 miles	15 hours	19 mins.
Azores to Lisbon	1,034 ,,	9 ,,	42 ,,
Lisbon to Plymouth	895 ,,	5 ,,	1 ,,

The attempt made on May 18, 1919, by the late Mr. H. G. Hawker and Lieut.-Command Grieve in a single-engine Sopwith machine failed, the aviators being picked up 1,000 miles fr land by the small ship *Mary*.

Three weeks later the direct crossing was successfully accomplished from St. John's to Galw Bay, Ireland, by a Vickers-Vimy double-engined (Rolls-Royce) aeroplane (fig. 5), piloted Captain John Alcock, D.F.C., and navigated by Lieut. Arthur Whitten Brown. The 1900 nauti miles were compassed in 15 hours, 57 minutes. For this performance the airmen were knighted His Majesty the King.

In the following month, a British airship, R34, starting on July 2, 1919, from England, cross the Atlantic to Newfoundland, and went on to New York, whence it returned direct to its starti point, arriving on July 13. This flight was remarkable for the fact that the airship was, duri the whole of its six-thousand-mile trip, in wireless communication with the Air Ministry in Londo Moreover, it was furnished with continuous information as to weather conditions ahead of and was able to modify its route in order to avoid storm-swept areas.

In 1927 the Atlantic was flown several times. On May 20, at 8 A.M., Capt. C. Lindbergh s out from New York on a Ryan monoplane fitted with a 220-h.p. Wright Whirlwind engine, wi the object of flying the distance of 3,600 miles to Paris. Le Bourget was reached at 10.22 P. on May 21. The pilot was single-handed, and he had neither wireless nor the special navigati instruments usually employed for such purposes. The fuselage of the machine was of st construction, and the wings were braced by sloping struts to the fuselage. The landing gear h a wide track with no axle. The gross weight of the machine with 425 gallons of fuel and 28 gallo of oil was 4,750 lbs., and the speed range with full load was 69–123 m.p.h.

Another of the Atlantic crossings was made by Commander Byrd on June 29. A total cr of four and extensive equipment were carried. A machine called the 'America' was used, bei a Fokker monoplane with three Wright Whirlwind engines. The start was made at dawn fr Roosevelt Field, Long Island, and after leaving Newfoundland the machine ran into fog whi caused the crew to lose sight of sea and sky for nineteen hours. On reaching France at nightfa on June 30, the weather became adverse and the crew were lost for some hours. Eventually was decided to find the coast and alight on the water, and in doing this at 2.30 A.M., near t village of Ver-sur-Mer, between Cherbourg and Havre, the machine was damaged but the cr were unhurt.

Anglo-Australian Flight.

The Australian Government prize of 10,000*l.* for a flight from England to Australia, in a heavier-than-air machine of British construction, was also won by a Vickers-Vimy aeroplane, piloted by Captain Ross Smith, accompanied by his brother, Lieut. K. M. Smith, and two sergeant mechanics. This wonderful journey, commenced on November 12, 1919, was completed in twenty-eight days, the total flying time being only 124 hours. This makes it evident that by organising relays of aeroplanes it would be possible to provide a mail service to Australia with a transit time of less than one week.

FIG. 5.—Atlantic Flight: Vickers-Vimy Rolls-Royce Aeroplane. (Now in Victoria and Albert Museum.)

Length 47 ft.
Span 70 ft.
H.P. 700 (2 Eagle Rolls-Royce of 350 h.p.)
Total weight 16,000 lbs.
Time crossing Atlantic 15 hrs. 57 mins.
Carried 867 galls. of petrol. (Used two-thirds of this.)
Cruising speed 80 m.p.h.
Maximum speed 105 m.p.h.
Climbs to 25,000 ft.

First Flight across Asia.

Lieuts. Ferrarin and Masiero started from Rome on February 14, 1920, and flew across Asia to Japan, arriving at Tokyo on May 31. Intermediate stops were made at the under-mentioned cities: Adalia, Bagdad, Bunder Abbas, Delhi, Calcutta, Rangoon, Bangkok, Canton, Tsingtao, Peking, Seoul, and Osaka.

London to Turin, Direct Flight.

On May 31, 1920, Mr. Bert Hinkler, an Australian pilot, left Croydon at 4.50 A.M., flying a Baby Avro with a 35 h.p. Green engine—which engine had been built in 1910.

Passing over Dover, Paris, Lyons, and clearing the Alps, he arrived, without an intermediate stop, at Turin at 2.20 P.M. on the same day.

Six hundred and fifty miles in 9½ hours on twenty gallons of petrol.

For fuel economy this flight brings the aeroplane into competition with the motor-car.

London to Rangoon.

In November 1924 a flight was made by Mr. A. J. Cobham, with Air Vice-Marshall Sir W. Sefton Brancker as a passenger, from Croydon Aerodrome to Rangoon, and the return journey was completed on March 18, 1925.

During the flight 17,000 miles were covered in a flying time of 220 hours, and the aeroplane used was a D.H. 50 fitted with a 230 h.p. Siddeley Puma V. engine.

During one portion of the journey the aeroplane was forced to land in a snowstorm, and it had to be dismantled, transported 50 miles by road, and re-erected by unskilled personnel, all of which was accomplished in 36 hours.

London—Cape Town—London.

On March 12, 1926, Mr. Alan Cobham (Sir A. Cobham) completed a successful flight from Stag Lane aerodrome in London to Cape Town and return. The aeroplane used was a D.H. 50 J. fitted with a 385-h.p. Armstrong Siddeley Jaguar engine (see p. 2061), and the total distance flown was 17,000 miles. The homeward journey was accomplished in 15 days.

England—Australia—England.

Between June 30 and October 1, 1926, Mr. Alan Cobham (Sir A. Cobham) accomplished a successful flight from England to Melbourne and return. The journey covered a distance of 28,000 miles and was performed on a D.H. 50 J. aeroplane fitted with a Siddeley Jaguar engine (see p. 2061) of 358 h.p.

It took 37 days to fly from England to Port Darwin, Australia, a distance of approximately 11,380 miles, and then another 8 days to fly to Melbourne, a further distance of 2,650 miles. On the homeward journey it took 5 days from Melbourne to Port Darwin, and then 28 days to reach England. The total flying time was 320 hours.

Round Australia.

On June 29, at 14·45 hours, Mr. Kingsford Smith and Mr. Ulm arrived at Mascot aerodrome Sydney, after having flown round Australia in ten days on a Bristol Tourer (240-h.p. Puma engine)

The Longest Oversea Flight.

On June 29 Lieuts. Maitland and Hegenberger, of the U.S. Air Corps, arrived at Honolulu after having flown across the Eastern Pacific from San Francisco in a Fokker F. VII-3m. (three 200-h.p. Wright Whirlwind engines).

The distance of 2,400 miles was covered in 25 hours 13 minutes. This is the longest flight made entirely over the sea.

BRITISH SPEED RECORDS.

In December 1921, at Martlesham Heath, Mr. J. H. James achieved a maximum speed of 212 m.p.h. over the measured kilometre, and averaged in four trials 196 m.p.h. This was accomplished on a Bamel machine with Napier 'Lion' engine.

AERIAL DERBY, 1923.

The 1923 Aerial Derby was won by L. Carter on a 'Gloster' aeroplane built by the Gloucestershire Aircraft Company, with a 450-h.p. Napier 'Lion' engine.

The speed of the winner for the two-circuit 200-miles route worked out at 192·4 miles per hour

There was no race in 1924.

FLYING BOAT TROPHY, 1923.

The International Flying Boat Trophy—open to all flying boats in the world—was won for U.S.A. by Lieut. David Ruttenhouse on a Curtiss Navy Racer with Curtiss D 12 465 h.p. engine

The speed of the winner averaged 177·38 miles per hour.

KING'S CUP RACE, 1923.

His Majesty the King presented, in 1912, a cup to the Royal Aero Club for competition in an air race around Britain.

Croydon was the starting-point, and calls had to be made at Birmingham and Newcastle *en route* to Glasgow, where the aviators stayed over night, completing the circuit on the second day via Manchester and Bristol.

Twenty-two competitors started, and eleven completed the circuit. The first prize was won by Captain F. L. Barnard on a war-time D.H. 4A., with a 350 h.p. Rolls-Royce Eagle VIII engine. His average speed for the whole circuit of 180 miles was 123 miles per hour.

F. P. Raynham, in a Martinsyde F. 6, with a 200 h.p. Wolseley 'Viper' engine, was second; average speed 105 miles per hour; and Alan J. Cobham, in a D.H. 9B., with 230 h.p. Siddeley 'Puma,' was third, average speed 810 miles per hour.

In 1925 the race was flown on two consecutive days over a circuit of Britain commencing and finishing at Croydon and passing the following places:

Harrogate, Newcastle, Renfrew, Blackpool, Shotwick, and Bristol.

On the first day the competitors went in the direction of Croydon to Harrogate, and the second day from Croydon to Bristol. The total distance of each circuit was 804 miles, and the result of the race was as follows:

	Aeroplane.	Engine.	Pilot.	Net Flying Time. First Day.			Second Day.		
				Hrs.	Mins.	Secs.	Hrs.	Mins.	Secs.
1.	A. W. Siskin V.	395 h.p. Jaguar	Barnard	6	11	17	5	18	58
2.	D.H. 37 Sylvia	275 h.p. Falcon	Hemming	9	59	14	6	43	51
3.	A. W. Siskin IV.	395 h.p. Jaguar	Jones	7	1	51	5	41	3

King's Cup Race, 1926.

In 1926 it was a handicap race, and was flown on July 9 and 10 over a total distance of 1,464 miles. The course for each day consisted of two triangular laps, each being flown twice, with the start and finish at Hendon. One of the laps was via Martlesham and Cambridge, a distance of 166 miles, and the other was via Coventry and Cheltenham, a distance of 200 miles. At Hendon a compulsory stop of either 30 minutes or 1 hour was made between each lap, and competitors were not to land at any other points.

There were sixteen entrants for the race, two of which proved non-starters. During the race nine machines retired, and the final result was as follows:

Position.	Identification Letters.	Machine.	Engine.	Pilot.	Total Time, 732 miles.	Total Time, 1,464 miles.	Average Speed.
					h. m. s.	h. m. s.	m.p.h.
1	G-EBMO	D.H. 60 Moth	27-60 Cirrus I.	Capt. H. S. Broad.	8 5 53	16 22 20	90·4
2	G-EBIP	Vickers Vixen	450 Napier Lion.	Flt. Lt. E.R.C Scholefield.	5 11 51	10 25 0	142·2
3	G-EBKL	Martinsyde A.D.C. 1.	395 Siddeley Jaguar.	Sqd. Ldr. H.W.G.Jones	4 54 12	9 45 14	151·9
4	G-EBLW	D.H. 60 Moth	27-60 Cirrus I.	Capt. W. J. McDonough	8 55 58	18 13 6	80·25
5	G-EBLI	D.H. 60 Moth	27-60 Cirrus I.	Capt. F.G.M. Sparks	9 14 51	18 9 38	80·4

King's Cup Race, 1927.

In 1927 the race was flown on July 30. It consisted of a total distance of approximately 540 miles, composed of three courses of approximately 180 miles each. The first course, which was flown twice, covered the counties of Leicestershire, Rutlandshire, Huntingdonshire, Cambridgeshire, Norfolk, and Lincolnshire, and the turning-points were at Spittlegate, Huntingdon, King's Lynn, and Cranwell. The second course passed over Nottinghamshire, Yorkshire, and Lincolnshire, with turning-points at Howden (Yorks.) and Skegness. The start and finish of each course was at Hucknall, Notts, and the competitors had to alight at the aerodrome after each course and make a compulsory stop of 30 minutes. All the competitors were handicapped according to the assumed capabilities of their machines.

There were 26 entrants for the race, 10 of which proved non-starters, and 6 machines finished the race.

The times and speeds of the first three machines to finish were as follows :

Position.	Identification Letters.	Machine.	Engine.	Pilot.	Handicap Allowance.	Total Flying Time.	Average Speed.
					h. m. s.	h. m. s.	m.p.h.
1	G–EBME	Moth	Cirrus I.	W. L. Hope	3 25 9	5 50 14	92·3
2	G–EBRL	Widgeon III.	Cirrus II.	Capt. Mac-Donough	2 14 28	5 15 49	102·8
3	G–EBIP	Vixen	Lion	Flt.-Lt. Scholefield	1 3 32	3 49 23	141·6

The International Schneider Cup Seaplane Race.

The International Schneider Cup Race has been an annual event to determine the highest speed attainable among international aircraft. In 1925 the race was won by the United States of America, and in accordance with the conditions of the race the next contest had to be held in America. In 1926 this event was flown in Hampton Roads, U.S.A. Only two nations—Italy and America—were represented.

Italy was the winner, with an average speed for the course of 246·49 m.p.h.

The Italian seaplane, Macchi M39 monoplanes fitted with 800 h.p. Fiat engines, which won the race, was of the monoplane type with twin floats. The fuselage was supported on an inverted 'V' formation of struts, the lower ends of which were attached to the floats. The floats were connected by cross struts and also carried the ends of bracing wires, which in conjunction with other bracing wires in the top of the fuselage, assisted to hold the main planes in position.

In 1927 the race was at Venice, over a course of 218 miles laid out on the Lido. Again, only two countries were represented, but this time it was Italy and Great Britain. Unfortunately, the Italian machines failed to complete the course and the race was won by Great Britain. The winning machine—a Supermarine S. 5 Seaplane with Napier engine—was piloted by Flight Lieutenant S. N. Webster, R.A.F., and its average speed was 281·49 m.p.h. This was not only a record for the course, but was the highest speed ever recorded for any mode of transport.

Light Aeroplane Trials.

Trials were carried out at a meeting organised by the Royal Aero Club and held at Lympne in September of 1926.

The types of light aeroplanes which were entered for the competition were, in general, similar to those used in the competition of the previous year.

The results were as follows :—

Lympne Open Handicap.

Place.	Machine and Engine.	Speed, m.p.h.
1st	R.A.E. Cygnet (Cherub III.)	78·2
2nd	Pixie III. (Cherub III.)	75·25
3rd	Brownie (Cherub III.)	76·4
4th	Avro 'Avian' (Genet)	97·8

Grosvenor Cup Race.

Place.	Machine and Engine.	Speed, m.p.h.
1st	Blackburn 'Blue Bird' (Genet.)	84·95
2nd	Parnall 'Pixie' (Cherub III.)	75·18
3rd	R.A.E. Hurricane (Cherub III.)	84·79

Daily Mail Competition.

In this competition the machine had to fly over prescribed courses on six consecutive days, covering in all 1,994 miles. No replacements were allowed. A prize of £3,000 was awarded to the winner.

The first three places in the race were awarded as follows :—

Machine and Engine.	Average Speed, m.p.h.
Cygnet (Cherub III.)	64·98
Cygnet (Cherub III.)	55·68
Brownie (Cherub III.)	69·71

Notes on Airships for Commercial Purposes.

(Published by the Air Ministry.)

(*Abstract.*)

The airship is essentially a long-distance weight-carrying craft as compared with the short-distance high-speed aeroplane. An airship with a speed of 77·6 m.p.h. can be considered slow only relatively to the aeroplane, being fast in comparison with land and sea methods of transport.

An airship is not liable to forced descent in case of engine failure, as is the aeroplane. Quite large repairs to engines, such as the changing of a cylinder, are possible in an airship.

The airship can be used over land of a wooded or broken nature, such as to be unsuitable for the landing of aeroplanes, and on journeys involving non-stop flights of 1,000 miles and upwards. It can be used in flying at night or in fog or clouds, and the great lift permits of much more comfortable accommodation being provided than is possible in an aeroplane. In the case of a rigid airship, for example, a walk of 400 or 500 ft. may be taken along the keel.

Official statistics show that only one airship has been lost in this country owing to catching fire in the air, although 83,360 hours have been flown and over 2½ million miles covered during the war. In the case referred to the flight was an experimental one with a new type of ship, and the cause has since been ascertained and eliminated.

For commercial purposes large rigid airship stations should be established at distances of 2,000–3,000 miles apart, mainly for trans-oceanic traffic, while the aeroplane would be used for bringing passengers and merchandise to these from the neighbouring countries.

Although airships are generally considered to be fair-weather craft, up to the end of November there were only nine days in 1918 when no airship flight took place in the British Isles—which are notorious for possessing almost the worst weather conditions of any country in the world.

The latest German rigid airship has a disposable lift available for crew, fuel, merchandise, etc., of over 38 tons, which gives her a theoretical endurance (if all the available lift be employed in carrying petrol) of 177·5 hours (7 days) at a cruising speed of 45 m.p.h.—the maximum speed being 77·6 m.p.h.—during which 8,000 miles would be covered.

An airship has been successfully moored out for six weeks in a perfectly open expanse to a specially designed mast. Only two or three men are required to look after the ship, and winds of up to 52 m.p.h. have been ridden out without any damage resulting.

A system of recovering water-ballast during flight would obviate waste of hydrogen by preventing the ship becoming 'light,' owing to the consumption of fuel during a long voyage.

Increase in size of aeroplanes brings many difficulties in its train with no compensating improvement in efficiency, but increase in size of airships results in a reduction of the difficulties experienced at present, and gives improved efficiency.

PROGRESS IN HEAVIER-THAN-AIR (H/A) AND LIGHTER-THAN-AIR (L/A) MACHINES: 1914–1918.

In 1914 the average endurance of a German rigid at cruising speed was under one day, and the maximum full speed about 50 m.p.h. In 1918 (German L.70 class, 2,195,000 cub. ft. capacity) the endurance at 45 m.p.h. has risen to 177·5 hours (7·4 days) and the maximum full speed to 77 m.p.h. The ceiling has correspondingly increased from 6,000 ft. to 23,000 ft. The British R.38 class (2,720,000 cub. ft. capacity) has an estimated cruising endurance at 45 m.p.h. of 211 hours (8·8 days), 34 hours greater than the German L.70 class.

The D.H.10A has been taken as the best all-round aeroplane in August, 1918. Although the two-engined Handley-Page and Caproni have greater endurance and weight-carrying capacity their all-round efficiency appears inferior to the D.H.10A. The Handley-Page V gives promise of having a slightly better performance than the D.H.10A.

Tables 1 and 2 give the progress in L/A and H/A since 1914. Table 3 shows the differences in performance between corresponding L/A and H/A craft of 1918.

TABLE 1. L/A.

—	August, 1914. Average figure for German Naval Zepp.	August, 1918. German L.70.	Progress.
Maximum speed at 10,000 ft.	50 m.p.h.	77·6 m.p.h.	55%
Endurance at 45 m.p.h.	20 hours	177·5 hours (7·4 days)	787·5%
Total lift.	30 tons	66·64 tons	122%
Disposable lift	8·5 tons	38·84 tons	357%
Efficiency ratio	27·3%	58·3%	113·5%
Static ceiling	6,000 ft.	21,000 ft.	250%
Indicated H.P.	800	2,100	162·5%

TABLE 2. H/A.

—	August, 1914. Avro.	August, 1918. D.H.10A.	Progress.
Speed at 10,000 ft.	70 m.p.h.	125 m.p.h.	78·3%
Endurance	4 hours	10 hours	150%
Total weight loaded	·737 tons	4·02 tons	445%
Useful load	·268 tons	1·45 tons	445%
Efficiency ratio	36·3%	36·1%	0·55% (Decrease)
Ceiling	14,000 ft.	22,500 ft.	35·7%
Indicated H.P.	80	810	913%
	August, 1914. Avro.	**August, 1918. Handley-Page.**	**Progress.**
Speed at 10,000 ft.	70 m.p.h.	85 m.p.h.	21·4%
Endurance	4 hours	12·5 hours	212·5%
Total weight loaded	·737 tons	5·97 tons	524%
Useful load	·268 tons	2·17 tons	709%
Efficiency ratio	36·3%	36·4%	0·28%
Ceiling	14,000 ft.	15,000 ft	7·1%
Indicated H.P.	80	720	800%

It will be seen that at the present time the largest rigids in commission have over 10 times the total lift of the corresponding H/A, and that the disposable lift is about 25 times greater.

The proportion of useful lift compared to gross lift is much higher in airships than in aeroplanes. An approximate figure for an aeroplane of average engine power is $\frac{1}{3}$, while in a rigid the useful lift available for fuel, crew, passengers, freight, etc., is well over $\frac{1}{2}$. In the case of L.70 the figure is 58·3 per cent., although this ship is the most heavily engined and fastest airship yet built.

TABLE 3. COMPARISON OF EXISTING H/A & L/A MACHINES.

August, 1918.	H/A. D.H.10A.	L/A. German L.70.	Percentage Superiority.
Speed at 10,000 ft.	125 m.p.h.	77·6 m.p.h.	H/A. 61·1%
Cruising endurance	14 hours	177·5 hours	L/A. 1,167%
Total lift (=weight loaded)	4·02 tons	66·64 tons	L/A. 1,557%
Disposable lift (=useful load)	1·45 tons	38·84 tons	L/A. 2,580%
Efficiency ratio	36·1%	58·3%	L/A. 61·5%
Ceiling	22,500 ft.	21,000 ft.	H/A. 7·1%
Indicated H.P.	810	2,100	L/A. 159%

It cannot be too strongly emphasised that many of the advantages apparently possessed y H/A at the present time result from their relatively small lift. Thus, an aeroplane of 60 tons otal lift, if found to be possible at all, would certainly be very much less convenient to land and andle on the ground than aeroplanes of existing sizes and would require overall dimensions bout twice those of the largest existing machines.

It is important to note that in H/A there is no automatic improvement in efficiency resulting rom greater dimensions. In L/A, on the other hand, such an automatic improvement takes lace to a very marked degree. The reason for this difference is as follows:—In similar H/A achines of different dimensions, the total lift, air resistance, and b.h.p.—other things being qual—all vary nearly as the plane areas, *i.e.* as the square of the linear dimensions.

It follows that the ratio $\frac{\text{weight of machinery}}{\text{total lift}}$ does not vary much with size of aircraft. The atio $\frac{\text{weight of structure}}{\text{total lift}}$ tends to increase with size of aircraft. Unit area of wing surface can ly exert a definite lifting effect, and as the aeroplane increases in size it is necessary to increase roportionally the weight of each preceding unit area of wing surface to make the aeroplane roportionally strong. A point is finally reached where every additional unit of wing surface sults in as much increased weight as its lifting effect, so that any further increase in size will volve a definite falling off in the total lifting capacity of the aeroplane. A further small increase size can be effected by increasing the number of planes; but, owing to the inefficiency of iddle plane surfaces, due to the blanketing effect of the top and bottom planes, the resulting ain in endurance will not be large, and it will only be effected at the price of a loss in efficiency.

A 10,000,000 cub. ft. capacity rigid has five times the lift of the present 2,000,000 cub. ft. apacity rigid, but the length of the former is only 1·7 times greater, and therefore the weight of e structure only five times greater $(1{\cdot}7)^3$—*i.e.* the weight of the structure is directly proportional the total lift.

This theoretical property of structure may, to a certain extent, be modified by the material ed. Thus, for ships of 2,000,000 to 4,000,000 cub. ft. capacity duralumin is the most suitable aterial for the hull structure, while for ships of 8,000,000 to 10,000,000 cub. ft. capacity, a ving in weight can be effected by the use of steel.

In H/A, therefore, all-round efficiency, as measured by the ratio of $\frac{\text{disposable lift}}{\text{total lift}}$, tends to crease with greater dimensions. Greater efficiency will, therefore, not result from increase size, but, on the contrary, great increase in size will not be attainable until greater ficiency has been first obtained by progress in design and materials.

In L/A, the total lift varies as the cube of the linear dimensions, while the air resistance and h.p.—other things being equal—vary as the square of the linear dimensions. Hence the ratio eight of machinery / total lift decreases automatically. Values for this 'coefficient of tractive resistance' r airships are given in Table 4 (p. 2046).

It will be seen that they vary from ·9 per cent. for a large rigid at 45 m.p.h. to 7·7 per cent. r a small rigid at 80 m.p.h., compared with 15 per cent., which may be taken as an average gure for H/A.

It will further be seen that as the size of the rigid increases, the coefficient of tractive resistance creases to a marked extent. With a proportionate increase in h.p., it is easier and proportionately more economical for a 10,000,000 cub. ft. capacity rigid to fly at 80 m.p.h. than for a 000,000 cub. ft. capacity rigid to fly at 60 m.p.h. In the case of H/A craft, however, increase size effects no decrease in the coefficient of tractive resistance.

TABLE 4.

Gross Lift of Rigid.	Coefficient of Tractive Resistance at		
	45 m.p.h.	60 m.p.h.	80 m.p.h.
	Per cent.	Per cent.	Per cent.
60 tons	1·9	3·8	7·7
80 ,, ...	1·7	3·4	6·7
100 ,, ...	1·5	3·0	6·0
150 ,, ...	1·3	2·5	5·0
200 ,, ...	1·1	2·2	4·4
250 ,, ...	1·0	2·0	4·0
300 ,, ...	0·9	1·8	3·6

The figures for tractive resistance are based on the German L.33 streamline form, and fro the experimental results already obtained by the National Physical Laboratory it is reasonat certain that a more efficient streamline form can be obtained which will appreciably reduce the figures.

As the ratio $\frac{\text{weight of structure}}{\text{total lift}}$ is, in airships, fairly constant, it follows that the ra $\frac{\text{disposable lift}}{\text{total lift}}$ increases with dimensions. The natural tendency will, therefore, be towards larg airships, in order to secure the benefit of the resulting gain in efficiency.

A further point of great importance emerges from the above. As the total lift varies (dimensions)^2 in H/A. and as (dimensions)^3 in L/A, increase in total lift is secured in the latt with less increase in dimensions than in the former. Thus, to secure five times the total lift must increase the dimensions 124 per cent. in H/A and only 70 per cent. in L/A.

If total lift is increased indefinitely in both types, the dimensions of the H/A will therefo ultimately pass those of L/A, when almost the last remaining advantage of the former over t latter will disappear.

The proportion of useful lift compared to gross lift is much higher in airships than in aeroplan An approximate figure for an aeroplane of average engine power is 33 per cent., while in a rig the useful lift available for fuel, crew, passengers, freight, etc., is well over 50 per cent. In t case of the German L.70 the figure is 58·3 per cent., as has already been mentioned.

It is concluded that the outstanding characteristics of H/A will remain as at present: h speed, handiness, moderate lift, independence of all weather conditions except the worst.

As regards L/A, the functions now performed by the smaller airships will be usurped more a more by H/A. Airships may be expected to develop in the direction of increased size to a lir which is not yet in view. The outstanding characteristics of L/A will be reasonably high spee very long endurance, great weight-carrying capacity for freight, stores, passengers, etc.

The line of policy to be adopted is to develop the aeroplane for transport over distances und say, 500–800 miles, and the rigid airship for trans-oceanic and possibly trans-continental flig of over this length.

Table 5 shows the approximate dimensions of a series of airships similar in form to R.33.

TABLE 5.

Capacity in cubic ft.	Gross lift in tons.	Length.	Diameter.
2,000,000	60·7	643′	79′
3,000,000	91·1	736′	90·4′
4,000,000	121·4	810	99·5′
5,000,000	151·8	872′	107·2′
6,000,000	182·2	927′	113·9′
7,000,000	212·5	976′	119·9′
8,000,000	242·8	1021′	125·4′
9,000,000	273·3	1061′	130·4′
10,000,000	303·6	1100′	135·1′

It will be seen that although a 10,000,000 cub. ft. capacity rigid has five times the gross and over five times the disposable lift of the present 2,000,000 cub. ft. capacity rigid, the dim sions of the large ship are only 1·7 times greater, and it could be docked in a shed of no m than one-third larger dimensions than those at Killeagh, *i.e.* 1,150′ long × 160′ high × 180′ wi compared with 850′ long × 130′ high × 150′ wide, for Killeagh.

As regards constructional sheds, the most economical method of accommodating such la airships would perhaps be to lengthen existing constructional sheds, which are sufficiently w

) at least 1,150 ft. long (present length 700 ft., and lower the floors as necessary to secure the equired height. A somewhat similar course could probably be taken with existing housing sheds.

If the endurance of a rigid is increased to a sufficient extent, it will be possible to carry out ights with a regularity comparable to that maintained by surface craft. The range is almost nlimited, and the weight-carrying capacity large. A 10,000,000 cub. ft. capacity rigid will ave a disposable lift of over 200 tons, which is available for petrol, ballast, crew, passengers, nd freight.

There is no other type of vessel which is so efficient.

With a rigid of about 10,000,000 cub. ft. capacity, and endurance of approximately three eeks at 40 to 45 m.p.h., with a maximum speed of 70 to 80 m.p.h., a ceiling of some 30,000 ft. an be obtained, and a maximum range of over 20,000 miles.

Standard Data for Airship Calculations.

(1) *Lift of Hydrogen* to be taken as 68 lbs. per 1,000 cu. ft. of gas space at sea level.

The variation of lift with height to be taken as proportional to the density of the 'Standard tmosphere.'

(2) *The Volume of Gas* assumed in lift calculations to be as follows :—

For rigids, the total volume of the gasbags when filled with a slight pressure not exceeding mm. at the bottom.

For non-rigids, designed volume of the envelope with ballonets empty, plus an allowance f 5 per cent. for stretch.

(3) *Gross Lift*, at sea level, is defined as the volume, determined as in para. (2), multiplied y the lift per unit volume, as given in para (1).

(4) *Standard Flying Height* to be taken as 2,000 ft. above sea level in the case of rigid airships, nd 1,000 ft. above sea level in the case of non-rigid airships.

Values of atmospheric density, pressure, and temperature at sea level and standard flying eight are :—

	Density. Lbs. per cu. ft.	Relative Density. Per cent.	Temperature. ° C. Abs.	Pressure. Mb.	Pressure. Lbs. per sq. in.
Sea level	·0782	100·0	282·0	1,014·0	14·70
1,000 ft. above sea level .	·0757	96·8	281·0	978·0	14·18
2,000 ft. above sea level .	·0733	93·8	279·7	943·4	13·68

(5) *Fixed Weights* are defined as all constant and non-consumable weights which an airship ould carry under all conditions of service, including :—

Structure.
Fabric.
Cars.
Machinery—including liquids in the system and radiators (not petrol or oil in service tanks or float tanks, or water in radiator headers intended as a reserve supply).
Gun mountings (ex guns and ammunition).
Wireless telegraphy equipment.
Approved navigating equipment (including instruments).
Approved allowance of handling and mooring ropes, etc.
Internal gassing hose.
All fixed tanks.
All pipe systems.
All electrical systems.

In the case of commercial ships, all passenger cars and car fittings should be taken as fixed eights.

(6) *Disposable Weights* are defined as all weights other than fixed weights, and therefore nclude :—

Crew and effects.
Food and fresh water.
All water ballast.
All fuel and oil.
All reserve water for radiators.
All slip containers.
All bedding.
Parachutes.
Life-saving jackets.
Oxygen apparatus.
Spares and tools.
Water ballast bags and all other approved gear and equipment not included in the fixed weights.
Passengers, merchandise, guns, ammunition, and bombs.

(7) *Dischargeable Weights* are defined as :—

All fuel and oil except reserve as defined in para. (9).
All ballast except emergency as defined in para. (9).
All slip containers (except such as may be necessary to contain reserve fuel, oil, and ballast).
Bedding.
All other loads which may have been raised by the 'Useful Lift' (see para. (9)).

(8) *Maximum Static Height or 'Static Ceiling'* to be calculated on the following assumptions :—

(*a*) The ship to be lightened by removal of all dischargeable weights (para. 7), and no others.
(*b*) All other disposable weights to be carried in accordance with approved complement and equipment (see para. (9)).
(*c*) The variation of lift with height to be taken in accordance with the standard atmosphere, as in para. (1).

(9) *Useful Lift* is defined as the lift available for :—

Fuel and oil,	Food and drinking water,
Passengers and merchandise,	Guns, ammunition, and bombs,

and to be determined by deducting from the gross lift at sea level the following :—

All fixed weights.
Ballast necessary to reach the standard flying height, amounting to :—
For non-rigids . . . 3·2 per cent. of gross lift (at 68 lbs. per 1,000 cu. ft.).
For rigids . . . 6·2 " " " " "
(See para. 4.)
Emergency water ballast, amounting to 3 per cent. of the gross lift at sea level.
Reserve fuel and oil for two hours' flight at normal full speed at standard flying height.
All tanks and containers not already included in the fixed weights.
Approved reserve of water for radiators.
Crew : Approved complement, the weight of each member being taken as 180 lbs., including clothing and personal kit.

All approved spares and tools.

Approved equipment :

Bedding.	Oxygen apparatus.
Parachutes.	Fire extinguishers.
Life-saving appliances.	Emergency ration (iron ration).

All other approved disposable equipment, *e.g.* First Aid equipment, which would be taken on board at commencement of flight under all conditions of service.

(10) *Speed* to be stated in knots, *i.e.* nautical miles (6,080 ft.) per hour, for all classes.

Speeds in all cases to be calculated under the standard atmospheric conditions corresponding to standard flying height, as laid down in para. 4.
Maximum speed.
Normal full speed, to be defined as 90 per cent. max. speed.
Cruising speed, to be defined as 80 per cent. max. speed.
Comparison speed. 40 knots.

(11) *Endurance* to be calculated on the following assumptions :—

The whole of the useful lift (para. 9) to be employed for fuel, oil, food, and drinking water.
Rate of fuel and oil consumption to be the approved figure for the ship at the speed in question and at the standard flying height (para. 4), with corresponding atmospheric conditions.

Rate of consumption of food and fresh water to be taken as 10 lbs. per day for each member of the approved complement of crew ; that is as $\frac{\text{complement} \times 10 \text{ lbs.}}{24}$ per hour.

Thus if 'A' be the total fuel and oil consumption in lbs. per hour at a given speed, and if 'B' be the consumption of food and fresh water in lbs. per hour : the endurance in hours at that speed $= \frac{\text{Useful Lift}}{A + B}$.

Helicopters.

Details of Air Ministry Competitions.

In 1923 the Air Ministry announced a competition for the design of helicopters or equivalent types of flying machines, and offered prizes to the total value of £50,000 for successful designs. The machines had to comply with certain conditions, which took the form of four tests to which the designs had to be subjected for competition purposes. The first test required that the machine should carry a pilot, fuel for one hour's flight, and 150 lbs. of military load, and thus loaded it should make a vertical flight from the ground to a height of 2,000 ft., afterwards descending and landing without damage. For this test two wind conditions were specified, one in which the ground wind did not exceed 5 m.p.h., and the other in which the ground wind exceeded 10 m.p.h. but did not exceed 20 m.p.h.

In the second test the machine was required to rise from the ground and remain in the air for half an hour at 2,000 ft. over a certain prescribed ground area, the ground wind being not less than 5 m.p.h. and not greater than 20 m.p.h., and subsequently landing without damage.

The conditions for the third test were similar, except that in this case the machine had to r over a prescribed closed circuit not less than 20 miles in length, at an air speed of not less an 60 m.p.h.

In the fourth test the machine had to be manœuvred in the air into a position over a given point a the ground, and had to descend from a height of not less than 500 ft. with the engine off, and ight without damage within a 100 ft. of the given point.

The prize for the first-mentioned test was £5,000, and sums of £15,000, £20,000, and £10,000 spectively were offered in respect of the other three tests.

In 1925 the Air Ministry announced that no machine had been submitted for test in accordance ith the above conditions, but as the provision of the original competition allowed for a second mpetition, the latter is to be arranged with a final date of test of April 30, 1926.

Use of Helium for Airships.

Next to hydrogen, helium is the lightest gas known. It is both non-inflammable and non-plosive, and possesses 92 per cent. of the lifting power of hydrogen, so that it is a most suitable ling for airship envelopes. By the use of helium, the engines of airships can be placed within e gas envelope if desired. A further advantage of helium over hydrogen is that the buoyancy n be increased at will by heating or cooling the gas by electric or other means. Moreover, the ss of gas from diffusion through the envelope is less with helium than with hydrogen by about) per cent.

The weight of 1,000 cu. ft. of dry air (reckoned at a barometric pressure of 29·5 ins. and a mperature of 55·5° Fahr.) is 76·03 lbs.; of the same bulk of pure hydrogen, 5·284 lbs., and of lium 10·46 lbs. The 'lift' of hydrogen per 1,000 cu. ft. is, therefore, 76·03 less 5·284 lbs., 70·746 lbs., and of helium 76·03 less 10·46—*i.e.* 65·57 lbs.

High-flying Oxygen Breathing Apparatus.

High-pressure Apparatus.

In this apparatus the oxygen in gaseous form is stored in a specially constructed seamless ld-drawn steel tube charged to a pressure of 2,250 lbs. per sq. in. (150 atmospheres).

The tubes were produced during the war in two sizes, one capable of holding 500 litres at the ove-mentioned pressure and the other 300 litres. They are extremely light, weighing 4 lbs. d 6¾ lbs. respectively for the smaller and larger sizes.

The tubes before being passed by the Aeronautical Inspection Department are subjected to internal pressure test of 3,750 lbs. per sq. in., being inserted in suitable water-jackets for easuring any increase in volume. The cylinders are rejected if the permanent increase of lume (after the hydraulic pressure is removed) exceeds the increase of volume under pressure 20 per cent. Two per cent. of each batch of tubes after manufacture are also subjected to proof pressure test to destruction, and if the bursting pressure is less than 4,250 lbs. per sq. in. rther samples are selected and treated in like manner, and if these fail under destruction test e whole batch is rejected. They may, however, be heat-treated again.

The final test (flattening test) is carried out on the uninjured portion of those selected from itches in previous destruction test, and the cylinders are flattened until the inner surfaces are in. apart. If cracking results from this treatment, as before, the rest of the batch are scrapped, though they may be re-heat-treated.

In the necks of the cylinders are sweated valves with forged bronze bodies and parallel-readed shanks, with screwed inlet and outlet connections, each valve weighing approximately ozs. All valves are tested hydraulically to 2,250 lbs. per sq. in. The cylinders when valved e subjected to a final compressed air test at about 1,000 lbs. and immersed in water to ensure perfect joint between cylinder and valve.

The cylinders are fixed in the aeroplanes in convenient positions by means of specially constructed spring clips, and from the cylinders the gas is led through fine copper tubing some 10 ft. length to the oxygen regulator, which performs the double function of reducing the gas from gh to low breathing pressure and at the same time regulating the flow to the airmen.

The regulator consists in the main of a pressure gauge for indicating the pressure of gas ceived from the cylinders already described; a reducing valve for reducing the pressure of gas om the pressure in the cylinder to a normal breathing pressure of between 1 and 2 atmospheres solute; a control valve for regulating the delivery according to the height of the aeroplane id a flow indicator to indicate that gas is flowing.

An improved indicator has a graduated tube introduced which has the additional function recording the exact rate of flow of gas.

There are two distinct types of control valve, an automatic control by means of a diaphragm alve in one model and a hand-controlled valve in the other model. In aerial combat the hand-ntrolled instrument was preferred, whereas on long-distance flights the automatic valve was voured. In the former case the airmen were able to inhale any quantity and cut off at leisure otherwise engaged, and in the latter case, where long duration was necessary, the oxygen was nsumed economically.

The low-pressure gas after leaving the regulator passes along a flexible tube to the breathin mask, which in the latest type is embodied in the pilot's headgear, being readily detachab by means of a separate strap on the main portion of the helmet. The pilot inhales the oxyge by means of a pipe-mouthpiece which is swivelled and can be easily discarded.

The 300-litre cylinder at altitudes between 10,000 ft. and 15,000 ft. is capable of supplyin oxygen at an average rate of flow of 1·35 litre per minute continuously for approximatel 3½ hours, but between altitudes of 15,000 ft. and 20,000 ft., where an increased rate of flow necessary, owing to decrease in atmospheric pressure, the same quantity of gas at an averag rate of flow of 2·55 litres per minute would only be available for approximately two hours.

Liquid Oxygen Breathing Apparatus.

In this type of apparatus the liquid oxygen is first placed in a vaporiser, which has an inn spherical chamber varying in sizes to accommodate from 1 to 5 litres, according to the lengt of flight and altitude.

The vaporiser embodies the ordinary vacuum flask principle where an inner and outer vess are constructed and the space between the two rarefied down to about 1/1000 mm. of mercur vacuum.

A small quantity of specially selected charcoal is placed in a tube in the inner vessel to absor any moisture. The ends of the tube which terminate in the vacuum space are covered wit gauze. The vaporisers vary in weight, the largest, of 5 litres capacity, weighing approximatel 12 lbs. when empty and capable of holding 12 lbs. of liquid oxygen when charged.

The vaporiser thus consists of inner and outer vessels, neck, and charcoal receptacle, and i the neck is a syphon tube which passes into the body of the vessel. The oxygen in liquid for passes up this tube into the heating and evaporation coils, which are bent round the neck i the form of solid drawn copper tubes. The oxygen after leaving these tubes passes into a flas boiler which, not being evacuated, is at a much higher temperature than the liquid oxyge and in consequence the latter is converted into the gaseous state.

To cause additional radiating surface a number of blind tubes are added underneath the flas boiler.

The oxygen then passes along to the pressure gauge which indicates the pressure of the oxyge from the vaporiser, and is graduated to accommodate pressures from 0 to 25 lbs. per sq. in.

From experiments it has been ascertained that the best results are obtained when the oxyge passes from the vaporiser at a pressure of about 5 lbs. per sq. in.

The oxygen from the vaporiser passes by means of a rubber connection to the control fittin the function of which is to control the supply of oxygen to the airmen. The fitting consist simply of control valve and pressure release valve, which is used to indicate the quantity o oxygen passing to the airmen's breathing masks. The flow of oxygen is indicated by the impac of a jet of gas upon a pivoted vane provided with a pointer moving over a dial. The calibratio of the flowmeter is from 0 to 6 litres per minute, and the quantities of oxygen required for airme at varying altitudes are as given in the description of the high-pressure breathing apparatus.

Liquid oxygen storage vessels known as containers, and capable of holding approximatel 27 litres of the liquid, are also specially constructed on the vacuum principle and used for chargin the vaporisers. The container forms a convenient means of storing the liquid, and owing to th very high vacuum which is created between the inner and outer vessels the loss of liquid oxyge due to evaporation is brought to an absolute minimum.

The liquid oxygen apparatus has one great advantage over the high-pressure type in tha there is no danger in connection with the use thereof in aerial warfare, owing to high-pressur gas being non-existent. In the case of the gaseous oxygen apparatus, the very high pressure t which the steel tubes are charged creates a source of danger which frequently results in damag to pilot and aeroplane when the tubes are struck by enemy bullets.

Liquid Oxygen Plant.

The plant as manufactured by Messrs. Société L'Air Liquide, Boulogne-sur-Seine, Paris was designed for the purpose of mounting on a railway truck and capable of delivering at leas 15 litres of liquid oxygen per hour with 96 per cent. purity. The plant, fig. 6, works on the well known Claude principle and is made up of the following components :—

1. Petrol engine to supply motive power (the particular engine used was the 100 h.p Ricardo engine).

2. Air compressor.

3. Water separator.

4. Purifier and drier to decarbonise the air.

5. Liquefaction and rectification column, each in itself comprises:—(a) A temperature xchanger to cool the compressed air. (b) An expansion engine which is responsible for rapid rop in temperature. (c) Brake dynamo and rheostat to absorb the power given out by the xpansion engine which would be otherwise wasted. (d) Liquefying column embodying rectifier.

The air is first drawn into the two-stage compressor (A), fig. 6, from the atmosphere, and assed at a high pressure of about 45 atmospheres to the separator (B) where moisture absorbed om the injection water in the cylinders of the compressor is removed. The air then passes uccessively through the purifying chambers (C, C), filled with caustic soda or caustic potash, om whence it emerges perfectly dry and free from CO_2.

The dried and purified air passes into the temperature exchanger (D) and traverses the nest small tubes (E) therein, which are cooled by expanded and cold gas flowing in the opposite irection. The air, considerably cooled, leaves the temperature exchanger, part entering the xpansion engine (F) and the other part a nest of tubes (G) in the liquefier (H). The air enter- ig the expansion engine does external work on the piston and is expanded and thus cooled.

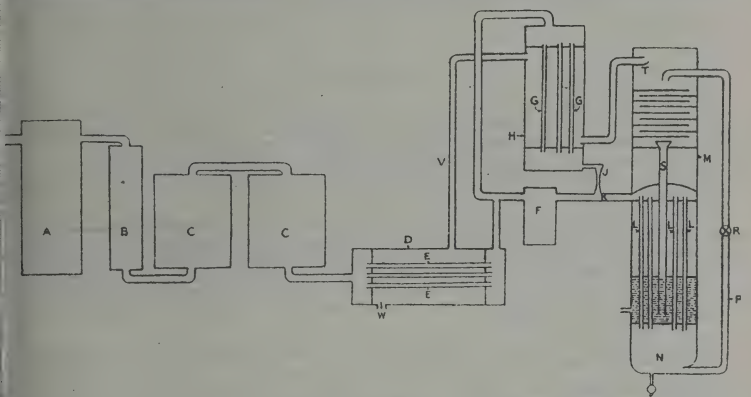


FIG. 6.—Diagram illustrating Liquid Oxygen Plant.

The air in the nest of tubes (G) in the liquefier is cooled by expanded and cold gas flowing i the opposite direction, and, under the continued action of cooling and pressure, liquefies, nd, passing through the needle valve (J), mixes in the pipe (K) with the cold and expanded ir issuing from the expansion engine. The cold air and the liquid air enter the top of another est of tubes (L) called the vaporiser, which is contained in the rectification column (M). On aving these tubes the mixture of gas and liquid enters a sump (N) at the bottom of the column, nd from thence rises through the pipe (P) and regulating valve (R) to the top of the column. he top portion of the rectifying column contains a series of staggered and perforated trays. he liquid in the mixture descends through the trays and enters the vaporiser by means of the ipe (S). The gas in the mixture, which contains a large quantity of nitrogen, since nitrogen as a lower boiling point than oxygen, leaves the top of the column by the pipe (T), entering the quefier in the space surrounding the nest of tubes (G), thus cooling the compressed air in the ubes, and from thence enters the temperature exchanger (D) by the pipe (V) in the space rrounding the nest of tubes (E). Thus it fulfils the same function of cooling the compressed ir flowing in the opposite direction; it ultimately leaves by the pipe (W) warmed, but still at ome degrees below the temperature of the incoming air.

When the liquid air supply is sufficiently large for liquid oxygen to be formed, the valve (R) slowly closed down, but not completely shut. The exhaust pressure in the expansion engine hen rises to the same as that of the liquid air in the nest of tubes (L) in the vaporiser, and causes he surrounding liquid to boil. The gas thus formed, and consisting mainly of nitrogen, rises hrough the plates, while all the liquid formed rises through the valve (R) and flows into the top f the column; the liquid thus descends through the trays, while the gas ascends and eventually nds its way into the atmosphere through pipe (W). Thus it will be seen that the continued ction of progressive refrigeration gradually purifies the liquid in the column (M) and which pproaches pure liquid oxygen. In the same manner the gas, passing through pipe (T) and ventually through pipe (W), gradually becomes richer in nitrogen and with greater cooling effect n the oncoming compressed air in the temperature exchanger.

At a test, the first signs of liquid were not observed until two hours after the starting of the plant. It was not possible to analyse the purities of the liquid oxygen directly, although the purity of the evaporated gas was taken. The relative density of the liquid oxygen was found to be approximately 1·11, and the flow of liquid per hour was never less than 17·2 litres.

The original specification called for 18 to 22 litres. At a second test, the liquid was produced one and a half hours after the plant was re-started, and a further two hours realised the total of 43·6 litres, giving an increased average per hour of 21·8 litres.

The compressor was running at an average speed of 245 r.p.m., and in two stages compressed the gas to a maximum of 45 atmospheres.

The expansion engine was running at about 160 r.p.m., and the dynamo for absorbing the waste energy from the expansion engine was able to give an average output of 35 amps. at average pressure of 70 volts. The average purity of the oxygen gas was 92 per cent. and the average purity of oxygen liquid 97 per cent.

Parachutes.

In the early days of the war the use of man-carrying parachutes was confined entirely to kite balloons and proved of very great service in life saving. It is estimated that at least six hundred of our balloon observers effected their escape by this means.

At this very early period on the Western front the parachute then in use was of Spencer manufacture, known as the 'conical' type, afterwards superseded by another Spencer type, known as the 'flat-case' type.

The conical type of parachute consists of a silk body having a flattened hemispherical form with 48 cords attached to its periphery at equal distances and terminating in a single rope. In the centre of the body there is a hole 9 ins. in diameter through which the current of air escapes as the parachute descends. This gives stability to the parachute, which would otherwise swing violently, although the swinging to a certain extent cannot be prevented in any parachute. The parachute and cordage are packed into a conical canvas case which is hung mouth downwards from the basket of the kite balloon.

The flat-case type of parachute is another method of packing and consists of a flat case fastened to the side of the basket and into which the parachute is packed.

It was towards the end of the war before parachutes were seriously considered by the Air Ministry for use with aeroplanes. The urgency for aeroplane man-dropping parachutes was so apparent that a special parachute department of the Air Ministry was created. When this section was formed there were in existence several types of parachutes, of which perhaps three stood out prominently from the rest as being very suitably adapted for aeroplanes.

When an aeroplane is under control and flying on a level keel, exit by parachute is comparatively safe provided always that ordinary precautions are taken, but with an aeroplane on fire or completely out of control escape is always problematical and dangerous. The parachute does however, provide the airman with a chance of saving his life, whereas without this chance he would otherwise go to almost certain death.

The 'Guardian Angel' type of parachute differs from other types in that it has the advantage of a 'positive opening,' which means that the parachute on delivery always leaves its case with its mouth open. This is effected in the A1 type by the following means—The silk body is pleated until it forms a cube and is then folded down upon a disc of Duralumin some 24 inches in diameter, another similar disc being placed above it. The two discs are separated by a Duralumin distance tube of about five inches diameter. The rigging lines (in the form of stout tapes) are folded in fillets below the discs and fastened by boxwood toggles to the periphery of the parachute and the whole is covered and kept weathertight by a waterproof cover. The parachute when folded resembles in outline an ordinary plum cake with a handle on the top, the lower extremities of the tapes, twelve in number, being fastened to a central bolt of Duralumin, which is ultimately attached to the harness of the aviator. When the aviator leaves the aeroplane and his weight comes upon the centre bolt the lower portion of the cover comes away, the tapes are pulled out to their full extent, and the parachute body is pulled out over the lower disc in the form of a pleated silken tube 2 ft. in diameter and 14 ft. long filled with air. The parachute, continuing to descend in this condition, cannot fail to expand to its full extent, and this fact gives great confidence to the user. This parachute when packed weighs 30 lbs. and measures 24 ins. in diameter and about 12 ins. through, and its cost is considerable, being in the neighbourhood of 100*l*. The rate of descent averages 15 ft. a second for a 12-stone man, a perfectly safe rate of

ged. From 80 to 90 yards of silk are required for the manufacture of this parachute. In its est form the parachute is packed upon a bent wood ring, the Duralumin discs done away with, d other modifications made, so that the 'Guardian Angel' D4 type with Taylor-shaped body w weighs 18 lbs., measures 20 ft. across, and is compressible into about 5 ins. in depth. The st is also proportionately reduced.

Drops from an aeroplane going at 130 miles per hour have been made.

The 'Guardian Angel' parachute invariably opens in the first 100 ft. of falling.

The 'Mears Knapsack' type is a Spencer parachute pleated and folded in such a way as to ake its opening a practical certainty.

It has never been known to fail to open, but has no mechanical means of extending its mouth on delivery. After longitudinal pleating of the body a strip of canvas ending in a length of bbing is placed upon it and is rolled up with the silk in much the form of a snail. The para- ute with rigging is then placed in a weather-proof knapsack with the webbing protruding, hich is attached to the aeroplane. The knapsack is worn by the aviator either on his back or ached to his harness in front. When the aviator jumps, the reaction between his falling weight d the moving plane causes the webbing to pull the parachute out of the knapsack, and the rachute then unfolds and expands, leaving the strip of canvas and the webbing still attached the aeroplane. This parachute has many good qualities in that the aviator is well clear of the ving plane before the parachute unfurls and is, therefore, more or less free from the danger fouling. It is also cheap, and easy to pack and comparatively light in weight.

The 'Smiths Salvus' parachute also possesses the good quality of the positive opening like D4 and also is better adapted for the forward positions in large machines such as Handley- ge or Vickers-Vimy, as the distance of fall before the body inflates can be regulated according the type of aeroplane it is to be used for. In this parachute the periphery of the body is held a wooden ring, making it a positive opening type until a certain distance from the aeroplane s been covered, when the periophery is released automatically and the body expanded to its l extent.

The weight of this parachute is about 19 to 20 lbs., the diameter packed, 21 ins., and the pth about 8 to 10 ins. It is a very good and reliable appliance.

SECTION XXXIII

PART II

AERO ENGINES.

(Contributed by Ernest W. Birch, A.M.I.A.E.)

Engines for Aircraft are either air- or water-cooled, and operate on the four-stroke cycle. The various types in use are Vertical, Vee, Radial, and Rotary. The majority of engines are water-cooled, but the air-cooled engine is receiving great attention and has the following advantages: (*a*) Less sensitive to sudden heat or cold; is easier to start and requires less warming up in cold weather; the oil does not heat unduly, and remains at working temperatures. (*b*) Top overhauls are easier to make. The grinding of valves involves only the removal of a cylinder, with no alteration to the timing—water-cooled engines, as a rule, require either the removal of the engine, or the dismantling of the camshafts and valve mechanism, and the whole engine requires retiming on assembly. (*c*) Due to the reduction in the number of parts, the radial air-cooled engine can usually be built cheaper than the water-cooled engine. The tendency in water-cooled engines is towards block construction to give a more rigid and lighter structure; this, however, involves the rejection of an entire block for the defect of a single cylinder.

Air-cooled engines are not confined to fixed-radial and rotary types. In America the 'Liberty 12,' which is normally a water-cooled engine, has been developed as an air-cooled engine, and as such has developed slightly more than its rated output as a water-cooled engine.

The most successful engines at the present time are really refinements of types available for some years past. Some of these improvements are greater compactness, resulting in lighter weight and increased rigidity; higher crankshaft speeds; improvements in valve operating mechanism, valve cooling and valve materials; improvement in bearing design, and improvement in volumetric efficiency. The success of the inverted 'Vee' type, and the static radial air-cooled engine, of reduction gearing and of the rotary inductor supercharger, has contributed a large share to recent progress in engines.

ROLLS ROYCE ENGINES. ('EAGLE' SERIES.)

This engine is of the 12-cylinder water-cooled 'Vee' type, fitted with an epicyclic reduction gear, magneto ignition, and complete with propeller-hub, and engine supporting brackets suitable for tubular bearers.

The leading particulars for 'Eagle' Series IX. engines are:—

Number of cylinders, 12; bore, 4½ ins.; stroke, 6⅞ ins.; normal b.h.p., 360; normal speed (crankshaft), 1,800 r.p.m.; maximum speed (crankshaft), 2,000 r.p.m.; normal speed (propeller), 1,080 r.p.m.; gear ratio, 0·60.

Petrol consumption on the ground at normal b.h p. and normal r.p.m., 25 galls. per hour.

Oil consumption, 1 gall. per hour.

Weight, including reduction gear, propeller-boss, exhaust pipes—less radiator, water and oil, 965 lbs.

Cylinders.—Two rows of six at 60° with each other of built-up all steel construction, being machined from 0·6 per cent. carbon steel forgings with the heads integral with cylinder barrels. Water jackets, die pressed sheet steel, acetylene welded at joints. Valve seatings machined in cylinder heads.

Valves.—One inlet and one exhaust per cylinder, operated by overhead camshafts and rockers. Valves made from high chromium steel forgings, working in phosphor-bronze guides.

. *Camshafts.*—Driven by means of inclined tubular shafts with bevel gear at upper and lowe ends. Out-of-alignment and expansion effects are allowed for by hardened serrated coupling Each camshaft has five phosphor-bronze bearings which are in halves, and bolted together. Valv rockers provided with hardened steel rollers and adjustable tappets.

The gears for driving the camshaft and all auxiliaries are driven from the rear end of crank shaft, through the medium of a spring-controlled friction damped pinion, in order to eliminat from all auxiliary drives any torsional crankshaft vibration.

Connecting Rods.—' H ' section of the articulated type, machined all over. Big end of mai rod is white-metal lined, the small end being fitted with phosphor-bronze bush. Both ends o the articulated rod fitted with phosphor-bronze bushes. All bearings positively lubricated b oil under pressure.

Crankshaft.—Six-throw, all journals and crank pins being bored for lightness and to conve oil to bearings and connecting rods. The crankshaft is carried in seven bearings of ampl proportions.

Pistons.—Of ' Zephyr ' type, with five piston rings, arranged as four compression rings abov the gudgeon pin, and one scraper ring below, at the base of the skirt. Gudgeon pins locked t prevent axial and rotational movement.

Crankcase.—Made in two halves of box section, suitably ribbed. The main bearings are hel in the top half by steel caps, these being held by long bolts which pass through the top half o the crankcase. The bearings are in halves and consist of phosphor-bronze shells, white-meta lined.

Propeller Hub.—Provided with internal serrations engaging similar serrations on the propelle shaft. To locate the hub radially and to secure it against any axial movement two opposed tapers are utilised, one consisting of a split conical phosphor-bronze ring on the propeller shaft and the other of a conical nut on the extremity of the shaft, each engaging conical seats in th hub. The loose flange is fitted on serrations of the hub, the whole being provided with a numbe of hollow bolts which pass through the propeller.

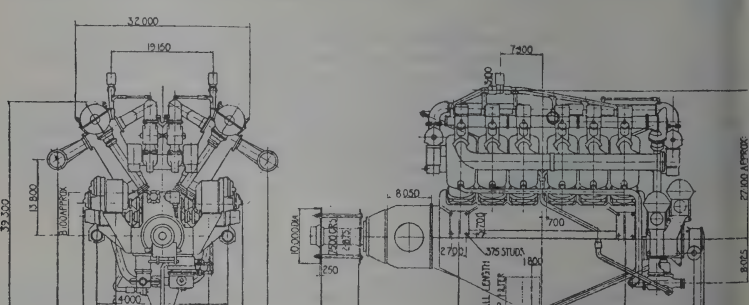


FIG. 1.—Rolls Royce ' Eagle ' Engine (Series VIII.).

Reduction Gear.—A compound epicyclic reduction gear is fitted on the front end of the crank shaft, through which is transmitted the drive to the propeller. The annulus driving gear is fixed on the flange of the crankshaft, which rotates the three sets of planet gears round the sunwheel. The latter is the fixed member of the gear and is prevented from rotating by means of a friction anchorage in the form of a multi-plate clutch, the plates being anchored to the casing and the sunwheel alternately and pressed together by springs.

This arrangement limits the maximum torque which may be imposed on the gears, the clutch being designed to slip if a certain torque is exceeded, due, for instance, to periodic stresses set up by propeller vibrations or pre-ignition. Lubrication of all working parts is effected from engine

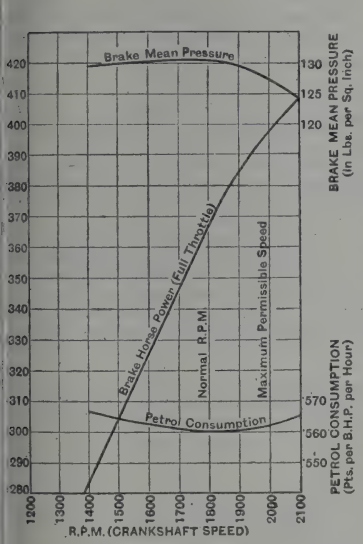
ankshaft, and the whole gear is totally enclosed in a casing carried from the front end of the ankcase.

Four 6-terminal high tension magnetos are fitted, and two sparking plugs per cylinder.

The lubrication of the engine is on the ' dry sump ' system, the bulk of the oil being carried a service tank separate from the engine. The ' scavenger ' and ' pressure ' pumps are arranged a unit, being bolted to the under side of the engine timing gear case, and driven from the ing gear.

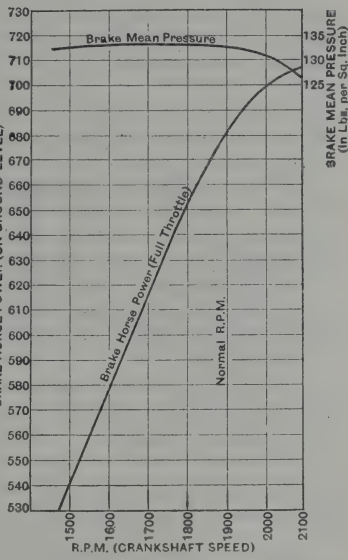
Materials Used in Construction.

Cylinders, 0·6 per cent. carbon steel forgings ; *valves*, high chromium steel ; *camshaft*, 5 per nt. nickel case hardening steel ; *valve rockers*, 3 per cent. nickel steel forgings ; *gears*, 5 per cent. kel case hardening steel ; *pistons*, aluminium alloy ; *connecting rods*, 3½ per cent. nickel steel ; *nkshaft*, nickel-chrome steel forging ; *propeller hub*, 3½ per cent. nickel-steel forging.



Rolls Royce ' Eagle,' Series IX.

Compression ratio = 5·22.
Atmospheric temperature = 16° C.
Atmospheric pressure = 29·97″ Hg.



Rolls Royce ' Condor,' Series III.

Compression ratio = 5·3.
Atmospheric temperature = 16° C.
Atmospheric pressure = 29·97″ Hg.

FIG. 2.—B.h.p. and Consumption Curves for Rolls Royce Engines.

ROLLS ROYCE ENGINES. (' CONDOR ' SERIES III.)

The ' Condor ' engine is of the 12-cylinder water-cooled ' Vee ' type, fitted with a spur drive duction gear for the airscrew.

The leading particulars are :—

Number of cylinders, 12 ; bore, 5½ ins. ; stroke, 7½ ins. ; normal b.h.p., 665 ; normal speed ankshaft), 1,900 r.p.m. ; maximum speed (crankshaft), 2,100 r.p.m. ; normal speed (propeller) th 0·582 reduction gear, 1,106 r.p.m.

Fuel consumption at normal power and speed, 45 galls. per hour.

Oil consumption, 1·9 galls. per hour.

Weight of engine, 1,154 lbs. (including carburettors, magnetos, engine feet, distributor an pipes for power starter, etc., but excluding reduction gear, exhaust boxes, radiator, airscrew oil, fuel and water).

Weight of engine as above, but including reduction gear, 1,310 lbs.

Rolls Royce Engines (Series F10).

This is the latest type of engine built by Rolls Royce, Ltd. It is a twelve-cylinder V engin 5 ins. bore by 5½ ins. stroke, and develops 485 h.p. at 2,100 normal r.p.m., corresponding to b.h.p. M.E.P. of 140 lbs. sq. in.

The leading particulars are as follows :—

Two banks of six cylinders, each bank being formed from one aluminium alloy casting, wit inserted steel cylinder barrels, in direct contact with the cooling water. Cylinder heads and g passages formed integrally with the cylinder castings, and inserted seatings are used for the tw inlet and two exhaust valves in each cylinder. Cylinder blocks secured to crank chamber by lor studs passing through the complete depth of the cylinder casting, and abut on the crank chamb by means of flanges formed on the cylinder liners.

Pistons of forged aluminium alloy. Crankshaft arranged to be coupled at the driving en either to a propeller shaft carried in an extension piece bolted to the crank chamber or to th pinion of a spur-type reduction gear. Steel connecting rods of the superimposed type.

Valves actuated by single overhead camshaft carried in each cylinder block, operating throug the medium of rockers. Valve mechanism lubricated by low-pressure oil, and is complete enclosed. Inlet valves situated towards the inside of the Vee between the cylinder blocks, which space is carried two double carburettors, each throat feeding three cylinders.

Ignition by two completely independent 12-cylinder magnetos driven by a cross shaft at th wheel-case end of the engine, one magneto dealing with the plugs on the inlet side of the engin and the other dealing with the plugs near the exhaust valves on the outside of the cylinder block

Two scavenging and one pressure pump for the lubricating system placed within the oil bas One scavenging pump evacuates oil from the front end of the engine and delivers into a well the rear end, where the whole of the drainage oil is then ejected from the engine by the secon scavenger pump. The pressure pump delivers high-pressure oil to the crankshaft journals an connecting rod ends.

The overflow from the high-pressure system is led through two blow-off valves in series bac to the crank chamber, the cavity between these valves forming a source of low-pressure oil fo lubricating the valve gear and any other low-duty bearings not dealt with by splash.

This scheme provides that in the event of an engine being partly disabled the first bearin to be starved of oil will be the low-duty ones.

A water pump is carried on the bottom of the wheelcase at the engine rear, having a doub volute with a lead to each cylinder block. The whole of the cylinder outlet water is carri serially through the two induction pipe jackets, with the exception of two small water lea provided to maintain circulation at the rear end of the blocks.

A petrol pump of the gear pattern fitted on wheelcase, also a gun gear, the drive of which c be readily adjusted for timing.

A hand-starting gear is provided and provision is made for fitting a gas starter.

Napier Engine. (Lion.)

The leading particulars are as follows :

Number and arrangement of cylinders, 12, three blocks of four each, one vertical, two 60° ; bore, 5½ ins. ; stroke, 5½ ins. ; Compression ratio, 5·8–1 (high), 5·0–1 (low) ; norm b.h.p. and speed, 450 b.h.p. at 2,000 r.p.m. (high compression) ; normal b.h.p. and spee 425 b.h.p. at 2,000 r.p.m. (low compression) ; direction of rotation of crank, anti-clockwis viewed from front ; direction of rotation of air screw, clockwise, *i.e.* L.H. tractor or R.H. pushe ratio of gear reduction to airscrew, 41–27 ; oil pressure, maximum 70 lbs./sq. in., normal 55– lbs./sq. in., minimum 40 lbs./sq. in. ; oil consumption, 6–12 pints per hour ; type of carburett special Napier Claudel Hobson, single and double (see page 2067).

Fuel consumption, 235 pints per hour at normal load near ground.

Type of magneto, two B.Th.H. A.V. 12E (dual ignition).

Firing order, 1, 5, 9, 3, 7, 11, 4, 8, 12, 2, 6, 10.

Numbering of cylinders, airscrew { 12, 11, 10, 9 / 5, 6, 7, 8 / 4, 3, 2, 1.

Speed of magneto, 1½ engine speed.

Magneto timing, 40° before t.d.c. at full advance on exhaust side, 45° before t.d.c. on ·t side.

Inlet valve opens (deg. on crank), 10° after t.d.c.

Inlet valve closes (deg. on crank), 51° 15′ after b.d.c.

Maximum lift of inlet valves, 0·344 ins.

Clearance of inlet valve, 0·018–0·022 in.

Exhaust valve opens (deg. on crank), 48° before b.d.c.

Exhaust valve closes (deg. on crank), 10° 44′ after t.d.c.

Maximum lift of exhaust valves, 0·354 in.

Clearance of exhaust valve, 0·018–0·022 in.

Weight of engine complete without water, fuel, or oil, 910 lbs. (approx.).

Maximum speed, 2,200 r.p.m.

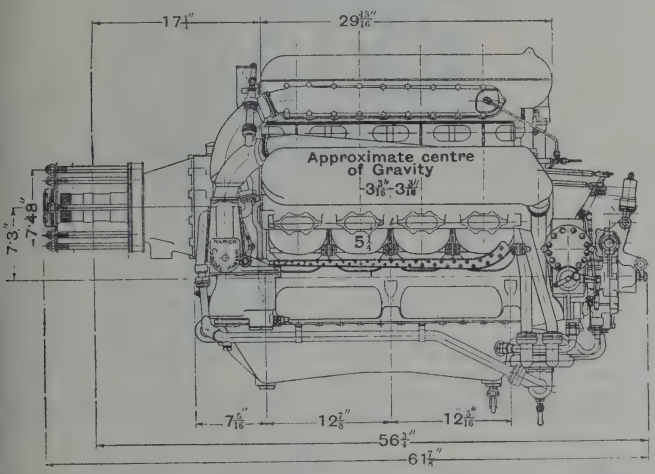


FIG. 3. Napier 'Lion' Engine.

Weight per h.p., 2·1 lbs. on rated power, 1·89 lbs. on average power at maximum speed.

Oil consumption on Air Ministry 2-hour endurance test, maximum 0·036 lb. per b.h.p. ır; average, 0·0235 lb. per b.h.p. hour.

Fuel consumption, 0·527 lb. per b.h.p. hour with fuel of a specific gravity of 0·765 at full d and normal speed. Average fuel consumption at 90 per cent. full load = 0·49 lb. per ı.p. hour.

Cylinders.—Steel forgings machined all over. Water jackets of steel. Detachable aluminium inder head containing inlet and exhaust passages, valves and valve actuating mechanism.

Pistons.—Of aluminium alloy, fitted with two gas and two scraper rings. Hollow gudgeon as of large diameter, fixed in steel bushes.

Valves.—Two inlet and two exhaust per cylinder, each fitted with two coil springs and erated direct by overhead camshaft driven through bevel gearing by vertical shafts from the ankshaft.

Connecting Rods.—The master rod, coupled to the pistons of the vertical block of cylinders, formed with lugs on either side, to which are attached the short auxiliary rods for the pistons the right and left groups of cylinders. The big ends are white-metal lined, anchor pins and ıer parts work in bushes.

Crankshaft.—Machined from solid steel forging. The four throws are in one plane and journals, bearings and crankpins are of large diameter and bored out. The shaft is carried five substantial roller bearings and a large plain bearing at the forward end.

The method of assembly of the roller bearings on the crankshaft is shown in fig. 5.

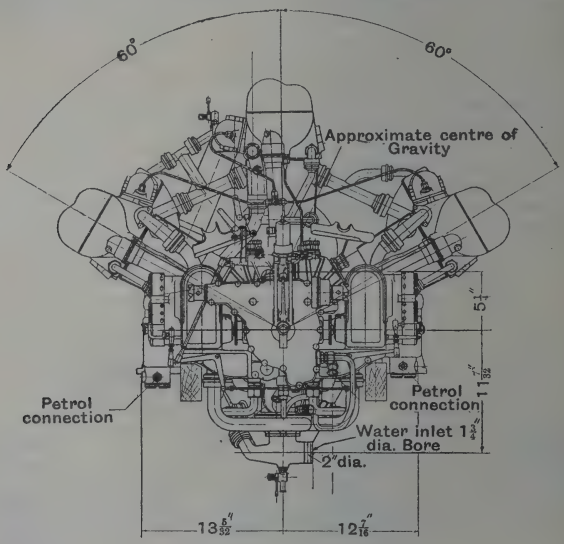


FIG. 4.—Napier 'Lion' Engine (Rear View).

Airscrew Shaft and Drive.—Shaft rotates clockwise when viewed from the airscrew end. is carried on two roller bearings and fitted with a large double thrust ball bearing, to take t thrust of either a 'Tractor' or 'Pusher' airscrew.

Water Pump.—Centrifugal type, mounted at rear end of engine and running at cranksh speed. Water is delivered through a separate outlet to each of the three cylinder blocks.

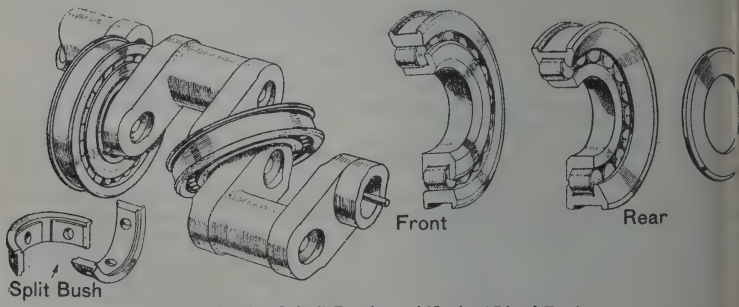


FIG. 5.—Crankshaft Bearings of Napier 'Lion' Engine.

Oil Pumps.—Two suction and one pressure type; the suction pumps scavenge the oil sur and return the oil to the supply tank. The pressure pump takes the oil from the supply tank a delivers to the working parts of the engine under pressure.

Lubrication.—By pressure throughout to big ends, gudgeon pins, bearings of camshaft and ward bearing of crankshaft. Reduction gears lubricated by oil projected on to the teeth. re tappets and cams lubricated by oil escaping from the camshaft bearings.

Armstrong Siddeley 'Jaguar' Engine.*

Air-cooled static radial type, having 14 cylinders arranged in two banks of seven, and king on two cranks set at 180° to each other. Normal rated h.p. 385; maximum h.p. 425 1870 r.p.m. Total weight, 770 lbs.

The body of the engine consists of a cast aluminium crank case B, which is attached to the oplane by means of a pressed steel bearer flange F, and which is bored to receive the

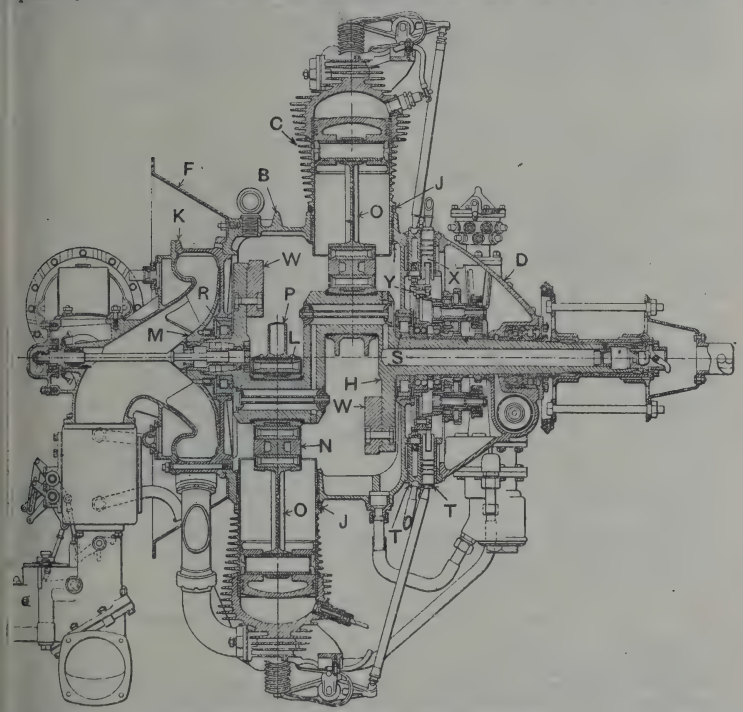


Fig. 6.—Armstrong Siddeley 'Jaguar' Engine.

inders C, and the valve tappet guides T. A back cover attached to the engine body carries magnetos and carburettors, and also the rear crankshaft bearing R. The inside of the back rer forms a casing for an induction fan M, which is attached to the crankshaft.

The crankshaft is a one-piece alloy steel forging and is balanced by weights W, which are tachable. A master connecting-rod O is rigidly attached to a master ring N, and is attached the piston of the top vertical cylinder in the front bank of cylinders and to the bottom vertical linder in the rear bank.

There are six auxiliary tubular connecting-rods P, which are free to hinge in the master ring, ing attached to it by the hardened steel pins L.

Hollow floating gudgeon pins are used in the piston, the pistons being of aluminium alloy th two cast-iron gas rings and two scraper rings. A hardened steel ring, Y, embodies three et and three exhaust cams, and is operated by planetary reduction gearing which drives it at e-sixth engine speed in an opposite direction to that of the crankshaft.

* *This type of engine was used by Sir Alan Cobham in his flight to Australia and back.*

Lubrication is on the dry-base system, two gear type pumps being fitted, one to feed s the other to scavenge the oil. Oil is supplied to the feed pump from a supply tank, and is th forced through a filter to the hollow crankshaft at a rate of about 2½ galls. per minute. released from the engine the oil drains back to the sump, and is returned to the supply tank the scavenge pump through oil-jackets surrounding the induction-fan casing and heater b By these means the oil is cooled, and the incoming gas heated.

Armstrong Siddeley 'Genet.'

This is a low-powered engine, the general design of which is similar to the 'Jaguar.'

General characteristics are: Five cylinder, air-cooled radial. Steel cylinders, screwed s shrunk on aluminium heads with inclined valves operated by push rods. One piece cranksh with counterbalance weights. Forged 'Y' alloy pistons. Oil pumps and magnetos mounted front cover of crankcase, carburettor at back communicating with induction chamber contain a mixing fan. Dry sump lubrication and provision for dual ignition.

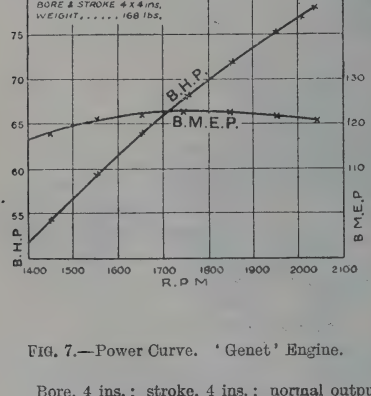
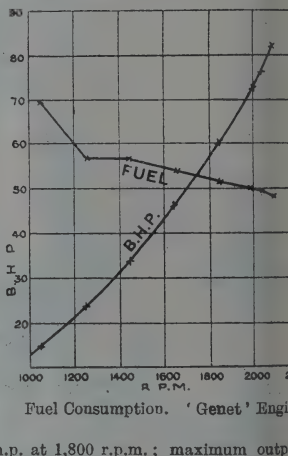


Fig. 7.—Power Curve. 'Genet' Engine.



Fuel Consumption. 'Genet' Engi

Bore, 4 ins.; stroke, 4 ins.; normal output, 60 b.h.p. at 1,800 r.p.m.; maximum outp 72 b.h.p. at 2,035 r.p.m.; weight, 168 lbs.

Fuel consumption, 0·57 pint per b.h.p. hour.

Wright 'Whirlwind' Engine. Model J–5 Series.

This engine (fig. 8) is of the air-cooled, static radial type.

The leading particulars are as follows:—

Number of cylinders, 9; bore, 4½ ins.; stroke, 5½ ins.; displacement, 788 cubic ins.; co pression ratio, 5·2 : 1; guaranteed h.p. at sea level, 200 h.p. at 1,800 r.p.m. Average weig (dry), 508 lbs. Length overall (ex. starter), 34 ins. Diameter overall, 45 ins. Distance, mou ing flange to end of propeller hub, 27$\frac{17}{32}$ ins. Fuel consumption at rated power, 0·60 lb. h.p. hour. Oil consumption at rated power, 0·025 lb. per h.p. hour.

The cylinder consists of a head H with integral fins cast in aluminium alloy screwed a shrunk on to a forged steel barrel B with integral fins and holding-down flange. Combust chamber hemispherical with valves inclined at 35° to cylinder axis. Two sparking plugs cylinder located in bronze bushings, diametrically opposite in the sides of the combustion chamb at an angle of 10° to crankshaft axis. Cylinder head contains two ports, the axes of which at right angles to each other, one for attachment of inlet pipe, and the other for attachment exhaust manifold. Cylinder attached to crankcase by eight studs.

Crankcase built up of five aluminium alloy castings. Front section S_1 includes thrust bear housing, magneto brackets, magneto and cam-driving gears. Intermediate section S_2 conta cam and valve tappet mechanism and housing for front crankshaft bearing. Main section S_4 provided with pads for attachment of cylinders and contains the flange for mounting t engine, and the housing for rear crankshaft bearing and intake passages P. Rear section contains drives for oil and fuel pumps, gun synchronisers and tachometers. It also provide mounting for engine starter and housing for main oil strainer.

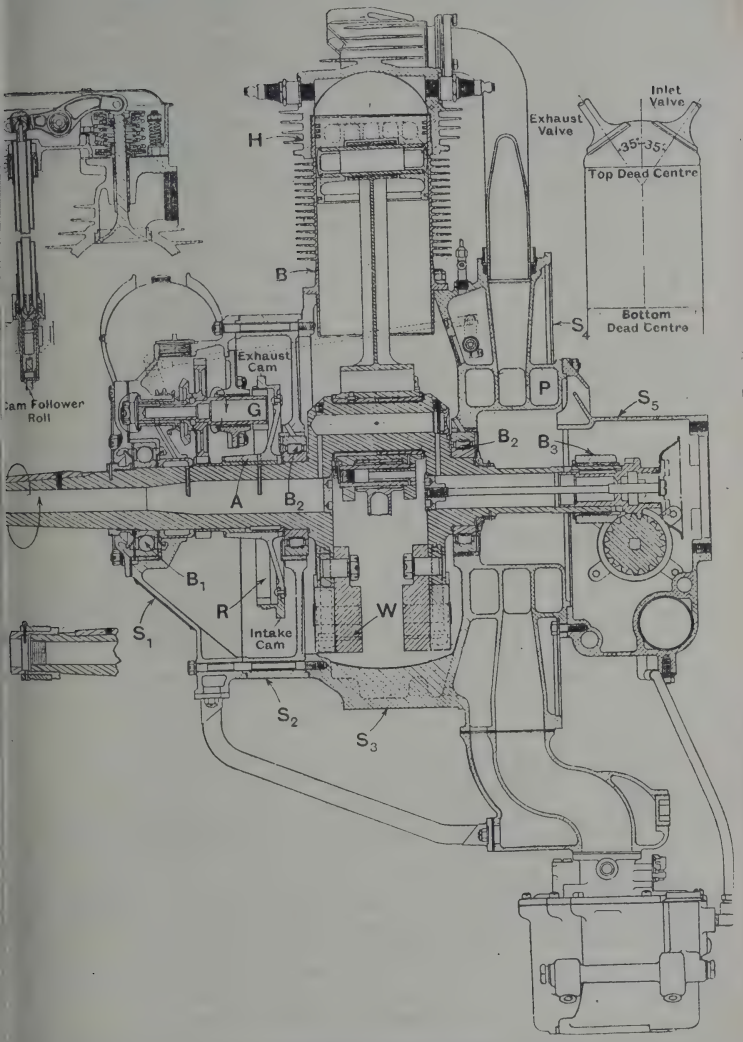


FIG. 8.—Wright 'Whirlwind' Engine.

Model J–5 Series.

Crankshaft, single throw, counterbalanced type, chrome-nickel steel forging machined over and hollow throughout its length. Counterweights W bolted to extensions of crank chee Shaft runs in four bearings, ball thrust bearing B_1, two main ball bearings B_2, and a plain bear B_3 in rear crankcase section.

Valve-operating mechanism actuated by cam located in intermediate crankcase section, a consists of a hardened steel ring R with eight lobes on the outside, and an internal gear G on inside, which is riveted to an aluminium hub A riding on the sleeve portion of the cam dr gear, which is keyed to crankshaft. Cam followers of roller type. Push rods of nickel st tubing with hardened steel balls pressed into either end. Valve gear enclosed by rocker a housings, which form the support for rocker arm pins. Connecting rods consist of one mas and eight link rods machined from chrome nickel steel forgings, master rod provided with st backed babbit-lined bearing at big end. Gudgeon and knuckle pin bearings of bronze.

Pistons cast aluminium alloy with three compression rings above gudgeon pin and one scraper ring at bottom of skirt.

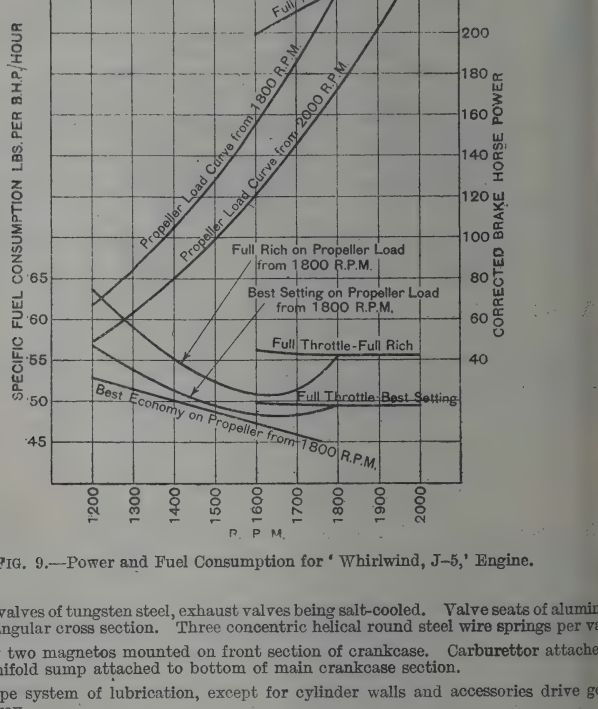


FIG. 9.—Power and Fuel Consumption for 'Whirlwind, J–5,' Engine.

Tulip-type valves of tungsten steel, exhaust valves being salt-cooled. Valve seats of alumini bronze of rectangular cross section. Three concentric helical round steel wire springs per val

Ignition by two magnetos mounted on front section of crankcase. Carburettor attached oil jacket, manifold sump attached to bottom of main crankcase section.

Pressure-type system of lubrication, except for cylinder walls and accessories drive ge which is by spray.

A.D.C. AIRCRAFT CO.'S 'NIMBUS' ENGINE.

This engine is one of the lightest of its type yet produced. It has six water-cooled vert cylinders, with three valves per cylinder, one large inlet and two exhaust. The inlet valves operated by short rockers, while the exhaust valves are operated directly from the overh camshaft. Aluminium alloy pistons are used.

No gear reduction is employed, the air-screw being direct driven.

Bore, 152 mm.; stroke, 190 mm.; normal output, 305 b.h.p. at 1,450 r.p.m.; maximum put, 335 b.h.p. at 1,600 r.p.m.; petrol consumption at normal output, 0·52 pint per h.p. hour; consumption, 0·017 pint per h.p. hour; compression ratio, 5·4 : 1; b.m.e.p. 132 lbs. per in.; weight dry (complete with airscrew boss, but less radiator and water), 670 lbs. ± 10 lbs.

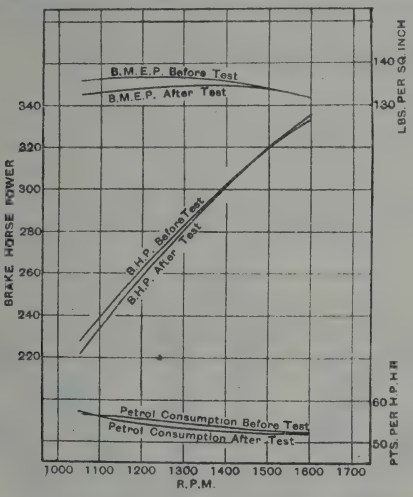


FIG. 10.—Power and Fuel Consumption Curves. 'Nimbus' Engine.

A.D.C. AIRCRAFT CO.'S 'AIRDISCO' ENGINE.

This engine is suitable for training or light commercial machines.

Air-cooled, 8-cylinder 'Vee' type, with cylinders set at 90°. Cylinders of cast-iron with olling fins with detachable head of aluminium alloy, the whole assembly being secured to the nkcase by four long studs passing through lugs on the cylinder heads.

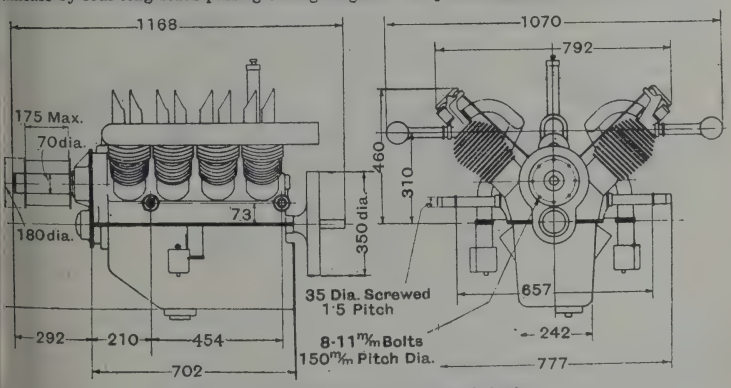


FIG. 11.—Main Dimensions of 'Airdisco' Engine.

Aluminium alloy piston with two cast-iron rings; gudgeon pin fixed in small end of rod and ating in piston.

The valves are both of the overhead type, operated through rockers by push rods, the rockers ing supported by brackets cast on the cylinder heads.

Connecting rods of the main and articulating type, the articulating rod running on a harden steel pin in a phosphor-bronze bush. The big end bearing is white metal and cast direct in the main rod.

Power transmitted from crankshaft to propeller shaft by gears with a 2 : 1 reduction ratio.

Bore, 105 mm.; stroke, 130 mm.; normal output, 128 b.h.p. at 1,800 r.p.m.; maximu output, 140 b.h.p. at 2,000 r.p.m.; weight (less fuel and oil), 452 lbs.; weight per h.p. (at norm output), 3·53 lbs.

Petrol consumption at normal output, 0·62 pint per h.p. hour.

Oil consumption at normal output, 0·04 pint per h.p. hour.

'Bristol' Jupiter Series VII. Engine.

The 9-cylinder 'Bristol' Jupiter engine is of the air-cooled static radial type with gear-driv blower, and is manufactured by the Bristol Aeroplane Co.

Leading particulars are as follows :—

Number of cylinders, 9; bore, 5¾ ins.; stroke, 7½ ins. Total swept volume, 1,753 cubic in Normal r.p.m., 1,775 above 12,000 ft., maximum r.p.m. 1,950 above 15,000 ft. Dry weigl 770 lbs. Fuel consumptiom, 0·59 pint/b.h.p. hour. Direction of rotation, L.H. tractor.

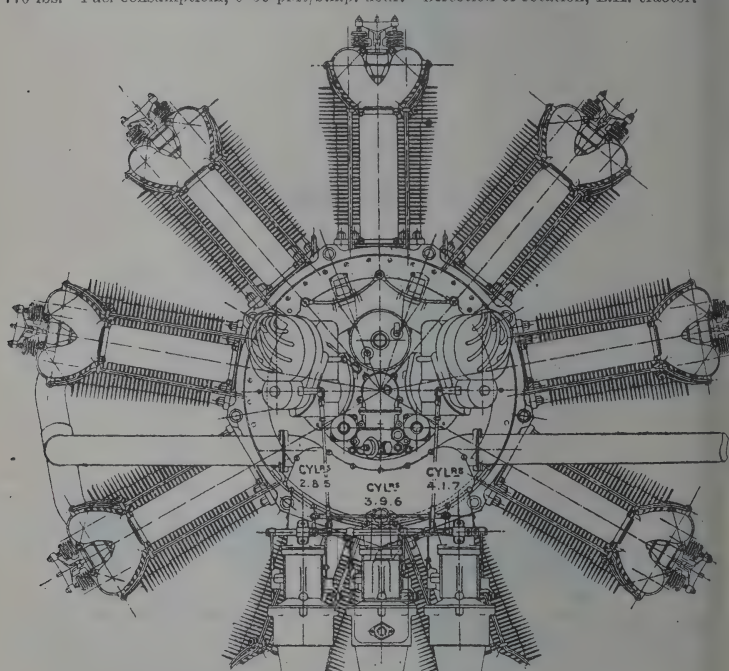


Fig. 12.—The 'Bristol' Jupiter Engine (Rear View).

Rating.

Ground.—Engine throttled to 370 b.h.p. at 1,535 normal ground r.p.m.

Climbing.—Throttle opened up progressively to full at 12,000 ft., normal r.p.m. increasi progressively to 1,775 r.p.m. at this altitude, engine developing 440 b.h.p.

Level Flight.—Maximum full throttle r.p.m. of 1950 not permissible till 15,000 ft. altitud engine then developing 460 b.h.p.

The airscrew is direct driven, but the engines can be supplied fitted with epicyclic ge reduction to drive the airscrew at 1,200 r.p.m.

The crankcase is an aluminium alloy casting in two sections, held together by long bolts, ich also hold the engine to the fuselage.

The steel cylinders are machined from solid billets, and are bolted to the crankcase. Three burettors are fitted, each feeding three cylinders.

'BRISTOL' JUPITER SERIES VII. ENGINE (with bevel type reduction gear).

Leading Particulars.—9 cylinders, air-cooled radial; bore, 5¾ ins.; stroke, 7½ ins. Total oke volume, 1,753 cubic ins. Compression ratio, 5·3 : 1 (commercial type 5 : 1). Normal ine speed, 2,000 r.p.m. Maximum engine speed, 2,200 r.p.m. Gear ratio, 0·5 : 1. Propeller, H. tractor. Normal propeller speed, 1,000 r.p.m. Maximum propeller speed, 1,100 r.p.m. rmal power, 485 b.h.p. at 2,000 r.p.m. (commercial type 465 b.h.p.). Maximum power, 5 b.h.p. at 2,200 r.p.m. (commercial type 505 b.h.p.). Oil pressure, 40 lbs./sq. in. Tachometer ve ½ engine r.p.m. Fuel, standard service, 80 20 petrol-benzol. Oil, Castrol 'R' or pure ated pharmaceutical castor. Dry weight, 830 lbs.

A 3-cylinder, air-cooled radial engine developing 100 h.p. is also made. This engine runs 1,600 r.p.m., and has steel cylinders 5¾ ins. bore × 6¼ ins. stroke, with aluminium heads. e smallest engine made by this company is the 'Cherub,' Series III. This engine has two posed cylinders of 90 mm. bore, stroke 96·5 mm., and a capacity of 1,288 c.c. It develops a ximum output of 36 b.h.p. at 3,200 r.p.m. and weighs 95 lbs., or 2·88 lbs. per b.h.p.; normal put, 34 b.h.p. at 2,900 r.p.m.

Fuel consumption, 2 galls. per hour; oil consumption, 1 pint per hour.

The cylinders have steel barrels and aluminium alloy heads carrying the screw-in alloy steel ve seats, guides, valves, inlet and exhaust passages. Inlet and exhaust valves of cobalt-chrome el are interchangeable, and have three concentric springs each. The camshaft lies across the nkcase below the crankshaft and is driven by spur gears, and operates the valves through ker shafts which run parallel to the cylinder axes from crankcase to cylinder head.

Aluminium alloy pistons, with three rings, are used.

Carburation.

With radial and rotary engines it is usual to fit a simple type of carburettor, there being no t chamber, the petrol flow being hand adjusted to suit engine speed and atmospheric conditions.

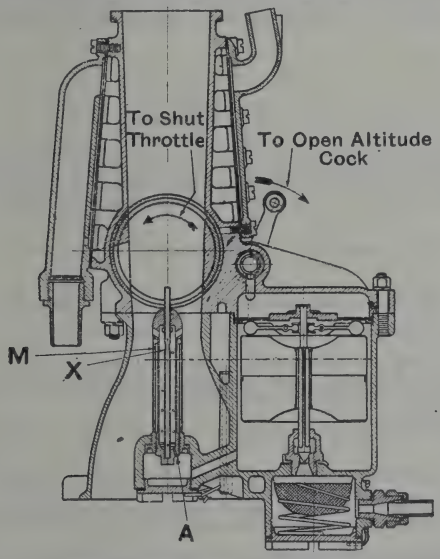


FIG. 13.—Napier Claudel-Hobson Water Jacketed Carburettor.

th stationary engines two or more carburettors are fitted according to the size of the engine presentative types are the Zenith and Claudel-Hobson, which are fitted with float chambers

and designed to give a practically constant mixture under the usual variations of load and spee These carburettors require to be carefully adjusted to each engine so as to give the same resul the operation of adjusting being known as ' synchronising.'

Aero engine carburettors must operate under variable circumstances. As the machine ris the density of the atmosphere decreases, and the quantity of fuel required per cu. ft. of free becomes less. The desired reduction in petrol flow is controlled by hand adjustment, either throttling the supply to the jet or, in the case of carburettors with float chambers, by reduci the pressure difference between the float chamber and the jet.

The Napier-Claudel Water Jacketed Carburettor is shown in fig. 13, and is designed for u with the ' Lion ' engine. It operates on the standard Claudel diffuser principle, the holes A a X being the main and pilot jets respectively. Water is delivered into the jackets on t induction pipes through pipes connected to the outlet flanges on the cylinder heads. Fr the induction jackets the water is led through short pipes to the water jackets of the carburetto and thence through a return pipe to the water pump.

On tractor type engines the series parallel type main and slow running jets are used, where on pusher type engines the series type jets are used.

The jets shown in fig. 13 are the series type; the series parallel type main jets have additional pilot jet hole drilled through their base central with the pilot jet, the pilot jet bei specially calibrated to function correctly with this type of main jet.

The altitude compensation is of the ' Vacuum control ' type. The areas of the various passag are specially proportioned for the ' Lion ' engine. The functioning of the pressure balance a altitude control systems depends on the maintenance of an air pressure or depression above t petrol in the float chamber.

The arrangement of the induction piping is a most important factor in getting go carburation; sudden changes in the speed of the charge, and sharp bends, cause a considera loss. Also there must be no dip in the pipes. The usual methods of heating are by wat circulation, by exhaust gases, and by hot air taken into the carburettor. The purpose of t choke tube is to obtain the correct velocity of air around the jets in order to get the best mixtu at all speeds. The main jet has most influence at high speeds, and the compensator, whi corrects the irregularities of the main jet, has the greatest influence at low speeds.

Water Cooling.

Water cooling of aircraft engines has followed automobile practice in general principl but there has been great diversity of opinion as to radiator design. The honeycomb type m now be considered as standard, with round tubes and hexagonally bulged ends. This gives maximum cooling surface with minimum solid frontal area and therefore minimum he resistance.

From a series of tests on different radiators (Aeronautical Research Committee R. & M. No. 9 it was found that:

(*a*) Heat dissipation can be represented as a function of the cooling area ratio ($i.e.$ $\frac{\text{cooling area}}{\text{frontal area}}$) and drag as a function of cooling area ratio and diameter.

(*b*) A round bulge gave a better performance than the hexagonal, mainly on account of t smaller drag. For tubes of the same length : diameter ratio, large diameters a better than small, mainly on account of the drag.

(*c*) Shutters have comparatively little effect on heat dissipation until they are more th half shut.

(*d*) The shuttered results suggest the use of longer tubes in order to cut down the frontal ar

(*e*) Geometrical considerations suggest the development of hexagonal tube radiators, as th would have greater cooling area for the same tube length and a smaller capacity.

Opinions of designers vary greatly as to the best position of the radiator. The ' nose ' positi in which the radiator is placed immediately behind the propeller, has many adherents, but excelle results are also obtained when the radiator is placed in two halves on the sides of the fusel or below the fuselage. The radiator may also be placed in the top plane centre section.

Radiator Shutters.

In machines designed for flying at high altitudes, it is necessary to provide a variable cooling rice to obviate the danger of the radiator freezing when high speeds are obtained as in diving. e device most generally used is a Venetian-blind type of shutter, which can be closed to prevent air having access to the radiator. It is controlled by the pilot, who is also provided with a ator thermometer, to indicate the circulating water temperature.

Average Weight of Power Plants.

	Lbs./h.p.		Lbs./h.p.
ter-cooled engines	2·50	Air-cooled engine accessories	0·383
-cooled engines	2·33	Water-cooled engine + accessories	3·50
ter-cooled engine accessories	1·00	Twin water-cooled engines + accessories	3·75
in water-cooled engines accessories	1·25	Air-cooled engines + accessories	2·50

Engine accessories include: radiator and shutters, cooling water, piping and cocks for fuel, and water, exhaust pipes, pumps, starting gear, propeller. Fuel and oil tanks *not included*, these vary with duration of flight.

Weight as a Percentage of Engine Weight.

	Per cent.
Water-cooled engine accessories	43
Twin water-cooled engine accessories	47
Air-cooled engine accessories	16

Weight of Honeycomb Radiators.

Weight of honeycomb radiators in lbs. = 0·4 × radiating surface in sq. ft. (approx.).

Weight of Tanks.

Weight of Fuel, Oil, or Water in lbs.	Approximate Weight of Tanks in lbs.		
	Steel. (Fuel.)	Self Sealing. (Fuel.)	Oil or Water.
200	30	50	27
400	50	75	40
600	65	95	50
800	75	110	—
1000	87	125	—

eight of Power Plant as Percentage of Gross Weight of Complete Plane.

	Average value. Per cent.
Engine	18·5
Fuel and oil tanks	3·0
Radiator, shutters, and cowling	2·75
Cooling water	2·75
Airscrew	2·50
Piping, pumps, cocks, etc.	0·50
Engine starting gear	0·50
Total	30·50

DIMENSIONS, LOADS, RUBBING FACTORS, ETC., OF REPRESENTATIVE AERO ENGINES.

Type.	Engine.	Bore and Stroke.	Normal R.P.M.	Approximate H.P. delivered per Crank Pin.	No. Cylinders per Crank Pin.	Centrifugal Weight per Crank Pin.	Reciprocating Weight per Cylinder.	Crank Pin Diameter.	Effective Bearing Length.	Projected Bearing Area.	Bearing Pressure. Lbs. per Sq. In.		Rubbing Velocity.	Rubbing Factor.	Usual Oil Pressure.
											Max.	Mean.			
		Ins.				Lbs.	Lbs.	Ins.	Ins.	Sq.Ins.			Ft. Sec.		Lbs. Sq. in.
6-Cylinder Vertical	Maybach	6·5 × 7·1	1,400	47	1	5·14	17·35	2·6	2·6	6·76	1,730	520	15·85	8,250	6
	Rausie—E6	5 × 6	1,650	29	1	3·73	5·95	$2\frac{1}{8}$	$2\frac{1}{8}$	4·52	1,640	454	15·3	6,950	45
	Liberty—6	5 × 7	1,800	40	1	3·7	5·9	$2\frac{3}{16}$	$2\frac{3}{16}$	5·2	1,060	468	18·66	8,750	40
8-Cylinder Vee	Hispano—300	5·51 × 5·9	1,800	80	2–90° V.	6·2	7·2	$2\frac{1}{8}$	$2\frac{3}{8}$	5·04	1,586	856	16·7	14,360	70
	Wright—H2	5·51 × 5·9	2,000	100	2–90° V.	6·2	6·06	$2\frac{1}{8}$	$2\frac{7}{16}$	5·19	1,835	944	18·6	17,520	70
12-Cylinder Vee	Rolls Royce—Eagle, Series IX	$4\frac{1}{2}$ × $6\frac{1}{2}$	1,800	59	2–60° V.	3·95	3·75	$2\frac{1}{4}$	$1\frac{7}{8}$	4·23	1,180	624	17·7	11,050	40
	Packard—2025	$5\frac{1}{2}$ × $6\frac{1}{2}$	1,800	90	2–60° V.	8·02	8·06	$2\frac{1}{2}$	$2\frac{7}{8}$	6·08	1,220	840	19·7	16,500	55
	Packard—1237	5 × $5\frac{1}{4}$	1,800	50	2–60° V.	5·01	5·83	$2\frac{1}{4}$	$2\frac{1}{4}$	5·06	1,080	580	17·5	10,150	40
	Liberty—12	5 × 7	1,700	70	2–45° V.	6·3	6·2	$2\frac{3}{4}$	$2\frac{3}{16}$	5·2	1,035	750	17·6	13,200	40
	Curtiss—K12	$4\frac{1}{2}$ × 6	2,250	70	2–60° V.	4·4	3·25	$2\frac{1}{2}$	$1\frac{7}{8}$	4·73	1,036	759	24·6	18,675	85
12-Cylinder W.	Napier Lion	$5\frac{1}{2}$ × $5\frac{1}{8}$	1,925	115	3–60° W.	6·4	5·5	$2\frac{3}{4}$	$2\frac{3}{4}$	7·55	1,100	629	23·1	14,500	50
18-Cylinder W.	U.S.A.—W—1	$5\frac{1}{2}$ × $6\frac{1}{2}$	1,800	133	3–40° W.	11·2	7·4	3	$2\frac{7}{16}$	7·31	1,250	872	23·5	20,500	50
	U.S.A.—W—2	$6\frac{1}{2}$ × $7\frac{1}{2}$	1,400	167	3–40° W.	16·3	11·4	$3\frac{3}{8}$	$2\frac{1}{2}$	8·43	1,145	819	20·6	16,900	40
9-Cylinder Radial	Lawrance	$4\frac{1}{2}$ × $5\frac{1}{2}$	1,800	220	9 Radial	17·2	4·16	2	3·45	6·9	1,188	971	15·7	15,250	30

Manufacturer.	Rated H.P.	Rated R.P.M.	Bare Engine Weight. Lbs.	Weight per rated H.P. Lbs.	No. of Cylinders.	Bore and Stroke. Ins.	Displacement. Cubic ins.	Compression Ratio.	B.M.E.P. Lbs./sq. in.	Angle between Cylinder Banks.	Oil Consumption. Lbs./h.p./hour (rated load).	Fuel Consumption. Lbs./h.p./hour (rated load).	Cooling.
Curtiss Aeroplane and Motor Co.:													
OX—5	90	1,400	390	4·33	8	4·0 × 5·0	502·8	4·92	111	90° V.	0·03	0·60	Water
D—12	400	2,000	694	1·73	12	4·5 × 6·0	1,145	6·0	114	60° V.	0·01	0·51	,,
V—1400	500	2,100	660	1·32	12	4·875 × 6·25	1,400	5·6	134	60° V.	—	—	,,
Wright Aeronautical Corp.:													
E—4	190	1,800	467	2·46	8	4·7 × 5·1	718·9	6·0	122	90° V.	0·025	0·50	,,
I	150	1,450	467	3·11	8	4·7 × 5·1	718·9	4·72	117·3	90° V.	0·023	0·515	,,
T. A	600	2,000	1,150	1·91	12	5·75 × 6·25	1,947	5·4	122	60° V.	0·025	0·50	,,
U.S.A. Liberty—12	400	1,700	844	2·11	12	5·0 × 7·0	1,649	5·42	119·5	45° V.	0·032	0·496	,,
Packard Motor Co.:													
1—A—1500	510	2,100	738	1·45	12	5·375 × 5·5	1,500	5·5	129	60° V.	0·015	0·50	,,
2500	800	2,000	1,150	1·38	12	6·375 × 6·5	2 489	5·7	127	60° V.	0·045	0·50	,,
	1,250	2,700	1,402	1·50	24	5·375 × 5·0	2,775	—	—	90° X.	—	—	,,
Wright Aeronautical Corp.:													
J—4—A	200	1,800	470	2·35	9	4·5 × 5·5	786	5·0	112	Fixed radial	0·025	0·52	Air
L—4	60	1,800	160	2·66	3	4·25 × 5·25	223	5·0	120	,, ,,	0·03	0·50	,,
R—1200	400	1,900	640	1·60	9	5·5 × 5·5	1,176	5·0	124	,, ,,	—	—	,,
P—2	425	1,700	820	1·93	9	6·0 × 6·5	1,654	5·0	120	,, ,,	—	—	,,
J—5	200	1,800	508	2·54	9	4·5 × 5·5	788	5·2	—	,, ,,	0·025	0·60	,,
Curtiss Aeroplane and Motor Co.:													
R—1454	400	1,700	790	1·97	9	5·625 × 6·5	1,454	5·4	128	,, ,,	—	—	,,
Air-Cooled Liberty	420	1,800	950	2·26	12	4·625 × 7·0	1,412	5·4	132	Inverted 45° V.	—	—	,,

SECTION XXXIV

FUELS: SOLID, LIQUID, AND GASEOUS

By Harold Moore, M.Sc.(Tech.), M.I.Pet.Tech., F.C.S., A.I.M.E.
(Author of 'Liquid Fuels for Internal Combustion Engines'),
and R. B. Hobson, A.M.C.T., A.M.I.Pet.Tech.

(With Contributions by Arthur Grounds, B.Sc., A.I.C.,
C. Harvey, Alwyne Meade, A.M.I.C.E., E. W. L. Nicol, M.I.Mar.E.,
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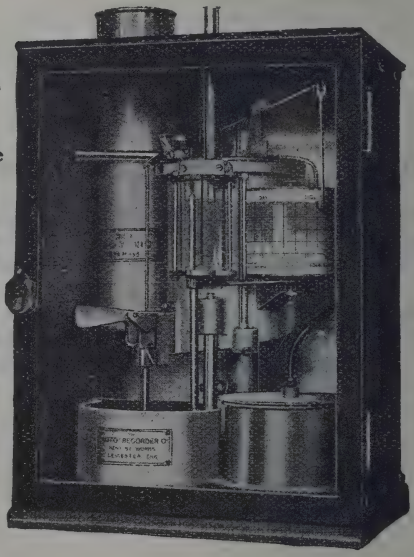

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SECTION XXXIV

FUELS: SOLID, LIQUID, AND GASEOUS.

(Contributed by Harold Moore, M.Sc.(Tech.), M.I.Pet.Tech., F.C.S., and R. B. Hobson, A.M.C.T., Consulting Chemists.)

COMBUSTION.

The heat yielded by burning any fuel is produced by the combination of the carbon, drogen, and sulphur present in it with the oxygen of the atmosphere. A little heat may be her liberated or absorbed by the decomposition of the compounds present in the fuel into their ments. When a fuel is burned in a furnace, or in an internal combustion engine, under rect conditions, the carbon burns to form carbon dioxide (CO_2), the hydrogen to form ter (H_2O), and the sulphur, which is not usually present in large quantities, to form sulphur xide (SO_2). If insufficient air be present the carbon is incompletely burned, and forms, to ne extent, carbon monoxide (CO), a considerable amount of heat being lost by this reaction cing place. The weight of air theoretically required for complete combustion may be ertained by the formula:

$$\text{Air required in lbs.} = 0{\cdot}116\,[C + 3\,(H - \tfrac{1}{8}\,O)],$$

ere C, H, and O are the percentages of carbon, hydrogen, and oxygen respectively present in e fuel.

Both the theoretical quantity of air required, and the percentage of carbon dioxide theoretically rect in the flue gas, are dependent upon the ultimate composition of the fuel. In practice the required is generally greater or less than by the formula.

Calorific Value of Coal.

If it is impossible to determine the calorific value of coal in a calorimeter it can be roughly imated from the ultimate composition by the formula:—

Net calorific value = [8,137 C + 29,100 (H − ⅛O) + 2,500 S − 600 H_2O] ÷ 100, where H, and O are the percentages of carbon, hydrogen, and oxygen respectively present, d H_2O the percentage of hygroscopic water present.

When the ultimate analysis is not known and it is desired to obtain a rough estimate of the lorific power from the proximate analysis, this can be obtained by the formula:

$$\text{Calorific value} = 1{\cdot}8(82C + aV)\ \text{B.Th.U.}$$

which C = per cent. fixed carbon, V = per cent. volatile matter, and a is a constant computed om the following: $a_1 = 100V/(C + V)$.

a_1	5	10	15	20	25	30	35	38	40
a	145	130	117	109	103	98	94	85	80

Ash and Moisture Content.

The question of ash content is a serious one, as its removal from boilers involves labour and pense. The clinker to be removed from a steam plant is greater in quantity than the weight ash content obtained by calculation from the results obtained in the laboratory.

High moisture content not only shows that water is being bought for coal. It must remembered that this moisture has to be driven off in the form of steam, and in this way tak up heat from the combustion zone, and is liable to cause smoking, with consequent reduction efficiency.

Combustion Computation.

The total heat per pound of water vapour as found in air and in flue gases may be comput within one B.Th.U., by the formula $H = 1{,}057 + 0{\cdot}46t$, where t is the Fahrenheit temperatu This formula frees the computer from all need for tables so far as computing moisture los concerned, while at the same time ensures a degree of accuracy sufficient for all practical purpos

Internal Combustion Engines' Exhaust Gases.

The exhaust gases from internal combustion engines are subject to the same considerat as flue gases. They, however, cannot be regulated so as to produce a definite CO_2 percent as to obtain this result it would be necessary to throttle down the incoming air, thus loa the engine by increasing the difference in pressure between exhaust and inlet, in which ca

Theoretical Composition of Exhaust Gas with Varying Amounts of Exc Air when Fuel has the Composition: Carbon 88 %, Hydrogen 12 %.

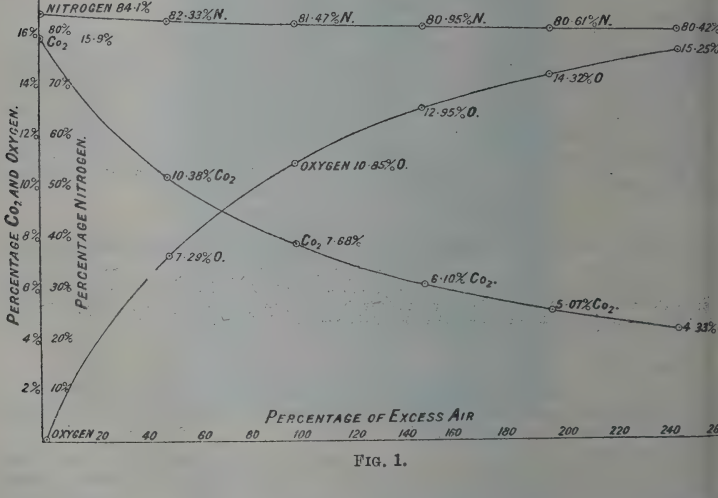


Fig. 1.

loss of efficiency would occur. The graphs in fig. 1 show the composition of the exhaust g of an engine burning heavy petroleum (about 88 per cent. C and 12 per cent. H) with va quantities of excess air. Diesel oil engines running at full load generally take about 100 cent. excess air: semi-Diesel engines a somewhat greater percentage excess air.

Composition of Flue Gases.

With an average steam coal the theoretical quantity of air for combustion would yield a gas containing some 18·5 per cent. of carbon dioxide, but if only the calculated quantity o be admitted to the furnace there is danger of loss of heat by the formation of some ca monoxide, and if the supply of air be any less than the calculated quantity, a very serious lo certain to take place for this reason. On the other hand, a slight excess of air over calculated amount does not result in great loss of heat. It is therefore desirable to allow a s excess of air. The best working is obtained by endeavouring to maintain a proportion of a 14 per cent. of carbon dioxide in the flue gas.

Most methods for the estimation of carbon dioxide are based on the absorption of this gas by potassium hydroxide (caustic potash) solution, the process consisting in measuring a volume of flue gas at a definite temperature, and then absorbing the CO_2 by means of a 35 per cent. solution of caustic potash, after which the volume of gas is again measured, the reduction in volume indicating the volume of CO_2 originally present. Many simple forms of chemical apparatus are available for this purpose.

It is frequently desirable in gas analysis to estimate carbon monoxide and oxygen as well as carbon dioxide. Similar apparatus with other absorbent solutions for the respective gases may be used. In the common form of Orsat apparatus, pipettes containing absorption solutions of caustic potash (for CO_2), acid cuprous chloride (for carbon monoxide), and alkaline pyrogallol (for oxygen) are used. The apparatus also contains a measuring burette and levelling bottle, and is generally built up in a wooden case to make the complete set easily portable.

In some cases it is necessary to estimate methane or other hydrocarbons in gas, in which case means are provided for exploding the gas with oxygen, after which the newly-formed CO_2 may be estimated, and the content of hydrocarbon gases calculated therefrom. Special forms of apparatus, made solely for the object of estimating methane and carbon monoxide, are available.

CO_2 OR CARBON DIOXIDE.

For the control of combustion, beyond occasional tests of carbon monoxide, the only product which requires frequent estimation is carbon dioxide. The process of distillation which goes on in a boiler furnace, resulting in the separation of the gases and fixed constituents in the fuel, requires widely different and constantly varying conditions in the matter of air supply for the attainment of perfect combustion. Efficient combustion (i.e. economical combustion) is secured by burning the correct proportion of fuel and air under the varying conditions of coal and atmosphere. The point, therefore, to aim at is to generate the required steam by burning as much air as possible and as little fuel as necessary. The burnt air given off passes up the flue in the form of carbon dioxide (CO_2), therefore the object to achieve is to secure as large an amount of CO_2 (say from 10 per cent. to 14 per cent.) as is possible. The relation of coal consumption to CO_2 in the flue gases has been worked out, and the result is given in standard treatises on fuel. These results are as follows:

Temp. of Exit Gases.		Percentage of CO_2 in Exit Gases.											
		4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
F.°	C.°	Total Percentage of Fuel wasted.											
400	204	32·4	26·2	21·8	18·9	16·4	14·9	13·4	12·3	11·4	10·6	9·8	9·2
500	260	40·5	32·7	27·3	23·6	20·8	18·6	16·8	15·4	14·2	13·2	12·3	11·6
600	316	48·6	39·3	32·8	28·3	24·9	22·3	20·2	18·5	17·1	15·9	14·8	13·9
700	371	56·7	45·8	38·2	33·1	29·1	26·0	23·5	21·6	19·9	18·5	17·2	16·2
800	427	64·8	52 4	43·7	37·8	33·2	29·7	26·9	24·7	22·8	21·2	19·7	18·5

The above figures necessarily include the unavoidable loss present in every boiler plant, and the performance of any plant must be judged by comparing the total losses given in the respective columns. The figures in the columns below the 'Percentage of CO_2 in Exit Gases,' represent the wastage of coal with that percentage of CO_2. For example, take the third column and the second line. Temperature of Exit Gases °F. 500—percentage of CO_2, 6 per cent. The wastage of coal is 27·3 per cent. Following the line on to the tenth column, it is shown that with 13 per cent. of CO_2 the coal wastage is 13·2 per cent.

PRECAUTIONS IN TAKING TEST SAMPLES OF FLUE GAS.

It is the practice of many engineers when obtaining accumulative test samples of flue gases to collect these samples over water. Owing to the solubility of the component gases, especially carbon dioxide, in water and the variations of these solubilities with the temperature and pressure, this liquid should not be used to collect the sample if accurate results are desired. If water be used, it will absorb carbon dioxide, for example, until it becomes saturated with this gas with respect to that gas mixture. This results in a loss of some of the carbon dioxide that was in the gas. Then if a gas cleaner in carbon dioxide is collected over the same water, the water will give

up carbon dioxide and increase the carbon dioxide content of the gas. If, instead of water, saturated solution of sodium chloride is used, these errors will be greatly reduced, as the gas much less soluble in this solution.

The common practice of collecting flue gas from the outlet of a boiler by the use of comm iron pipe for the sampling tube is objectionable if the temperature of the gas being sampled sufficiently high to raise the temperature of the sampling tube to 750° F. When the temperatu of the iron reaches 750° F. it starts to react with the carbon dioxide in the gas, forming iron oxi and reducing the carbon dioxide to carbon monoxide. Thus a sample of gas drawn through a iron pipe when at or above this temperature would have its composition completely change appearing to contain high carbon monoxide and low carbon dioxide. For sampling at the high temperatures the tube should be made of silica or clay, or be fitted with a water jacket that it may be cooled. (*Power.*)

CO_2 Recorders.

The majority of CO_2 recorders depend upon the absorption of CO_2 by caustic potash solutio a definite quantity of flue gas being intermittently measured out, and then the CO_2 absorbe and a record made of the diminution of volume, the chart being adjusted to read in volum percentages of CO_2 present in the flue gas.

The 'Auto' CO_2 Recorder.

In fig. 2 is shown, in diagrammatic form, the construction of the instrument known as t 'Auto' CO_2 Recorder, which has been designed and constructed by the *Auto Recorder Compan* and is now in successful operation in connection with a large number of boiler installations this country and on the Continent. The action of the apparatus is as follows:

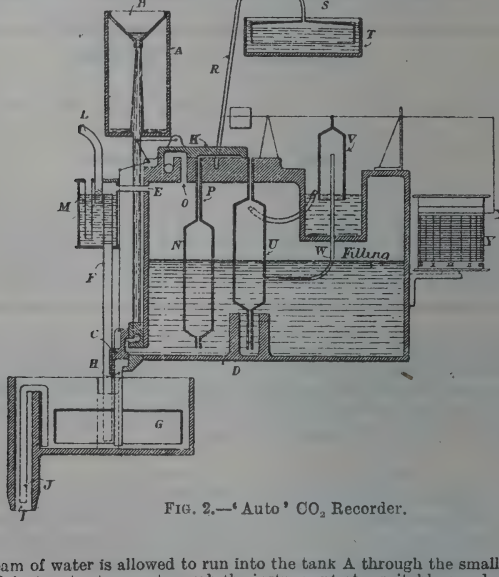


Fig. 2.—'Auto' CO_2 Recorder.

A small stream of water is allowed to run into the tank A through the small funnel B, whi only allows sufficient water to pass to work the instrument at a suitable speed. The water ru from the tank A through the valve C into the chamber D. When the chamber D is filled up to t pipe E, the water overflows down the pipe F and under the float G, which it raises, thereby movi

he valve C upwards and shutting off the water supply from the tank A into the chamber D. 'his motion of the valve C opens a communication from the chamber D through the pipe H, the 'ater rising over the float G until it flows down the pipe I, and the chamber D is empty; the ipe J then acts as a syphon and drains the water from under the float G, which is then allowed) fall again, and the chamber D to be once more filled. By this means the chamber D is lternately filled and emptied, and, as the float is connected by a system of levers to the dis- ·ibuting slide valve K, the water flowing through is the prime mover of the instrument.

The operation of gas analysis is very simple. The pipe L is connected to the supply of gas to e analysed and, as the end of the pipe dips slightly into the water seal in M, no gas can be drawn ack. When the water in the chamber D is running out, there is a slight vacuum in this chamber hich draws the gas through the pipes L and E, and, as the first measuring vessel N is in ommunication with the chamber D through the passages O and P and the slide valve K (this alve having moved over to the right by the rising of the float G), it is entirely filled with flue gas. Much more gas is drawn in than is analysed, in order that the sample may be as fresh as possible. 'hen the water reverses and begins again to run into D (the valve K having moved over to the *ft*, by the sinking of the float G), the gas enclosed in the vessel N is sent through the pipes P and , and under the dome S, which stands immersed in a solution of caustic potash contained in the essel T. This dome is of large area, and the gas is in a thin layer between the wet dome and the)p of the solution, so that the absorption of the CO_2 is rapid. After the water has risen and :pelled all the gas from the vessel N into the absorber, and has again begun to run out, the alve K having moved over to the *right*, the water, as it descends in the second measuring vessel , draws in from the absorber S the gas which has not been absorbed. As the measurer U is of ie same capacity as the measurer N, it follows that, if there is not sufficient gas received from ie absorber S to fill it, it will, after emptying the absorber, draw the remainder from under the ell V through the pipe W, and cause the bell to descend; the greater the amount of CO_2 absorbed ie lower the bell V will be pulled down. As the bell is suspended from a balanced lever, which as a pen X attached to it, the pen marks the chart Y, which is placed round a clockwork drum, ie lines made by the pen being of varying lengths, according to the amount of CO_2 which was the quantity of gas in the first measurer N.

It has been found that one of the greatest troubles with recorders of this kind is to keep the pes from the flue to the instrument clean; in the 'Auto' Recorder this is effected by a special ter.

THE 'W.R.' PATENT CO_2 INDICATOR.

(*W.R. Patents, Ltd., London and Leeds.*)

The W.R. CO_2 or Combustion Indicator is an apparatus which continually, automatically, id accurately indicates the percentage of CO_2 which is passing through the flues at any hour the day and night. With this Indicator installed on the boiler plant the percentage of CO_2 otained can be seen at once, and the necessary steps taken to increase this amount and thus ve fuel.

Fig. 3 shows a new type recently introduced and placed on the market. It can be used in l cases of combustion where any class of fuel is used, and where CO_2 is a product of this mbustion. The arrangement adopted differs materially from other CO_2 indicators.

The method employed in the 'W.R.' Patent CO_2 Recorder depends on the difference of essure generated on the two sides of a porous pot, one side of which is exposed to flue gas hilst the other contains soda lime granules contained in a paper cylinder which absorbs the coming CO_2.

An aspirator, S, worked by the natural draught which it increases, is fixed at a point near the chimney base as possible, and continually aspirates gases from the flue it is desired keep under observation. The path of gases is shown by the arrows. They are first drawn rough a filter F, and pass from thence into a chamber containing a porous pot, inside which a dry reagent, R. The flow of gas is shown by continuous bubbling through water in vessel A pipe connects the chamber with a vessel containing water into which dips one end of iother pipe, G, the other end of which is taken into the inside of the porous pot. Some of e gases penetrate into the interior of this pot, and are absorbed by the reagent, with the sult that a partial vacuum is formed, and the water is forced up the pipe G. The latter is ovided with a scale so graduated that the percentage of CO_2 in the flue gases can be read.

The W.R. Indicator is prompt in its action, having a lag of three minutes only. Its deviation om absolute accuracy has been found to be only 0·1 per cent. It is well constructed; has no echanically moving parts; is fireproof and foolproof, and can be worked by any boy of

average intelligence. With each Indicator the manufacturers furnish a blue print showing the method of fitting to each particular boiler, also special detailed instructions for installing the apparatus, which operation can be completed in from four to six hours by any works' engineer or fitter. In cases where a recording graph is desired, one of a specially approved form can be supplied by W.R. Patents, Ltd. The cartridges last 24 hours of continuous working.

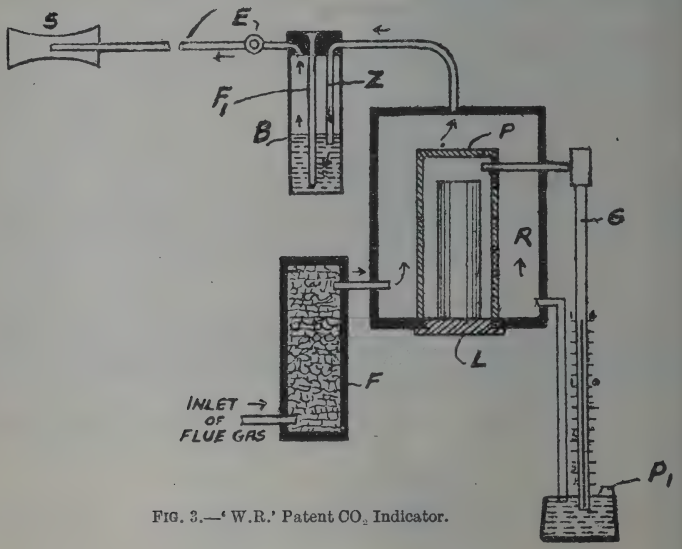


FIG. 3.—'W.R.' Patent CO_2 Indicator.

'Galvanised Iron Pipe' should never be used for connecting a CO_2 machine, that draws a continuous sample, to the sampling point at the boiler. The sulphur dioxide in the flue gas attacks the zinc coating on the pipe, forming zinc sulphate. This soon plugs the pipe and prevents the flue gas sample from being drawn through it.

Thermal Efficiency.

Petrol engines give maximum efficiency with an excess of air, and maximum power with insufficient air.

The following table gives the thermal full load efficiency obtainable when converting the heat of fuels into work by various types of engines:—

Type of Engine.	Thermal Efficiency.
	Per cent.
Reciprocating steam engine and boiler	12
Steam turbine and boiler	18
Petrol engine	22
Gas engine with producer	24
Gas engine with suction producer	26
Petrol engine (aircraft)	27
Semi-Diesel oil engine	34
Alcohol engine	36
Diesel oil engine	36

THERMAL EFFICIENCY CURVE.

Curve A (fig. 4) represents the best thermal efficiency that can be expected from gas-engine lants; B, a moderate efficiency from the same plant; C, a poor efficiency from gas plant, but robably the very best that can be expected from a large gas-fired turbo-generator plant; D may e considered a good thermal efficiency for the latter.

These efficiencies can only be expected in power plants working at a high load factor.

(*A. Hugh Seabrook.*)

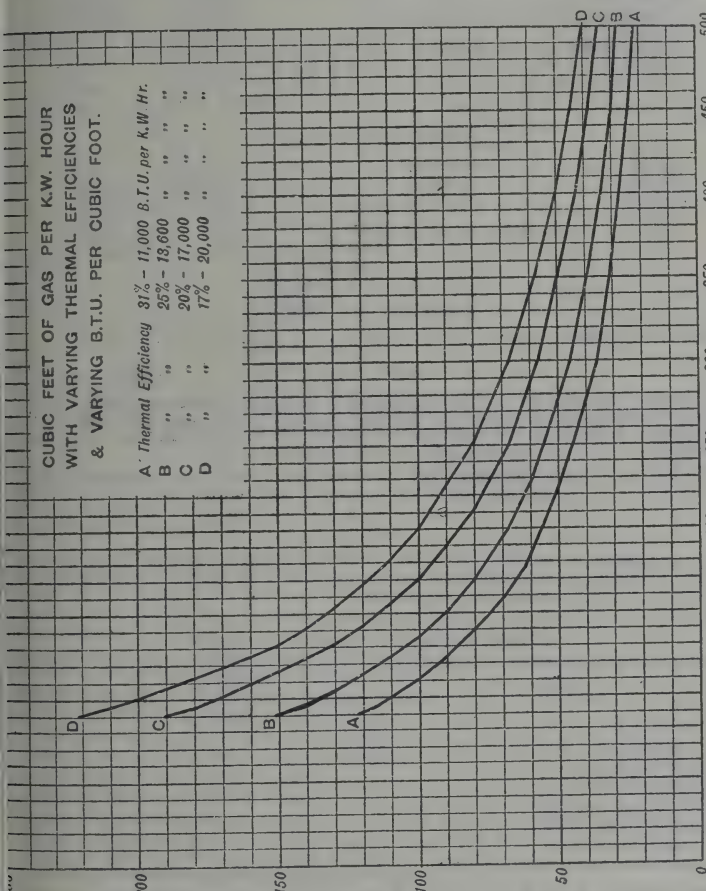


FIG. 4.—Thermal Efficiency Curve.

TEMPERATURES OF SPONTANEOUS IGNITION.

The thermal efficiency of internal-combustion engines is dependent upon the compression pressure employed in the engines. The compression pressure permissible in engines on constant volume cycle is dependent upon the temperature of spontaneous ignition of the fuel employed.

The following are recent figures for the spontaneous ignition temperatures of fuels :—

SPONTANEOUS IGNITION TEMPERATURES (IN OXYGEN).

Liquids.	Sp. Gr.	S.I.T.	
Pratt's perfection spirit No. I.	0·710	272 C.°	522 F.°
" " No. II.	0·724	270	518
Paraffin oil	0·782	253	487
Gas oil (petroleum)	—	254	489
Various crude petroleums and residua	—	254 to 275	489 to 527
Shale oil	—	253	487
Commercial 100 per cent. benzol	0·875	566	1,051
Creosote oil	1·010	415	779
Coke-oven tar oil	1·046	478	892

(*Moore*, '*J.S.C.I.*', Feb. 15, 1917.)

Gaseous Fuels (in Air).		
Hydrogen	758 C.°	1,396 F.°
Carbon monoxide	910	1,670
Ethylene	895 to 905	1,643 to 1,661
Coal gas	850	1,562
Petrol gas	900	1,652
Methane (No ignition below 1,000)	1,000	1,832

(*McDavid*, '*J.C.S.*,' *Nov.* 1917, p. 1003.)

SOLID FUELS.

The most important naturally occurring solid fuels are :—

Coal ; Lignite ; Peat ; Wood.

These may be burned in the raw state, or may be subjected to destructive distillation. In the latter case solid, liquid, and gaseous products are evolved. The more important solid fuel which may be prepared by this treatment are coke (of two kinds, metallurgical and gas-work coke), lignite coke (of little value), peat charcoal, and wood charcoal.

Powdered coal is sometimes made into briquettes by the addition of a small percentage o coal-tar pitch or other binding material, and pressing in moulds.

COAL.

The composition of coal from various fields varies considerably according to the condition to which the coal has been subjected during its formation. Its variation in composition can be seen from the following table of coal analyses :—

ULTIMATE COMPOSITION OF COAL (*Brame*).*

Type of Coal.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Fixed Carbon.	Volatile Matter.
Lignites and brown coals	69·5	5·5	25·0	52·0	48·0
Splint coal (Fife)	82·0	5·0	12·8	61·0	39·0
Gas coal (Durham)	85·0	5·5	8·2	66·0	34·0
Coking coal	87·3	5·05	6·9	73·5	26·5
Smokeless steam (Welsh)	91·3	4·05	3·9	85·5	14·5
Anthracite (Scotch)	91·1	3·5	4·65	88·5	11·5
Anthracite (Welsh)	91·0	3·9	4·28	93·0	7·0

Coal possesses a sp. gr. of from 1·2 to 1·5 (water = 1) mainly depending on its composition It also varies considerably in hardness and texture. The combustible portion of coal usually consists of from 73 to 93 per cent. carbon, 3 to 6 per cent. hydrogen, 2 to 20 per cent. oxygen 1 to 2·5 per cent. nitrogen, and 0·5 to 5 per cent. sulphur. When completely burned coals yield from 1 to 15 per cent. ash. The moisture content varies within very wide limits. The heat value of coal is generally from 12,000 to 16,000 B.Th.U. gross. A comparison of the properties of coal with those of other solid fuels may be seen in the following table :—

* '**Fuels: Solid, Liquid, and Gaseous,**' p. 32.

CALORIFIC PROPERTIES OF VARIOUS FUELS.

Substance.	Calorific Power.		Observed by
	Calories.	B.Th.U.	
Scotch peat briquettes (16 per cent. H_2O)	4,754	8,558	F. Mollwo Perkin.
Coke from Scotch peat	7,600	13,680	,,
Oak (containing 13·3 per cent. H_2O)	3,990	7,182	Gottlieb.
,, ,, 11·8 ,,	4,155	7,479	,,
Yoke elm ,, 12·2 ,,	4,151	7,490	,,
Beech ,, 12·95 ,,	4,168	7,502	,,
,, ,, 13·95 ,,	4,101	7,382	,,
,, ,, 13·75 ,,	4,114	7,405	,,
Birch ,, 11·83 ,,	4,207	7,573	,,
Pine ,, 12·17 ,,	4,422	7,960	,,
Fir ,, 11·80 ,,	4,485	8,073	,,
Anthracite	8,400	15,120	Dosch.
Anthracite from Westphalia	7,575	13,635	Langbein.
Short flame sinter coal	8,200	14,760	Dosch.
Kentucky coal (U.S.A.)	7,785	14,013	U.S. Geological Survey.
Illinois coal ,,	7,056	12,701	,,
Pennsylvania coal ,,	7,875	14,175	,,
Coke	6,900	12,420	Dosch.
,,	6,919	12,454	Langbein.
Lignite	4,000	7,200	Dosch.
Earthy lignite	3,000	5,400	,,
Lignite briquettes	4,668	8,402	Langbein.
Lignite from Saxony (moist)	2,622	4,720	,,
Peat	4,230	7,614	,,
Sawdust briquettes	4,065	7,317	,,
Spanish lignite	5,761	10,369	H. Moore.
Asphaltum (extracted from petroleum)	9,550	17.190	,,

Analysis of Coal.

The chemical tests usually made upon coal are to ascertain the calorific value, coke value, ash content, moisture content, and ultimate composition. The volatile matter per cent. is obtained by deducting the coke value of the dry coal from 100. The 'fixed carbon' is obtained by deducting the ash content from the coke value.

ANALYSES OF COALS. (*Gray & Robinson.*)

Constituents.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Carbon	62·55	65·50	68·64	69·50	72·14	73·77	74·99	74·57	77·00	76·71	78·80	85·70
Hydrogen	3·87	4·23	4·33	4·42	4·40	4·55	4·66	4·74	4·51	4·67	4·92	2·97
Sulphur	1·62	0·67	1·33	0·67	0·61	0·41	0·55	0·47	0·78	0·73	0·50	0·62
Water	8·63	7·92	8·96	9·28	8·34	7·99	7·21	6·95	2·31	1·94	2·72	3·15
Ash	11·78	10·15	6·90	5·97	4·22	1·76	2·68	1·37	7·17	8·49	4·18	3·59
Oxygen and nitrogen	11·55	11·53	9·84	10·16	10·29	11·52	9·91	11·90	8·23	7·46	8·88	3·90
Coke	61·74	61·06	57·53	59·12	58·47	56·93	56·59	56·84	74·61	72·32	66·43	92 03
Fixed carbon	49·96	50·92	50·63	53·15	54·25	55·17	53·91	55·47	67·44	63·83	62·25	88 ·44

1. Splint coal, Lochgelly, Fife.
2. Boiler fuel (a mixture), Fife.
3. Ell coal, Bothwell.
4. Main coal, Bothwell.
5. Poytshaw coal, Bothwell.
6. Dunfermline splint, Cowdenbeath, Pit 10.
7. Splint coal, Bothwell.
8. Dunfermline splint, Cowdenbeath, Pit 7.
9. Boiler fuel, Aitken Pit, Kelty.
10. Haughrigg coking coal, Kilsyth.
11. Coking coal, Kilsyth.
12. Anthracite, Kilsyth.

The Commercial Selection of Coals.

(*Contributed by Chas. F. Wade, A.M.I.Mech.E., A.M.I.E.E.*)

The commercial value of a coal for any specific purpose and for direct combustion purposes will be dependent upon the following factors:—

(i) The lower or net calorific value.
(ii) The amount of volatile matter and nature of coke.
(iii) The amount and nature of the ash content.
(iv) Its physical suitability for the particular conditions under which it is to be burned.
(v) The price per ton, delivered on site.
(vi) Local cost of labour for handling, firing, and removal of ashes.

The net calorific value (i) calls for both a test for calorific value and also either an ultimate analysis or calculation in order to arrive at the hydrogen content of the fuel. The latter calculation or estimate is made from the percentage of volatile matter in the coal as disclosed by proximate analysis.

The net commercial calorific value will vary with the conditions obtaining in individual installations, and will depend upon the final temperature of the gases leaving the boilers or furnaces, together with the total hydrogen in the fuel as fired.

The total hydrogen will be the sum of the hydrogen combined in the fuel and that forming one-ninth of the moisture. Lower commercial calorific value for any specific plant will be

$$\text{HCV} - \left\{ 9\text{H} \left([212 - t] + 970{\cdot}4 + 0{\cdot}47\ [\text{T} - 212] \right) \right\},$$

where,

HCV = higher or calorimeter value of fuel in B.Th.U. per lb. as fired;

t = temperature of the fuel in °F., as fired;

T = final temperature of waste gases.

H = hydrogen fraction of the fuel as fired;

In the absence of direct ultimate analysis of the coal, the percentage of hydrogen in the fuel may be closely estimated by the following formula (Diederichs'):—

$$\text{H} = \text{V} \left(\frac{7{\cdot}35}{\text{V} + 10} \right) - 0{\cdot}013,$$

where,

H = percentage of hydrogen in the combustible; V = percentage of volatile matter in the combustible.

Combustible = coal, less sum of moisture and ash.

(ii) The amount of volatile matter and nature of the coke are found simultaneously in the proximate analysis. This test will give the correct classification of the coal as to its qualifying characteristics for special uses. The ratio of volatile matter to fixed carbon is of the greatest importance in deciding the suitability or otherwise of a coal for use on any particular plant; all other things being equal, the fuel with the lowest volatile content which can be efficiently consumed in the specific furnace conditions will be the most economical in use. This can only be definitely determined by the careful working test of a sample delivery of the fuel, and careful note made of the percentage of CO_2 in the waste gases, together with the final temperature of the gases and the percentage of combustible on the ash heap. The following general classification of coals will be of assistance in selecting suitable fuels for given purposes from the commercial viewpoint of economy in use.

Class of Coal.	Per Cent. Volatile Matter in Combustible.	Economical Application.
Short flame non-caking, semi-bituminous, or Welsh steam coals	12–20	Steam raising with strong draught.
Short flame caking coals	20–25	As above and coke manufacture.
Medium flame, moderately caking coals	25–32	Steam raising, domestic grates.
Long flame caking coals	32–40	Gas manufacture.
Long flame non-caking North Country coals	over 40	Furnaces, gas producers.

Burning a coal in a furnace which has insufficient draught for complete combustion will result in excessive waste of unburned carbon as coke in the ashes. Burning a coal of an unnecessarily high volatile content will produce an unnecessarily high loss in the waste gases, due to the hydrogen content, smoke will be difficult to avoid, and hydrogen loss will not be shown on any commercial form of flue gas analysis apparatus.

The amount of ash and moisture will not affect the classification given above.

(iii) The amount of the ash in the coal will not only reduce its commercial value by the reduction in actual calorific value, but also by its physical effect will reduce the value at a greater rate than that of the percentage of ash. For ordinary conditions of firing and draught, without steam jets, the rate of fall in practical value with the ash content will gradually increase until at 40 per cent. ash the fuel will be unburnable and valueless. This is for average ash.

The nature of the ash is chiefly affected by the percentage of iron in its composition, the fluxing effect of ferric oxide in the ferruginous ash coals causing the formation of liquid slag at comparatively low temperatures, which closes up the fire-bar spaces, assists in the fusion of firebars, and entraps appreciable quantities of unburned combustible. Ferruginous ash is distinguished by its red colour, the percentage of iron being roughly indicated by the depth of the coloration of the ash in the crucible after proximate analysis for ash.

(iv) The physical suitability of the coal for particular conditions depends upon the construction of the firegrates, type of mechanical stoker, and the amount of draught available. Under practically every condition of use mixed coals as regards size should be avoided. For hand-fired boilers and furnaces screened cobbles or nuts should always be selected. Large steam coal is

o be avoided; if fired as received, in lumps, efficient combustion is impossible, while breaking down results in uneven fires and waste due to the formation of a quantity of slack in the process. Fine slacks are unsuited for hand-firing on plain grates, but can be burned very efficiently on special forced-draught grates fitted with steam jets and closely spaced firebars. High ash coals may be more efficiently burned on these grates than with plain natural or induced draught.

(v) The price per ton of coal, delivered, together with the cost of labour in handling and incidental work, is the last test of the value of the coal to be applied after all the technical deductions already referred to have been made, and is to be utilised to arrive at the net number of B.Th.U.'s per unit of cost under practical conditions of work.

Wherever possible, the following procedure should be adopted in selecting the most economically suitable coals for contract purposes:—

A sample delivery should be ordered of sufficient size to allow of observation under practical working conditions for a long enough period to ascertain the maximum hourly evaporation under forced and economical conditions of work, probable ash-heap loss, chimney loss, etc. This cannot be carried out without the proper equipment of testing instruments. This working observation will allow of a close estimate of labour and power costs. A low-grade slack of about 10,000 B.Th.U. per lb. will probably call for a power and labour cost quite double that involved in the use of good quality washed nuts of 14,000 B.Th.U. per lb. This shows the uselessness of evaluation on the calorific value alone. Standing losses on the plant, such as conduction and convection, etc., vary directly as the number of boilers, etc., used.

Final evaluation should be made as follows:—

Gross or higher calorific value of the coal, air-dried, then deduct the following:—

Hydrogen loss under practical conditions of waste gas temperature;

Heat loss in waste gases due to excess air as per CO_2 and temperature readings;

Loss due to unburned carbon in ash-heap per lb. of fuel used.

The final figure thus obtained gives the practical working value of the fuel in B.Th.U. per lb.

To the price of the coal must be added the following costs:—

Cost of attendance for firing per ton of coal used;

" power, such as stoker, fan, conveyor, economiser drive, etc., per ton of coal used;

" ash removal per ton of coal used.

From the data thus obtained the ultimate cost of, say, 100,000 B.Th.U. is obtainable for the actual conditions existing with the particular plant upon which the coal is to be used.

The system which has been used with success is to reduce the value of each coal to a figure of merit consisting of its comparative value with pure carbon as a standard, the latter being taken as '100.' The average final temperature of the gases is ascertained in the usual manner. The chimney loss for pure carbon burned perfectly without excess air is then calculated for the conditions of waste gas temperature obtaining on the plant. Taking the calorific value of pure carbon as 14,544 B.Th.U. per lb., the '100' figure of merit for this plant will be 14,544 minus the gas loss per lb. of carbon. This represents theoretical perfection with the plant. The actual results obtained for the coal under examination are expressed as a percentage of the pure carbon theoretical figure, and this is taken as the relative figure of merit for the fuel.

(*C. F. Wade.*)

Economic Effects of Impurities in Coal.

Each per cent. of sulphur reduces the boiler capacity by about 1·5 per cent. In experiments made in America with a chain grate stoker, using Illinois coal mixed with various percentages of ash, the efficiency dropped gradually as the ash increased up to 35 per cent., after which the efficiency dropped to zero rapidly with a fuel containing 40 per cent. of ash.

Loss of Thermal Value of Coal by Storage.

An average of 741 tests, in America, of a particular coal showed, after three years in the open air, a reduction of from 35 to 28·3 per cent. of volatile combustible matter, indicating a thermal value loss of 20 per cent.

Coal in storage should be inspected regularly. If the temperature reaches 150° F. the pile should be carefully watched, and if the temperature rises to 175° or 180° F. the coal should be removed as promptly as possible. The coal should be thoroughly cooled before being replaced in storage.

Temperature of Decomposition of Coal.

The temperatures at which coals begin to decompose are of considerable importance, both for technical purposes and as an aid to the study of the constitution of coal. There is little published information of a precise nature on this point, and it is frequently assumed that coal may be heated to 250° C., for purposes such as drying, without causing any modification in the coal substance. A general investigation of the behaviour of coal on heating is now being carried out at H.M. Fuel Research Station, and a report recently issued by H.M. Stationery Office deals with the results of experiments to determine the temperatures at which products of decomposition of various types of coal are first given off when the coal is heated. It is shown that when bituminous coals are heated, oil fumes may appear at temperatures as low as 215° C. The investigations are continuing and further reports will be issued in due course.

Utilisation of Anthracite Wastes.

A series of tests made in America, consisting of 30, 50, and 70 per cent. run-of-mine coking coal mixed with anthracite culm, showed that the pulverised bituminous coal alone produced better results, except the mixture of 30 per cent. culm with 70 per cent. bituminous, which was equal to that of the bituminous coal alone.

Stowage Space of Coal.

The stowage space occupied by coal is 40 to 42 cubic feet for one ton of Welsh steam coal, 45 cubic feet for one ton of North country coal, and 45 to 50 cubic feet per ton of Scotch coal.

EVAPORATIVE POWER OF FUELS.

The heat required to evaporate one pound of water at boiling point is 967 B.Th.U.

To raise water from 100° F. to boiling point and evaporate into steam at 212° F. 1,078 B.Th.U. per pound of water are required.

By dividing the calorific power (in B.Th.U.) of a fuel by 1,078 we obtain the *theoretical* quantity of water which it will raise from a feed-water temperature of 100° F. and evaporate at 212° F.

In practice a good boiler develops a thermal efficiency of about 70 per cent., and the actual evaporation obtained is therefore about 70 per cent. of the theoretical figure.

Evaporative Power of Coal.

Coal.	Calorific value. B.Th.U.	Evaporative power from 100° F. (37·7° C.) to Saturated Steam at 212° F. (100° C.).	
		Theory.	Practice. (70 % efficiency.)
Welsh anthracite . .	15,000 to 15,500	13·9–14·4 lbs.	9·7–10·1 lbs.
Scotch anthracite . .	14,500 to 15,000	13·45–13·9 ,,	9·4–9·7 ,,
Welsh navigation coal .	14,000 to 15,000	13·00–13·9 ,,	9·1–9·7 ,,
Average British steam coal	12,000 to 13,500	11·1–12·5 ,,	7·8–8·75 ,,

(See also Table of Evaporative Values, page 2090.)

Evaporation Factors.

To reduce results to 'from and at 212° F.'

Temp. of Feed Water in F.°	Boiler Pressure in Pounds per Square Inch.												
	60	80	100	120	140	160	180	200	220	240	260	280	300
40	1·209	1·214	1·218	1·222	1·226	1·229	1·232	1·234	1·237	1·239	1·241	1·243	1·245
50	1·198	1·204	1·208	1·212	1·215	1·218	1·221	1·224	1·226	1·229	1·231	1·233	1·235
60	1·188	1·193	1·198	1·202	1·205	1·208	1·211	1·214	1·216	1·218	1·220	1·222	1·224
70	1·178	1·183	1·187	1·191	1·194	1·197	1·200	1·203	1·206	1·208	1·210	1·212	1·214
80	1·167	1·173	1·177	1·181	1·184	1·187	1·190	1·193	1·195	1·198	1·200	1·202	1·204
90	1·157	1·162	1·167	1·170	1·174	1·177	1·180	1·183	1·185	1·187	1·189	1·191	1·193
100	1·147	1·152	1·156	1·160	1·164	1·167	1·170	1·172	1·175	1·177	1·179	1·181	1·183
110	1·136	1·142	1·146	1·150	1·153	1·156	1·159	1·162	1·164	1·167	1·169	1·171	1·173
120	1·126	1·131	1·136	1·140	1·143	1·146	1·149	1·151	1·154	1·156	1·158	1·160	1·162
130	1·116	1·121	1·125	1·129	1·132	1·136	1·138	1·141	1·144	1·146	1·148	1·150	1·152
140	1·105	1·110	1·115	1·119	1·122	1·125	1·128	1·131	1·133	1·135	1·137	1·139	1·141
150	1·095	1·100	1·104	1·108	1·111	1·115	1·118	1·120	1·123	1·125	1·127	1·129	1·131
160	1·084	1·090	1·094	1·098	1·101	1·104	1·107	1·110	1·112	1·115	1·117	1·119	1·121
170	1·074	1·079	1·083	1·087	1·091	1·094	1·097	1·099	1·102	1·104	1·106	1·108	1·110
180	1·063	1·069	1·073	1·077	1·080	1·083	1·086	1·089	1·091	1·094	1·096	1·098	1·100
190	1·053	1·058	1·062	1·066	1·070	1·073	1·076	1·078	1·081	1·083	1·085	1·087	1·089
200	1·042	1·048	1·052	1·056	1·059	1·063	1·065	1·068	1·071	1·073	1·075	1·077	1·079
210	1·032	1·037	1·042	1·046	1·049	1·052	1·055	1·057	1·060	1·062	1·064	1·066	1·068

For every 10° superheat, 0·0055 is to be added to the above factors.

Coke.

Coke is produced by the destructive distillation of bituminous coal either in coke ovens or n gasworks.

Coke-oven coke is produced by slowly heating the coal to a high temperature, about 1,000° C., by which means a hard product, almost entirely free from volatile matter, is obtained. This coke is employed in blast-furnaces, and commands a slightly higher price than the product of the gas-works. It possesses a calorific power slightly lower than that of pure carbon (14,540 B.Th.U.).

The process employed in coke ovens, namely, the gradual heating of the coal to a very high temperature, results in the production of a very hard, unfriable coke, which will withstand the high crushing stresses necessary for metallurgical operations, especially blast-furnace work. It contains all the ash, and nearly half the sulphur, present in the original coal.

Gasworks coke is a product from the horizontal, inclined, or vertical retorts used in the manufacture of coal gas. In all such plants the heat is applied more rapidly than in coke ovens, and the resulting coke is softer and more friable than coke-oven coke. The process is, of course, primarily designed to give a high yield of gas, and the coke is a by-product.

Gas coke of average quality has a calorific power of about 12,500 B.Th.U. per lb., as sold, including moisture. Coke breeze, or coke dust, is about 10,000 B.Th.U. per lb.

Experiments made with quite dry coke and a sample artificially watered up to 16 per cent. of its weight show that a given quantity in a given time furnished 228 B.Th.U. wet and 365 B.Th.U. dry, approximately 39 per cent. advantage in favour of dry coke. The proportion of moisture in coke may vary from 2 per cent. to 20 per cent., and in the condition indicated in the experiment the heat in the grate or boiler was partly used to dry out the water, which escaped as moisture into the flues, carrying heat with it and thereby reducing efficiency.

Low-Temperature Distillation of Coal.

This consists in the gradual heating of bituminous coal to a comparatively low maximum temperature (500 to 600° C.). The retorting vessels employed are designed in such a way as to ensure the rapid removal of the volatile products. By such a process a low yield of very rich gas is obtained, and a high yield of thin tar. The tar is richer in low boiling-point fractions than the tars produced by the gasworks or coke-oven plants. The residual coke contains approximately 10 per cent. of volatile matter, and may be marketed for use in domestic fires, for which purpose it is claimed to be easily ignitable, and at the same time to give off the major portion of its heat as radiant heat, and to burn without generating smoke. Until recently the process has not met with success, largely on account of mechanical difficulties in the operation of the retorts; these difficulties, however, appear to be now overcome by 'Low-temperature Carbonisation, Ltd.,' in their production of 'Coalite.'

COALITE.

The following results were obtained in a test by the Government Fuel Research Board *:

The coal used in the test was a good average Yorkshire coal, and one which has been frequently tested in every way at the Fuel Research Station.

The yield of products per ton of coal carbonised was as follows:

'Coalite'	13·92 cwts.
Gas	5,620 cubic feet or, 39·6 therms, after stripping of motor spirit. (See †.)
'Coalite' crude oil	18·62 gallons.
Ammonia liquor	26·00 gallons.
Crude motor spirit from scrubbing the gas	1·78 gallons.
Equivalent ammonium sulphate	13·55 lbs.

The 'Coalite' produced was of a very suitable size (1 to 3-inch pieces), containing only 4·6 per cent. of breeze, and was quite suitable to withstand the rough handling natural to rail or road transport. Analysis of this fuel showed a slightly lower percentage of volatile matter than usual, but when burnt in a household grate it readily ignited and gave a good hot fire.

The yield of crude oil was high, showing 68 per cent. of that obtained in the standard assay apparatus developed by the Fuel Research Board, and upon examination proved to be a normal low-temperature coal oil.

The yield of gas was greater than that anticipated from this particular coal, and averaged $\left(\frac{39{\cdot}6 \times 100{,}000}{5{,}620}\right)$† = 705 B.Th.U. per cubic foot after being stripped of its crude motor spirit.

The motor spirit obtained by scrubbing the gas was 1·78 gallons per ton, but as the crude oil also contained 1·09 gallons, the total yield of this product amounted to 2·87 gallons per ton: a most satisfactory result.

The ammonia was also higher than expected, and, when converted into ammonium sulphate, yielded 13·55 lbs.

* Report published by H.M. Stationery Office, Kingsway London, W.C., price 9*d*.

YIELD FROM ONE TON OF AVERAGE COAL (say 25-30 per cent. volatile matter).

	Low-temperature Carbonisation.	High-temperature Carbonisation.	
		Gasworks.	Coke Ovens.
Temperature of carbonisation	1,000° F.	About 1,800° F.	About 1,800° F.
Gas	6,000-6,500 cubic feet of rich gas, 700–750 B.Th.U. per cubic foot.	12,000 cubic feet of medium quality (town's) gas, 550 B.Th.U. per cubic foot.	11,500 cubic feet of poor quality coke-oven gas, 450 B.Th.U. per cubic foot.
Liquid	20 gallons coalite oil (fractionated to, say, 3 galls. motor spirit, 8-9 galls. Diesel or fuel oil, and 8-9 galls. lubricating oil).	10 gallons coal tar. (Fractionated to about half-gallon motor spirit, carbolic acid, a large amount of naphthalene, fuel oil, &c.)	8 gallons coal tar.
Sulphate of ammonia (from the ammonia)	15 lbs.	25 lbs.	28 lbs.
Residue in retort	14 cwt. of smokeless fuel coalite containing about 9-10 per cent. volatile matter.	13¼ cwt. of soft coke, containing about 1 per cent. volatile matter.	14-14½ cwt. of hard coke, containing less than ½ per cent. volatile matter.

(*David Brownlie, A.I.Mech.E.*)

From one ton (American, 2,000 lbs.) of bituminous coal, the Colorado Fuel and Iron Company of Denver, U.S.A., obtains in actual practice the following products, viz.:

Coke	1,400 lbs.	Pure benzol	1¼ gals.
Coke breeze	60 lbs.	Toluol	½ gal.
Gas	7,500 cu. ft.	Zylol	2/10 gal.
Ammonium sulphate	25 lbs.	Pitch	5 lbs.
Tar	10 gals.	Naphthalene	¼ lb.
Light oil	3½ gals.	Creosote	1 qt.
Motor benzol	2½ gals.	Paint	1 qt.

[Annual capacity of ovens, 540,000 tons (American) coke.]

Coke as a Boiler Fuel.

(*Contributed by E. W. L. Nicol, M.I.Mar.E., A.M.I.E.E.*)

With a view to cheapening the cost of steam raising by improving steam-boiler efficiency and to eliminate the emission of visible smoke, gas coke is now largely used as fuel in lieu of crude coal. In hand-fired boilers, coke exclusively is used under ordinary natural draught conditions. With a draught of 0·25 in. W.G. over the fire, the average rate of combustion is 12 lbs. to 14 lbs. of suitably graded coke per sq. ft. of grate area per hour. Some form of impelled draught is necessary if this rate is insufficient. The forced draught apparatus usually employed is some form of steam-jet blower applied to the enclosed ashpit of the boiler, and used to maintain 'balanced' draught over the fire (fig. 5). The steam consumption of the jets should not exceed 3 per cent. of the total steam generated when burning graded coke at a rate of 20 lbs. per grate-foot-hour. For hand-fired boilers the minimum allowance of grate area should be 1 sq. ft. per 22 to 25 lbs. of coke consumed per hour. In practice it is found that this rate can be exceeded only at the expense of efficiency.

Unlike coal, the combustion of coke is practically completed on the grate, a supply of secondary air over the fire being unnecessary. This tends to localise the heating effect to the boiler furnace area. The introduction of a circulator, *b*, tends to neutralise this effect and set up active circulation of the water in the boiler. The operation of cleaning fires, and the losses incidental thereto, due to inrush of cold air and consequent loss of steam pressure, are minimised by the use of the Gallagher Crompton baffle bridge *a*, also shown in the figure. During the cleaning operation the live fuel is heaped up on the baffle bridge.

In mechanically-stoked boilers fitted with both forced and induced draught, average rates of combustion exceeding 40 lbs. of graded coke per grate-foot-hour are maintained. Types of

mechanical stokers specially adapted for use with coke or coke breeze include the 'Underfeed travelling grate' and the 'Babcock balanced draught chain grate.' Existing chain grate

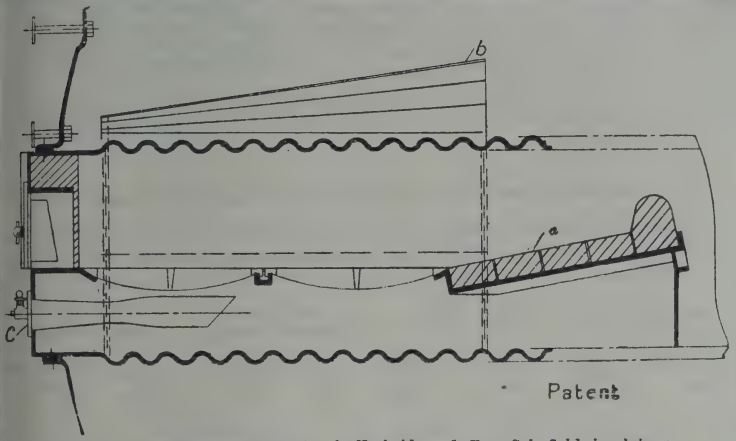


FIG. 5.—*a*, Gallagher Crompton baffle bridge: *b*, Ross Schofield circulator; *c*, Steam Jet forced draught.

mechanical stokers have largely been adapted to use admixtures of coke or breeze up to 75 per cent. at full normal rates under ordinary natural draught conditions, by means of the patent 'Sandwich' system (fig. 6), which is designed to feed, from a double hopper, well-defined layers

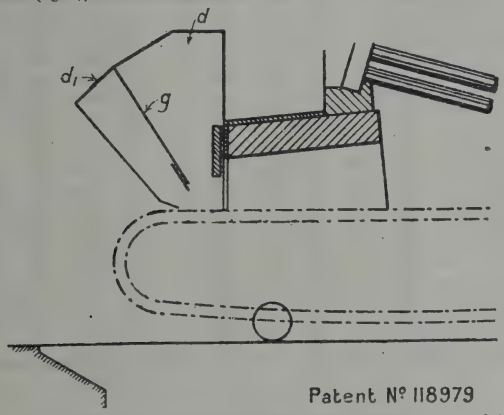


FIG. 6.—Sandwich System as applied to Chain-grate Stoker. d_1, coal hopper; *d*, coke hopper; *g*, separating diaphragm.

of coal slack and suitably graded coke of any desired thickness, the coal being uppermost. Using this system at the L.C.C. Greenwich Power Station, the General Manager gives the following data relating to the year 1919–1920:—

Tons of fuel burnt	176,400	Average percentage of ash	10·0
Average price for coal	41*s.* 11·3*d.*	calorific value of breeze	9,000 B.Th.U.
,, calorific value	10,780 B.Th.U.	,, percentage of ash	18 to 20
,, percentage of ash	14·59	Coke and breeze consumed	25,000 tons
,, calorific value of coke	11,500 B.Th.U.		

With coal at 42*s.* per ton, and coke breeze at 22*s.* 6*d.* per ton, the fuel cost per 1,000 gallons evaporated was 19*s.* 6*d.* with equal quantities of each fuel, as against 23*s.* 2*d.* with Scotch nuts alone, a saving of about 16 per cent. The official report says. 'Apart from the saving in money, low grade classes of fuel can be dealt with on the Sandwich system at a much higher efficiency than would be the case if burnt separately. The results have been extremely satisfactory and a saving of about £8,000 a year can be effected.' Average evaporation obtained with 50 per cent. mixture of coal and breeze, 7·25 lbs.; with coal and coke 9 lbs. from and at 212° Fahr. Gas coke is also used extensively as fuel for road transport vehicles of both the under-type ('Scotinel,' 'Leyland,' and 'Atkinson') and the over-type wagon ('Foden' and 'Garrett,' etc.). The following table shows the fuel cost of evaporation from and at 212° Fahr. with common solid fuels at varying prices:—

APPROXIMATE FUEL COST OF EVAPORATION FROM AND AT 212° FAHR.

(*Compiled by E. W. L. Nicol, M.I.Mar.E., A.M.I.E.E., Fuel Expert to the London Coke Committee.*)

Coal Slack.		Hard Steam Coal.		Smokeless Welsh Coal.		Gas Coke.	
Mechanically Stoked.		Hand Fired: Natural Draught.		Hand Fired: Natural Draught.		Hand Fired: Forced Draught.	
At per Ton.	Evaporative Value. 7·5 lbs.	At per Ton.	Evaporative Value. 9·5 lbs.	At per Ton.	Evaporative Value. 10·5 lbs.	At per Ton.	Evaporative Value. 9 lbs. net.
	per 1,000 gallons evaporated.		per 1,000 gallons evaporated.		per 1,000 gallons evaporated.		per 1,000 gallons evaporated.
s. *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*
19 0	11 4	26 0	12 2	28 0	11 10	25 0	12 4
20 0	11 11	27 0	12 8	29 0	12 4	26 0	12 10
21 0	12 6	28 0	13 1	30 0	12 9	27 0	13 5
22 0	13 1	29 0	13 7	31 0	13 2	28 0	13 11
23 0	13 8	30 0	14 0	32 0	13 7	29 0	14 5
24 0	14 4	31 0	14 6	33 0	14 0	30 0	14 10
25 0	14 11	32 0	15 0	34 0	14 5	31 0	15 4
26 0	15 6	33 0	15 6	35 0	14 10	32 0	15 10
27 0	16 1	34 0	16 0	36 0	15 4	33 0	16 4
28 0	16 8	35 0	16 5	37 0	15 9	34 0	16 10
29 0	17 4	36 0	16 11	38 0	16 1	35 0	17 4
30 0	17 11	37 0	17 5	39 0	16 6	36 0	17 10
31 0	18 6	38 0	17 10	40 0	16 11	37 0	18 4
32 0	19 1	39 0	18 4	41 0	17 4	38 0	18 10
33 0	19 8	40 0	18 9	42 0	17 9	39 0	19 5
34 0	20 4	41 0	19 2	43 0	18 2	40 0	19 11
35 0	20 11	42 0	19 8	44 0	18 7	41 0	20 5
36 0	21 6	43 0	20 2	45 0	19 0	42 0	20 10
37 0	22 1	44 0	20 8	46 0	19 5	43 0	21 4
38 0	22 8	45 0	21 1	47 0	19 10	44 0	21 10
39 0	23 4	46 0	21 7	48 0	20 4	45 0	22 4
40 0	23 11	47 0	22 0	49 0	20 9	46 0	22 10
41 0	24 6	48 0	22 6	50 0	21 2	47 0	23 4
42 0	25 1	49 0	23 0	51 0	27 7	48 0	23 10

Anthracite.

(*Contributed by A. Leonard Summers, Author of 'The Anthracite Industry,' &c.*)

The bulk of the anthracite produced in Great Britain is mined in the western portion of the South Wales coalfield, the best qualities in Carmarthenshire and Glamorganshire. It consists virtually of carbon—as much as 94 per cent. in the better qualities—with only a small proportion of the constituents of bitumen. It is jet-black, with a metallic lustre, very hard, slow burning, absolutely smokeless, gives intense heat, and burns with a bright red glow. These qualities fit it for many purposes. It is used largely for smelting; in the burning of lime and brick; for the generation of steam; and in the United States and on the Continent of Europe extensively for domestic heating and cooking. For malting and horticultural purposes, owing to its purity and

reedom from arsenic, etc., it is in immense demand; while in Norway, Sweden, and Italy, Welsh nthracite is used for making carbide of calcium.

The American coalfield (Pennsylvania) produces the largest amount of anthracite—about 00 million tons per annum—the Welsh output being only about 5,000,000 tons a year at present, hough capable of a much greater yield, the major part of the field being still untouched.

One ton of anthracite used in a pressure or suction-gas plant will give power equal to 10 tons f the best steam coal used under boilers. Some typical figures for a suction-gas plant using nthracite were produced by a test carried out at the Metropolitan Reservoirs, Chingford, under he direction of their chief engineer. A guarantee had been given that the consumption would not xceed 1·1 lb. of anthracite per actual b.h.p. hour, and in the report it was stated that the average uel consumption for the four main pumps was 0·913 lb. per b.h.p. hour, whilst the small pump ave the figure of 0·8 lb. of anthracite. The general average for the whole of the pumps was ·904 lb. of anthracite per actual b.h.p. hour, and the guarantee lift of the pumps was exceeded by lmost 20 per cent. The producer tests showed that 1 lb. of anthracite yields 82·1 cu. ft. of as at standard temperature and pressure, the net calorific value being 146·3 B.Th.U. per cu. ft., iving a yield of 12,011 B.Th.U. per lb. of anthracite. The calorific value of the anthracite upplied was 14,600 B.Th.U. The fuel used under the boilers which supplied steam for the roducer was taken into account.

A ton of Welsh anthracite will produce from 170,000 to 220,000 cu. ft. of gas for power urposes. The following is a typical analysis of good Welsh anthracite:

Carbon	92·73 per cent.
Hydrogen	3·37 ,,
Oxygen and nitrogen	2·69 ,,
Sulphur	0·45 ,,
Ash	0·76 ,,
	100·00 ,,

In furnace installations where crude gas can be used bituminous fuels are generally used, as he gas is supplied direct to the furnace along with the tar and soot. In small furnaces, where mall burners are used, or where necessary to convey gas a long distance, it is generally not possible o use crude gas, and anthracite is more convenient than bituminous coal. The average consumption in a pressure gas-producer is about 13 lbs. of anthracite per 1,000 cu. ft. of gas, and at normal prices this would work out between 2*d.* and 3*d.* per 1,000 cu. ft. of gas, and the overall consumption for producer and engine should be about 1 lb. of anthracite per b.h.p. hour.

The principal anthracite collieries are equipped with electrical and other machinery, the preparation of the coal being very elaborate—breaking, screening, washing, etc. A revolving breaker deals with the large coal; this coal travels to the various 'screens' for sizing. These sizing screens are placed one above another at an angle and worked on a shaking principle. Thus he coal is kept steadily on the move to obviate congestion. The large collieries break and screen heir product into at least eleven different sizes. The screens are perforated with round holes, through or over which the coal passes in sizes from 2½ ins. by 4 ins. (the largest cobbles) to ⅛ in. by ¼ in. 'grains'). Similar moving belts, but not perforated, convey the screened coal to the pickers, who remove by hand whatever shale it may contain. Impurities are picked from the cobbles nd large coal prior to the coal going to the breaker. These picking belts also load the coal into he railway trucks, but only convey the larger sizes, viz. machine-made cobbles and machine-made French' nuts. Sizes below the French nut cannot be conveniently picked and sorted by hand, nd are therefore transferred to a washer. The 'washery' belts work with the same shaking novement, carrying the small coals, such as stove nuts, peas, beans, pea-nuts, etc., through tanks f water to remove the small particles of stone. To ensure the maintenance of a maximum tandard of quality, a coal examiner usually twice daily takes and tests samples of coal from the screens and washery, and the percentage of waste material detected rarely exceeds 1 per cent.

What is known in the trade as 'rubbly culm' is the rough small coal which passes between ongitudinal bars 1¼ in. apart. It is used principally for lime-burning and steam-raising.

The 'duff,' or very fine, small anthracite, is used in the manufacture of patent fuel and cement making.

In regard to ordinary boiler furnace utilisation of anthracite not much advance has been made, due to the narrow conception of boiler-house practice, coupled with the question of availability. When anthracite is used for this purpose it must not be disturbed, and should be stoked with a

thin bed, very evenly, and if this minimum attention is given an evaporation of from 8–10 lbs. water per hour can be easily maintained. Tests made in London in which anthracite peas we used showed an evaporation of 12·2 lbs. of water per lb. of coal in one test, and 11·3 lbs. in anothe Sometimes the draught or other conditions render the use of anthracite alone impossible, but i blending with other fuels gives very satisfactory results. Where mechanical stoking is used larger proportion of anthracite—say 2 to 1—can be used, as distinct from equal quantities whe hand-firing is adopted.

An important aspect of anthracite has been the recent utilisation of the large accumulations duff and washery refuse. Hitherto, anthracite dust could not be satisfactorily burnt on standa furnaces, and considering that this fuel has a calorific value of 12,000 to 13,000, with over 80 p cent. fixed carbon, and about 10 to 12 per cent. of ash, it was obvious that valuable material w lying dormant in the dumps. Therefore a new furnace was introduced, with air spaces su divided into a large number of small holes, and other modifications. The following results of tes at a Welsh colliery show the great increase made in evaporation :

Test No.	Class of Fuel.	Evaporation in Lbs. Steam per Hour.	Remarks.
1	Duff, good quality	3,500	Jet pressure 60 lbs.
2	'Grains'	4,400	,, ,, 30 ,,
3	Duff	3 125	,, ,, 45 ,,
4	Duff	3,000	,, ,, 25–30 ,,
5	'Grains'	5,750	,, ,, 30 ,,
6	Duff	4,250	,, ,, 40–50 ,,
7	Duff	4,875	,, ,, 55–85 ,,

The first four tests were carried out on the old type, and tests 5, 6, and 7 on the newly design bar-furnace.

Burnt under proper conditions, there is no better coal for steam-raising than Welsh anthracit At one works using English coal it was necessary to employ two Lancashire boilers 30 ft. l 7 ft. 6 in., but after a patent furnace was fitted and anthracite coal introduced, *one* of the boilers was sufficient to do the work previously done by the two boilers.

Below are the standard sizes of Welsh anthracite :—

Cobbles	$2\frac{1}{2}'' \times 4''$	'Beans'	$\frac{1}{2}'' \times \frac{3}{4}''$
'French' Nuts	$1\frac{3}{4}'' \times 2\frac{1}{2}''$	'Peas'	$\frac{1}{4}'' \times \frac{5}{8}''$
Stove nuts	$1'' \times 1\frac{3}{4}''$	'Grains'	$\frac{1}{8}'' \times \frac{1}{4}''$
'Pea-nuts'	$\frac{1}{2}'' \times 1\frac{1}{4}''$		

Lignite.

The composition of lignite, and its properties, lie between those of wood and coal.

Lignite occurs in most European countries and is abundantly found in the Colonies, but doe not occur in quantities in the British Isles. Lignites vary widely in composition, but generall between the following limits : carbon 55 to 80 per cent., hydrogen 5 to 7 per cent., oxygen 10 t 35 per cent. (in the dry state). The calorific value is from 9,000 to 13,000 B.Th.U. on dry sampl The high ash and water contents of lignite frequently make it unsuitable for direct combustio but good grades may be used for steam raising. Lignite is frequently subjected to destructiv distillation, whereby valuable liquid products are obtained. It may also be used for the manu facture of fuel briquettes, or be utilised in gas producers.

Peat.

Large deposits of peat occur within the British Isles, but little use has been made of the hitherto, the high water content (80 to 96 per cent. when in bog, and 30 to 60 per cent. after a drying) being a great drawback to their utilisation. Peat is suitable for use in gas producer and is sometimes carbonised, when peat charcoal is the main fuel product.

Anderson and Dillner (*Jour. Soc. Chem. Ind.*, 1902, 459) give the following calorific powers for peat (in the dry state) :—

Average from bog	8,100 to 11,000* B.Th.U.
Reed grass peat	7,450 to 9,820 ,,
Mud peat	7,825 to 8,200 ,,

Wood.

When freshly cut, wood contains up to 50 per cent. of water, but this can be reduced to about 20 per cent. by air drying. The composition of dry wood is about 49·5 per cent. carbon, 6 per cent. hydrogen, 44 per cent. oxygen, and ·5 per cent. ash, and the heat value is generally a little below 9,000 B.Th.U. It only finds use in countries where large forests exist and where coal is not readily obtainable.

Wood Charcoal.

Wood charcoal consists mainly of carbon and possesses a calorific value of 11,000 to 13,500 B.Th.U. (Brame). Its use as a fuel is very limited.

Briquette Fuel.

(*Contributed by Arthur Grounds, B.Sc., A.I.C., Assoc. M.I.Min.E., Consulting Chemist.*)

Briquettes can be used on hand-fired boilers, without the necessity of installing special stokers to deal with the fuel. The composition of the fuel can be varied from an anthracitic fuel, suitable for consumption in domestic grates, and giving a high degree of radiant heat, to a briquette of higher volatile matter, suitable for industrial boiler firing, and giving the long flame necessary for the heating of Lancashire, Cornish, and water-tube boilers. The shape, size, and weight of the briquettes must be suitable for the purpose for which they are to be used, and for the nature and duration of the transport and storage to which they will be subjected. Their degree of cohesion should be at least equal to that of good coal, and the loss by attrition and crumbling during ordinary handling and transport should not exceed 5 per cent. by weight. Their mean specific gravity should not be below 1·24, whilst the ash content of the dry fuel should not exceed 12 per cent., and is preferably below 10 per cent. They should not contain over 5 per cent. of moisture, nor should they absorb water, whilst they should not be affected in physical character by immersion in water over a long period. Their calorific value should be at least equal to that of good coal.

Artificial fuel is made in many sizes and shapes, from the 'boulet' of 30–40 grms. weight (1–1½ ozs.) to the large block of 28 lbs. weight. The latter block is chiefly made for export to the West Indies and Egypt, and to other tropical and sub-tropical countries, as a weight of 28 lbs. corresponds roughly to that which a native labourer or coolie can carry. Between these two sizes of fuel there are the normal ovoid, about the size of a hen's egg, weighing 70–100 grms., and the larger ovoid of 200–250 grms., which has lately been developed. These ovoids are chiefly used for domestic fuel, and are largely anthracitic, whilst for steam raising the block form is most popular, the common size being the 10-lb. block, measuring 10 ins. by 5 ins. by 4 ins. Ovoid fuel has lately been made in the 'boulet' size for use in suction gas producers, and for use with automatic stokers, in place of screened nuts. The blocks are made in various shapes, either as bricks with rounded corners, quadratic flattened cube shape, or grooved in order to facilitate their breaking up in the stokehold. They may be marked with the makers' name, or with some distinguishing mark, or may be quite plain.

Domestic ovoids may be made from anthracite and a binder alone, although this has the disadvantage that, as pitch is the binder generally used, when the fuel is placed on the fire, the pitch burns off very easily at first, and then the anthracite, being a non-caking coal, falls to powder in the fire, and the result is a dull, black-looking mass. To avoid this, these ovoids are generally made from a mixture of about 80 per cent. of anthracite duff, with 10 per cent. of a good coking coal and 10 per cent. of pitch.

When placed on the fire, the pitch at first burns off and the heat of combustion leads to the carbonisation of the bituminous coking coal, which cakes and acts as an agglutinant, binding the non-caking anthracite together, and this burns very slowly and gives out a large amount of radiant heat per unit weight. This is the cheapest form of artificial fuel, as anthracite duff is the cheapest form of raw material and forms 80 per cent. of the total weight of the fuel. The binder generally used for the process is coke-oven or gas-works pitch, the grade used being known in the trade as 'medium-soft coal-tar pitch, suitable for the manufacture of briquettes.' Blast-furnace pitch is used to a certain extent, but it is inferior to coke-oven or gas-works pitch in binding power, and contains a much higher percentage of ash, and, on carbonisation, it gives

* Exceptionally high.

a swollen, instead of a sintered coke. The ash in a good pitch should not exceed 0·5 per cent whilst that in blast-furnace pitch varies from 5 per cent. to 25 per cent., or even more, according to the dust-catching arrangements at the blast-furnace from which it has been obtained. The volatile organic matter of the pitch is determined by heating 1 grm. of the pitch in a platinum or porcelain crucible over a bunsen flame for seven minutes, the flame being 18 cms. high, and the crucible being held on a triangle of fine wire, about 7 cms. above the mouth of the burner. The crucible is provided with a lid, and is weighed after heating for seven minutes, with subsequent cooling, the loss in weight giving the volatile matter. The ash can be determined by igniting the coke obtained as above until all the combustible matter has been burnt off. The residual coke from the volatile matter estimation should be in the form of a flat button. If the button is not flat, but conical in shape or puffed up, the pitch will not be suitable for the purpose. The twisting point is measured by immersing a bar of pitch, 2 ins. by $\frac{1}{4}$ in. cross section, in water at gradually increasing temperatures for a period of two minutes. The pitch is then withdrawn and a very slight pressure exerted with the fingers in the attempt to twist it round. If the pitch is still too hard, the water is heated again until it has risen in temperature another 5° C., and the pitch is again immersed for two minutes, and then tested to see if it will twist. When this is possible, the temperature of the water is taken, and this temperature is known as the 'twisting point.'

A suitable pitch for briquette manufacture should have a twisting point of 50–60° C. The melting point is determined by immersing a cube of pitch, of $\frac{3}{4}$-in. side, stuck on a No. 12 copper wire, bent horizontally, in a beaker of water. The water is gradually heated so that a rise in temperature of 5° C. or 9° F. per minute is obtained. When the cube of pitch softens and drops to the bottom of the beaker, the temperature is noted, and this is taken as the melting point. For a coke-oven or gas-works pitch of suitable quality, the melting point is usually about 85°–100° C.

The solubility in carbon disulphide is determined by weighing out 0·5 grm. of the pitch into a flask and adding 200 c.c. of carbon disulphide. The flask is heated on a water bath or an electric heater, under a reflux condenser, for an hour, and is then removed and cooled. The free carbon is filtered off through two filter papers, and is well washed with carbon disulphide, the washings being added to the filtrate. The carbon disulphide is then distilled off from the filtrate, which has been caught in a weighed flask, when the increase in weight of the flask gives the amount of matter soluble in carbon disulphide. This figure is a useful indication of the binding power of the pitch, as those pitches which give high solubility figures are generally found to be excellent binders. This figure should be in the region of 66–84 per cent. The difference between the percentage of matter soluble in carbon disulphide and 100 is the 'free carbon.'

Other tests are necessary for special purposes, but those cited are the usual tests adopted. A typical analysis of a suitable pitch would be: Volatile organic matter, 70·4 per cent.; coke, 29·6 per cent.; ash, 0·3 per cent.; fixed carbon, 29·3 per cent.; soluble in carbon disulphide, 75·5 per cent.; free carbon, 24·5 per cent. Twisting point, 56·5° C.; melting point, 97·0° C.

The amount of binder necessary varies with the coals being used, but, generally speaking, it increases with the hardness of the coals being briquetted. Thus, about 10–11 per cent. is necessary for hard anthracites, about 8·5–9 per cent. for steam coals, and 6·5–8·5 per cent. for bituminous coals, according to their volatile matter content. The hardness of the coal is roughly proportional to the volatile matter content of the coal, and the more bituminous coals, with a volatile matter content of 33–40 per cent., can be briquetted fairly easily by fine grinding (97 per cent. of the material should pass a 200-mesh screen) and pressing, taking care that the air is extracted from the fine coal before pressing. The pressure necessary for the production of briquettes made in this way is about 10 tons per sq. in. The cohesion is then about equal to that of a pitch-bound briquette. The fuel is said to stand handling well and to be weather-proof. The fuel can also be made from all coals possessing a volatile matter content of 11–12 per cent. and over, but the more bituminous coals already described are the most suitable for this purpose. Anthracite cannot be briquetted in this way. The great advantage of this process is the elimination of the binder, as the cost of pitch is a very serious item in the fuel-works balance sheet. For example, at the end of 1920, the cost of pitch had risen to £12 per ton, and assuming the pitch content of fuel to be 10 per cent., the cost of *pitch alone* in 1 ton of the fuel would be £1 4*s*. In the manufacture of the usual briquettes, with pitch as a binder, creosote and anthracene oil fractions are frequently used for the purpose of obtaining the optimum binding power of the pitch. The oil is mixed with the pitch in the pug mill in which the materials are mixed thoroughly, and the oil dissolves the pitch, which then flows more evenly over the grains of coal and coats them evenly without undue waste. By this means it is possible to cut down the pitch consumption by about 10–15 per cent., a very considerable amount when cost is taken into account.

As already mentioned, anthracitic fuel would not be suitable for steam-raising, and the coals most generally used for the manufacture of fuel intended for this purpose are blends of bituminous,

anthracite, and steam coals. The following table shows the analysis of these coals, from which it will be seen that the steam coals contain more volatile matter than anthracite, whilst the bituminous coals contain still more volatile matter than the steam coals.

Fuel.	Moisture.*	On Dry Coal.			
		Volatile Organic Matter.	Coke.	Fixed Carbon.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Anthracite . . .	0·2– 3·5	5·0–10·0	90·0–95·0	83·0–92·0	3–7
Dry steam coals . .	1·0– 4·0	10·0–13·0	87·0–90·0	80·0–85·0	5–7
True steam coals . .	2·5– 5·0	13·0–16·5	83·5–87·0	76·5–82·0	5–7
Semi-bituminous coals .	4·0– 6·0	17·0–20·0	80·0–83·0	71·0–77·0	6–9
True bituminous coking coals . . .	4·0–10·0	20·0–28·0	72·0–80·0	60·0–74·0	6–12
Caking coals . .	4·0–10·0	28·0–40·0	60·0–72·0	48·0–66·0	6–12
Lignites, or brown coals	10·0–40·0	40·0–55·0	45·0–60·0	Varies	Varies

A good mixture for the manufacture of briquettes for steam-raising would consist of 50 per cent. steam coal, 20 per cent. bituminous coal, and 20 per cent. of anthracite duff with 10 per cent. of pitch as a binder. This would give a finished fuel of approximately the following composition :—Volatile organic matter, 21·0 per cent.; coke, 79·0 per cent.; fixed carbon, 73·0 per cent.; ash, 6·0 per cent. This is assuming that clean coals had been used in its manufacture, and such coals could be produced by washing the small coals in one or other of the washers on the market, such as the Draper, Hoyle, British Baum, Notanos, or other plant.

Briquettes can easily be prepared to specification by varying the percentages of the constituent coals used for any particular purpose. Thus, if a briquette is desired for furnace or other purposes which shall give a long flame, this can be obtained by putting in an extra large percentage of bituminous coal, whilst we have seen that for domestic fuel anthracite is introduced in order to make the fuel burn slowly and to give radiant heat, instead of throwing a large number of B.Th.U.'s up the chimney in the form of volatile constituents. Resin is sometimes used as a binder, in addition to pitch, and this substance has, roughly, twice the binding power of medium soft pitch, but briquettes made with resin alone fall and soften in the fire and are therefore unsuitable.

A large number of inorganic binders have been tried with varying degrees of success, but these are objectionable on account of the fact that they introduce still more ash into the fuel than is due to the coal alone. Such materials are Portland cement, silicate of soda, lime, clay, spent tanning materials, and sulphite cellulose liquor. Coal tar has also been used, but the resultant briquette is too weak and softens in tropical countries. Various organic materials have also been tried, such as molasses and sugar residues, jelly from Irish moss, mucilage, waste starch, etc., but the only satisfactory binder seems to be pitch.

In the manufacture of blocks, the coal is generally crushed in a disintegrator of the squirrel-cage type, whilst the pitch is broken up in a pitch-cracker, falling on to a grating provided with longitudinal slots, through which revolving arms protrude, which arms carry the pitch forward and crush it against the breaker plate. The mixture of coal and pitch is sometimes subjected to a crushing either in a second disintegrator or in a mill of the Jeffrey swing-hammer, or fixed beater type, such as the Alexander Pulvergrinder, made by Messrs. Briquette Machinery Ltd., of Leeds. The coal should not be too finely ground, as a large amount of fine coal leads to the breaking down of the binding power of the pitch. The pitch, however, should be ground to as fine a degree as possible, so as to obtain the maximum spreading effect with the least possible quantity. The coal and pitch mixture is elevated into a pug, or cooking chamber, above the press, where it is thoroughly admixed, steam being blown in at the same time. Using steam at 400° F., the steam consumption for a press turning out 17–20 tons per hour of briquettes is about 2,200 lbs. Such a press absorbs about 45–50 B.H.P., and runs at 30–40 strokes per minute. The pressure necessary for briquetting steam and bituminous coal mixtures with 9–10 per cent. pitch is about 30–35 cwt. per sq. in. Ovoid fuel is made in roll presses, the fuel mixture being

* The moisture varies according to the amount of exposure to which the coal has been subjected and to the degree of humidity of the atmosphere, but the above are given as the average of a large number of results. The ash content in general increases with increase of volatile matter content.

fed between the rolls, after cooking, at a temperature just above that of the twisting point o the pitch used, *i.e.*, about 60–70° C., with a normal pitch. The ovoids are caught on a shake screen as they emerge from the press, so that all fines are removed, and are then loaded direc into either wagons or ships, provision being made for cooling, to prevent sticking of the fue and possible fusion into a solid mass.

In some of the processes recently devised for the purpose of low-temperature carbonisatior the low-temperature coke is fed direct from the retort to a press and is briquetted without th addition of any further binder.

The Smith continuous system of carbonisation, which produces 'Carbocoal,' is a combinatio of low- and high-temperature carbonisation with briquetting. The coal, sized to pass a $\frac{3}{8}$-i mesh screen, is subjected to carbonisation at 480° C., the resulting product being a friable residu called semi-carbocoal, which contains 7–10 per cent. of volatile matter. This process takes som two to three hours for completion, but is continuous. The semi-carbocoal is reground, mixed wit pitch, and briquetted. The briquettes contain about 15 per cent. volatile matter, and thes are carbonised at 1,000–1,100° C., the residue being a hard coke containing 3–4 per cent. volatil matter. The tar yield from the primary carbonisation contains the products usually obtaine from low-temperature processes, *i.e.*, paraffin bodies predominate, whilst the tar yield from th high-temperature process gives heavy oils and pitch, with an increased yield of ammoniur sulphate. The gas yield from the first stage is 5,000–6,700 cub. ft. per ton, with a calorifi value of 650–700 B.Th.U.'s. per cub. ft. whilst from the second stage there are obtained 4,48 cub. ft. of gas of calorific value 350–400 B.Th.U.'s. per cub. ft. The average yield is therefor about 10,630 cub. ft. of gas of calorific value 584 B.Th.U.'s per cub. ft.

Other processes merely briquette the low-temperature coke whilst hot, and either recarbonis at high temperature or sell the product as a smokeless fuel for domestic purposes.

A great amount of work has been done of late in Canada by the Lignite Utilisation Boar on the briquetting of lignite. The Souris lignites are of very low grade in the raw state, bu by carbonising at 600° C. a residue is obtained which resembles charcoal and which produce an excellent briquette on binding with pitch and pressing in a roll press. The size of the lignit used is under 1/10-in. mesh, 60 per cent. of the material sizing between 1/10 and 1/20-in. mesh The binders used are coal-tar and petroleum pitches, with sulphite liquor and various wast flour residues as subsidiary bodies. The quantity of binder required, however, is much high than that which is necessary for the production of ovoids from anthracite fines, and this woul seem to be a critical factor where the cost of pitch is high. It was found that 13 per cent. c coal-tar pitch was necessary to produce a sound fuel.

The strength of fuel is generally measured in an empirical way by the 'cohesion test.' Thi is carried out by revolving 100 lbs. of the fuel in a horizontal cylindrical drum, 3 ft. long an 2 ft. 6 ins. diameter, provided with three internal ribs of angle iron 6 ins. deep, for two and a ha minutes at 28 revolutions per minute. The fuel is sawn out of the solid block into pieces 1 lb in weight, and after the test is completed the residue in the drum is screened over a sieve c $1\frac{1}{2}$-in. mesh, and the portion remaining on the sieve is weighed. This weight, in lbs., is calle the 'cohesion' value of the fuel. The revolution of the drum is supposed to represent th rolling of the ship, the attrition in the drum corresponding to the attrition in the ship due t projecting girders, baulks, etc. The cohesion value should not be less than 55 per cent., and good fuel will often average over a long period 72–82 per cent.

The chemical tests on fuel are the same as are carried out on coal, and these will be foun in any book on the evaluation of coal, such as 'Fuel,' by Coste and Andrews, or 'The Analysi of Coal and its By-Products,' by S. R. Illingworth.

Firebars.

The following proportions are for the usual cast-iron bars :—

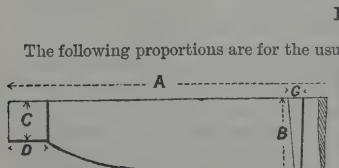


FIG. 7.

A.		B.	C.	D.	E.	F.	G.	H.
Ft.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
2	0	$3\frac{1}{4}$	1⅝	$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
2	6	$3\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
3	0	$3\frac{1}{2}$	$1\frac{3}{4}$	2	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
3	6	$3\frac{3}{4}$	2	2	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
4	0	$4\frac{1}{4}$	2	$2\frac{1}{4}$	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
4	3	$4\frac{3}{4}$	2	$2\frac{1}{4}$	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
4	6	5	$2\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{5}{8}$	1	$\frac{3}{4}$	$\frac{3}{8}$
4	9	$5\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{5}{8}$	1	$\frac{7}{8}$	$\frac{3}{8}$
5	0	$5\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{3}{8}$

Firebars require to be suited to the fuel. Clean riddled coal-nuts or cobbles may be burne on a $\frac{1}{4}$-in. bar with $\frac{1}{4}$ in. to $\frac{1}{2}$ in. spaces, but slack coal requires wider bars and narrow spaces Bars are often made with projecting fingers or corrugations in plan, thus increasing the lengt of air space considerably, though reducing it in respect of the increased width of the bar body

uch bars are made to rock for the purpose of shaking the ashes out of the fire and of breaking p clinker. Air, to supply a secondary demand behind the bridge for the combustion of the ases, is often admitted through hollow bars which heat the air and keep themselves cooler ereby, and under suitable conditions good results may be obtained.

Some firegrates are built up of short bars or links pinned together to form a side travelling and or chain ; such grates are self-cleaning and are much used in mechanical stokers, and are ood, if provided with suitable air control damper plates below. Other firegrates have a some- hat steeply inclined surface, and may be built up either of longitudinal bars or of transverse ars, in which latter case they form the so-called ' step ' grate. Such grates may have a creeping r a shaking movement of the bars in order to assist gravity to lower the burning fuel down ill to make up at the foot of the slope the vacant space left as the fuel burns away. The fuel ; mechanically fed in, above, or at the head of the sloping grate surface, and gradually descends nder the combined influence of gravity and the moving bars. A dumping device is often dded at the foot of the slope by means of which the ash and refuse may be cleared from the rnace by movement of a lever.

Grates for anthracite coal, which develops an intense heat in the fire—not sending off much as by the heat-absorbing process of distillation—are often made in the form of flat plates with number of perforated nipples or little mounds raised half an inch above the general surface. he space between the air mounds fills level with dust and preserves the iron surface from heat nd checks the adherence of clinker.

Firegrate bearers must never be rested upon the actual plates of furnace tubes of internally red boilers, but must rest on angle bracket pieces riveted to the plates by not less than two ivets each. For convenience in handling it is usual to employ two or three bars in the length f a 6-ft. grate.

Hollow bars are necessarily (or more conveniently) made in one length : this, however, makes hem cumbersome, and is one cause of their being sometimes unpopular, for they are heavy to emove and replace when cleaning ; but where conditions are favourable, hollow bars with utlets to the surface and a steam-impelled supply of air through the bars will beget economy, y enabling a cheaper grade of fuel to be employed.

Coal Combustion and Smoke.

Bituminous coal cannot be burned smokelessly except under certain proper conditions. hese are that the whole of the products of combustion must be allowed to travel over the full ength of the fire towards the bridge ; that additional air must be admitted in fine streams above he fire after each fresh charge of fuel. The fresh air thus admitted mingles with the gases from he fuel, and the mixture must be hot enough to burn at the bridge, beyond which point there ust be a clear space in which combustion may complete itself. The combustion chamber may vith advantage be wholly or partially brick-lined. The draught necessary should be not less han 30 ft. per sec. To compel air to enter over the fire, dampers are sometimes fitted to the sh pits.

The most satisfactory results in coal combustion are obtained with the thickest possible fires, ut the thickness of a fire depends on the draught and on the size of the fuel. The largest fuel vill bear the thickest fire and the strongest draught. The three factors are interdependent.

The combustion space should be at least in a good red heat so as to ensure burning all the ombustible into carbon dioxide and water, which would give smokeless operation. Although bout 14 lbs. of air is required to burn one pound of soft coal completely, only half this amount hould be admitted through the grate; the remainder should be supplied over the fuel bed. If his can be well preheated, smokeless combustion is practically assured.

Leaving the door open a short interval after feeding fresh coal, supplies an extra quantity f this secondary air when most needed. Poor draft always causes smoke and lowered efficiency. mple combustion space, involving high settings on boilers, is required with such fuels as Indiana ituminous, pulverised coal, or oil.

There are two general ways of firing bituminous coal. One is to place a thick bed of coal on he front grates. Here it will coke, and the gases given off will pass over incandescent fuel and e consumed, the coked fuel then being pushed over the remaining grate area. This is well dapted to return tubular boilers.

The second method is that of spreading the new coal evenly over the grate in small quantities t a time through alternate doors. One-half of the fuel bed is kept incandescent. A uniform size f coal, neither coarse nor fine, gives best results. High-volatile coals require a bed of four to six nches, and those with less volatile somewhat thicker beds.

Where gases rise directly upwards from a grate amongst water tubes without the admixture by travel pointed out above, smoke is inevitable.

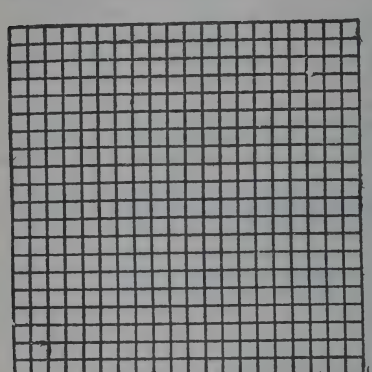
Fine dust fuel can now be burned at the rate of 40 lbs. per sq. ft. of furnace area per hour. Given furnace room, the cheapest fuel is usually the most economical. In practice the best economy is that due to the use of the cheapest fuel which can be employed to raise the steam necessary.

The foregoing, of course, is qualified by the amount of ash in the coal where the extreme of removal is great.

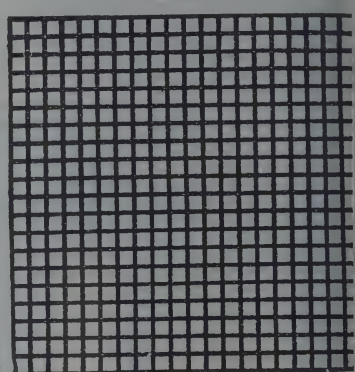
With externally fired boilers which permit of a liberal design of furnace with suitably disposed firebrick, smoke can readily be prevented. It is less easy to secure perfect combustion with

internally fired boilers, because of the difficulty of applying durable firebrick linings. But t question of smoke prevention is wholly one of air mixture and temperature. The burni gases must not too soon be brought into contact with cold plates or tubes.

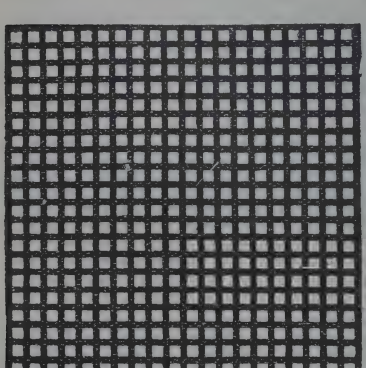
In burning bituminous coal only a part of the total heat is generated at the grate. Part of t heat of the fuel is absorbed in driving off the volatile parts of the coal in gaseous form. This he becomes latent and very materially reduces the furnace temperature. The gases pass off, contai ing a third of the total heat capacity of the coal, as well as the heat of gasification. Unless mix



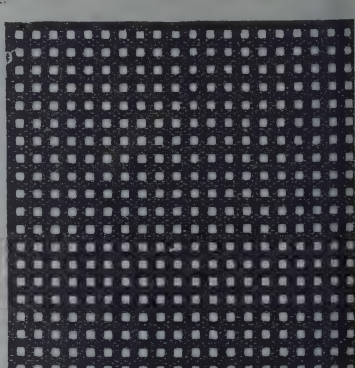
2. Light grey smoke.



3. Darker grey smoke.



4. Very dark grey smoke.



5. Black smoke.

FIG. 8.

with air and burned later, these gases may be totally lost. To burn bituminous coal not onl demands thorough air mixture, but also a sufficient temperature, and the heat of the burnin gases must not be abstracted by too early bringing them into contact with the cool surfaces the boiler. Sufficient length and clear space must be afforded for combustion to complete itsel or black smoke will be formed. The furnace arrangements of the Lancashire boiler are correct form, but the water-cooled plates are a hindrance to certain combustion in the case of hand-firing when high temperature mechanical-stoker conditions are obtained, however, it is much easi to prevent smoke with bituminous coal in a Lancashire boiler than it is in a water-tube boiler.

Water-tube boilers require a special setting to enable them to burn coal smokelessly. No furnace a be smokeless where the gases from the fire rise vertically and pass amongst cold-water tubes. uminous fuel can rarely be burned satisfactorily unless there is some extent of firebrick lining protect the gases from too early chilling. Cross water-pipes in the inner flues of the Lancare or Cornish boiler are bad, and will seriously hinder perfect combustion and produce black oke.

Colour of Smoke.

The colour of smoke is best indicated by Ringelmann's smoke charts, which are numbered from . 1, all white, to No. 6, all black. In fig. 8 intermediate sizes 2, 3, 4, 5, are shown, the lo of line to space breadth being respectively, 10 : 90 ; 23 : 77 ; 37 : 63 : and 55 : 45. Large arts drawn to these proportions and hung about 50 feet from the observer where the chimney) can be seen simultaneously, if possible, are very great aids in correctly estimating the relative okness of smoke.

The four scales of the figure are called light grey, darker grey, very dark grey, and black, extreme all white or all black being respectively no smoke or dense black.

MECHANICAL STOKERS.

Mechanical stokers are of two types, coking and sprinkling. In coking stokers the combustion the volatile hydrocarbons contained in the fuel is effected at a different portion of the grate rface from the combustion of the fixed carbon or coke. Sometimes an independent air supply provided for the combustion of each portion of the fuel. In coking stokers the fuel is ually fed on to the front of a moving grate, the volatile portion being expelled and burnt ar the front, while the fixed portion is burnt whilst being conveyed towards the back of the e by the movement of the grate surface. The incombustible portion of the fuel (ash) is opped into a chamber behind the grate. The movement of the grate surface may be reciproting, or it may be a continuous movement backwards. The 'Underfeed' class of grate also longs to the coking type. In this class the fuel is forced onwards and upwards in a central ough by a helix conveyor or ram ; it rises along the whole length of the trough, to the ex of the grate surface which is like a flattened Λ in cross-section ; the hydrocarbons are pelled and burnt near the apex, and the coke is supposed to be burnt whilst it is conveyed ften by a rocking movement of the overlapping grate-bars) to the sides of the furnace. In rinkling stokers the fuel is thrown on to the grate surface by means of a throwing shovel or uivalent device, and almost the whole of the grate surface is utilised for the combustion of th volatile and fixed portions of the fuel. The furnace bars of this type of stoker are usually ven a reciprocating movement in order to provide for the continuous and automatic removal clinker.

The relative advantages of the two types of machine stokers depend largely on the class of fuel be burnt ; but, in general, it may be said that, if properly worked, the sprinkling type will ually generate more steam from a given boiler, and with at least equal efficiency. On the other nd, with coals containing a high percentage of volatile matter, machines of the coking type can worked smokelessly with less skill on the fireman's part than is needed by sprinkling machines.

The Babcock and Wilcox Patent Improved Mechanical Chain Grate Stoker.

The grate of this stoker (*Babcock & Wilcox, Ltd.*), as illustrated on page 1659, consists an endless chain of short interlocking cast-iron grate bars, linked together, running on gle irons and rollers, and driven by a revolving shaft and sprocket wheels at the front d of the stoker. The necessary power to drive the revolving drum is transmitted rough a link chain and sprocket wheels from a shaft arranged either overhead or underround. The starting or stopping of the stoker, or the variation of speed, is effected rough the Babcock & Wilcox patent gear box, which can be driven at varying speeds. his box forms an oil bath in which the gear runs, and also contains an efficient clutch r putting the driving gear out of action should any unusual strain arise from an obstruction the grate. Any small repair, such as replacing a link, can be carried out with the stoker in lace under the boiler ; but in case of need the whole stoker can be brought out clear of the oiler, the frames being provided with wheels running on rails placed at the sides of the ashpit. he slack of the chain can be taken up from the front end of the stoker, thus avoiding the ecessity for obtaining access to the back end for tightening the grate. The grate bars or links re of a special interlocking pattern, which allow the smallest coals to be used, and, while proiding for an ample supply of air for the combustion of the fuel, prevent the influx of cold air t the back of the grate. The coal is fed over the whole width of the grate, and the depth of the re is regulated by the adjustment of the vertically lifting fire-door.

The feed of the coal is slow, and the gas evolved from the fresh fuel as it drops on to the rate readily perfects its combustion by passing over the incandescent fuel further on. The epth of the fire being regulated by a vertically lifting fire-door, the stoker can be adjusted in

a moment to suit the class of fuel to be consumed and varying demands for steam, both by depth of the fire and the speed of the grate. Where the special requirements of the work ma it desirable, the stoker can be fitted with an arrangement of vanes for cutting off the air supp to a portion of the grate during periods of light load, thus enabling the general efficiency to kept up under all conditions of work.

Babcock & Wilcox also manufacture forced draught chain grate stokers of both the compa mental and the boxed-in type, for efficiently burning low-grade and other difficult fuels. Wh average quality coal is used forced draught is not necessary, and by simply opening the two fr ashpit doors—an operation occupying only a few minutes—the stoker can be used as an ordin natural draught plant.

Bennis Stokers.

(Ed. Bennis & Co. Ltd., Little Hulton, Bolton.)

The Bennis Sprinkler Stoker.

This apparatus, fig. 9, affords a perfectly regular output of steam under the most try conditions; its flexibility permits a rapid response to urgent demands for increased stea Minimum labour costs, low fuel bills, and smokelessness are a few of the leading advanta

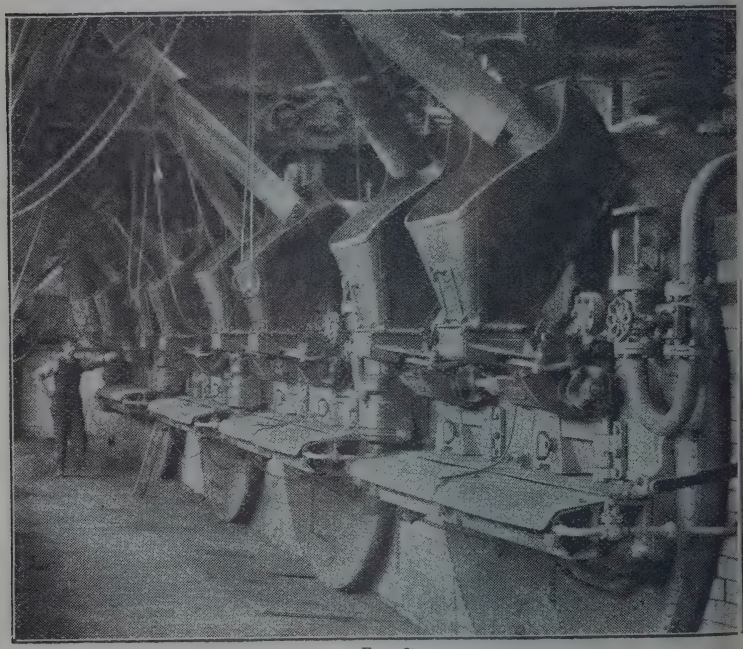


Fig. 9.

that accrue where the sprinkler stoker is in operation. The fuel fed into the hopper of t stoker—preferably mechanically fed—is led to the front of the pusher plate where it is even pushed over a ledge formed by the base of the feeding-box. The weight of fuel pushed regulated, the fuel being deposited on to a flat plate called the shovel box, and then project into the fire at intervals by an angular shovel actuated by patent pneumatic gear and effectual scattered over different portions of the grate where and as the fire requires it.

The pneumatic gear actuating the shovel, which includes an air cushion to obviate t possibility of shock or jar on the boiler front, is noiseless in operation.

An integral portion of the sprinkler stoker is the self-cleaning compressed air furnace, whi prevents clinkering, and ensures perfectly clean fire-bars.

THE BENNIS SELF-CLEANING COMPRESSED AIR FURNACE ARRANGED FOR HAND-FIRING IN COLLIERIES.

This furnace, fig. 10, thus arranged burns any class of fuel, large or small, and burns with special advantage poor quality and refuse fuels, pond settlings, coal pickings, large lumps or small, coke dust, shale, or material which contains a large percentage of ash or clinker. With such refuse it is stated to be able to generate steam as quickly as furnaces fitted with stationary bars burning a higher grade coal. The furnace consists of a strong cast-iron front lined with fire-brick, and fitted with a door of ample size for hand-firing.

THE BENNIS PATENT CHAIN GRATE STOKER.

This arrangement, fig. 11, is applicable to any water-tube boiler or to return-tube boilers—where the fire is under the boiler shell and the flame returns through the tubes—to brewers' coppers and similar furnaces. One of the principal advantages claimed for this particular chain grate is that a larger grate area can be obtained under the boiler than with those of other makes. The Bennis chain grate with the patent halved link was the first chain grate capable of satisfactorily burning fine slack coals. There are many improvements connected with this grate, in addition to the central improvement which gives to the grate its distinction.

The Bennis patent link can be easily fitted to chain grates of other makes, and many successful replacements have been carried out, with the result that considerable economies have been effected by using cheaper coal.

THE BENNIS COKING STOKER.

This stoker, fig. 12, is an improvement on the ordinary type of coker, as it ignites the fuel and cokes it at a more rapid rate than is possible with other types. It is claimed that the immediate result is a higher evaporative boiler duty and greater economical efficiency. It consists of a machine supplied with hoppers into which the fuel is fed. Beneath the hoppers are duplicate feed-boxes with reciprocating feeder rams which feed the coal into the furnace intermittently. A sight hole situated between the feed-boxes makes it easily possible to ascertain the state of the fire at any moment. The feeder rams are worked by means of levers. The rate of the coal feed is easily adjustable. Large air-cooled fire doors are provided beneath the feeder-boxes, their object being to pass cool air into the protection plates fitted immediately round the stoker front on the fireside, thereby preventing damage to the stoker front and also to the boiler.

The Illinois Patent Chain Grate Stokers.

(Vickers Boiler Co., Ltd.)

The Illinois patent Chain Grate Stokers, for forced draught, natural draught, and induced draught, are made under licence by Vickers Boiler Co., Ltd., who hold the sole manufacturing and selling rights in all countries outside the United States.

Broadly, the stoker is of two standard types, viz.:

Type 'A' for natural or induced draught, fitted with air control dampers, and

Type 'G' for forced draught fitted with cast-iron air compartments, hopper bottoms, and device for the discharge of riddlings.

These stokers are of heavy and substantial construction, the frames are of heavy section, well braced and ribbed. The side frames, which, owing to their position inside the casing, are subjected to high temperatures, are independent of the head frames which are outside the setting.

Adjustable ledge plates are arranged at the top of the stoker side frames to prevent leakage of air between these and the chain, and also to prevent the riddling of fine coal. These ledge plates are so set that the distance between them gradually increases towards the rear of the stoker to permit of expansion of the grate and prevent the possibility of the chain binding between the frames.

Drive.

The grates are driven from the front by uniformly spaced driving sprockets which engage on loose rollers on the chain rods, and not on the links or rods, thus minimising frictional loss and reducing the power required, as also the maintenance. The arrangement also ensures a uniform distribution of the driving power over the whole width of the grate.

Idler drums are used on the rear shaft.

The advantages of driving the grate from the front are :

(*a*) The links are in compression, and consequently their strength is greatly increased over that of cast iron in tension.

(*b*) The spaces between the top links are kept closed, and therefore the riddling of fine coal is prevented.

(*c*) The driving sprockets are accessible through inspection doors in the head frame.

(*Continued on p.* 2104.)

BENNIS STOKERS.

FIG. 10.—BACK VIEW OF THE BENNIS COMPRESSED AIR FURNACE.

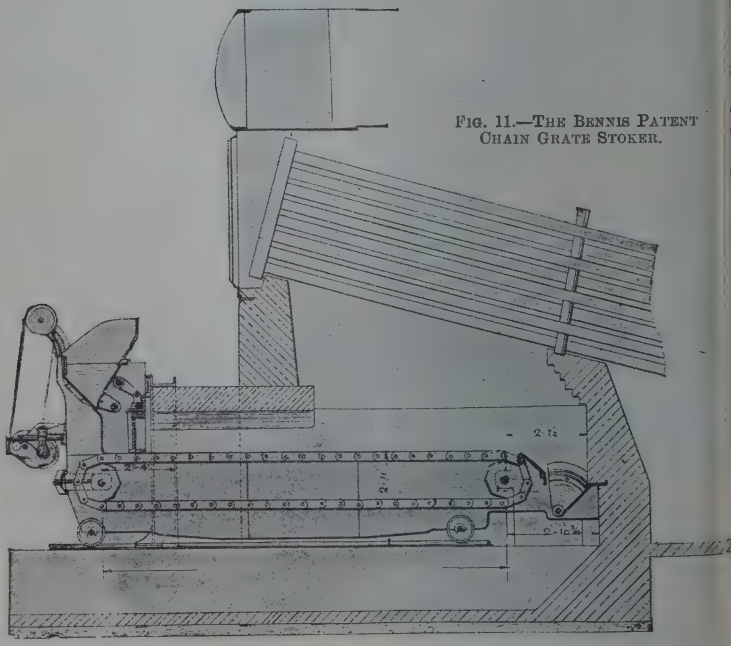


FIG. 11.—THE BENNIS PATENT CHAIN GRATE STOKER.

THE BENNIS HIGH TEMPERATURE SMOKELESS AND GRITLESS COKING STOKER.

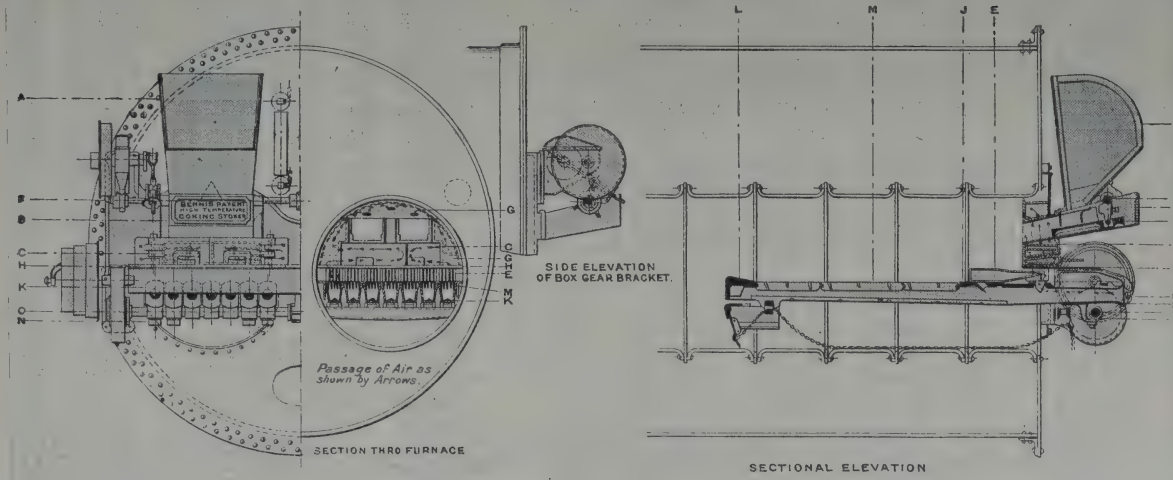


FIG. 12.

The Illinois Patent Chain Grate Stoker—*cont.*

The Grate.

The grate is composed of a number of links connected by means of twisted chain rods; tl use of these rods prevents the accumulation of dust, rust, and ashes between the rods and link with a consequent reduction in power consumption and maintenance cost.

The grate tension can be adjusted at any time while the stoker is in operation.

Special repair links are made and supplied for expeditious maintenance under runnir conditions.

Grate Support.

Chain skids are used instead of the roller construction.

The stokers are made up to 24 ft. in width in a single stoker, which necessitates the use suspended arches.

Illinois Stokers are in use in this country at the present time up to a width of 18 ft. 6 ins., ar stokers up to a width of 24 ft. are in hand.

The forced-draught stoker 'G' is of the compartment type.

The air is delivered from the main air supply duct to a wind box in the side wall extendir the full length of the grate.

Stokers of medium width are supplied with air on the one side only; the wider stokers a provided with a wind box on each side.

The whole length of the active grate surface is divided into a number of compartments. Eac compartment has its own opening into the wind box controlled by a circular plate damper. The dampers can be locked in any desired position by means of an operating lever and lock plac outside the wind box.

When the stoker has a wind box on both sides, dampers are provided on each wind box. Tl compartments are constructed of cast iron with hopper bottom and riddling discharging devic

For the burning of anthracite coal, coke breeze, lignite, or other high-moisture or low-volati fuels, mechanical ignition is provided by means of a mechanical ignition zone at the front end of tl stoker, comprising a small compartment running across the entire width of the stoker; in th compartment a suction is maintained whereby a small portion of the hot furnace gases are drav down through the incoming green coal, causing the fuel to be completely ignited for its enti depth.

The stoker throughout is of robust construction, with a view to ensuring continuity of operatio freedom from trouble, and low maintenance cost.

The Erith-Roe Stokers.

(*Erith's Engineering Co., Ltd.*)

These stokers, for water-tube boilers, figs. 13 and 14 (p. 2105), are of the inclined multiple reto underfeed type, in which the fuel is fed from the bottom of the stoker hoppers into a series of reto units, from which it gradually rises to the surface of the fuel-bed and passes down an inclined plan so that the ash and clinker finally fall into the ash hoppers in a continuous manner, witho manual labour.

A heavy fuel-bed is carried, and the *surface* of the fire is maintained in an incandescent cond tion, so that the heat radiates direct to the boiler tubes; coking arches being entirely dispens with, their cost and upkeep is eliminated.

The upkeep cost of the stoker is low, due to the metal being kept covered with the incomir fuel that has not risen into the zone of high-temperature furnace combustion.

A regulated supply of air from a fan is furnished to the air chamber below the stoker, and suitably distributed through the retort tuyeres, etc., at the requisite pressure to secure 'balanc draught' conditions. A special baffle in the air chamber (which forms the subject of an addition patent) has been found of considerable value in improving the air distribution, so that the mir mum of excess air, combined with a very high percentage of CO_2, can be maintained in regul service. Under these regulated and controlled conditions, low-grade slack and other fine coal c say, 10,000 B.Th.U.'s per lb., or less, can now be burned with a thermal efficiency nearly equal that obtainable with high-grade fuel.

The robust and simple operating mechanism of the stoker consists of a slow-moving crankshaf which is normally run at about one revolution per minute; it operates, in series, the coal-feedir rams and distributing pushers within each retort, together with the stepped slicing bars reciproca ing between each retort (which automatically slice the fires and keep them open and porous) well as the reciprocating extension grates over which the refuse passes before it finally falls in the ash hoppers at the rear.

In the Erith-Roe stoker provision is made for the immediate and *independent* adjustment the levers controlling the movement of the fuel-bed, which experience has shown to be essential f

ERITH'S Feedwater HEATERS are of the OPEN type, ensuring protection from the Oil in exhaust steam and maximum HEAT RECOVERY without any working cost.
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ERITH'S HEATER-SOFTENERS are furnished for BAD WATERS needing either Soda-Ash Solution and/or Lime Treatment to keep Boiler Plants FREE from damage due to SCALE.

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OVER

ERITH-ROE MULTIPLE RETORT STOKERS

(See editorial matter on pages 2104 and 2105).

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Our patented improvements enable the proportion of air to fuel to be more closely controlled than has previously been possible; and the simple adjustments regulating the movements of the entire fuel-bed can be immediately set to suit varying fuels.

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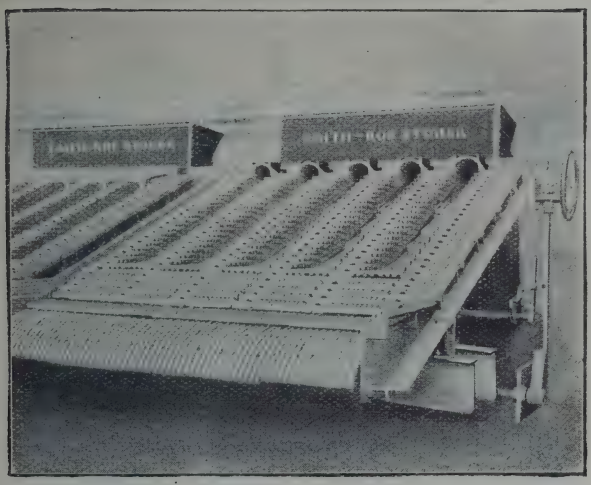


FIG. 13.

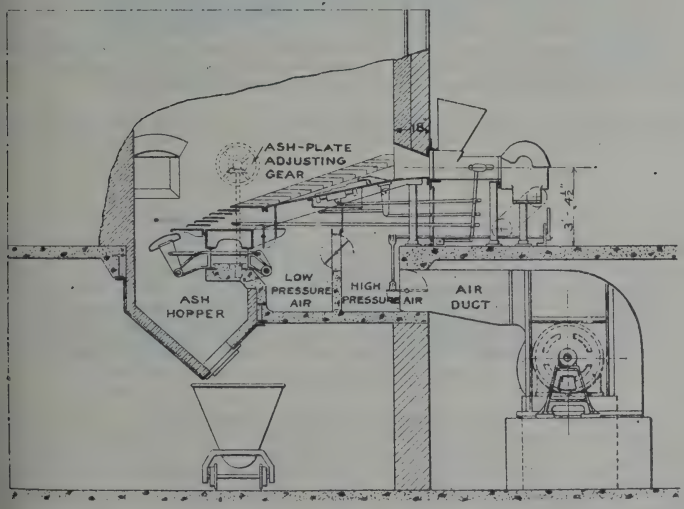


FIG. 14.

burning the widest range of fuels to the best advantage. No alteration from the original adjustment is, however, required, unless the conditions are materially altered through the coal being changed, etc. The Erith-Roe stoker is a British invention, and is being increasingly adopted for centratation and industrial service at home and in the Colonies.

The Underfeed Stoker Co.'s Stokers.

(The Underfeed Stoker Co. Ltd.)

THE 'B' TYPE STOKER FOR LANCASHIRE BOILER.

In this stoker the fresh fuel for the maintenance of the combustion is continuously supplie from *below* the level of the fire and gradually advanced upward to the zone of combustion b the arrangement shown by fig. 15.

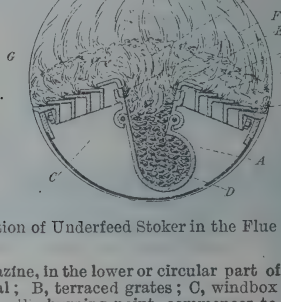


FIG. 15.—Cross-Section of Underfeed Stoker in the Flue of a Lancashire Boiler.

A is a retort or fuel magazine, in the lower or circular part of which revolves a taper-feedir worm which conveys the coal; B, terraced grates; C, windbox; and D, green coal; the latt being gradually pushed up to the burning point, commences to ignite at the point E, where meets the incoming air from the tuyeres F' and F'. Here the coal is coked, i.e. deprived of i volatile hydrocarbon gases. These being mixed with air introduced at this point through th air inlets of the fuel magazine, and escape being possible only by rising through the glowin coke above, the gases are heated to such a high temperature that they are completely consume without smoke, while the combustion of the fixed carbon of the coal is completed by the a introduced through the apertures in the sides of the terraced grates B.

The effect of this method of underfeeding is to keep a continually clear, bright surface incandescent fuel, combustion with even highly bituminous coals being complete.

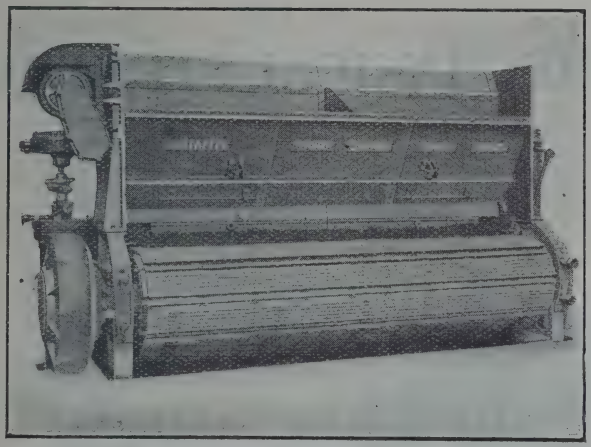
THE CLASS 'A' STOKER.

In this stoker, the unit idea of construction adopted combines the impelled draugh fans and driving mechanism with the grate itself, with many resulting advantages. It will b seen from fig. 16 that the fans are mounted one on each side of the fuel hopper, with short, eas connecting air ducts leading to the air chambers of the grates. The driving motor, bolted to base plate which forms the front side of the hopper, has its armature shaft extended at each en to carry the fan wheels. This shaft runs at from 850–1,000 r.p.m., and by means of a chain the 'silent' type in conjunction with a worm and wheel, both encased in a common chamber, th speed is reduced to 9–10 r.p.m. From this mechanism a direct connection is made to the grat change-speed gear. This gear has eight different adjustments for speed, varying the travel the grate from a combustion of fuel for 8 lbs. per sq. ft. to 60 lbs. per sq. ft. of grate area.

The whole of the driving mechanism, whether high speed or low speed, runs in dust-tight, o bath chambers, and the oiling arrangements are reduced to the greatest simplicity. Some of th advantages claimed are :—The reduction of the power required to drive the complete machin comprising fans and grate, to one-third of one per cent. of the steam generated by the boiler the removal of the dust and dirt of the boiler room at the point where it is created, thus keepin a clean, well-ventilated room; the avoidance of large air-carrying ducts, and what was formerl the necessity of breaking joints with duct at such times as it was necessary to remove the stoke from the furnace.

The air pressures employed in the air chamber of the stoker vary from $\frac{1}{4}$ in. to $\frac{7}{8}$ in., dependin upon the nature of the fuel. The higher pressure is employed in such fuels as coke breeze, whic is very fine in texture and lies very closely upon the grate.

THE "L" TYPE TRAVELLING GRATE STOKER



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THE 'UNDERFEED' CLASS 'E' STOKER.

In this stoker, figs. 17 and 18 (*The Underfeed Stoker Co. Ltd.*), the fuel is deposited by coal-conveying machinery or hand labour, in a large hopper, and conveyed under the fire by means of a reciprocating sliding bottom which runs the full length of the trough. As the coal rises from the trough it is distributed to the sides of the furnace by means of moving bars.

The coking and burning coal is constantly carried, by the action of the moving bars, to the dumping trays along each side wall, where the resulting clinker and ash are deposited. These dumping trays are operated by levers on the outside of the furnace, enabling the ash and clinker to be automatically discharged.

The sliding bottom is actuated by a steam motor shown in fig. 17 at C, the number of strokes of which may be varied from one in three minutes to fifteen in one minute, each stroke carrying into the furnace about 6 lbs. of coal.

The movement of the piston of cylinder C is transmitted directly through the piston rod to the crosshead D, which is bolted to the sliding bottom E. This sliding bottom extends the full length of the retort. The block B has the same movement as D and E; thus the coal is fed by block B from the bottom of hopper A on to the sliding bottom E, which not only carries it to the back end of the furnace, but forces it to rise the full length of the trough. As the coal rises in the trough, or coking retort, it is flooded on to the bars F. These bars are alternately moving and fixed. The moving bars work transversely to the retort. The extent of the movement is from ¼ in. to 1 in., depending upon the size of the furnace and other conditions. On the bottom of each moving bar are cast two lugs which engage with the bulb of the longitudinal rocking bars H. These rocking bars in turn receive their movement through the agency of two spirals and nuts, which mechanism is entirely outside the furnace. The nuts are bolted to the crosshead D and therefore reciprocate with the bottom E. The reciprocation of the nuts causes the spiral to rock to and fro.

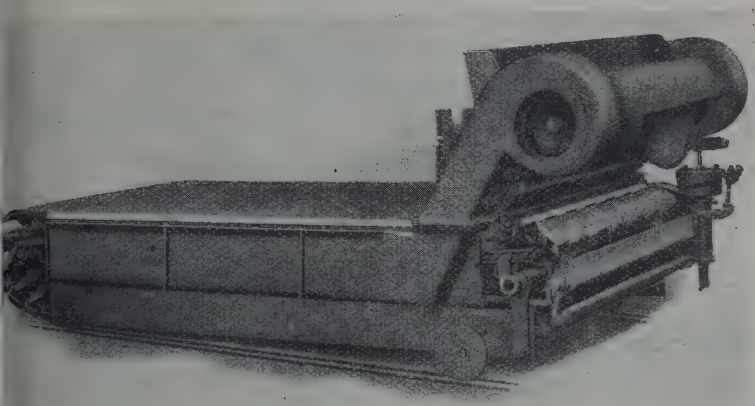


FIG. 16.

The movement of the grates, in addition to carrying the burning fuel to the sides of the furnace, also conveys the clinker down and deposits it on dump plates K, which are fastened to hinge-bar L. This hinge-bar is actuated by a lever, conveniently placed outside the furnace, to dump the accumulation of ash and clinker into the ash-pit.

One of the important features of this stoker is the distribution of the air, which enters the stoker through the aperture N, controlled by the wind gate O. This wind gate is adjusted by the crank P. The air, upon entering the wind box Q, passes upward along each side of the trough, or retort, and is discharged, partly through the holes R, into the retort. The remaining air passes through the bars F, which are made hollow. These bars have no openings in their top surfaces, and no air can find its way into the fire above until it has passed through the aperture S at the bottom end of the bar, from which aperture it is discharged into the enclosed air

THE UNDERFEED STOKER CO.'S CLASS 'E' STOKER.

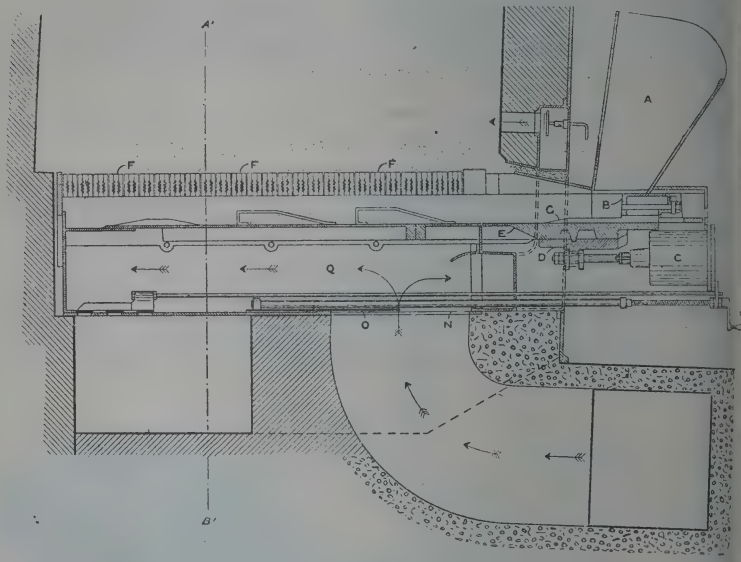


FIG. 17.

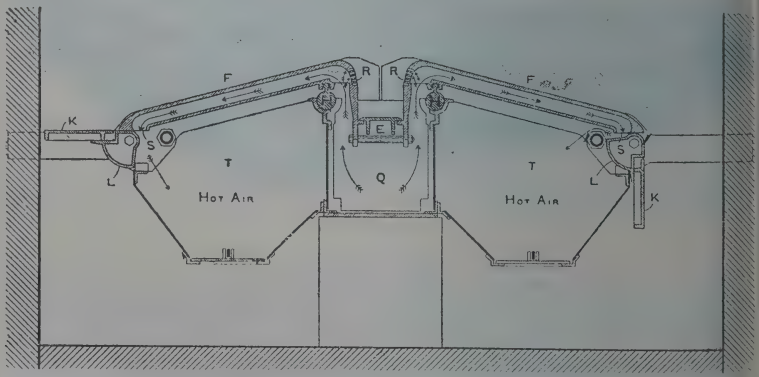
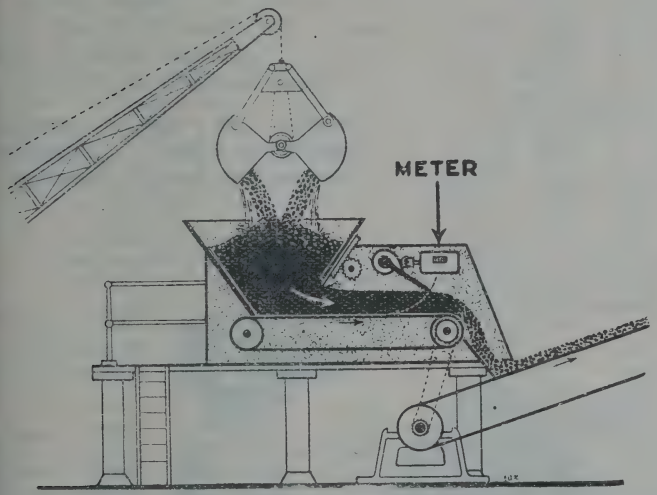


FIG. 18.

LEA
"CUBI-METERS"

FOR MEASURING BULK-SUPPLIES OF COAL



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These machines are a development of the Lea Coal Meter, for chain-grate stokers, of which over 2,500 are now in successful use.

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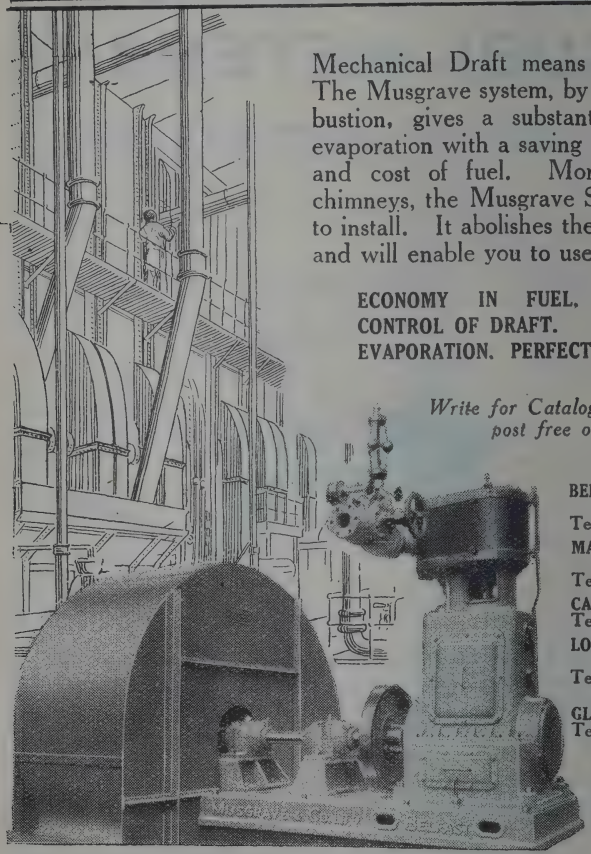
F. 2108

Mechanical Draft



Mechanical Draft means cheaper steam The Musgrave system, by improving com bustion, gives a substantial increase i evaporation with a saving both in quantit and cost of fuel. More efficient tha chimneys, the Musgrave System costs les to install. It abolishes the smoke nuisanc and will enable you to use low-grade fue

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hambers T. From here the air rises and passes through the small spaces between the bars into he coked fuel. The action of the air in passing through the bars keeps them cool, thus greatly rolonging their life. The heat taken off the bars in this way raises the temperature of the air n the air chambers T to from 350° F. to 400° F. The pressure of air in the chamber T varies rom zero to $\frac{3}{8}$ of an inch of water.

As the casing forming the air chambers T is sealed from the main ash-pit of the furnace here is no escape of air into the furnace when the dump plates K are dropped.

MECHANICAL DRAUGHT.

Various mechanical methods have been introduced for increasing the draught for boilers; his may be accomplished by an exhausting fan drawing the products of combustion through he flues, or by blowing air into a closed stokehold or an enclosed ashpit, and forcing the air hrough the fire with the necessary pressure, which varies according to rate of combustion esired. There is also a combination of these mechanical means, termed 'balanced draught,' in vhich air is forced under pressure into the ashpit by one fan and the gases are drawn off by n exhausting fan so arranged that there is neither pressure nor vacuum above the fire. Another nethod is the 'ejector draught' system in which the flue gases are drawn up the chimney by high speed jet of air.

The advantage of mechanical draught produced by a fan is that the first cost is less than half hat of a chimney; also the draught is independent of atmospheric conditions, can be varied nstantaneously to suit the demand for steam, permits of economisers, and allows the reduction f the temperature of the waste gases to be carried to the lowest practicable point. It increases he capacity of the boiler, and permits of a more perfect combustion with less excess of air. t allows the use of lower grade and less expensive fuel, and so produces steam more cheaply.

Any desired rate of combustion from the normal of 20 lbs., to 30 or 40 lbs. of coal per square oot of grate area, may be maintained with a mechanical draught plant. The air volume required lepends upon the style of boiler, condition of boiler setting, skilful stoking, the kind of coal used, nd other factors; in round numbers 250 to 300 cub. ft. of air will be required per lb. of coal; hese figures represent about 12 per cent. and 10 per cent. CO_2 respectively.

To drive a fan requires about $\frac{1}{2}$ to 1 per cent. of the total power generated. The full benefits f mechanical draught are only obtained where means are employed to utilise to the fullest ex- ent the heat of the flue gases (by means of superheaters or economisers) before the latter are lischarged into the chimney. The cost of installing a fan and engine is very much less than he cost of a chimney, so that mechanical draught is economical in first cost.

Fan draught enables a heated air supply to be employed, and it is said that by heating the ir supply to 180° the fire temperature will be raised an additional 360°, owing to better ombustion, etc.

The Musgrave System.

(*Musgrave & Co., Ltd., Belfast.*)

This is an induced system of mechanical draft. The action of the fan is substantially the ame as that of a chimney, the gases being drawn through the furnace and discharged up the stack; his is usually found to be a very convenient and natural method of applying mechanical draft, nvolving little or no alteration to existing boiler plant, and having a wide range of flexibility. The fact that the draft is set up by suction instead of pressure gives a more uniform flow of air hrough the fuel, thus reducing the tendency to blow holes through the fire. All leakage being nward, all danger of discharge of flame and smoke at the furnace doors is avoided. In tubular oilers better contact is obtained between the gases and tube surfaces, the tendency with forced draft being for the gases to form a contracted vein at the front end of the tubes, resulting in a onsequent loss of heat transmission.

With the induced system the fullest possible use can be made of economisers, either in the orm of feed-water or air heaters. There being no necessity to maintain a high gas temperature n the chimney to create draft, as is the case when natural draft is depended on, the whole of the vailable heat in the gases may theoretically be utilized, and the maximum economy obtained. In actual practice, however, the temperature to which the gases may efficiently be reduced is bout 300° F.; to reduce the gas temperature below this figure, the increased cost of economisers or air heaters involved, the additional draft required, and the corrosion due to the condensation of acids from the gases on the cooling surfaces, render further reduction impracticable.

To obtain flexibility and perfect control in a mechanical draft installation, an independent fan drive by steam engine or electric motor is preferable to a drive from a line shaft by means of belt or rope; the speed of the engine or motor can be immediately adjusted to suit the varying draft requirements, and in suitable cases an entirely automatic control can be utilised. The steam consumption of the engine will not exceed $1\frac{1}{2}$ or 2 per cent. as a maximum of the total steam generated, while the steam jet type of blower absorbs from 5 to 10 per cent. of this total.

The great loss of heat where chimney draft alone is depended upon puts it out of consideration altogether in modern plants.

To obtain maximum economy the design of the fan must be correctly proportioned to the required duty, so that the air supply necessary for efficient combustion may be obtained with the minimum expenditure of power under all conditions. All flues should be as short and direct as possible, avoiding all unnecessary bends, changes of section, and obstructive dampers.

Musgrave's induced draft fans are constructed both of the multiblade and straight-bladed types, depending upon the duty. The former with their higher rotational speed are more suitable for use with direct-coupled motor or turbine drive, the latter for engine drive.

Where large quantities of dust are entrained in the waste gases, the straight-bladed wheel is better, owing to its freedom from all possibility of clogging.

The casing may be either of the full or three-quarter housing type: in the latter case, the lower portion of the periphery is formed in brickwork or concrete. The shaft carrying the wheel is usually overhung, being adequately supported in two ring oiling bearings of ample size. For normal gas temperatures the bearing adjoining the fan housing is provided with a water-cooling jacket. For particularly high temperatures both bearings are jacketed, and occasionally a forced lubrication system adopted. Reliability is assured by the provision of ample bearing surfaces in engine and fan bearings, and sound scientific and mechanical design throughout.

The Sturtevant Systems.

Figs. 19 to 21 show the various systems installed by the *Sturtevant Engineering Co. Ltd., London*, which are in use in power stations, workshops, factories, warships, passenger and freight steamers, etc.

Induced Draught (fig. 19). This is the most commonly adopted system, as it is generally applicable to an existing boiler installation, and is economical in operation. The products of combustion are drawn through the flues, economisers, etc., by an exhaust fan, and discharged to an existing stack or to a short length of steel chimney built just high enough to carry the gases above surrounding buildings. The fan is fitted with water-cooled bearings.

Forced Draught (fig. 19A) is advantageous for burning small or low-grade fuel. The fan blows air under pressure into the closed ashpit, and the gases are discharged either to existing stack or short steel chimney. For ship use the closed stokehold method is generally used.

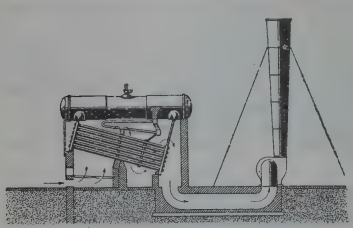


FIG. 19.

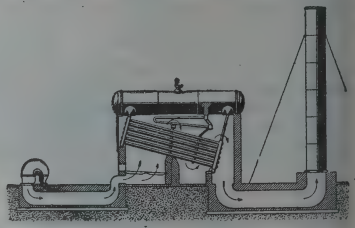


FIG. 19A.

Balanced Draught (fig. 20) is a combination of induced and forced draught. Air is forced under pressure into the closed ashpit by one fan, and the gases are drawn off by an exhausting fan so arranged that there is neither pressure nor vacuum above the fire. This is only used in special cases, owing to the cost being much higher than either fig. 18 or fig. 19.

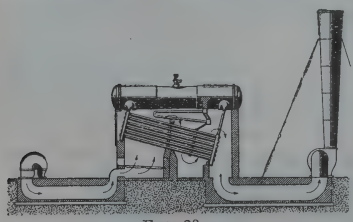


FIG. 20.

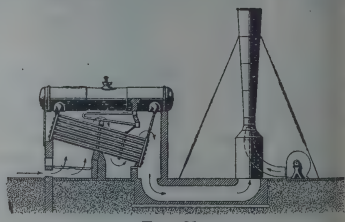


FIG. 21.

Indirect Induced Draught with Ejector (fig. 21). The combustion gases are drawn up a chimney of special design by the effect of a high speed jet of air, which if desired can be mixed with a portion of hot gases. This system is of special value in cases where the flue gases are corrosive or excessively hot, as they need not pass through the fan. This plant requires very careful designing, otherwise the efficiency is very low indeed.

The Howden Forced Draught System.

The principles on which this system of forced draught (*James Howden & Co. Ltd., Glasgow*) based are (1) the supplying under pressure of hot air for combustion in quantities suited to the ıality of coal used; and (2) the utilisation of the heat in the waste gases for the purpose of ising the temperature of the air for combustion.

Briefly stated, the following are the principal advantages of this method of combustion :—

(1) Great increase in the steaming power of the boilers. (At least 30 per cent. and probably uch more over best natural draught conditions. Probably as much as 50 per cent. could be ıtained if necessary, though quite such a high rate is not recommended for regular working.)

(2) Unequalled economy in fuel. (At least 10 per cent. and frequently 15 per cent. per lb. of ater evaporated over the best natural draught conditions and probably much more.)

(3) Reduced size and weight of boilers for a given power, giving correspondingly additional ıace available for other purposes.

(4) Complete control of combustion and steam supply under all conditions of the atmosphere. With this system of draught the volume and pressure of the air for combustion is entirely ıntrolled by the fan and the manipulation of the air valves in the furnace fronts.)

(5) Capability of burning all classes of coal and coke. Low-grade fuel can always be burned ıtisfactorily where this system of forced draught is applied. Under natural draught conditions ıis is often difficult and sometimes impossible owing to the inability of supplying the greater olume of air always required where the greater quantity of inferior fuel is used. For the reasons ıated in (4) this difficulty is surmounted, the additional quantity and pressure of air necessary ing easily obtained by running the fan a little faster.

(6) Preservation of the boilers on account of the more uniform temperature maintained in the ırnaces. Boilers fitted with the Howden system of draught are less liable to the leakage and ouble generally present under natural draught conditions; the reasons being that no cold air ver enters the furnace during the period of working, and much greater uniformity of temperature maintained than under natural draught conditions. Sudden alternations from heat to cold, and ıe consequent contraction and expansion, have an injurious effect on the internal parts of steam oilers, and such sudden fluctuations in temperature are prevented by the use of this system. Vhen the furnace doors are opened the air pressure in the ashpit immediately ceases, and only the ot air from the upper air supply valve passes into the furnace, first in a direction vertically ownwards, thereby forming a hot screen over the furnace mouth and preventing access of cold ir. Such conditions when firing or cleaning fires are also conducive to economy. The benefit of ıe system regarding fluctuations of furnace temperature is most marked and appreciated when ı is compared with the working conditions of the closed stokehold system. In the latter a con-iderable air-pressure is generally used, so that the fluctuation in temperature of furnace is both apid and violent and puts a severe strain on the boiler structure. This is quite obviated in the Howden system.

(7) Reduction of smoke.

(8) No high chimney required. For land installations a small iron funnel, sufficient to carry ff the waste gases clear of the surrounding buildings, is ample for the purpose.

(9) Coolness in boiler-room and ease of working. With this system the air casing, reservoirs, nd furnace fronts on the boiler end effectually prevent radiation into the stokehold, which is hereby kept quite cool, making the work easier than with the closed stokehold system, which is ery trying for the firemen.

(10) Great reserve power available in case of emergency.

The general arrangement of the Howden system consists of a fan (driven by a steam engine, lectric motor, or belt), which supplies the air for combustion, discharging it through a conduit nto the air-heating chambers. In these air-heating chambers the air circulates round a series of ubes. The waste gases, after leaving the boiler, and before entering the uptake, pass upward hrough these tubes in the air-heating chambers, or in the Lancashire type of boiler horizontally hrough tubes in air heaters in the side flues, thus giving up part of their heat to the air, which hen passes along passages into air-tight reservoirs or chambers surrounding the furnace fronts. From these chambers the air is passed through furnace fronts by valves into the ashpits, and over he fires through air distributing boxes in proportions exactly suited to the kind of fuel used and he rate of combustion required, thus ensuring a very perfect combustion of fuel.

In the furnace fronts the ashpit air valves are operated by one handle, and a safety locking levice is also fitted, which prevents the furnace door from being opened until the ashpit air valves ire closed. In marine type boilers, retarders are also fitted (one in each boiler tube).

Silley patent smokebox door fastenings form an important adjunct to the forced draught ıpparatus. These fastenings ensure a thoroughly air-tight smokebox and entirely obviate the rouble usually experienced with buckling, etc., in doors secured by other methods.

At the present time there are about 6,600 installations of the Howden system fitted, and the number is rapidly increasing every year. The aggregate i.h.p. of these is over 24,000,000. They comprise steamers for almost all the principal steamship companies of the world, and a consider-able number of installations on land boilers. Many warships, and the principal fast Channel steamers, are also fitted with the system.

The Howden Air Preheater.

This new type of air-preheater, manufactured by *Messrs. Howden & Co., Ltd.*, is much more efficient than the smoke-tube type. In addition to its suitability for cylindrical boilers it is also adaptable for water-tube boilers on land and sea, and other types of furnaces. By this arrangement the temperature of the waste gases is reduced by about 300° F. and this heat is returned to the furnaces when it can do useful work, thus materially increasing the efficiency of the boiler. See also p. 2384.

PULVERISED COAL.

(Contributed by L. C. Harvey, London.)

General.

Coal in pulverised form was first successfully applied to cement-burning kilns. This method of heating cement kilns has now become universal practice, the steady long flame with its resulting continuous and unvarying heat development inside the rotary kiln being ideal for this work. Moreover, the ash which has always been a source of trouble in other applications does not apply in this industry, where ash forms a useful addition to the ultimate product.

For cement burning the coal is reduced to a fineness of about 80 per cent. through a 100-mesh screen (10,000 holes to the square inch). It is essential to pulverise to a greater degree of fineness for general applications. A coarser product can be permitted when burning high volatile fuel (30 per cent. V.M. and upwards), or in the case of very large steam-raising units, as now installed in the latest super-power stations in America and elsewhere (see p. 2118), but the American standard of fineness, *i.e.* 85 per cent. through a 200-mesh screen (40,000 holes to the square inch) should be accepted for general boiler firing and for all metallurgical work.

This fine degree of coal-dust, coupled with a low pressure on the air supply, thereby decreasing the velocity of the gases passing through the furnace or boiler, and a wider adaptation of the principle of turbulent mixing of the fuel and air, resulted in the removal of the former troubles due to the formation of ash slag in chequer-work, on metal to be heated, or on boiler tubes.

Great progress continues to be made in the application of pulverised coal to metallurgical furnaces, and in a very marked degree to power-house boilers.

The extended use of pulverised fuel as a means of firing boilers and other furnaces in America continues to increase the annual tonnage of coal burned in this manner, and the estimated total consumption of pulverised coal in the United States of America is now appreciably over 30 million tons per annum.

Many important plants are now in operation in France, Belgium, Germany, and other Continental countries. Particular attention is being given to the development of pulverised fuel firing in Europe by the International Combustion Company, who have made rapid strides in the development of the 'Lopulco' system and patents, and have so equipped several power stations in Great Britain (p. 2123).

At the Tennessee Coal, Iron, and Railroad Company's works, and at the Ford Company's works in America, boilers of considerable size are installed for firing either with blast-furnace gas or with pulverised coal. The original practice of using gas and coal together has been discontinued in favour of burning one fuel or the other. It was thought at the outset that the firing of gas in conjunction with pulverised coal prevented the formation of ash clinker, but subsequent improvement in the method of firing pulverised coal has demonstrated that the best results can be obtained when using either one or the other fuel alone, excepting only when pulverised coal must be introduced at times of shortage of blast-furnace gas.

The old fallacy so frequently advanced in connection with pulverised coal firing is the 'ash nuisance' from boiler-house chimneys. Tests carried out at Milwaukee show that as little as 15 per cent., and as much as 85 per cent., of the ash in coal passes out at the chimney top under certain conditions. These conditions are controllable, and whatever may be the amount permitted to escape into the atmosphere, this dust is unlikely to become a nuisance, for it is in such fine particles that the dust rises into space, and careful tests have failed to discover any trace of ash deposit within city boundaries.

There are now some hundreds of large plants in continuous operation within city boundaries. In not one instance, to the writer's knowledge, has any complaint been forthcoming. The reverse is usually the experience—smokeless and dustless conditions in the vicinity of pulverised fuel-fired boilers, furnaces, and kilns.

Pulverised coal-fired boilers are now guaranteed to give a continuous evaporation of 13 lbs. (from and at 212° F.) of water per sq. ft. of heating surface, at a boiler and furnace efficiency of 81 to 83 per cent. and a peak load evaporation approaching 20 lbs. per sq. ft., with water-tube furnace linings in series with the boiler elements.

It is expected that the design of water-tube boilers for pulverised coal-firing will undergo considerable change. Water-tube protective linings for combustion chambers, the Murray Fin

ubes, have demonstrated new principles of steam generation. The 'Wood' boiler wherein the ain steam generation is effected in a tube-lined combustion chamber has given the first con- rmation of the exceptionally high steaming rates, due to radiant transmission of heat, which will e obtainable from these new types of boilers.

Some further progress has been made in the firing of locomotives with pulverised fuel in hile, where the 'Fuller' equipments are in use for the burning of the local lignite. The tended use of pulverised lignite as a locomotive fuel is also under consideration in Austria.

Difficulties with the deposit of ash across the tubes at the firebox end are still sufficiently rious to prevent any considerable advance in the application of pulverised fuel for locomotives nder present known systems. The pre-gasification of pulverised fuel is a new method which ay remove these defects.

The use of pulverised fuel for this purpose remains practically dormant, but the statistics elative thereto are retained pending the revival of this application. The great development of nall, high-speed pulveriser units and the turbulent mixing types of burners will undoubtedly fluence renewed attention to locomotive firing in various countries.

For the firing of marine boilers there is every reason to expect that pulverised coal will enter to competition with oil fuel. Extensive investigations carried out at the League Island Navy ard, U.S.A., with various types of pulveriser mills and burners, have clearly shown that marine oilers can be successfully fired in this manner. The self-contained unit mill is preferred for use n board ship. The development of low-temperature distillation will be of great influence. he residual fuel is ideal for marine use—soft, friable, readily pulverised, of reasonable volatile and sh content, free from spontaneous combustion tendencies, and therefore safe for storage in ships' unkers. Previously pulverised semi-coke, such as the product of the 'McEwen Runge' process). 2124), offers special advantages. Oil or coal burners, the Peabody, the Buell, etc., are equally ultable for either fuel.

Mill House Plant for Central System.

Fig. 22 shows an outline arrangement of a typical coal-pulverising plant with screen separator ill and rotary coal-fired dryer.

The coal delivered by rail wagon is crushed to $\frac{3}{4}$-in. cube and passed up the No. 1 elevator o the crushed coal storage bin.

From this bin the crushed coal is fed by gravity into the rotary dryer, wherein the moisture ontent of the coal is reduced to 1 per cent. This is a necessity for bulk pulverisation, storage, and or conveying the fuel through pipes.

Rotary coal dryers are fitted with furnaces, either hand fired, stoker fired, or arranged for urning powdered coal. The hot gases from the furnace should not pass through the dryer in irect contact with the coal until these gases have been considerably cooled. Some dryers are so lesigned that the hot gases do not pass over the coal before they have travelled the full length f the dryer through a central tube, when they are diverted into the outer portion of the dryer nd pass back to the furnace end in direct contact with the coal. For high volatile coal this type s essential.

The average coal consumption in the dryer is about 20 to 30 lbs. of coal per ton for a reduction f 10 per cent. in the moisture content. When coal is very wet it then becomes necessary to ass the coal twice through the dryer. The final temperature of the coal leaving the dryer should ot be above 250° F.

From the dryer the coal passes up No. 2 elevator to the dried coal bin, passing over a magnetic eparator pulley in order to remove any pieces of iron from the coal, and is fed by gravity into the ulveriser.

With the static dryer, which has no moving parts, a portion of the waste gases from the boilers, enerally about 10 per cent., is forced through the coal, with the result that the coal is thoroughly ried without any loss of the volatile constituents or fine dust.

The stationary type of dryer has been generally adopted for power-house installations. Initial troubles, regarding the flow of coal from the dryer and uneven or over-heating, have been eliminated.

Raw coal can be delivered to the bunker above the dryer, from whence it falls by gravity through the dryer to the pulveriser mill. Thus, the rotary dryer motor, the No. 2 elevator, and, if necessary, the dry coal bunker, shown in fig. 22, are dispensed with, and only in special cases are rotary coal-fired dryers necessary.

The application of this dryer does away with a considerable portion of conveying machinery, for handling both the raw coal and the dry coal at the same time, eliminating expensive plant and fuel used to dry coal. As much as 2 to 3 per cent. of the coal purchased is sometimes employed in drying fuel in revolving dryers, with the static dryer this coal is replaced by waste gases from the boilers. On the Continent the revolving disc, grid, or shelf type of dryer heated by super-heated steam is favoured.

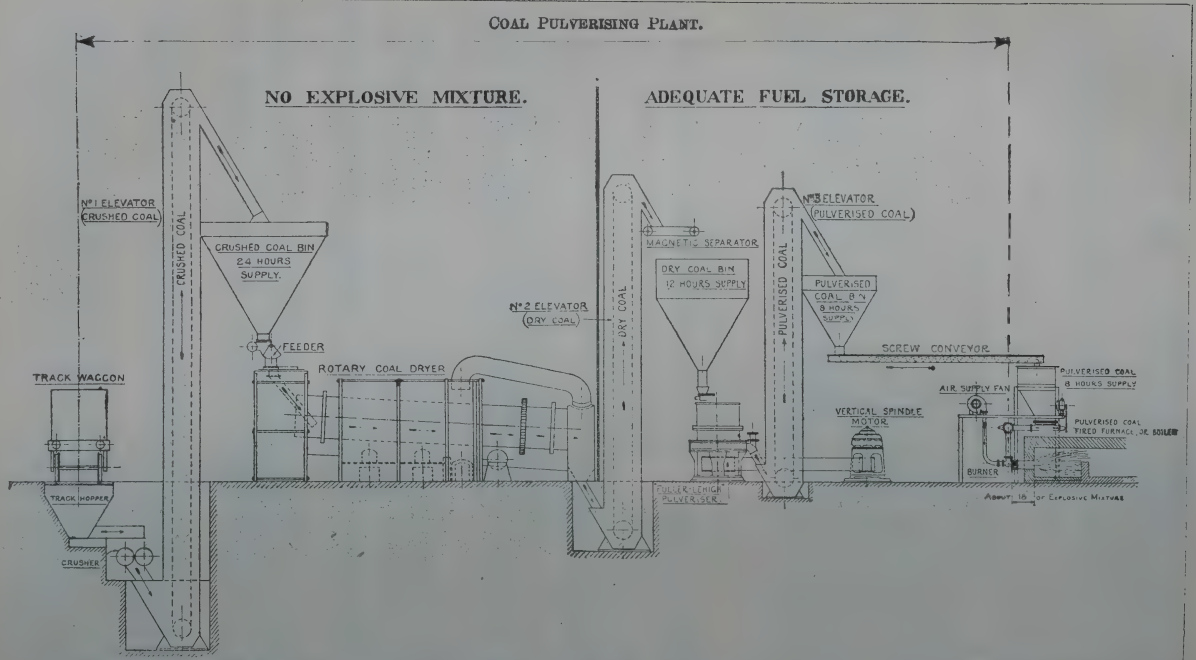


FIG. 22.—General View of 'Central' Pulverised Coal Plant, showing flow of coal from the Track Wagon to the furnaces, and indicating the positions of the Coal Crusher, Elevators, Coal Dryer, Pulveriser Mill, Magnetic Separator, Screw Conveyor, Furnace or Boiler Bin, and Screw Feeder. In place of the Screw Conveyor either the Fuller-Kinyon Pump (p. 2116) or the air-pressure system is now generally adopted for long-distance transmission.

Screen separator mills, such as the 'Fuller,' made by the Fuller Lehigh Company, have been used very extensively in the cement industry for pulverising the coal and for grinding the cement clinker. In this type of mill the fine particles of coal are thrown tangentially through the mill screen; the fine product is then raised by means of No. 3 elevator to the powdered coal bin, or it is delivered direct into the screw conveyor or into a Fuller-Kinyon type of pump, for transport to the bins at the furnaces.

In the air-separator type of mill the fine coal-dust is exhausted through a fan and deposited by means of the upward air current into the cyclone collector, whence it is delivered into the powdered coal storage bin, or direct on to the screw conveyor or pump.

The power required for operating a screen separator mill with its pulverised fuel (No. 3) elevator is somewhat less than the power required for operating a screen separator mill and exhaust fan. The wear and tear on the latter may be excessive when abrasive hard coal is pulverised, but the vacuum extraction of the coal-dust from the mill tends towards a cleaner mill-house.

Against the screen separator mill may be placed the occasional damage to the screen by a stray piece of iron. Any perforation of the screen due to this cause permits coarse coal to escape with the pulverised product.

Both types are in general use, and at the present time the advocates of one are as numerous as the advocates of the other.

Hardinge ball mills in conjunction with Hummer screen separation are also in use for pulverised coal production.

Transportation of Pulverised Coal.

The original method of transporting coal-dust was by means of weathertight screw conveyors. This method, fig. 22, p. 2114, although used to some extent for small and compact installations, has given place to air pressure and pump transmission systems for larger plants or greater distance delivery.

The Quigley Furnace Specialities Co.* introduced an excellent system of transporting the coal-dust from 'blowing tanks' situate at the mill house. The coal-dust is forced from these tanks by means of compressed air applied to the top of the coal, and the coal is forced through 3-in. or 4-in. pipes to the bins at the furnaces, and over distances up to ½ mile.

Semi-automatic solenoid controlled switch valves are placed at the branches from the main supply pipe. This method of transportation is very compact, convenient, and successful in use.

In the Bonot * 'air-transmission system,' the coal-dust is mixed at the mill house with approximately 50 per cent. of the air required for combustion. The mixture is forced through the supply pipes at a velocity of about a mile a minute, and ordinary branch pipes are taken to the furnaces. No furnace bins are therefore needed with this system. Care must be exercised in arranging this system to suit existing conditions, so that danger of accidental explosion taking place in conveyor mains may be realised and necessary precautions taken.

The Fuller-Kinyon * system of pumping powdered coal through supply pipes has now been developed by the Fuller Engineering Company, whereby a small quantity of air delivered by a pressure blower is pumped into the powdered coal to prevent 'packing,' so that the fuel can be transported long distances with a minimum of power. Ordinary pipes are used which can be laid underground or placed overhead in the same way as for water pipes. (See fig. 23, p. 2116.)

For any one of these methods of conveying pulverised fuel the product must be dry, otherwise packing troubles will occur.

Feeders.

Whenever coal-dust is held in bulk at furnace bins, feeders are attached thereto fitted with screws or worms to introduce the dust into the air-blast as it enters the furnace, or compressed air is used as a means of syphoning out the fuel.

The screw or worm of the feeder is usually operated by means of a variable speed motor.

One of the best types of variable speed feeder-mixers forms the basis of the 'Lopulco' system (p. 2121) of applying pulverised coal to boilers and other furnaces.

The Quigley * feeders have adjustable jaws to govern the supply of dust, and in this way constant-speed motors can be used.

The Simon Carves table feeders have been used with considerable success. This type consists of a horizontal circular table with pockets pierced to take the fuel supply. The rate of rotation is

* The Quigley, the Bonot, the Buell, and the Fuller patents and designs are now associated with the Babcock and Wilcox, Ltd., Companies.

THE FULLER-KINYON PULVERISED COAL PUMPING SYSTEM.

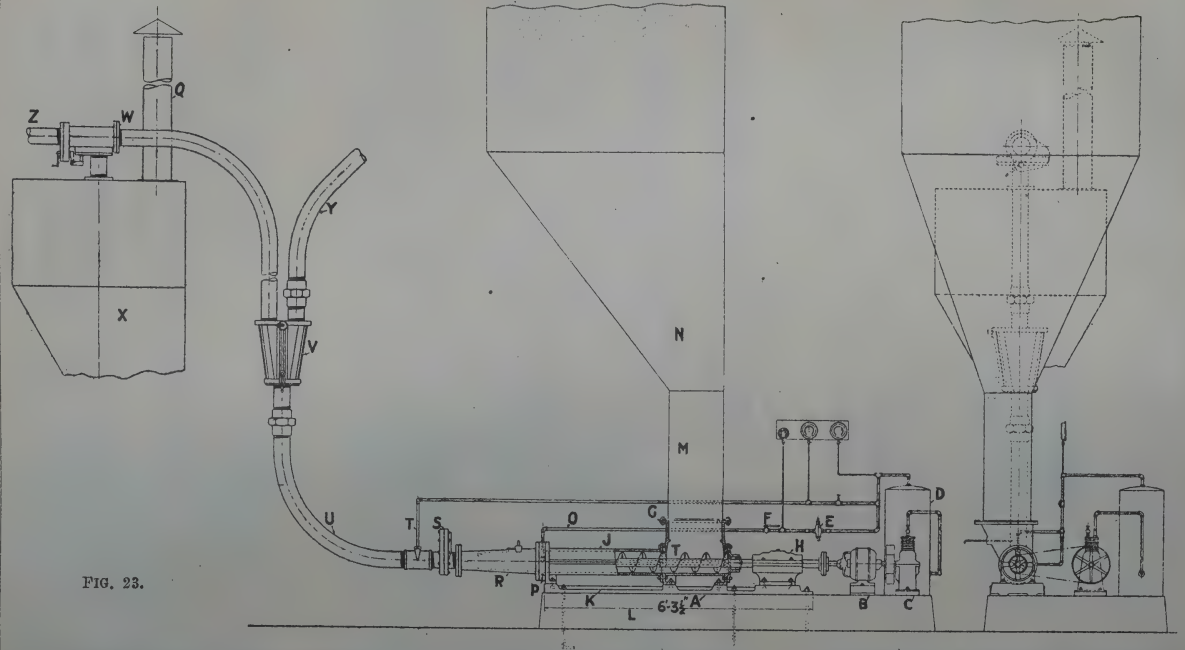


FIG. 23.

A, Fuller-Kinyon 6" Pulverised Material Pump. B, Electric Motor. C, Air Compressor. D, Air Receiver. E, Pressure Reducing Valve.
F, Air Valve. G, Pump Hopper. H, Main Bearing. I, Forcing Worm. J, Pump Barrel. K, Pump Base. L, Foundation.
M, Supply Spout. N, Material Bin. O, Aerating Line. P, Aerating Ring. Q, Vent Stack to Receiving Bin. R, Reducing Nozzle.
S, Single Diverting Valve. T, Conduit Clearing Air Line. U, Convertor Conduit. V, Distributing Valve. W, Double Diverting Valve.
X, Receiving Bin. Y, Branch Conveyor. Z, Continuation of Conveyor.

ontrolled by friction concentric disc drive, and constant speed motors can be employed. On the ame principle a single Bailey feeder can be used over a range of 1,000 lbs. to 10,000 lbs. per hour or the supply to any number of burners.

In the 'air-transmission system' no feeders at all are required at the furnaces.

Burners.

The usual type of coal-dust burner met with in general practice has been of very simple onstruction, merely consisting of an air-carrying supply pipe into which coal dust is fed by the crew feeder. These simple types of burner have given fairly good results, but later practice as established the necessity for a more intimate mixing of the air and powdered coal.

Many special burners have therefore been devised whereby a pre-mixing of coal dust and air s effected before the final stream of air for combustion is introduced.

Exceptionally good results have been recently obtained with the turbulent mixing types of urners, such as the Peabody, the Buell, the Bailey-Tenney, and the Couch burners, to effect a hort diffused flame.

In each type a well-conceived combination of air and coal passages with adjustable or deflec- ion plates or vanes renders it possible to control the direction, length, and intensity of flame.

By reason of the thorough mixture of air and coal, pulverised coal can be applied direct to he fire tubes of Lancashire and Cornish boilers without the use of external combustion cham- ers, unless high ash coal is used, when it is preferable to collect much of the ash prior to its assage through the boiler tubes. These burners also eliminate the extensive furnace alterations equired for long flame burners.

No difficulty is experienced in burning low ash coal (10–15 per cent.) without external com- ustion chambers.

By reason of wide diffusion of the air and coal-dust mixture, the areas of combustion chambers sually provided for hand or stoker firing are in most cases sufficient.

An actual example of results obtained with the 'Buell' burners, as applied to the stoker ettings of a B. & W. boiler of 3,240 sq. ft. of heating surface, without external combustion hambers, is as follows :—

	Stoker Firing.	'Buell' Burner.
Coal—B.Th.U. per lb.	12,562	10,370
,, lbs. per hour	1,792	1,175
Water evaporated from and at 212° F. per hour	13,365	10,552
,, Per lb. of coal	7·4	9·0
Efficiency of boiler and furnace	57 per cent.	83 per cent.

Another method of liberating a very greatly increased number of B.Th.U. in a small com- ustion area has been developed by the Fuller Engineering Company in their 'Well'-type Burner, hich consists of a rectangular chamber with pulverised coal burners at each angle, these pro- ucing a high degree of turbulence within the water-cooled burner chamber. (See Combustion rea, p. 2119.)

Power of Motors.

Mill House Plant (for 40 tons per 10 hours).

Preliminary crusher (not required with slack coal)	15 to 20 h.p.
Nos. 1, 2, and 3 elevators	7½ h.p. each
Dryer	10 to 15 h.p.
Pulveriser mill screen separation	60 ,, 75 h.p.
,, ,, air ,,	80 ,, 100 h.p.

(Mill capacity, 4 to 5 tons per hour.)

Fuel Transportation (say 5 tons per hour, 300 ft. and 40 ft. lift).

*By screw conveyor	15 h.p. (motor).
†By air pressure	75 ,, (compressor).
*By air mixture	60 ,, (fan mixer).
*By screw pump	20 ,, (screw pump and compressor).

* Continuous operation. † Intermittent operation.

(For an approximation of power used, see note below, 'Progress in America.')

Coal-dust Feeders.

Constant or variable speed motors . . . . . 1 to 3 h.p.

($\frac{1}{2}$ h.p. motors are sometimes used, but are generally unsuitable under mill conditions.)

Air Fans.

No accurate figure can be given for the power required for air fans, as this will depend upon the size of burner used. The total quantity of air per pound of coal allowed is usually 180 cub. ft., 120 cub. ft. being supplied at a pressure of 3 or 4 ozs. per square inch; the remainder is induced at the burner.

Pre-Gasification of Coal.

Much of the success obtained in the various applications of pulverised coal has been due to the fine and uniform pulverisation of the coal, and the provision of combustion chambers of considerable cubic area.

Until the advent of the turbulent mixing type of burner, the latter requirement precluded the development of pulverised coal-firing for such purposes as marine boilers, Lancashire boilers, locomotives, and the smaller range of trial furnaces.

A greater measure of success is still to be obtained by subjecting pulverised coal to temperatures in the neighbourhood of 1,000° C. at high velocity, and with an air supply sufficient only to maintain this refractory surface temperature, gas can be generated and delivered direct to furnaces or boiler firing chambers with little loss of the sensible heat.

Developments are now in train for the practical application of pulverised coal in this manner, and when success has been established it will extend the use of pulverised coal for general application, and it will be the means of very greatly reducing the combustion chamber sizes now essential for the burning of pulverised coal in the direct way. Moreover, it will doubtless be possible to utilise such generators or pre-gasifiers with either liquid fuel or pulverised coal.

Progress in America.

The amount of pulverised coal used in the U.S.A. up to 1912, chiefly in the cement industry, was approximately six million tons per annum. In the copper, steel, and iron industries for locomotives and boiler work, and including the cement industry, the annual usage of coal in powdered form is now upwards of 30 million tons, following the adoption of pulverised coal-firing at the 200,000 kw. super-power station at Milwaukee. Many other new American power stations have been equipped for pulverised coal firing, one of the latest stations being the 600,000 kw. station of the Union Electric Supply Co., at 54th Street, New York.

Many of the most recent super-power stations in America and elsewhere are now operating with or have been arranged for pulverised coal firing, and, among others, the following stations have been equipped with boilers of very considerable size:—

	Approximate Heating Surface of each Boiler. Sq. Ft.
Milwaukee Electric Railway & Light Co., U.S.A.	32,200
Allegheny Steam Heating Co., Pittsburg, U.S.A.	30,800
Ford Company, River Rouge, Detroit, U.S.A.	28,480
Detroit Edison Co. (Marysville), Detroit, U.S.A.	29,800
Detroit Edison Co. (Trenton Tunnel), Detroit (Projector), U.S.A.	28,720
Cleveland Electric Illuminating Co., Cleveland, U.S.A.	30,600
Providence Electric Railway Co., Boston, U.S.A.	12,600
Berlin Electricity Works, Rummelsburg, Germany	17,200
Duquesne Light Co., Brunots Island, U.S.A.	26,500
Western Pennsylvania Power Co., Springdale, U.S.A.	15,300
Metropolitan Edison Co., Middletown, U.S.A.	14,680
Union Electric Light & Power Co., Cahokia, U.S.A.	18,010
Union d'Électricité, Gennevilliers, France	20,200
Union d'Électricité, Vitry, France	16,670
Nippon Electric Co., Tokio, Japan	10,080
Hams Hall, Birmingham, England	20,000

At the Cleveland Electric Illuminating Company's plant, the coal, which is of high volatile ntent (33 per cent.), is pulverised to a fineness of 60 per cent. through a 200 mesh, and 85 per nt. through a 100 mesh screen. Operating power has been determined at 14·5 kw. for production, kw. for screw conveyors, and 4 kw. per ton for feeders and air blowers. Ratio of furnace lume to effective heating surface of boiler is 0·85, or 0·95 to total heating surface, furnace lume being 29,150 cubic ft.

The rating of each boiler is 3,060 h.p., and each boiler operates at 225 per cent. rating on ntinuous load, and at 300 per cent. rating at peak load.

A specia lfeature of this installation, as at other American power plants, is the automatic ntrol of the fuel and air required for combustion, in direct relation to the load on the boiler, means of the system perfected by the Bailey Meter Company of Cleveland.

Combustion Area.

The ratio of combustion area to boiler-heating surface at the Cleveland plant is referred to ove. The ratio at the Cahokia power station is somewhat less, being 0·635 of the effective ating surface of the boiler.

American practice has established satisfactory results for boiler firing, when burning between 6 and 2·0 lbs. of coal (calorific value, 12,500 B.Th.U. per lb.) per hour per cu. ft. of combus- n area. At normal steaming this means that in each cu. ft. of combustion area there can liberated about 18,000 B.Th.U. per hour, and at maximum load about 25,000 B.Th.U.

In Germany, at a special pulverised coal research station, a definite figure for metallurgical gh temperature work has been fixed at 33,500 B.Th.U. per hour per cu. ft. of total combustion ea. The special Well-type burner recently adopted by the Fuller Engineering Company, ferred to under 'Burners' (p. 2117), makes it possible to liberate a much higher number of .Th.U. per cubic foot of combustion area per hour, and it is claimed that this type of burner, ith pulverised coal, has been burned at the rate of upwards of 100,000 B.Th.U. per cu. ft. per our.

On the above bases of B.Th.U. per cu. ft. of combustion area, calculations can be made for oiler and metallurgical work, for any quality of coal: the higher the ash content, the lower ill be the B.Th.U. value per lb., and consequently the larger the combustion area necessary. he greatest obstacle to the general use of pulverised coal for industrial purposes has been the er-increasing cubic areas of combustion chambers to such a pitch that prices are quoted for the tter which are half the total cost of boilers.

The development of the turbulent mixing types of burners has clearly shown that combustion ambers can be greatly curtailed when using burners giving wide flaring or diffusion effects. ee 'Burners,' p. 2117.)

Self-contained Pulveriser Units.

Great attention has been given to the perfecting of these small unit mills, which can be placed ongside the boilers or furnaces to be heated. So much progress has been made in design, duction of power consumption, maintenance costs, etc., that their installation at French and erman iron and steel works and at American power houses has been generally accepted. Whereas power consumption was anything up to 30 kw. per ton of coal, these units now operate s 12 to 15 kw. for similar fuel as burned at the furnace, including air supply. These units are so pulverising fuel containing up to 15 per cent. of moisture, but this moist fuel must necessarily e supplied direct to the furnace burners, and not stored in bunkers.

The figures given in the table on p. 2131 represent the capital outlay required for complete ill-house plants of various capacities. The initial cost of same, with transportation system, rnace bins, motors, feeders, etc., necessitates an expenditure which, in many cases, will or an only be contemplated when actual results have proved that the collective advantages nd economies thereby introduced render such an investment wholly attractive.

For smaller fuel requirements and for testing pulverised-coal firing upon individual boilers r furnaces, a self-contained pulveriser unit can be conveniently installed. There are now many fficient machines of this type available, and built upon entirely novel principles is the 'Atritor' nit, which embodies the use of eddy currents of air within the grinding zone for the dual purpose f rapid agitation and deflocculation of coal particles and the exposure of maximum surface or driving off moisture. In this unit, therefore, is combined the operation of drying and ulverising.

The French 'Rex' machine is also novel in its provision of carborundum grinding element and also in its fuel and air regulation and totalising adjustments. The power consumption wi this unit is also exceptionally low; 6 to 10 kw. per ton of bituminous coal.

Coal containing comparatively high percentages of moisture—20 per cent. or so—can pulverised in several of the well-known types of units, and through the medium of hot air, up 500° C.; the resultant fuel powder will be practically bone dry. Coal containing 5 per cent. 10 per cent. of moisture can be dried and pulverised with air at atmospheric temperature, t resultant degree of fineness depending upon the humidity in the atmosphere at the time grinding.

By the installation of self-contained units the value of pulverised-coal firing for any specif purpose can be ascertained, so that the question of capital outlay upon a complete mill-hou plant and attendant equipment can be based upon the results ascertained in this manner.

The makers of the well-known Bettington sectional water-tube boilers and self-containe pulveriser units have generally improved the construction of both these, so much so that t boiler should find an extended use, and the pulveriser, which is particularly silent and efficien a useful and general application.

Self-contained pulveriser units have been widely adopted on the Continent, many electr light stations now being fitted with this class of equipment, and some details of the Clark Chapman Turbo Pulveriser unit are given below. This unit is very similar to the Fren 'Resolutor' unit in general use for boilers and metallurgical furnaces on the Continent. T German B. & W. unit and the Bema Mill are also extensively installed.

The Clarke, Chapman Turbo Pulveriser.

(Clarke, Chapman & Co., Ltd., Gateshead-on-Tyne.)

This pulveriser is a self-contained unit, complete with beaters, primary and secondary a fans being mounted on or shaft and driven by belt electric motor as desire If fitted with motor, th whole is mounted on bed plate, making a very nea and efficient plant.

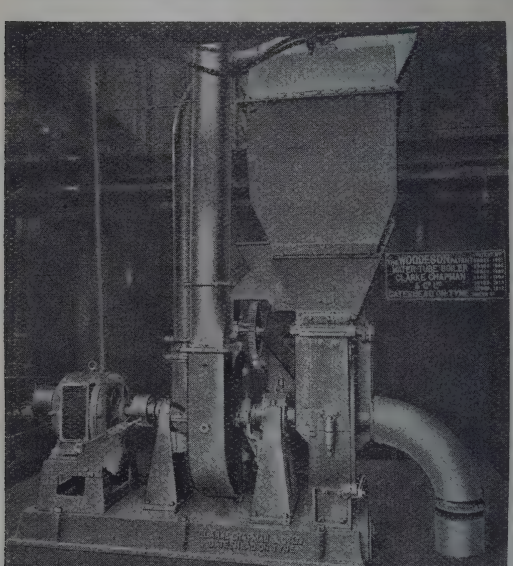


FIG. 24.—The Clarke, Chapman Turbo Pulveriser, dealing with 2¼ tons of coal per hour, firing 'Woodeson Patent Water-Tube Boiler.'

The coal in this machin is pulverised entirely b impact and is fitted with simple means of controllin the fineness of the pul verised product. This ad justment, apart from th coal feed, is the only on on the machine, and th operation of the plant i most simple.

In many pulveriser extraordinary precaution have to be taken to exclud tramp iron, but in the cas of the Clarke, Chapma Pulveriser it is recom mended that a grid havin 1½ in. mesh be fitted ove the hopper, and then an tramp iron which can pas will do no harm whateve to the machine.

A special chamber i provided for its reception and this may be cleaned ou periodically. This machin is being regulary made i standard sizes up to 8 ton per hour.

The Lopulco System.

(International Combustion, Ltd.)

A typical arrangement of a boiler fitted with Lopulco plant is shown in fig. 25 (p. 2122).

In such a system the raw coal—in pieces of a size that will pass through a 1½-in. diameter ring is passed through a dryer to bring the total moisture below 6 per cent., and is then fed to a Raymond pulveriser which has 4 to 6 pendulum rollers running inside the grinding ring.

The coal is fed to the grinding chamber by means of a feeder, where it is picked up by rotating ploughs which throw it between the rollers and the grinding ring, and as soon as it is reduced to the required fineness it is separated from the coarser particles by a current of air which is drawn through the pulveriser by an exhauster fan. This air carries the fine particles to a cyclone collector situated at the top of the boiler-house, and as fast as the particles are swirled out, the carrying air returns to the pulveriser to bring up a fresh supply.

The degree of fineness is adjusted to suit the amount of volatiles contained in the fuel; for example, bituminous coals having a high percentage of volatiles do not require to be ground so fine as semi-anthracite coal which has low volatiles.

A suitable condition of fineness for good bituminous is such that 90 per cent. will pass through a 100-mesh sieve—that is to say, a wire mesh having 10,000 holes to the square inch—and also that no particles are left on a 40-mesh sieve.

The pulverised fuel is stored in bins which are large enough for several hours supply to each boiler, and is fed as required from the bins by means of groups of feeders which are driven by variable-speed electric motors.

A certain amount of primary or carrying air is introduced with the coal at the feeders in order to supply the Lopulco burners with a heavy homogeneous mixture.

There is a burner to each feeder, the number depending on the size of the boilers (see tabular data (page 2123), which give particulars of some installations carried out by *International Combustion, Ltd.*).

Each burner has a fishtail nozzle which gives a flat stream of fuel and primary air, and this shape is adopted because it provides for greater exposure of the coal particles than would be possible with a round nozzle of sufficient diameter to carry the same amount of fuel and air.

Outside the nozzle there are passages through which air is induced in such quantity as to ensure the rapid ignition of the mixture, and also for the purpose of cooling the nozzle, this amount being regulated by two adjustable dampers.

The flames are projected downwards into the combustion chamber with enough velocity to give a U-shaped flame, the hottest zone being thus in the middle of the combustion chamber.

As the flame reaches the lower part of the combustion chamber, it loses its downward velocity and doubles back on itself, and the resultant hot gases are drawn upwards through the boiler tubes. In its downward travel the flame encounters horizontal currents of secondary air which are induced through ports in the front wall, and as this air is drawn at right angles to the flame, it mingles intimately with all the incandescent particles, thus giving perfect combustion, so that at all loads it is possible to give a high percentage of CO_2 in the product of combustion.

The amount of secondary air is induced through doors which are controlled by a single hand wheel, and the opening of each door is so adjusted that the correct amount of air for completing combustion enters the furnace in correct proportion.

The furnace is entirely steel cased and insulated with special insulating tiles and built of first quality firebricks, etc., in such manner as to provide freedom for the brickwork to expand and contract without buckling or binding.

The combustion chamber walls may be air-cooled or water-cooled, or a combination of air and water cooling may be adopted. With the former the walls are made hollow, and the secondary air circulated in them before it enters the combustion chamber. In this way the air required for combustion is advantageously pre-heated, while the brickwork is maintained at a reasonably low temperature. With water-cooling the tubes may be located in front of the brickwork or embedded in the brickwork. As an alternative, the Murray Water-Cooled Wall may be employed. This consists of a number of 4-in. diam. tubes, fitted with a pair of diametrically opposed fins welded on, grouped together, and connected to headers at each end. The Murray Wall has the great advantage that where fitted in a combustion chamber, no refractory brickwork is in contact with the hot gases.

Across the bottom of the combustion chamber there is a screen of water tubes which forms part of the boiler, these tubes being of seamless steel expanded into forged steel headers. The particles of ash which drop from the flames pass between the tubes and are thus chilled below melting point, so that they fall into the ash hopper and are easily removed as fine dry particles.

The following figures give the power required for a Lopulco equipment to deal with 6 tons of pulverised fuel per hour.

Motor for fan of the dryer	12 kw.
Motor for Raymond pulveriser	40 ,,
Motor for fan of pulveriser	33 ,,
Two motors for six feeders	5 ,,
Motor for fan for fuel	17 ,,

This works out at 17·8 kw. per ton of coal pulverised per hour, which, at a halfpenny per unit, is 9*d.* per ton; *i.e.* about one per cent. of the total steam production is required to work the pulverising plant.

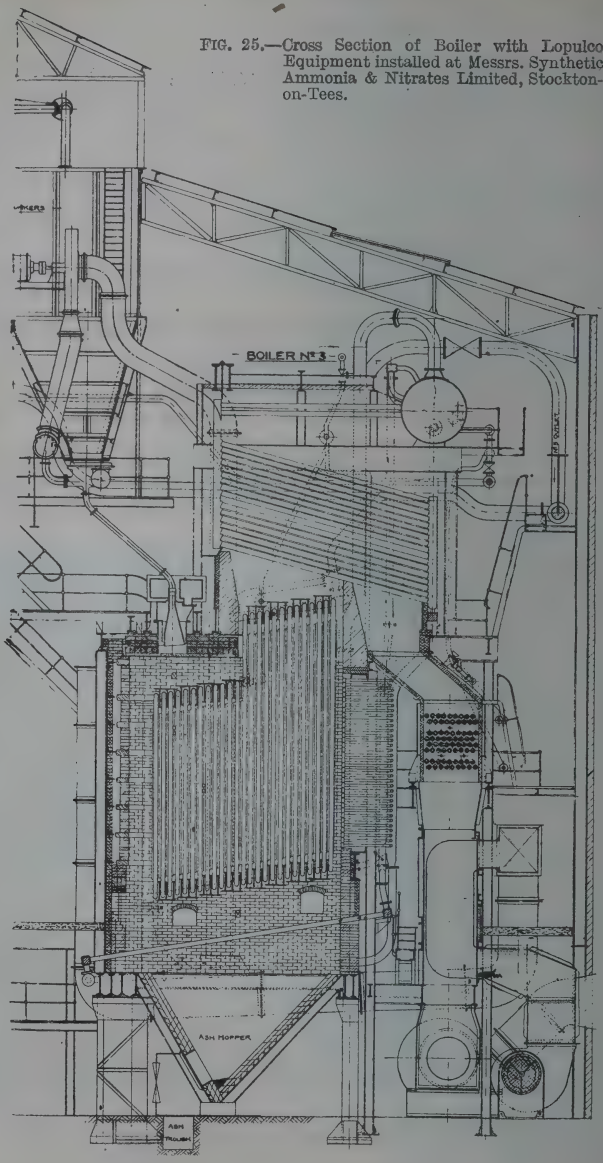
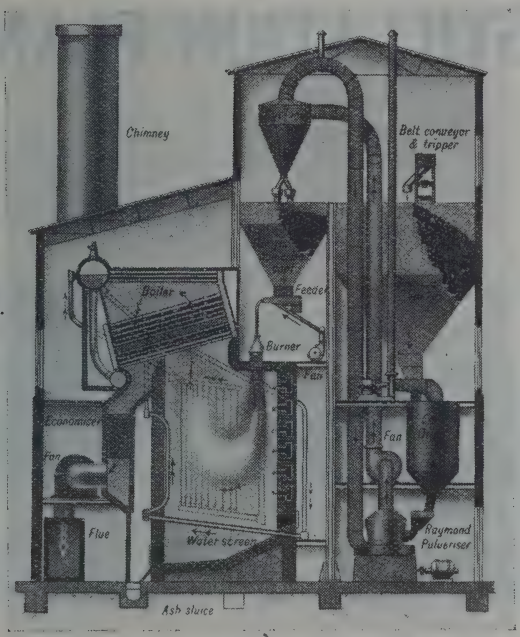


FIG. 25.—Cross Section of Boiler with Lopulco Equipment installed at Messrs. Synthetic Ammonia & Nitrates Limited, Stockton-on-Tees.

"LOPULCO"

PULVERISED FUEL SYSTEM OF BOILER FIRING.



Diagrammatic section through BOILER HOUSE.

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F. 2122

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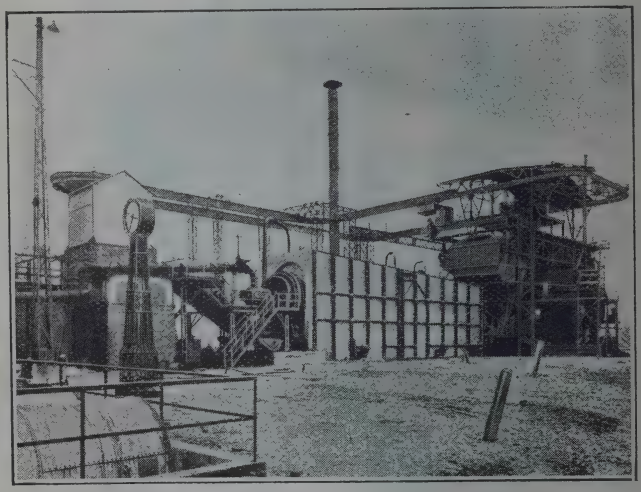

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F. 2123

POWER HOUSE CONTRACTS TO UTILISE PULVERISED FUEL ON THE LOPULCO SYSTEM IN GREAT BRITAIN.

(International Combustion, Ltd.)

Power House.	Contract Date. (Received.)	Number of Boilers.	Pressure, lbs. per sq. in.	Heating Surface of Boiler, sq. ft.	Heating Surface of Water-Screens, sq. ft.	Total Heating Surface.	Number of Pulverisers.	Number of Rollers per Pulveriser.	Number of Burners per Boiler.
Birmingham Corporation *	1924	6	320	5,400	154	33,324	4	6	4
County Boro. of Derby*	1924	2	300	8,850	148	17,996	2	6	6
Met. Boro. of St. Pancras (1st Order) *	1924	2	220	6,546	159	13,410	2	5	5
Met. Boro. of St. Pancras (2nd Order) *	1924	2	220	6,070	630	13,400	2	5	5
Met. Boro of Poplar *	1924	3	300	6,200	90	18,870	2	6	5
York St. Flax Spinning Co., Ltd.*	1924	1	250	9,270	171	9,441	1	4	4
Synthetic Ammonia and Nitrates Co., Ltd. (1st Order) *	1924	2	275	9,000	500	19.000	2	6	5
Synthetic Ammonia and Nitrates Co., Ltd. (2nd Order) *	1925	4	275	14,500	940	61,760	6	6	9
North Metropolitan Supply Co., Brimsdown †	1925	2	170	1,900	492	4,784	1 (unit)	—	2
North Metropolitan Supply Co., Brimsdown *	1925	5	325	10,100	900	55,000	3	6	8
North Metropolitan Supply Co., Willesden *	1924	1	200	7,200	220	7,420	1	6	6
Ashington Collieries *	1925	4	200	5,904	139	24,172	2	5	4
Pilkington Bros.*	1925	1	220	8,280	270	8,550	2 (unit)	—	4
Stewart & Lloyds, Ltd., Coatbridge †	1924	1	120	2,700	—	2,700	1	(unit)	1
Shell Mex, Ltd., Shell Haven, Essex	1926	3	160	7,320	189	22,527	3	6	4
County of London Electric Supply (Barking)	1926	10	375	16,510	1,784‡	182,940	10	6	10
Metro Carriage, Waggon & Finance Co., Ltd., Birmingham	1926	1	180	4,800	280	5,080	2	(unit)	2
West Midland Joint Electricity Authority, Walsall,	1926	3	305	8,560	530	27,270	6	(unit)	2
Hams Hall, Birmingham (60,000 k.w. station)	1927	5	375	20,000	2,398‡	111,990	25	(unit)§	5

* New boilers. † Old boilers.

‡ Including water-cooling system for side and rear walls.

§ Unit Pulverisers referred to above are the International Type with the exception of Hams all, Birmingham, which are Atritor Unit Mills.

The McEwen-Runge System.

(Coal Oil Extraction, Ltd.)

This process in the main involves the pulverisation of the fuel to be carbonised, and the elevation of this fuel to the top of an internally heated tower. The powdered fuel is caused to fall down this tower in the form of a cloud, meeting in its downward passage an upward current of hot inert gases. The large surfaces presented by the powdered fuel ensure a rapid interchange of heat, so that, in the very short time occupied in the passage of the fuel from the top to the bottom of the tower, carbonisation is effected. The carbonisation is progressive in that the fuel is gradually raised to the maximum temperature and the direction of travel of the fuel is contra to that of the gaseous distillation products.

The process is continuous, and consists merely in feeding to the top of the towers a regular supply of pulverised fuel and withdrawing from the bottom a finely subdivided semi-coke, which can be at once delivered to the burners of a furnace.

The McEwen-Runge process may be operated in a variety of ways to produce either a very rich gas, or it may be varied to yield a lower grade gas to suit local conditions and according to the local demand for this product.

It may be operated as a single-stage process or a two-stage process, but the following description is for the two-stage process, which has a higher thermal efficiency and is better suited to a wider range of fuels:—

In the two-stage process the treatment in the first stage serves to eliminate all free and cellular moisture, all CO_2, and gases of no heating value. In the second stage a higher temperature is employed and carbonisation is effected. The heat required for the first stage is extracted from the carbonised semi-coke by a heat exchanger, thus the sensible heat in the semi-coke leaving the retort is transferred to the coal in the first stage of the treatment, thereby securing a very high thermal efficiency.

An important feature in the McEwen-Runge process is that there are no moving parts in any part of the installation which is under heat, the coal dust being subjected to heat whilst in suspension, and in both (1) the preheating stage, and (2) the secondary or carbonising stage, the coal dust falls down against an uprising current of heated gas which may be composed of either (*a*) air alone, or (*b*) a part of the products of combustion, or (*c*) of both.

In the case of the preheating stage, a current of air, the heat for which is derived from the hot semi-coke dust, suffices (the air, of course, not being in direct contact with the hot dust, otherwise complete combustion of the latter would result). The two stages are carried out in steel towers lined with refractory material. These, which are superimposed, are about 30 ft. high and 6 ft internal diameter. The temperature of the gas or air current in the first stage is, at the point of entry, about 700° F., and 500° F. on leaving the retort, say an average of 600° F. The products of combustion or gases resulting from this moderate temperature treatment are neither large in quantity nor of particular value, consisting chiefly of carbonic acid gas, and they are dissipated into the atmosphere.

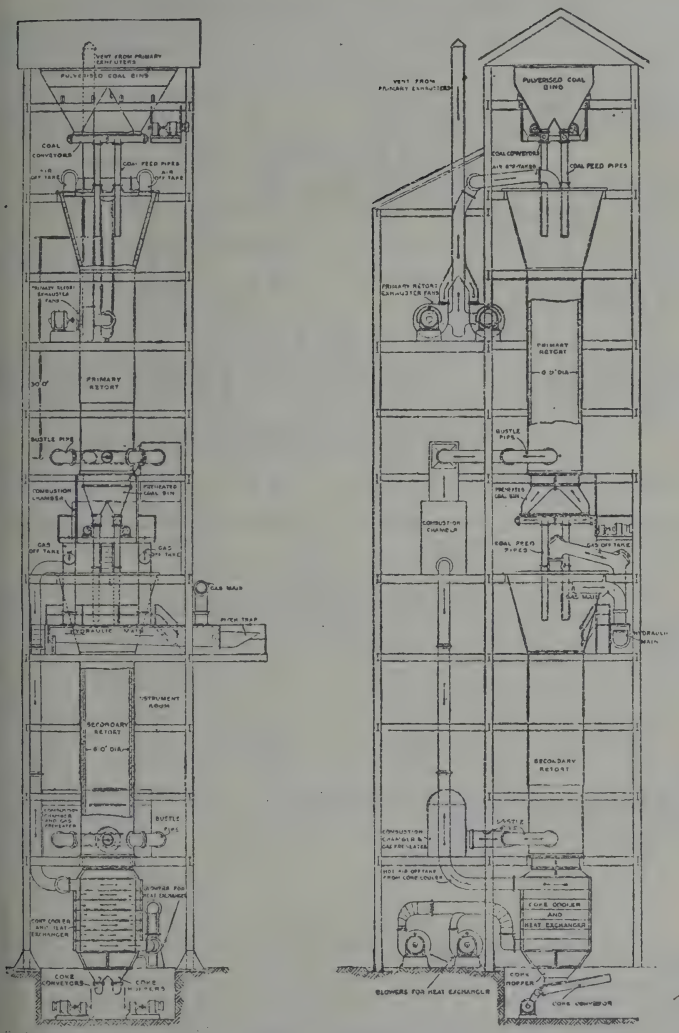
If the products of combustion are utilised for heating the carbonising current, that is, in the second stage, one-third of the gas manufactured is used for this purpose. In this stage the temperature of the incoming gas is about 1,500° F., *i.e.* at the bottom of the retort, and on leaving about 600° F., or an average temperature of 1,050° F.

The treatment of the dust in each stage occupies about 35 seconds. After treatment in the first stage the dust passes into a receiving hopper and is thence conveyed to the second or lower tower—the whole process taking only 6 minutes—and the throughput per unit per diem is 210 tons.

Fig. 26 shows the general arrangement of the towers with the two-stage process. The towers are superimposed. The coal from the pulveriser is elevated to a receiving hopper above the tower of the first stage. From this receiving hopper it is fed by means of automatic feeders, the speed of which can be regulated, through four distributing pipes which project about 8 ft. into the top of the tower, which latter has an enlarged area at the top, so that separation of dust from the issuing gases may be effected in a zone where the velocity, already low, is reduced and out of contact with the incoming fuel. Rising against the falling cloud of powdered fuel is a stream of a mixture of hot air and products of combustion; the hot air is, as previously stated, derived from the heat exchanger at the bottom of the second tower, the heat being extracted from the hot semi-coke. In the event of the heat units in this air being insufficient for the purpose of preheating the coal to the desired degree, the heat supply is supplemented by products of combustion which are caused to mix in a suitable mixing chamber with the hot air.

The preheated coal dust, still in the form of a finely subdivided powder, but showing some slight change in physical condition, when examined under the microscope, as compared with the original coal, is passed from the bottom of the tower, by means of automatic feeders similar to those already described, to the carbonising tower. In its passage down the carbonising tower the fuel meets an uprising current of hot gas, which may be (*a*) preheated permanent gas, (*b*) products of combustion introduced into the tower, (*c*) products of combustion generated within the tower by the admission of a suitable quantity of hot air.

From the bottom of the carbonising tower the finely subdivided semi-coke passes through the heat exchanger already referred to, and thence to conveyor arranged for the disposal of the fuel as circumstances may require.



General Arrangement.
McEwen-Runge Two-stage Coal Treatment. Capacity 200 Tons per Day.

FIG. 26.

Pulverised Coal for Locomotives.

The advantage for pulverised coal, lignite, etc., as a locomotive fuel are—

30 to 40 per cent. fuel economy as against hand-firing, running mileage and cylinder pow of engines increased, cost of firing tools and repairs to fire grating eliminated, no cinders sparks from the smoke stack, reduction of fire-box strains, firing conditions with pulverise coal firing analogous to oil-firing with similar fuel-bunkering facilities. Any local fuel with reason can be used.

The following fuels have been and can be used:

	A	B	C	D
Chicago and North-Western Railway.				
	Per Cent.	Per Cent.	Per Cent.	
Illinois bituminous	3·18–15·36	10·00	34·47	10,720–12,400
Kentucky bituminous	1·9 – 2·8	8·00	36·54	13,964
North Dakota lignite	1·8	9·32	47·25	10,960
New York Central Railway.				
Pennsylvania bituminous	0·51– 0·95	8·94–13·21	21·63–31·35	13,671–14,096
Brazilian bituminous	1·73– 9·15	23·14–29·33	9·5 –28·04	8,820–10,177
The Delaware and Hudson Railway				
Pennsylvania anthracite culm	0·5	12·22	8·30	12,000 (averag
,, bituminous	0·5	9·0	33·0	13,750

A. Range of moisture. B. Ash. C. Volatile matter.
D. Calorific value. B.Th.U. per lb. (dry).

On the Lehigh Valley Railway a locomotive has been run on a mixture of 55 per cent. r anthracite silt and 45 per cent. bituminous coal. Full steam pressure is maintained easily all times, and the anthracite silt contains 38·42 per cent. of ash, and has a B.Th.U. value 9,675, while the soft coal which is mixed with this has an ash content of 11·6 per cent. and B.Th.U. value of 12,650. Analyses of these coals are as follows:—

Anthracite Silt.	Per Cent.	Soft Coal.	Per Cent.
Moisture	2·26	Moisture	1·90
Volatile	10·39	Volatile	36·59
F.C.	49·30	F.C.	49·89
Ash	38·42	Ash	11·60

The raw coal and lignite to be burned on locomotives in Italy has the following analys figures representing the limits in each case are given:—

	Per Cent.		Per Cent.
Moisture	12·52 to 26·80	Volatile	31·5 to 60·94
Ash	11·6 to 32·60	Carbon	35·26 to 68·50

B.Th.U. values from 3,640 to 10,440

Locomotive Equipment.

A brief specification of the locomotive equipments supplied by the Fuller Engineering Co pany of America is given below:—

Special cast-iron coal hopper base to receive duplex feed screws. Vertical marine-ty steam engine for operating same, with intermediate connections, including gears, g shafts, shafting, etc.

Steam turbine driven fan for conveying the coal dust from the feeder to the tender.

Flexible steam connections between engine and tender, as well as flexible connecti for transporting the pulverised coal between engine and tender.

Burner, with necessary dampers and connections for operating same.

3,000° F. pyrometer for indicating fire-box temperatures. Electric revolution coun for indicating speed of engine driving coal-feed screws. Revolution counters for each p of feed screws, gauges, and valves for operating this equipment.

Mechanism for operating the slag pan or slag pans, as well as mechanism for operating the air dampers in the sides of the combustion chamber beneath the fire-box.

The equipment is started and coal supply commenced with a steam pressure of from 0 to pounds.

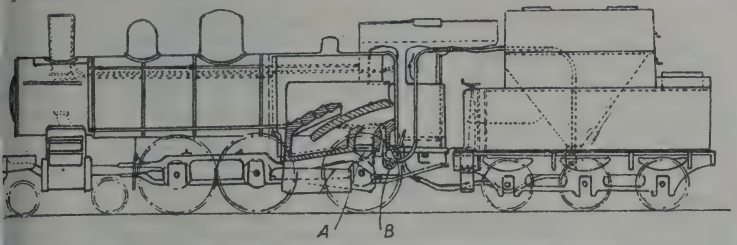


FIG. 26A.—Pulverised Peat Fired Locomotive on Swedish Railways.
A. Hand-fired Coal Grate. *B*. Peat and Air Mixture Inlet.

An article by *Bureau Engineer*, Carl Flodin (Centraltryckeriet, publishers, Stockholm, 916), includes full data regarding tests made with peat-fired eight-coupled freight locomotives: tractive power, 9,000 kg.; weight, 51,000 kg.; tender, 36,000 kg.; water capacity of nder, 14,000 kg.; pulverised peat, 4,000 kg.

It was found on these tests, for equal boiler duty, that 1 kg. of coal was equal to 1·4 kg. pulverised peat, the coal used having a calorific value of 7,240 cals. and the peat as used 400 cals., or approximately 13,000 and 7,900 B.Th U. per lb.

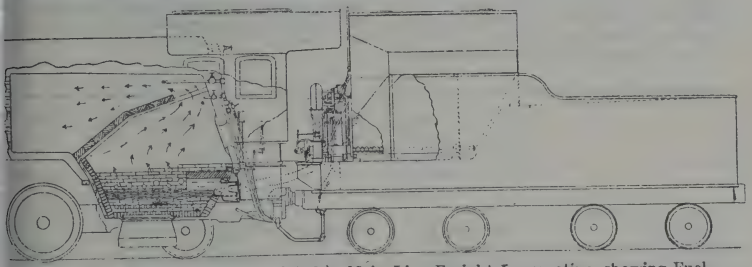


FIG. 27.—Fuller Equipment as fitted to Main Line Freight Locomotive, showing Fuel Hopper, Control Equipment, Burner, and Combustion Chamber.

The arrangement of the firebox setting, fig. 26A, allowed for a small grate on which coal was burnt nder the incoming mixture of powdered peat and air. On this small hand-fired grate 3 to 4 kgs. f coal were consumed per 100 kg. of peat; the analysis of peat and coal was as follows:—

	Powdered Peat. Per Cent.	Coal. Per Cent.
Carbon	47·0	75·5
Hydrogen	4·5	4·4
Oxygen	29·5	8·6
Sulphur	0·5	1·5
Nitrogen	1·1	1·2
Ash	3·2	6·2
Moisture	14·2	4·6
	100·0	100·0

Analogous tests made with coal-fired and powdered peat-fired locomotives gave the following verall boiler efficiencies and firebox temperature of gases:—

	Efficiency. Per Cent.	Temperature.
Hand coal-fired	65	1,510° F.
Pulverised peat-fired	73	1,670° F.

Recorded and corrected figures for parallel trips with coal and peat-fired locomotives are given, the following being the more important:—

Parallel Test Run.	Trip Number.	Weight of Loco., Tender and Wagons.	Wagons.	Average Speed, Km. per Hr.	Consumption of Fuel Kg. per 1,000 Kg. Inclusive Loco. and Tender.	Smoke-box Temp.	Kg. Steam per Kg. Fuel.
		Ton per 1000 Kg.	Ton per 1000 Kg.			° F.	
Service.							
A. Freight	1. Pulverised peat	787	700	29·2	37·5	255	4·47
	2. Coal . .	782	700	27·5	25·6	290	6·83
B. Freight	3. Coal . .	782	700	28·7	27·7	312	6·62
	4. Pulverised peat	787	700	27·0	40·7	294	4·56
C. Passenger	5. Pulverised peat	387	300	42·3	56·9	289	4·52
	6. Coal . .	382	300	41·7	39·0	268	7·0

Many grades of coal (in South Africa, for instance) are considered unsuitable for use on locomotives.

That it is quite possible to eliminate a large quantity, if not the whole, of imported coal or coal transported long distances by rail, is now being realised in various parts. Brazil has already supplanted imported railway coal to some extent by fuel which hitherto has been considered useless, and continuous extensions in this direction are to be made. The coal used in Brazil is of lower quality than the South African fuels, as the following comparative analyses of Brazilian and South African coals show:—

	Brazilian Coal, as used 'dry' in pulverised form for locomotive fuel.		South African Coal, Undried.		
			Durban.	Kroonstad.	Dundee.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Moisture . . .	7·90	1·73	1·60	8·29	0·84
Volatile . . .	28·04	9·50	27·10	31·27	25·30
Fixed carbon . . .	34·73	61·50	60·05	45·32	68·94
Ash	29·33	28·27	11·25	15·12	5·76
Sulphur	3·16	9·10	1·51	1·43	1·53
B.T.U. per lb. . . .	8,820	10,177	12,950	11,020	14,722
Evap. power . . .	9·20	10·40	13·40	11·40	15·23

The Brazilian coal analysis represents the fuel in pulverised form after treatment in a rotary dryer. The fuel is of friable nature, and the ash of such form that when subjected to heat flows round the lumps of fuel on a hand-fired grate, rendering it impossible to burn the coal. Kroonstad coal contains about the highest degree of moisture recorded—8·29 per cent.—whereas most South African coal contains but 1 or 2 per cent. of water, and for which drying plant would not be required. This is an important consideration.

Refractory Linings for Combustion Chambers.

The construction and composition of the linings of combustion chambers for pulverised coal fired furnaces are questions of considerable importance.

Although the experience gained of recent years has rendered it possible so to design combustion chambers that the refractory linings are not subjected to the severe destructive action from the flame and ash slag as heretofore, it is still highly desirable under all conditions to have

a lining that will not only withstand high temperatures, but will at the same time resist the corrosive chemical action of the ash under these conditions.

In the case of high temperature metallurgical furnaces the factor of corrosion is one that must be carefully considered in view of the presence of metallic oxides introduced through the furnace charge.

Most coal ash consists chiefly of alumina, silica, and iron oxide, together with very much smaller quantities of five or six metallic oxides.

Metallic oxides are of primary importance, in view of the fact that many of them have a marked fluxing action on almost any refractory material. Thus, a fuel ash that contains much iron oxide has in itself a destructive action on furnace linings, irrespective of any of its other constituents.

Apart from this, some fuel ash contains a predominating amount of basic material, whilst in other cases there may be an excess of acid material. When a furnace is to be fired generally or entirely with a fuel containing a basic ash it is highly desirable to provide a basic lining, for by so doing much of the trouble and expense for renewal and repair of furnace linings will be avoided.

Preliminary analysis and investigation in connection with the composition of the coal ash and furnace linings will often save expense and prevent lining troubles during the subsequent operation of the plant.

The more common and cheaper grades of refractory bricks usually contain a more or less equal amount of silica and alumina, and the slight excess of one or the other should be taken advantage of. Combustion chambers of suitable design and having the requisite combustion area will then run satisfactorily with linings of ordinary firebricks.

If, however, there are exceptional conditions to contend with, such as high temperatures, confined combustion space, chemically active ash, etc., it is necessary to make use of the best grades of refractory materials.

In many cases carborundum (silicon carbide) can be used as a facing material for linings with good results. Carborundum, however, although generally chemically inert, will not resist the action of iron oxide or ash containing much potassium or sodium compounds.

In some few cases pure silica bricks can be used when the fuel ash composition is suitable and high temperatures have to be withstood, but special provision must be made for expansion of the bricks.

Pure alumina, magnesite, or bauxite are all high-grade refractories that may be used to resist high temperatures when ash or slag is of a basic nature.

Advantages of Pulverised Coal.

The chief advantages of using coal in pulverised form are:—

Utilisation of low grade coals, peats (coals with 30 per cent. and 40 per cent. ash); lignites, anthracite slush and pit washings can be used.

Control of flame temperatures with uniform heat regulation and greatly reduced requirement of attendant labour—in fact, labour required is equivalent to oil-firing practice.

Increased efficiencies of furnaces due to direct firing of the fuel in minute particles, causing instantaneous and complete combustion, without smoke production.

Some approximate savings in fuel consumptions that have been realised in practice are as follows—

Boilers—80 per cent. efficiency, and savings of 15 to 50 per cent. over hand firing.

Open-Hearth Steel Furnaces—a saving of 300 lbs. per short ton of steel as against producer gas for small plants.

Puddling Furnaces—a saving of 1,500 lbs. per short ton of iron over hand firing, and from 300 to 500 lbs. over mechanical stokers.

Reheating Furnaces—20 to 40 per cent. saving over hand firing.

Heavy Forge Furnaces—25 per cent. saving over hand firing.

Light Forge Furnaces—20 to 40 per cent. saving over hand firing.

Annealing Furnaces—30 per cent. saving over hand firing.

Tinning and Galvanising—20 to 30 per cent. saving over hand firing.

Sheet and Pair Furnaces—30 to 40 per cent. saving over hand firing.

Copper Smelting Furnaces—40 per cent. saving over hand firing

Locomotives—30 to 50 per cent. saving over hand firing.

Cupolas—30 to 50 per cent. saving in coke and hotter iron.

Crucible (Brass Melting) Furnaces—The use of coal in place of metallurgical coke or oil.

The output from many of these furnaces has been greatly increased by reason of coal-dust firing, what are known as 'stickers' in the tin-plate trade having been reduced 60 per cent. whilst the quantity of tin and zinc used has been reduced considerably owing, in a great measure to the improved surface of the metal, and also to the more even heating of the kettles.

Reduced oxidisation of steel and iron heated in powdered coal-fired furnaces and increased life of annealing boxes have accounted for an annual saving of many thousand pounds in some works.

Very important economies have been made in firing malleable iron melting and annealing furnaces with pulverised coal, so much so that The Grindle Fuel Equipment Co. of America have specialised exclusively on this work.

Mills and Millhouse Plant.

TABLE SHOWING NUMBER OF PULVERISER MILLS REQUIRED FOR INSTALLATIONS OF VARIOUS CAPACITIES, LABOUR HOURS, COAL DRYERS, ETC.

Daily Output in Tons.	Output per Hour in Tons.	Number and Size of Mills.		Number and Size of Dryers.		Number of men per Shift.	Labour. Hours per Day.	No. 8-Hour Shifts per working Day.	Maximum Output per Shift. Tons.	Approx Output per Labour Hour. Tons.
		Running Plant.	Stand-by Plant.	Running Plant.	Stand-by Plant.					
		Ins.	Ins.	Tons.	Tons.					
5	¼	1–24	none	1–4	none	1	16	2	4	0·32
10	2	1–33	,,	1–4	,,	2	16	1	16	0·62
15	2	1–33	,,	1–4	,,	2	32	2	16	0·47
20	2	1–33	1–33	1–4	,,	2	32	2	16	0·625
30	2	1–33	1–33	1–4	,,	2	32	2	16	0·94
40	2	1–33	1–33	1–4	,,	2	32	2	16	1·25
50	4	1–42	1–42	1–4	,,	2	32	2	32	1·55
60	4	1–42	1–42	1–4	,,	2	32	2	32	1·87
70	4	1–42	1–42	1–4	,,	2	32	2	32	2·19
80	4	1–42	1–42	1–4	,,	2	48	3	32	1·62
90	4	1–42	1–42	1–4	,,	2	48	3	32	1·87
100	6	3–33	1–33	1–8	,,	2	48	3	48	2·1
150	8	2–42	1–42	1–8	1–8	2	48	3	64	3·1
200	12	3–42	1–42	1–10	1–10	3	48	2	96	4·2
250	12	3–42	1–42	1–14	1–14	3	72	3	96	3·5
300	16	4–42	1–42	1–14	1–14	3	72	3	128	4·2
350	16	4–42	1–42	1–14	1–14	3	72	3	128	4·9
400	20	5–42	1–42	2–10	1–10	4	96	3	160	4·2
450	20	5–42	1–42	2–10	1–10	4	96	3	160	4·7
500	24	6–42	1–42	2–14	1–14	5	120	3	192	4·2
550	24	6–42	1–42	2–14	1–14	5	120	3	192	4·6
600	28	7–42	2–42	2–14	1–14	6	144	3	224	4·2
650	28	7–42	2–42	2–14	1–14	6	144	3	224	4·5
700	32	8–42	2–42	2–14	1–14	6	144	3	256	4·9
750	36	9–42	2–42	4–10	1–10	7	168	3	288	4·5
800	40	10–42	3–42	4–10	1–10	8	192	3	320	4·2
850	40	10–42	3–42	6–10	1–10	8	192	3	320	4·4
900	40	5–57	1–57	4–14	1–14	6	144	3	320	6·25
950	48	6–57	1–57	4–14	1–14	6	144	3	384	6·6
1,000	48	6–57	1–57	4–14	1–14	6	144	3	384	6·9

In a properly designed plant, and with due attention to ordinary common-sense regulations there is *no fear of explosion* from the coal-dust, and, as has been already stated, the old trouble with the ash slag have been overcome

There are certainly many instances where the use of fuels in powdered form would show a handsome return for capital invested, and the following table will enable an estimate to be made as to economy that can be expected.

APPROXIMATE COST OF COMPLETE MILL HOUSE, PLANTS AND OPERATION EXPENSES.

If static dryers are installed the cost of plant can be reduced by 5 per cent. up to 350 tons, and by 7½ per cent. thereafter, and the cost for coal for rotary dryers is then omitted.

Daily Output in Tons.	Labour. Cost per Ton.	Power. Cost per Ton.*	Dryer Fuel, Cost per Ton. 2 per cent. of coal dried.	Repairs, Cost per Ton.	Without Stand-by Plant.				With Stand-by Plant.			
					Cost of Mill House Plant, including Building.	Interest per Ton at 6 per Cent.	Depreciation per Ton at 10 per Cent.	Total Preparation. Cost per Ton.	Cost of Mill House Plant, including Building.	Interest per Ton at 6 per Cent.	Depreciation per Ton at 10 per Cent.	Total Preparation. Cost per Ton.
	s. d.	*s. d.*	*d.*	*d.*	£	*s. d.*	*s. d.*	*s. d.*	£	*s. d.*	*s. d.*	*s. d.*
5	5 10	3 0	10½	4	3,500	2 9½	4 8	17 6	—	—	—	—
10	2 11½	2 10	10½	4	6,700	2 8	4 5½	14 1½	—	—	—	—
15	3 11	2 10	10½	4	6,700	1 9½	3 0	12 8¾	—	—	—	—
20	2 11	2 10	10	4	9,300	1 9	2 10½	11 6½	10,300	1 11½	3 3	12 1½
30	1 11¾	2 10	10	4	9,300	1 3	2 1	9 3¾	10,300	1 4½	2 3½	9 7¾
40	2 2	2 8	10	4	9,300	11	1 7	8 6	10,300	1 0½	1 9	8 9¼
50	1 2	2 8	10	4	11,100	10½	1 6	7 4½	12,700	1 0	1 8½	7 8½
60	1 0	2 8	10	4	11,100	9	1 3	6 10	12,700	10	1 5	7 1¼
70	10	2 8	10	4	11,100	7½	1 1	6 4½	12,700	8	1 2½	6 7¼
80	1 1	2 6	10	3¾	11,100	6½	11	6 2½	12,700	7	1 1	6 5¼
90	1 0	2 6	10	3¾	11,100	6	10	5 11¾	12,700	6½	11	6 1¾
100	10½	2 6	9¾	3¾	14,300	7	11½	6 0½	15,350	7½	1 0½	6 2
150	7	2 6	9¾	3¾	15,000	4¾	8	5 3¼	18,100	5¾	9¾	5 6
200	5¼	2 6	9¼	3¾	20,000	4¾	8	5 1½	25,500	6	1 0	5 6¾
250	6¼	2 6	9¼	3¾	20,000	4	6½	5 0¼	25,500	5	8½	5 3
300	5¼	2 6	9¼	3¾	26,100	4¼	7	5 0	31,600	5	8½	5 2¼
350	4½	2 6	9¼	3¾	28,300	4	6½	4 10½	32,000	4½	7¼	4 11½
400	5¼	2 6	9¼	3¾	28,300	3½	5¾	4 9¾	32,000	4	6½	4 11
450	4¾	2 6	9¼	3¾	31,000	3¼	5¼	4 8¾	35,500	3¾	6¼	4 10
500	5¼	2 6	9¼	3¾	31,000	3	5	4 8¼	35,500	3½	5¾	4 9½
550	4¾	2 4	9¼	3¾	32,000	2¾	4¾	4 5½	37,000	3½	5¾	4 6½
600	5¼	2 4	9¼	3¾	32,000	2½	4¼	4 5	37,000	3	5	4 6¼
650	5	2 4	9¼	3¾	32,000	2¼	4	4 4¼	37,000	2¾	4¼	4 5¼
700	4¾	2 4	9¼	3¾	35,000	2¾	4	4 3¾	41,000	2¾	4¾	4 4¾
750	5	2 4	9	3¾	37,000	2½	4	4 4	42,500	2¾	4¾	4 4¾
800	5¼	2 2	9	3½	43,000	2¾	4¼	4 2¾	50,500	3	5	4 4
850	5	2 2	9	3½	45,500	2½	4¼	4 2¼	53,500	3	5	4 1
900	3¾	2 2	9	3½	48,000	2½	4¼	4 0¼	54,000	2¾	4¾	4 3½
950	3¼	2 2	9	3½	49,500	2¼	4¼	4 0¼	55,200	2¾	4¾	4 1½
1000	3¼	2 2	9	3½	53,500	2¾	4¼	4 0½	59,500	2¾	4¾	4 1½

Cost of plant exclusive of foundations and erection.

* Can be reduced to ⅓rd for power-station plants.

The table of costs is based on the following assumptions :—

Labour at £4 per man per 44-hour week.

Power at 1½*d.* per kilowatt-hour (a high cost even for local supply), and an average allowance of 20 kw.-hours per ton of coal pulverised and delivered to the exit of mill house, including power for all operations. Dryers to be fired with pulverised coal, which is taken as 40*s.* per ton at the dryer burners ; an average allowance of 2 per cent. of the coal dried is made for dryer fuel, assuming the moisture content of coal to be reduced from 15 per cent. to 1 per cent.

Yearly output is based on 300 working days.

Vertical or Horizontal Flame Projection.

Pulverised coal can be applied to boiler furnaces through horizontal or vertical burners. As a general rule the burning of bituminous coal and lignite is best effected by means of horizontal burners, and when fuel of less than 20 per cent. volatile matter is to be burned the vertical burners are recommended.

Illustrations of four standard types of water-tube boilers as equipped with horizontal and vertical burners are shown in fig. 28. Horizontal burners are generally used for high volatile fuel and vertical burners for low volatile fuel.

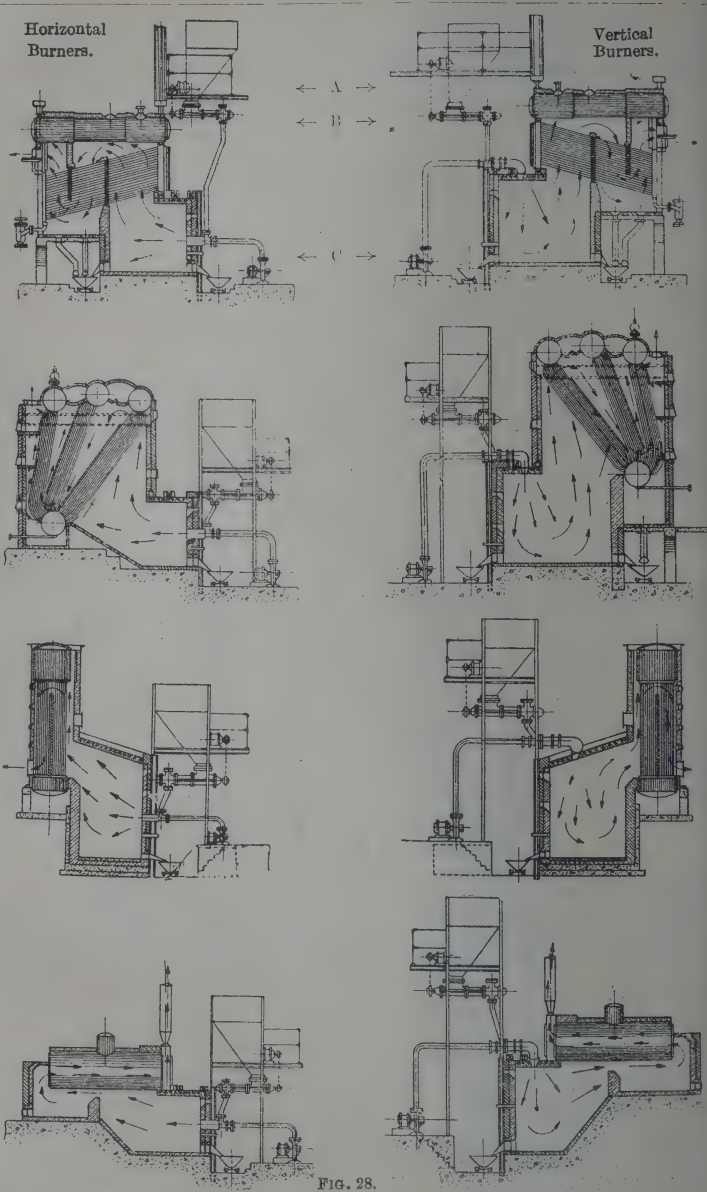


FIG. 28.

A. Fuel Bunker. B. Fuel Feeder. C. Air Supply Fan.

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SPECIALISTS IN SCREENS and SORTING BELTS.

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Combined Destructors, Screens and Sorting Belts designed to meet all Requirements

—

HEENAN & FROUDE LTD.
WORCESTER, ENG.

F. 2133

REFUSE DESTRUCTORS.

Calorific Value of Refuse.

The calorific value of refuse is about $\frac{1}{5}$ to $\frac{1}{7}$ that of an equal weight of good dry coal.

Average composition and calorific value of London ashbin refuse, containing the average percentage of water :—

Component parts of Refuse.	Amount in 100 lbs. of Refuse.	Calorific Value.
	Lbs.	B.Th.U.
Coal	·35	3,260
Coke	·15	1,200
Bones and offal	·37	1,970
Breeze and cinder	25·55	102,000
Rags	·40	1,330
Paper, straw, fibrous material, and vegetable refuse	13·15	33,100
Ash	47·00	Nil
Dust and dirt	9·75	,,
Bottles	·48	,,
Metals, including tins	·68	,,
Crockery	1·72	,,
Glass	·37	,,
	99·97	142,860

The above is the average of 1,000 cart-loads.

About 60 per cent. of the refuse is combustible.

The character of the refuse varies a great deal. In factory districts the percentage of unburnt cinder is high, whereas in residential districts with gardens it is much lower.

When it is considered that ordinary green garden refuse when piled in a heap over a nucleus of fire will consume itself, it is obvious that refuse containing cinders will contain enough heat, if properly applied, for its perfect destruction. It is essential that combustion should take place in brick cells, and that no heat should be abstracted until combustion is complete, after which the gases may be used for steam raising. If 40 per cent. only of the refuse is combustible, its calorific value per pound will be about 5,800 B.Th.U. if it were dry. Taking it only as 1,500, this is more than would raise the temperature of the whole gaseous and solid matter to a red heat. If half the weight were water, this would absorb about 600 B.Th.U. to evaporate and about 300 to become red hot, or 900 in all. The remainder of 600 B.Th.U. would raise the gases and solids to nearly 5,000° F. Thus destruction may be perfect with only the equivalent of one-tenth its weight of dry carbon. Inodorous combustion demands high temperature, and hence must occur in brick cells, with suitable movement of the fuel, so that the gases and steam cannot escape until fully incandescent.

Extract from Official Test of 'Heenan' Refuse Destructor at Pontypridd.

U.D.C. Electricity Generating Station, Treforest.

Date of test	February 10, 1910.
Plant tested	One unit (3 cells of 25 sq. ft.) 75 sq. ft. grate area, B. & W. Water Tube Boiler of 2,010 heating surface, Green's Economiser of 96 tubes, 4 ins. in diameter.
Duration of test, 10 A.M. to 6 P.M.	8 hours.
Weight of refuse burnt	18 tons, 1 cwt. 1 qr. = 40,460 lbs.
Rate of burning per hour	$\frac{18{\cdot}0625}{8}$ = 2·257 tons per hour.
Equivalent evaporation from and at 212° F. of destructor plant without economiser	3·223 lbs.
Mean temperature in combustion chamber over 8 hours	2,437° F. (1335° C.)
Average percentage of carbon dioxide in products of combustion under boiler	14·65 per cent.
The station is working non-condensing, the consumption basis being 40 lbs. of steam. Estimated per kilowatt, the units generated on test (an equivalent of 151 units per ton of refuse)	2,724 B.Th.U.
The actual was 104 B.Th.U. The total, 1,905 B.Th.U.	

Feb. 11, 1910. (*Signed*) J. E. Teasdel.

URBAN DISTRICT COUNCIL OF PONTYPRIDD.

Electricity Generating Station.

Comparative Statement of Coal and Refuse and Units Generated in the latter half of 1908 and 1909 respectively.

Month Ending.	Refuse Tons.	Coal Tons.	From Refuse Units.	From Coal Units.	Total Units.	Units per Ton Refuse.	Units per Ton Coal.
1908.							
Sept. 9 .	Refuse	219	—	77,658	77,658	—	355
Oct. 7 .	Des-	225	—	84,300	84,300	—	375
Nov. 4 .	tructor	275	—	92,567	92,567	—	336
Dec. 2 .	not yet	289	—	91,949	91,949	—	318
Dec. 30 .	in opera-	290	—	103,611	103,611	—	357
Jan. 27, 1909	tion.	269	—	100,955	100,955	—	375
		1,567	—	551,040	551,040	—	Av. 352
1909.							
Sept. 8 .	553	54	62,302	19,008	81,310	113	352
Oct. 6 .	660	66	65,622	23,232	88,854	99	352
Nov. 3 .	782	86	68,185	30,272	98,457	99	352
Dec. 1 .	776	57	85,894	20,064	105,958	110	352
Dec. 29 .	863	56	95,304	19,712	115,016	110	352
Jan. 26, 1910	917	46	98,966	16,192	115,158	108	352
	4,551	365	476,273	128,482	604,753	*Av. 104·5	Av. 352

* This does not take into account steam wasted in blowing off.

Total works costs reduced from 1·10 to ·82 per unit—1,500*l.* per annum on 100,000 units per month (four weeks).

Value of coal 13·5 shillings per ton (2,240 lbs.).

Note, in the preceding tables, that from September 1908 to the end of January 1909 the destructor had not been installed. In the corresponding months of 1909 and 1910 note the large reduction in the coal consumed, notwithstanding the increased current consumption.

At Rotterdam Messrs. *Heenan & Froude, Ltd.*, have installed a large combined destructor and generating station. The refuse collected daily suffices to drive a 1,250 kw. generator and supplies current for operating the whole of the cars of the city. This is one of the largest and best equipped stations in the world, having a destroying capacity of about 500 tons per day of 24 hours, although, at the present time, only something approximating one-half of this is available.

The following tables give particulars of the evaporation and the electrical output, as well as the refuse burnt on representative weeks during the months of September and October 1912. It will be noted that the quantity of refuse collected and delivered at the Destructor Depot is an increasing one, and it will further be noted that the calorific value of the refuse during the winter months rises appreciably.

ROTTERDAM INSTALLATION.

Log Sheet for week commencing September 14, 1912.

Day.	Refuse (Kgs.)	Water (Litres).	Total (Kw.).	Kw. per Ton.	Evap. per Kg.	Steam Lbs. per Kw.
Saturday	225,294	158,400	16,090	72	·70	21·7
Monday	198,350	137,100	15,730	81	·69	19·3
Tuesday	191,105	160,600	18,450	98	·84	19·3
Wednesday	203,200	166,500	18,700	94	·83	19·6
Thursday	200,645	173,500	18,160	91	·86	20·9
Friday	219,455	176,900	20,130	93	·81	19·3
Average	206,341	162,166	17,876	88	·79	19·8

Log Sheet for week commencing October 25, 1912.

Day.	Refuse (Kgs.).	Water (Litres).	Total (Kw.).	Kw. per Ton.	Evap. per Kg.	Steam Lbs. per Kw.
Friday	242,665	244,300	18,580	77	1·01	29
Saturday	230,595	255,100	16,730	72	1·11	34
Monday	233,318	218,500	16,530	71	·94	29
Tuesday	220,436	225,200	21,120	96	1·02	23
Wednesday . . .	194,596	213,300	21,520	111	1·10	22
Thursday	221,086	208,000	22,080	100	·95	21
Average	223,783	227,400	19,430	87	1·01	26

GENERATION OF ELECTRICITY BY DESTRUCTORS IN GREAT BRITAIN.

In the Annual Report of the Electricity Commission * it is stated that the total units generated by destructors during the year ending March, 31, 1926, was 25,636,974 (from 29 stations), as against 26,241,342 (from 27 stations) in 1925.

LIQUID FUELS.

Whereas solid fuels are solely used for external combustion it is possible to employ almost all liquid fuels for either external or internal combustion. On comparing the most important liquid fuel petroleum with the most important solid fuel, coal, many remarkable advantages of the former over the latter are found to exist. The heat value of petroleum is some 50 per cent. greater than that of average coal, the stowage space being slightly less. Liquid fuels are more convenient to store (places inaccessible to coal may be employed) and are more easily transported than solid fuels. Liquid fuel is almost entirely free from ash. When used for internal combustion the thermal efficiency of liquid fuels is double that of the solid fuels used for power production. Certain liquid fuels can be employed in high speed engines, whereby a higher power per unit weight of engine is obtainable than by any other type of prime mover.

The most important liquid fuels are petroleum, shale oils, coal tars and their products, and lignite tars and products.

Petroleum.

Petroleum occurs in the earth, and is generally found in strata of conglomerate or of oil sands. It is generally accompanied by gaseous and also by solid hydrocarbons. The crude oil is usually brown or black, and the products of different fields vary greatly both in physical and chemical properties.

Petroleum consists almost entirely of carbon and hydrogen. These are present in the form of compounds known as hydrocarbons. Hydrocarbons may be divided into three main groups, known as aliphatic, aromatic and hydroaromatic hydrocarbons. These groups may be subdivided into numerous series, the members of which possess certain definite relationships between the number of carbon and hydrogen atoms present in the molecules. The physical properties of the members of these series generally progress by fairly regular steps. The carbon atoms in the aliphatic hydrocarbons are connected together in the form of chains, and the more important series of this type of hydrocarbons are :—

Paraffin Series.
General formula—C_nH_{2n+2}

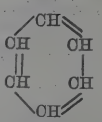
Methane	CH_4
Ethane	C_2H_6
Propane	C_3H_8
Butane	C_4H_{10}
Pentane	C_5H_{12}

Olefine Series.
General formula—C_nH_{2n}

Ethylene	C_2H_4
Propylene	C_3H_6
Butylene	C_4H_8
Pentylene	C_5H_{10}

* Generation of Electricity in Great Britain, year ending March 31st, 1926. H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.

The carbon atoms of the aromatic compounds are connected together in the form of rings a typical compound being :—

Benzene, formula C_6H_6 . . . 

The hydroaromatic compounds also contain carbon rings, but are richer in hydrogen than th aromatic hydrocarbons. A typical hydroaromatic compound is hexamethylene, C_6H_{12}.

Petroleum oils contain members of all these series, but the proportion varies according to th locality from which the oil has been obtained. Pennsylvanian oils consist mainly of aliphati hydrocarbons, Russian oil mainly of hydroaromatic compounds. The products of the destructiv distillation of coal consist mainly of aromatic compounds. Crude petroleum from Mexico an South America generally contains quantities of a viscous sulphur-containing body known a asphaltum, which has great influence on their properties as fuels. Little petroleum is consume in the crude state, it being usual to separate it into fractions boiling over various ranges b means of repeated distillations. Many petroleum fractions are also treated with sulphuric aci and with caustic soda in order to remove certain undesirable constituents.

The principal fuels obtained from petroleum are :—

Benzine	boiling from 70°–150° C., 155°–302° F.	Specific gravity ·700–·760
Kerosene, illuminating, or paraffin oil . . .	boiling from 150°–300° C., 302°–572° F.	„ „ about ·800
Gas oils, solar oils, etc. .	boiling from 250° C., 482° F. upwards.	„ „ „ ·850
Petroleum residuum, 'fuel oil,' boiling point varies greatly		„ „ ·880–·950

The world's production of petroleum in 1926 was 1,095,934,000 barrels, and the United State production was 770,874,000 barrels, or 70 per cent. of the total. The import of motor spirit o petrol into the U.K. in 1926 was 562 million gallons.

Benzine.

Benzine is the petroleum fraction from which motor spirits are prepared. Motor spirits are generally called petrol in this country. Petrol contains about 14 per cent. hydrogen and 86 per cent. carbon. Heavy fuel oils contain about 12 per cent. hydrogen and 88 per cent. carbon.

Kerosene.

Illuminating oil or kerosene, generally known in this country as 'Paraffin Oil,' possesses a specific gravity in the neighbourhood of ·800. It is slightly lower in calorific value than petrol, but on account of its higher specific gravity it yields more heat per unit volume of fuel. The ultimate composition of kerosene is approximately carbon 87 per cent. and hydrogen 13 per cent. Apart from illuminating purposes, kerosene finds frequent use as a fuel for vaporising engines. A large number of heavy distillates of petroleum are prepared for various technical purposes. Of these gas oil is probably the most important. Gas oil is prepared with a view to its use in the preparation of carburetted water gas or oil gas, and is also used as fuel for semi-Diesel and Diesel engines. It is a brown clear liquid of specific gravity about ·850, and has a net calorific value of about 18,000 B.Th.U. The distillates, whether prepared from asphaltic or non-asphaltic petroleum oils, are generally very similar in quality, though the proportion of each distillate yielded by the different crude oils may vary considerably. The residuum which is run off the still at the end of distillation, and is frequently marketed as 'fuel oils,' varies very greatly in properties according to the nature of the crude oil from which it originates. The non-asphaltic petroleum residuum which is sold as fuel oil is generally dark brown or black, almost opaque, quite mobile, and has a specific gravity of ·870 to ·920. It is largely used as a fuel for semi-Diesel and Diesel engines, also for boiler firing in the Navy. The residua prepared from asphaltic oils are usually black opaque liquids possessing high viscosities and specific gravities from ·920 to ·980, the viscosities and specific gravities being dependent on the asphaltum content.

Examples of analyses of the more important petroleum fuel products are given in he table on page 2142.

Shale Oil.

Shale exists in many parts of the British Empire, the shale oil industry being most fully eveloped in Scotland. The shale is mined in a similar manner to coal, and is then subjected o destructive distillation, the principal products of value being ammonia and crude shale oil. he crude oil is subjected to distillation, whereby a series of products similar to the petroleum istillates is obtained. The shale oils are richer in unsaturated bodies than petroleum. In fuel roperties they very closely resemble the petroleum products.

Petrol.

Petrol, known in France as 'Essence' and in America as 'Gasoline,' is a mixture of liquid ydrocarbons principally composed of the chemical 'paraffins,' Hexane C_6H_{14}, Heptane C_7H_{16}, ctane C_8H_{18}, and Nonane C_9H_{20}: these have boiling points 155°F., 208° F., 248° F., and 302° F. spectively. It is obtained by distillation from crude petroleum and, as now used, varies in . gr. at 60° F. from about 0·70 to 0·76, the average being about 0·725. The consumption Great Britain rose from about nineteen million gallons in 1905 to upwards of two hundred illion gallons in 1919. Petrol, being a mixture of hydrocarbons, has no fixed boiling point, d its density increases during evaporation; it was largely from this cause that surface car- rettors proved unsatisfactory, selective evaporation occurring and a heavy non-volatile sidduum being finally left; with the jet-carburettors now almost universally employed no lective action is possible.

As petrol is very expansible, tanks and closed vessels should never be quite filled with the uid, so as to avoid risk of rupture following a rise in temperature. Coefficient of expansion, 00063 per ° F. (0·001138 per ° C.).

The composition of commercial petrol averages about 85½ per cent. carbon and 14½ per cent. drogen, and the net calorific value per lb. varies but little from 18,600 B.Th.U.

Heavy petrol gives quite satisfactory results with modern carburettors; motor omnibuses ploy 0·760 spirit very largely on account of its lower cost.

It was formerly assumed that the suitability of a motor spirit could be determined from its ecific gravity, but in recent years the use of benzol in admixture with petroleum spirits has come common, and such a mixture is a very satisfactory fuel, in spite of its having a higher ecific gravity.

On the other hand, if the air supply exceed about 15 lbs. per lb. of petrol, there is an air excess l no CO appears in the exhaust; instead one gets free oxygen. The practical range is from out 11 air to 1 petrol, to 17 air to 1 petrol; recently the Royal Automobile Club has adopted the standard for carburettors such a mixture as would give an exhaust containing about er cent. of free oxygen; this prevents the presence of CO, and gives nearly the highest thermal ciency and also nearly the maximum power. Maximum thermal efficiency usually occurs h a somewhat greater excess of air, and maximum power with a slight defect of air, due in s latter case to the higher mean pressure obtained by reason of the considerable expansion the products of combustion with 'rich' mixtures. One lb. of petrol, occupying 4 cub. ft., uires for its complete combustion roundly 15 lbs. of air occupying 196 cub. ft. at 60° F.: the lbs. of mixture thus occupies a volume of 200 cub. ft. at 60° F., and contains 2 per cent. by ume of petrol vapour—that is, assuming that the petrol is gasified, and not atomised.

Theoretical Efficiency of Petrol Engines.

The theoretical efficiency, E, of an engine operating on the constant volume cycle is—

where, $$E = 1 - \left(\frac{1}{R}\right)^{n-1}$$

R = expansion ratio.

If no heat is lost, then $n = 1{\cdot}45$, but in practice heat is lost during compression, with a result t the exponential n is reduced to the value of 1·35. Ricardo states that when heat leakage, tional losses, and losses due to friction of gases have been allowed for, then $n = 1{\cdot}25$, so that maximum efficiency obtainable in practice may be considered to be

$$E = 1 - \left(\frac{1}{R}\right)^{0{\cdot}25}$$

COMPARISON OF PROPERTIES OF FUELS FOR PETROL ENGINES.

Description.	Sp. Gr. at 20° C.	Gross Cal. Value.	Retort Test.	Sulphur.	Sulphuric Acid Coloration Test.
		Calories.	Per Cent.	Per Cent.	
Pratt's Perfection	0·706	11,090	87 at 120° C.	0·44	Pale yellow.
„ No. II.	0·713	—	87 „	—	„ „
„ Taxibus	0·722	11,155	86 „	0·306	„ „
Mex. spirit	0·718	11,535	88 „	0·40	Deep yellow.
Mead King Robinson, Grade 700–725	0·714	—	88 „	—	Very pale yellow.
M.K.R., Grade 735–750	0·735	—	80 „	—	„ „
„ Grade 735–770	0·747	11,092	70 „	0·104	Pale yellow.
Benzol	0·875	9,877	100 at 100° C.	0·90	Very dark.
Alcohol (industrial)	0·819	6,115	100 at 80° C.	0·13	—

CRACKING PROCESS.

A very large proportion of the world's production of motor spirit is now obtained by cracking from heavier oils. The original Burton process has been largely replaced by the modern liquid phase cracking plants of Dubbs and Cross. In these the oil is heated while travelling rapidly through tubes arranged in a furnace, and thence passes to a reaction chamber, where the cracking mainly takes place. In the Dubbs plant a pressure of 300 lbs. per sq. in. is maintained, while the Cross plant employs a higher pressure of 800 lbs. per sq. in.

The specific gravities and distilling temperatures of petrols are liable to be varied from time to time as the market conditions warrant. The increased demand for motor spirit during recent years has been to a large extent met by including both higher and lower boiling distillates in the motor spirit fraction. By subjecting the crude oil to high temperatures in the absence of air, frequently accompanied by high pressures, a decomposition of the more complex hydrocarbons is brought about. This action, which is technically known as 'cracking,' results in large yields of motor spirit. The motor spirit prepared in this way is rich in unsaturated compounds, possesses a characteristic odour, and is higher in specific gravity than the direct distilled petrol which comes over between the same temperatures.

Some of the petrol at present being imported into this country is naturally rich in benzene and toluene, and this is particularly the case with the Borneo spirit imported by the Shell group and it has been found, both experimentally and in practice, that owing to the higher spontaneous ignition temperatures of benzene and toluene, mixtures containing these hydrocarbons do not so readily cause preignition or detonation in petrol engines. In view of this, petrol which does not naturally contain benzene has occasionally been mixed with benzene in order to decrease the liability to preignition.

Analyses of Pratt's No. 1 and Shell No. 1 spirit by Mr. Harold Moore, on behalf of *The Motor*,* gave the following results:—

Pratt's No. 1 Motor Spirit:—Specific gravity, 0·729 at 15° C. (59° F.).

ENGLER DISTILLATION TEST: Initial boiling point, 33° C. (91·4° F.).

Temperature	C.°	55	60	70	80	90	100	110	120
„	F.°	131	140	158	176	194	212	230	248
Drop per cent.		—	1·0	3·5	11·5	21·5	31·0	45·0	57·5
Temperature	C.°	130	130	140	150	160	170	180	190
„	F.°	266	266	284	302	320	338	356	374
Drop per cent.		67·5	67·5	77·0	83·0	87·5	91·5	93·0	94·5

Initial boiling point is the temperature at which the first drop falls from the bulb of the thermometer when the latter is placed ¼ in. below the outlet tube of flask.

Drop temperature is taken when the first drop leaves the end of the condenser.

Acid Coloration.—Acid has brick-red colour, and petrol separates out slowly.

Aromatic hydrocarbon content = 10·2 per cent. by weight.

* *The Motor*, September 7, 1921.

Shell No. 1 Motor Spirit: Specific gravity, 0·754 at 15° C.

ENGLER DISTILLATION TEST: Initial boiling point, 34° C.							
Temperature	C.°	57	70	80	90	100	110
,,	F.°						
Drop per cent.	.	—	1·5	6·0	12·5	24·0	39·0
Temperature	C.°	120	130	140	150	160	170
,,	F.°						
Drop per cent.	.	53·5	67·0	78·0	86·5	92·0	95·0

Acid Coloration.—Acid only slightly discoloured, light brown, and petrol separates out almost immediately.

Aromatic hydrocarbon content = 21 per cent. by weight.

DETONATION.

High efficiency in petrol engines is best attained by employing very high compression ratios, but in practice it is found that a high compression ratio is accompanied by 'pinking' or 'knocking' when running at slow speeds with heavy loads when ordinary motor spirit is used. For such spirits the limiting compression ratio is about 4·5 to 1. Benzol is very much less prone to give this phenomenon of knocking, or detonation, and it permits of the use of a considerably higher compression ratio. The use of alcohol as a fuel permits of a compression ratio of as much as 7 to 1. Certain organic compounds have been found by Midgley & Boyd to be much more efficient than benzol in preventing detonation; for example, tetraethyl lead is 625 times as powerful as benzene. Fuel containing a minute proportion of this anti-detonating agent has been extensively used in the U.S., and is known commercially as 'ethyl gas.'

Benzol.

Benzol had come into prominence before the war as an alternative home-produced fuel for the engines of motor vehicles, partly in consequence of the high price of petrol. Since the withdrawal of the restrictions on the use of benzol its use has become more general than before, though the motoring public do not yet fully appreciate its value as a fuel. Benzol is the commercial name for a mixture of hydrocarbons prepared by the distillation of coal tar, and also obtained by stripping the gas which is produced as a by-product from coke ovens. Commercial benzol consists almost entirely of a mixture of the hydrocarbon benzene (C_6H_6: not to be confused with the petroleum fraction 'benzine') and the hydrocarbon toluene (C_7H_8). The usual commercial grades are '90 per cent. benzol,' which on distillation yields 90 per cent. of distillate at 100° C., and consists of approximately 70 per cent. benzene and 30 per cent. toluene, together with traces of the xylenes (C_8H_{10}, and '100 per cent. benzol,' which on distillation yields 100 per cent. of distillate at 100° C., and contains a higher proportion of the hydrocarbon bezene than 90 per cent. benzol.

There is little to choose between these two bodies as motor fuels, and provided they have been satisfactorily refined they are both preferable to pure benzene, as the mixtures do not so readily solidify in cold weather. Pure benzene solidifies at a temperature of + 6° C. (43° F.), and boils at 80·4° C. It possesses a specific gravity of ·88 at 15° C., and a gross heat value of about 18,090 B.Th.U.

Both commercial benzol and pure benzene possess very high temperatures of spontaneous ignition, and they will withstand compressions of about 200 lbs. per square inch in internal combustion engines without being affected by preignition. This property, together with the high specific gravity, accounts for the increased mileage per gallon obtained when using benzol as fuel instead of petrol. Benzol gives about 16 per cent. greater mileage than petrol, and also gives greater power to the engine. When changing over from petrol to benzol it is advantageous slightly to reduce the size of jet, though it is not absolutely necessary to make any modification. The colour of benzol for motor use should be perfectly clear and white, as yellowish colour indicates unsatisfactory refining. Certain bodies (mainly phenols, unsaturated hydrocarbons and sulphur containing compounds) are present in benzol when it is first prepared by distillation. These compounds are removed by treatment with caustic soda solution and afterwards with concentrated sulphuric acid. If these bodies are not removed there is a liability for the benzol to form resinous substances after prolonged standing, and also to form gummy deposits in the engine. Petrol undergoes a similar refining process during its preparation, but it is rare to meet with badly refined petrol nowadays, as the quality necessary for the motor spirit market is well understood by the petroleum firms. Petrol and benzol are perfectly soluble in each other, and can be used with satisfaction in the form of mixtures.

British Standard Specification for Benzol for Motor Fuel.*

Report No. 135, 1921 (*Abstract*).

(1) The term 'Benzole' shall denote a liquid consisting essentially of a mixture of benzen and not more than 30 per cent. by volume of toluene and xylenes.

(2) The material shall be a clear 'water white' liquid, free from undissolved water an other visible impurities.

(3) The specific gravity at 15·5° C. (60° F.) shall be not less than 0·870, and not mor than 0·885.

(4) When 100 cc. of the material are distilled in the Standard Distillation Apparatus, at rate of 7 cc. per minute, there shall distil at 760 mm. pressure—

Not less than	60 cc.	at or below	90° C. (194° F.).
„ „	75 cc.	„	100° C. (212° F.).
„ „	90 cc.	„	120° C. (248° F.).

The flask shall be dry at a temperature not exceeding 125° C. (257° F.). The temperatur recorded by the thermometer shall be corrected for emergent stem and barometric pressure.

(5) The amount of non-volatile residue remaining when 20 cc. of the material are evaporated and subsequently heated for two hours on a water bath at 100° C. (212° F.), shall not excee 0·01 per cent. by weight.

(6) The coloration imparted to pure sulphuric acid (90 per cent. H_2SO_4), free from nitri acid, when 90 cc. of the material are shaken with 10 cc. of the acid for five minutes at ordinar temperatures, shall be not more than a light brown.

(7) The total sulphur content shall not exceed 0·4 per cent. by weight. Freedom from aci and alkali.

(8) The material shall give no reaction for free acid or alkali when tested.

(9) The material shall give no reaction for sulphuretted hydrogen when tested.

(10) The freezing point shall not be higher than — 14° C. (7° F.).

Detailed descriptions of the methods employed in testing are given in the original publication

Alcohol.

Although the heat value of alcohol per lb. is comparatively small, yet, on account o its heaviness as a vapour, and the small volume of air required to burn it compared with benzene and petrol, it yields 89·2 B.Th.U. per cub. ft. of mixture at 60° F. and atmospheri pressure. Moreover, the products of combustion are 6½ per cent. greater in volume than tha of the unburnt mixture, with corresponding increase in the pressure developed. There is thus thermally considered, not very much to choose between alcohol and petrol; alcohol is, in fact an excellent fuel for suitably designed internal combustion engines, and is largely used in Germany where its production is encouraged by the Government; in 1904 the price of alcohol in German was only 9*d.* per gallon when purchased in large bulk.

Mr. E. Bury of the Skinningrove Iron & Steel Works, Middlesbrough, has made trials of process for the abstraction of ethylene from coke-oven gas and its recovery as alcohol, by which an average yield of 1·6 gallons per ton of coal carbonised is obtained. The application of thi process to the whole of the 14,635,000 tons of coal reduced to coke in this country in 1918 would yield 23 million gallons of alcohol. It is calculated that the recovery of alcohol from the gas works of the country on similar lines would yield 27 million gallons per annum.

Alcohol has a great affinity for water, and ordinary commercial qualities contain water i various proportions up to about 15 per cent.; in the following table estimated calorific value per lb. are given for alcohol-water mixtures containing from 0 to 50 per cent. of the latte ingredient.

* By permission of the British Engineering Standards Association.

ESTIMATED CALORIFIC VALUE OF ALCOHOL-WATER MIXTURES

Proportions by Weight.		B.Th.U. per Lb.	
Alcohol.	Water.	Higher Value.	Lower Value.
Column :—	1	2	3
1·00	0·00	12,420	11,285
0·9	0·1	11,178	10,060
0·8	0·2	9,936	8,835
0·7	0·3	8,694	7,609
0·6	0·4	7,452	6,385
0·5	0·5	6,210	5,160

Alcohol engines require larger carburettors and piping and valves than are necessary when étrol is used. As the latent heat of alcohol much exceeds that of petrol, especially when water present in any considerable proportion, it is also necessary to well jacket the carburettor with ɔt water or exhaust gas, and to heat the in-going air to about 350°F. in order to ensure com-ɛte vaporisation. The cylinder-jacket water should also be kept nearly at 212°F.; too cool cylinder results in imperfect combustion of the mixture, acetic acid, aldehyde, etc., being formed stead of CO_2 and H_2O only, with loss of efficiency and corrosion of internal parts. Starting ɔ from cold is a special difficulty with alcohol, and engines are usually started with petrol, the cohol being turned on when everything is well warmed up. Some engines are arranged so as ɔ start and *stop* on petrol; in this way any traces of water or acid from the alcohol are cleared ɪt of the cylinders and passages during the last few revolutions of the engine, and risk of corro-ɔn of parts is thus avoided. Tests on a 14 horse-power 'Locomobile' alcohol engine of 8·28 ins. ɔre and 11·8 ins. stroke made by Prof. E. Meyer in 1901 showed a brake thermal efficiency of ɨ per cent., using alcohol containing about 13 per cent. of water. The volume ratio of com-ɛession was 5·9. The cylinder-jacket water temperature was maintained at 208°F. The engine n at 280 revs. per minute and developed 13·9 b.h.p. at full load.

COMPOSITE MOTOR SPIRITS.

Various mixtures containing alcohol, etc., have been put on the market as motor spirits. 'Natalite' is said to be a mixture of 40 per cent. of ether and 60 per cent. of alcohol (prepared om molasses), with traces of ammonia and denaturants, and is extensively used in South Africa. 'Discol,' used in this country, is a mixture of alcohol, heavy petrol, and benzol, containing about) per cent. of alcohol.

Coal Tars and Coal Tar Distillates.

When bituminous coal is subjected to destructive distillation, gas, coke, tar and ammonia e obtained. The physical and chemical properties of the tars are dependent upon the type of al from which they originate, and the conditions which exist in the carbonising chamber. ie appliances in use for the carbonisation of coal are mainly gas manufacturing plants and ke manufacturing plants. A few special plants exist which do not belong to either of these tegories.

Gas manufacturing plants may be divided into three classes—horizontal retort, inclined tort, and vertical retort plants. Retorts of the first type yield tars of high specific gravity, 15 to 1·25, rich in free carbon, and viscous. Vertical retorts yield thin brown tars of low avity (about 1·05), which are comparatively low in free carbon content and rich in aliphatic drocarbons. The tars from inclined retorts are intermediate between the products of hori-ntal and vertical plants in their chemical and physical properties.

Coke-oven tars are very variable, but usually approximate to horizontal retort tars in mposition.

Tars from gas producers are generally too high in water-content to be of use as fuels.

Blast furnaces yield tars containing large quantities of ash which render them useless in the w state.

Several processes for the low temperature carbonisation of coal have been advocated, but no rge quantity of the tar, which is exceptionally suitable for fuel purposes, is available.

The majority of coal tars may be employed for boiler firing purposes. Tars from vertical torts have been found suitable for use on both two and four cycle Diesel engines, providing at certain special adjustments or fittings are employed, large quantities of such tars being

PROPERTIES OF PETROLEUM FUELS. (*Moore.*)

Description of Fuel.	Sp. gr.	Water. %	Sulphur. %	Ash. %	Asphaltum. %	Coke Value. %	Flash Point. °F.	Temp. of Spont. Ignition in Oxygen. °C.	Viscosity in Redwood Units @70°F. 21·1° C.	Viscosity in Redwood Units @100°F. 37·7° C.	Calorific Power. Gross. Calories.	Gross. B.Th.U.	Net. Calories.	Net. B.Th.U.
Petrol (Pratt's perfection)	·706	None	0·44	None	None	None	Below 60	272	4·0	4·0	11,090	19,962	10,280	18,504
Petrol substitute	·762	,,	—	,,	,,	,,	,,	260	4·0	4·0	11,320	20,376	10,545	18,981
Petrolite	·814	,,	0·87	,,	,,	,,	104	251	5·0	5·0	11,020	19,836	10,294	18,529
Homelight kerosene	·807	,,	0·17	,,	,,	,,	82	251	4·54	4·45	10,960	19,728	10,295	18,531
Pennsylvanian gas oil	·850	,,	0·21	,,	,,	,,	0·35	184	254	7·7	7·0	10,880	19,584	10,198	18,347
Standard Mexican fuel oil	·948	0·75	2·91	0·09	25·4	12·20	200	259	1210	288	10,248	18,446	9,663	17,393
Light Mexican fuel oil	·914	Traces	2·27	None	5·6	5·09	235	259	56·8	24·6	10,600	19,080	9,963	17,933

Description of Fuel.	Engler Distillation Test. °C. Drop.	120	200	250	300	350	Retort Test (Bulb of Thermometer Immersed). °C. Drop.	100	120	200	250	300	350	400	420
		%	%	%	%	%		%	%	%	%	%	%	%	%
Petrol (Pratt's perfection)	—	—	—	—	—	—	—	—	87	—	—	—	—	—	—
Petrol substitute	—	0·5	95	—	—	—	—	0·5	2	90	—	—	—	—	—
Petrolite	137	—	22·5	63	95	—	—	—	—	—	—	—	—	—	—
Homelight kerosene	170	—	—	64	89	—	170	—	—	25	64	89	—	—	—
Pennsylvanian gas oil	—	—	—	—	—	—	206	—	—	—	—	32	—	—	—
Standard Mexican fuel oil	245	—	—	1	12	55	300	—	—	—	—	—	15	34	40
Light Mexican fuel oil	—	—	—	—	—	—	110	—	—	—	8	15	22	33	41

ised in Diesel engines on the Continent. Some coke-oven tars are suitable for use in Diesel engines. The compositions of several British coal tars are given in the accompanying table :—

PROPERTIES OF TARS. (*Moore.*)

Description.	Sp.Gr. at 15° C.	Per cent. Chemical Composition.					Ash.	Coke.	Calorific Power (Dry Tar).		Free Carbon.
		H_2O.	C.	H.	O.&N.	S.			Gross.	Net.	
Horizontal retort tar	1·180	1·75	91·5	5·2	2·6	0·5	0·2	24·0	9093	8645	18·2
Inclined retort tar	1·157	1·11	89·9	6·0	3·6	0·5	0·02	18·5	9096	8671	14·0
Vertical retort tar	1·089	2·25	88·0	6·8	3·8	0·6	0·03	6·1	9246	8664	1·7
Otto Hilgenstock coke oven tar	1·208	6·00	90·0	5·4	3·8	0·8	0·02	26·8	8921	8624	23·9
Simon-Carvé coke oven tar	1·090	0·50	88·1	5·6	6·1	0·2	0·07	6·0	9695	9261	traces
Chamber oven tar	1·082	1·29	88·2	6·9	4·6	0·3	traces	7·3	9229	8737	3·0
Low temperature carbonisation tar	1·058	3·00	85·8	8·1	5·5	0·9	0·11	8·2	9196	8776	2·2
Water gas tar	1·054	0·59	92·2	6·8	0·4	0·6	traces	18·7	8951	8647	6·8
Blast furnace tar	1·172	3·00	89·5	5·7	0·5	0·84	0·36	23·4	8563	8288	9·5

The volatile products obtained by the distillation of coal tar (mainly benzol and toluol) have been extensively used in automobile engines prior to the war. Creosote and anthracene oils are high boiling distillates of coal tars and are extensively employed for fuel purposes, both for external and internal combustion. The 'tar oil' sold for fuel is usually a mixture of both these above-mentioned fractions. Analyses of some tar oils, together with a petroleum residuum, and alcohol, are shown in the following table :—

PROPERTIES OF MISCELLANEOUS FUEL OILS. (*Moore.*)

Description.	Sp.Gr. (15°C)	Per cent. Chemical Composition.					Ash.	Coke.	Flash pt.	Calorific Power.	
		H_2O.	C.	H.	O.&N.	S.				Gross.	Net.
Coal tar creosote	1·053	traces	89·7	7·4	2·23	0·66	traces	1·30	93°C.	9342	8964
Blast furnace oil	0·907	0·00	82·6	9·9	7·22	0·29	0·00	1·26	70°C.	9992	9603
Vertical retort tar oil	1·019	0·70	85·8	7·9	5·1	0·5	traces	1·65	88°C.	9189	8762
Scottish shale oil	0·945	1·6	87·00	9·50	1·04	2·35	0·11	0·18	56°C.	9917	9245
Premier tarless process oil	0·995	traces	82·6	8·6	8·8	0·50	0·10	1·52	76°C.	9472	9008
Mexican fuel oil (petroleum)	0·952	1·00	83·6	10·9	1·5	2·85	0·17	12·2	93°C.	10350	9734
Mineralised alcohol (commercial)	0·822	—	46·6	12·7	40·56	0·13	—	—	below 20° C	6115	5421

Lignite Tars and Lignite Tar Distillates.

Lignite yields valuable liquid products by destructive distillation. The tar is of a butterke consistency and possesses a specific gravity of ·860 to ·920. Its sole use in the raw state is as uel for Diesel engines, for which purpose its richness in aliphatic hydrocarbons makes it behave milarly to petroleum. It therefore does not require either raised cylinder compressions or the se of an ignition oil.

Fuels for petrol engines and heavy oil engines can be obtained from lignite tar by distillaon. Their properties are very similar to those of the corresponding fractions obtained from etroleum.

Tar oils were used in considerable quantities on Diesel engines in this country during the war riod on account of the scarcity of petroleum. The difficulties encountered in burning tar oils e mainly due to their comparatively high spontaneous ignition temperature. The ignition of e fuel charge in a Diesel engine is dependent upon the temperature of compression, no special

ignition device being provided. With the fuel oils derived from petroleum or shale it has be found that a compression pressure of 450 to 500 lbs. is sufficient to ensure regular ignition und starting conditions and at all loads. Whereas the spontaneous ignition temperature (in atm sphere of oxygen) of petroleum and shale oils is in the neighbourhood of 270° C., this val for tar oils is generally over 400° C.* As a result of the high ignition point engines will n start, or run at low loads, on tar oil unless special means are taken for raising the temperatu of the air in the combustion space at the time of fuel injection. The more important metho adopted for this purpose are—(1) to heat the cycle air, blast air and fuel, (2) to increase t

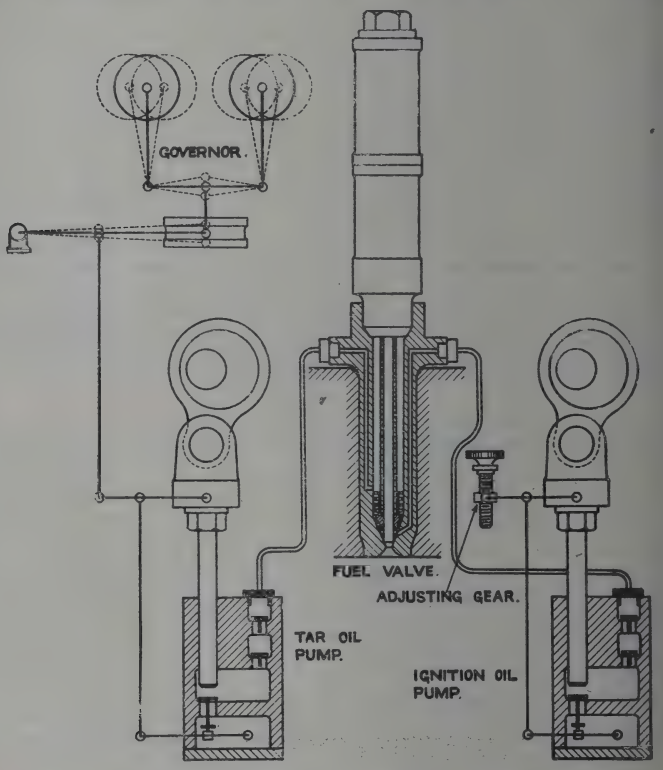


FIG. 29.—Diagrammatic Arrangement of Fuel Pumps for Tar Oil Engine.

compression ratio, (3) to employ an ignition oil, and (4) to inject a small charge of tar oil pr to the main tar oil charge.

Heating of cycle air, blast air and fuel is difficult to effect under starting conditions a has a deleterious action on the fuel valve when running. The increase of compression neces tates a specially heavy design of engine to withstand the higher stresses on liners, cylinder cov and bearings. To ensure certain starting on tar oils the compression would require to exce 600 lbs. The starting difficulty may be overcome by running the engine on a petroleum before closing down and when starting. If the engines can be always maintained at half load over, a compression pressure of about 550 lbs. per square inch will give good running.

* Moore, *Jour. Soc. Chem. Ind.*, February 15, 1917, p. 109.

The introduction of a small charge of a petroleum oil into the working cylinder prior to the ain charge of tar oil has been found the most satisfactory method of burning tar oils. The nition oil charge is pumped to the atomiser nearer the cylinder than the place where the main r oil charge enters. Thus when the fuel valve opens the ignition oil is first injected into the linder and is immediately followed by the tar oil charge. The combustion of the ignition oil ats the air in the cylinder so that the temperature exceeds the spontaneous ignition temperature the tar oil. The proportion of ignition oil is 6 to 8 per cent. of the total fuel at full load; at her loads the quantity of ignition oil remains practically constant, the proportion increasing about 50 per cent. at no load. This method has been found to yield satisfactory results at all ads, and under starting conditions, with cylinder compression pressures of 480 to 500 lbs. per uare inch. An arrangement of ignition oil gear as given in a paper by Mr. C. Day,* is shown fig. 29. Devices have been designed to give a small charge of tar oil prior to the main charge tar oil. The device is so arranged that the initial tar oil charge is not accompanied by any preciable blast air, the expansion of which would reduce the temperature of the combustion ace. Such devices are said to have given good results on the Continent, but are little used in is country.

In addition to the ignition question tar oils are particularly liable to form deposits in the omisers of Diesel engines. A résumé of some experiences of burning tar oils on Diesel engines is given by Mr. G. Porter in a paper read before the Diesel Engine Users' Association, May 24, 17. In this paper several specifications for tar oils for use in Diesel engines are given. An stract of these specifications is appended below :—

Specifications of Tar Oil Fuel for Diesel Engines.

(1) Specification of the M.A.N. Company :—

The tar oil must be a distillate of coal tar.

The oil must flow freely at 61° F., and on being cooled down to 46·5° F. and resting in a ace undisturbed by vibration no separation shall take place at this temperature within the ace of half an hour.

The following constituents shall not be present in quantities greater than the stated rcentages—

Ash	·05 per cent.
Sulphur	1·0 „

Proportions of water and coke residue not stated.

Per cent. insoluble in xylol ·2.

(2) Continental specification for tar oil quoted by Mr. C. Day in his paper on 'Tars and Tar ls as Fuel for Diesel Engines' (January 19, 1916) :—

Tar oils must not contain more than a trace of constituents insoluble in xylol.

The water content should not exceed 1 per cent.

The coke residue should not exceed 3 per cent.

At least 60 per cent. of the oil should be distilled on heating up to 300° C. (572° F.).

The net calorific value should not be less than 15,840 B.Th.U. per pound.

The open flash point must not be below 65° C. (143·6° F.).

The oil must be quite fluid at 61° F.

(3) Specification of tar oil proposed by Mr. C. Day (January 19, 1916) :—

The tar oil must be a product of the distillation of coal tar. No product that has not dergone distillation must be present.

Per cent. insoluble in xylol	Not more than	2·0
„ ash	„ „	0·08
„ water	„ „	2·5
„ coking residue	„ „	3·0

The oil must be liquid at 60° F. when maintained at that temperature for half an hour.

---

* C. Day. Paper read before the Diesel Engine Users' Association, January 19, 1916.

(4) Specification of tar oil by Mr. Batho (the Diesel Engine Users' Association, February 23 1916) :—

Specific gravity—Between 1·0 and 1·1.
Viscosity—Generally 2° Engler.
Flash point—100° F. to 130° F.
Colour—One drop on white paper should show no black residue, as is the case with tar.
Lower calorific value—Between 15,800 and 16,500 B.Th.U. per 1 lb.
Ash—Should not exceed 1 per cent. (unburnt residue of tar oil is mostly harmless).
Water—Should not exceed 1 per cent.
Sulphur—·5 to 1 per cent.

The burning of raw tars on Diesel engines has been accompanied by the same difficulties a the burning of tar oils, but an additional trouble is encountered on account of the free carbo which is always present in raw coal tars.

Furnace Firing with Liquid Fuel.

Liquid fuel possesses many advantages over coal or other solid fuels for furnace firing. Th advantages when using heavy petroleum oils may be briefly enumerated as follows :—

(1) Petroleum fuel oil possesses a gross heat value of approximately 19,200 B.Th.U., whils the gross heat value of coal averages about 14,000 B.Th.U. This fact alone shows two pound of oil to be about equivalent to three pounds of coal.

(2) In spite of its lower specific gravity, oil can be stored in less space than a correspondin weight of coal.

One ton of coal occupies about 43 cubic feet.
„ oil „ 40 „

For marine purposes oil is conveniently stored in ballast tanks and inaccessible places, whic could not be utilised for coal bunkerage.

(3) Oil rarely contains more than 0·1 per cent. of ash, a negligible quantity, while coa may contain as much as 15 per cent. ash. This ash necessitates the removal of clinker from th fires, and besides involving expense it causes a serious loss of heat.

(4) Oil can be conveyed by pipe line, a cheaper, cleaner and more rapid method than any method of coal conveying.

This is of great importance in naval work.

(5) Oil firing does not involve so much manual labour and attendance charges which accompany furnace firing with solid fuel.

(6) A boiler fired with oil will raise about 30 per cent. more steam than the same boiler coa fired.

(7) The furnace doors can be kept closed when oil firing, thereby increasing the efficiency of the boiler and lessening the wear and tear on the boiler plates caused by frequently being chilled with cold air, as is the case when burning solid fuel.

(8) Boilers can raise steam much more quickly when oil fired, thus lessening stand-by charges

(9) Boilers fitted for burning both solid and liquid fuel may be run on coal under norma conditions, while oil can be burned for peak loads, thus minimising the number of boilers i use.

1 lb. coal under favourable conditions raises 9 lbs. steam.
1 lb. oil under similar conditions raises 14½ lbs. steam.

It is essential that firing devices for liquid fuel should break the oil into an exceedingly fin state of division, so that the air can reach the oil readily and ensure speedy combustion.

The methods of breaking up the oil are :—

(1) By means of steam.
(2) By means of compressed air.
(3) By a high pressure on the oil, which is pulverised on passing through a fine jet.
(4) By means of mechanical breaking up in a pulverising chamber.

Steam Jets.

The majority of oil-burning installations used on land are operated by steam. Steam i always available at the face of the boiler, and at the same time steam burners, though not giving quite so high an efficiency as air burners, give a soft flame, which is less liable to injure the plate or tubes with which it comes into contact. For marine purposes there is a distinct disadvantage in the use of steam on the oil burners, as it causes the loss of a considerable quantity of water which has to be carried in storage tanks or else has to be specially prepared by a distillation plant whilst at sea. This drawback does not apply to land installations, where plenty of wate is usually available. Steam burners operate on a variety of principles, the majority of construc tions being somewhat in the form of an injector.

The Kermode steam jet burners, which have met with much success on land service, are designed to impart a rotary motion to the gases by passing the oil through a helical groove. The steam is passed through an annular space surrounding the oil duct, and in addition to causing atomisation, it is used to induce an air current which assists in the combustion of the fuel.

With the Holden steam jet burner, fuel steam and air are passed through annular spaces, the centre of the burner being left open to facilitate cleaning.

Another principle used for pulverising oil by a steam jet is to allow the oil to trickle from a weir over a thin slit through which the steam is passing. This system is used in the common type of burner known as the 'Mexican trough.' A modification of this principle is also used in the Ajax burner, made by Meldrums Ltd.

Compressed Air Burners

The use of compressed air for pulverising purposes allows a higher efficiency on boiler-firing installations. At the same time the saving is not so great as might be anticipated, as the steam or power used for driving the compressors is almost as great as the amount lost through steam burners. The flame has a higher temperature than that of the steam jet, and greater care must be taken to prevent it impinging on the plates. Some of the most recent types of compressed air burners will operate on air at low pressure (about 10 lbs. per square inch), and therefore do not necessitate costly air compressors, as they can be operated with complete satisfaction by low-pressure air from a rotary blower. Such burners are the 'White' burner, the 'J. Samuel White,' and one of the burners by Alldays & Onions.

The Oil Pressure System.

This is mainly used for marine purposes, and complete oil-burning installations on this principle are comparatively expensive, on account of the necessity for well-constructed and effective preheaters, filters, and the specially constructed fuel pumps.

In this type of burner the oil is forced through fine jets under a comparatively high pressure. Many burners are so constructed as to impart a rotary motion to the pulverised fuel (*e.g.* Korting burner). The pressure system, although expensive, is probably the most efficient of oil-burning appliances. The power consumed in driving the fuel pumps is almost negligible, and the combustion is excellent. The pressure system is meeting with much success in marine work at the present time. Good examples of this type of apparatus are made by the Wallsend Slipway Co., Kermode, and Korting.

Mechanical Pulverisers.

It is possible also to pulverise oil by mechanical means, such as breaking the oil up in a squirrel cage. The rich oil-fog thus produced can then be treated as a gas and burned together with secondary air in the furnace. Installations of this type, however, have not met with much success, probably on account of their high initial cost.

Atomisers.

Holden's steam atomiser is shown by fig. 30; fig. 31 shows the Guyot atomiser used in the French Navy.*

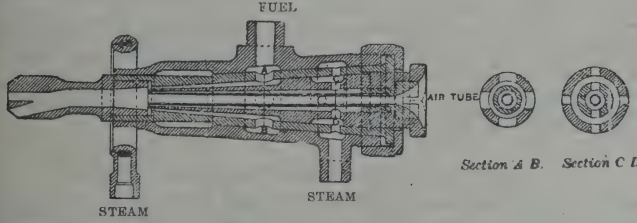


Fig. 30.

Where boilers have the mixed coal and oil system, the oil is best atomised into the front of the furnace, parallel with the grate and about 10 ins. above it.

Where liquid fuel is used alone, the draught required is very small, because the greater part of the draught is always spent in overcoming the resistance of the fuel bed on the grate.

* From 'Liquid Fuel and its Combustion,' by W. H. Booth.

Whereas the calorific capacity of liquid fuel is roundly 20,000 B.Th.U. per pound, as compare with 15,000 for best coal, the commercial value is more nearly as 2 : 1, because liquid fuel can t burned perfectly with very little excess of air, and the temperature in the furnace is higher, th boiler efficiency is better, the boiler being also cleaner, and there are no expenses for removal ashes and for flue cleaning. About 15½ pounds of air are required chemically to burn one poun of liquid fuel, or say 200 cubic feet of air. In the mixed system of coal and oil firing, a larg excess of air may be admitted through the coal fire, and will be used by the oil, which is atomise above the fire.

In locomotives the blast-pipe may be much enlarged for liquid fuel so as to soften the draugh The Macallan variable blast-cap is used on the G. E. Section of the L. & N.E. Railway for thi purpose. The flow of oil requires special regulation. Exactness is secured by such devices a a stop-cock, in which the hole through the plug is square and placed diagonally, thus admitting fine regulation.

To be successful, the burning of oil fuel must follow the lines of successful bituminous co combustion, viz., air mixture, space, and temperature; hence the need for refractory brick lining to keep off the too early chilling effect of cold plates. In steam raising, liquid fuel has a highe percentage efficiency than solid fuel, because less excess of air need be employed; furnace temper ture is higher, causing higher efficiency of heating surface, which is also cleaner. There is a larg

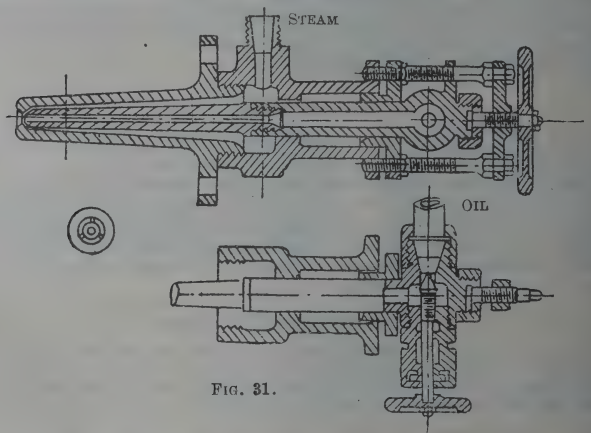


FIG. 31.

saving in labour of stoking, cleaning, ash removal, etc., but perhaps greater expense in firebrick renewals.

Liquid fuels can be burned by means of mechanical burners, without steam or air spraying, i heated to not much more than 140° F., and forced through a whirling jet nozzle at a pressure o not less than 40 lbs. per sq. in. and, with benefit, up to 150 lbs.

For general purposes ashore, high-pressure steam is a more satisfactory spraying agent than air

At sea, for forced draught conditions, the United States Navy Liquid Fuel Board consider a to be the best medium, especially as it avoids the otherwise inevitable loss of fresh water.

In the ss. 'Nebraskan,' oil heated to 175° F. was atomised by air of 1¼ lb. pressure. The oi had a pressure itself of 15 lbs., and a very fine spray resulted; the air was heated. Retarders were necessary in the 3-in. tubes of the Scotch boilers to enable the heat of the gases to be utilised by retarding the flow, or probably by mixing up the gas.

WALLSEND-HOWDEN PATENT LIQUID FUEL BURNING SYSTEM.

In this system the liquid fuel is injected into the furnaces under pressure by means of specia oil-fuel pumps, these pumps being fitted in duplicate so that one can act as a stand-by in cases of breakdown to the working pump. On its way to the burners the liquid fuel is passed through strainers and heaters in which it is thoroughly filtered and then heated to the correct temperature

The oil is forced into the furnace in the shape of a conical spray of exceeding fine particles which burst into flame at a distance of six to eight inches from the nozzle. The flame being conical, and there being no fire-bars fitted in the furnace, the whole circumference of the furnace is available for heating surface. This is a great advantage in the ordinary multitubular boiler, as the lower portion of the boiler becomes heated sooner than would be the case with coal and consequently the circulation of the water in the boiler is improved. Moreover, as the lowe

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MARINE ENGINES
WATER TUBE BOILERS
55FT MOTOR CRUISER
COASTAL MOTOR BOAT
MOTOR VAN
MOTOR OMNIBUS

portion of the boiler is heated up uniformly with the upper portions, and as there is no inrush of cold air, since there are no furnace doors to be opened, there is practically none of that straining action which results from unequal expansion and contraction, due to rapid changes consequent on the opening of the door in coal stoking.

In the improved construction of the furnace front arrangement (fig. 32), which constitutes the principal feature of the arrangement, each of the oil fuel spraying nozzles projects through a

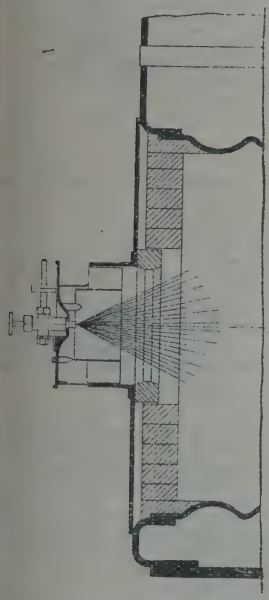


FIG. 32.—Arrangement for Working under Natural Draught or Closed Stokehold Draught.

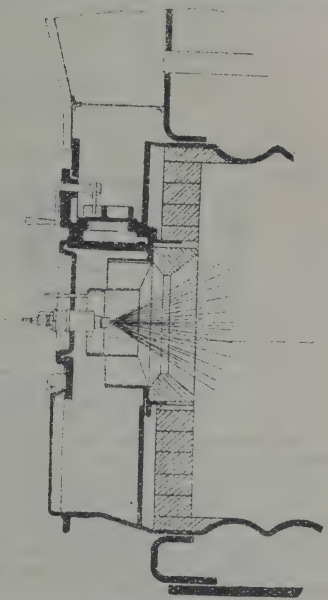


FIG. 33.—Arrangement for Working under Howden's Forced Draught.

baffle plate or the front plate of the casing into an air trunk having lateral openings at its outer end. This air trunk projects concentrically with a second air trunk carried by the furnace front, and the annular space between the inner and outer air trunks is fitted with deflectors constructed in such a manner as to give the air passing through the annulus a spiral motion. One result of this arrangement is, that the openings for the supply of air are so disposed that direct radiation of heat from the furnace is prevented. The admission of air through the second or outer air trunk keeps the outer casing cool, and hence radiation from this part is reduced to a minimum. A feature of the arrangement is the small amount of brickwork required.

With this system steam can be raised on any boiler from the start by means of oil fuel. This advantage is obtained by means of a special design of auxiliary heater and pump.

The Wallsend System is specially adapted for burning oil in conjunction with coal.

When burning liquid fuel on this system with Howden's Forced Draught, fig. 33, 16·22 pounds of water were evaporated (from and at 212° F.) per pound of oil burnt. The calorific value of the liquid fuel was 18,770 British Thermal Units, giving a boiler efficiency of 83·9 per cent.

THORNYCROFT OIL FUEL SYSTEM.

In this system, fig. 34, the oil is sprayed under pressure into the furnace by means of special patent sprayer having both edges of supply grooves tangential to the whirling chamber, the spray being produced within a steel cone of special construction which introduces and mixes the air and the oil-spray in such a manner as to produce perfect combustion. The system can be applied to either water-tube or marine type boilers. Water-tube boilers can be arranged for either oil only or coal combined with oil.

The oil, which may be of any crude description such as Texas, Borneo, Mazout, or Shale s stored in tanks in any part of the ship, and is drawn to the stokehold by a pump which for it through the necessary strainers and the tubular steam-heater to the sprayers.

Lighting up is effected with crude oil by means of a U tube and hand-pump. Steam can e raised in from half to three-quarters of an hour.

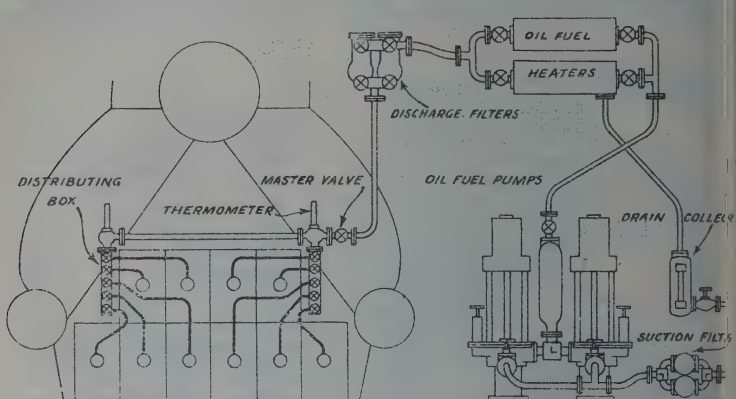


FIG. 34.—The Thornycroft Oil Fuel System.

When fitted in conjunction with Thornycroft boilers of latest design and fairly large size makers are prepared to guarantee that the equivalent evaporation will be at least 16 lbs. water from and at 212° F. per lb. of oil per hour, if the rate of evaporation does not exceed 4 t lbs. per sq. ft. from and at 212°, and they can guarantee a maximum output of 18½ lbs. sq. ft. from and at with an evaporation of 14 lbs. per lb. of oil from and at. This rapid rate evaporation has no detrimental effect on the boiler if the arrangement is properly designe while the combustion is smokeless up to moderate powers, and smoke is only just visible at t highest powers. These results enable very large powers to be developed on small weight, a with the highest efficiency, and at small cost. The number of men necessary for a stokeh developing 16,000 h.p. is only 3.

THE SMITH PATENT FUEL-BURNING SYSTEM.

(Swinney Bros. Ltd., Wansbeck Iron Works, Morpeth.)

With this system it is possible to burn oil or coal with the types of furnace fronts shown figs. 35 and 36, under forced or natural draught, and with a minimum of alteration necessary convert from one fuel to another; this is made possible by the arrangement of the burners, whic are placed at each side of the fire door; the system also allows the burning of coal and o together when necessary.

Furnace fronts designed for burning oil fuel only are also used with this system, and the (as well as those mentioned above) are made to suit all types of boilers for sea or land purpose such as those of the 'marine multitubular,' 'water tube,' Lancashire, etc., types.

When the 'Pressure Jet' system (fig. 37) is in operation, the oil is drawn from a storage tan through a suction filter by means of a pump; it is then delivered through the steam heater, whe the oil is raised to the required temperature, after which it passes through the delivery filter the burners, which project through the furnace fronts.

The 'suction filter' consists of two independent chambers, each having separate contr valves for the inlet and outlet, so that one chamber may be shut off for cleaning whilst the oth is in use.

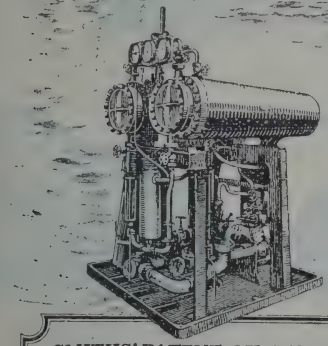
Although any make of 'oil pump' can be fitted in connection with this system, it is usual fit the well-known Weir's make.

The patent 'oil fuel heaters' are suitable for any class of light or heavy liquid fuel, and a also capable of dealing with any mixture of pitch and creosote.

The design of the heater is somewhat similar to the Admiralty type, as far as the tubes an method of securing them in the tube plates is concerned, but its special feature is that the nest tubes is not permanently fixed to the body flanges, but is so arranged that the nest may be with drawn at any time for cleaning or examination. As the inner tube plate and cover are not fixe to the heater body, but are moveable or 'floating,' this allows perfect expansion and contractio

The Patent Low Pressure Oil-Burning Installations for

TO-DAY



1. Suitable for all land and marine work.
2. Burns any class of Fuel Oil.
3. Plant complies with British B.O.T. Standard and all Classification and Insurance Societies' requirements.
4. Plants are built complete as self-contained units, single or duplicate, in sizes to suit all requirements.
5. Actual service efficiencies have been obtained equal to 85% boiler efficiency.

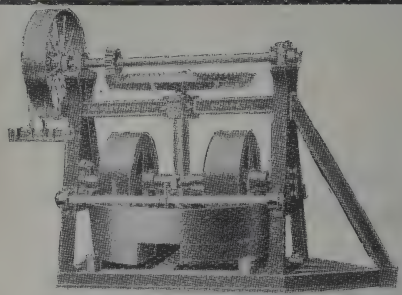
SMITHS' PATENT OIL-BURNING INSTALLATIONS

For estimates and full particulars apply to Sole Licensees and Manufacturers

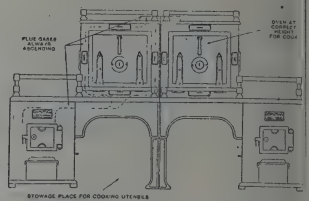
SWINNEY BROS. LTD., *Engineers & Ironfounders*

Wansbeck Ironworks, Morpeth. NORTHUMBERLAND

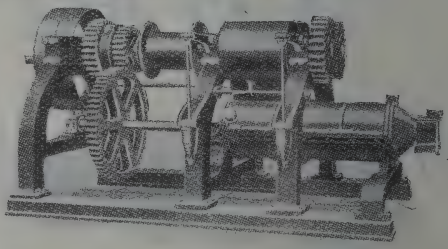
Telegrams: Civoil, Morpeth. *Telephone:* 92 Morpeth (2 lines)



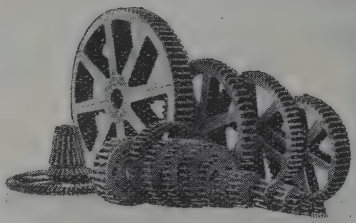
Grinding Mills for clay, mortar, etc.



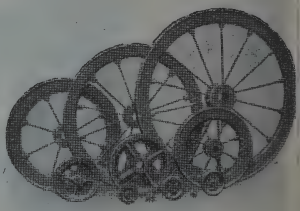
Galley Ranges, coal or oil fired



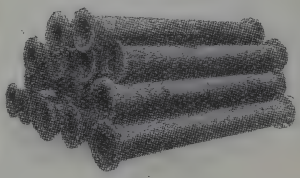
Brick-making Machinery



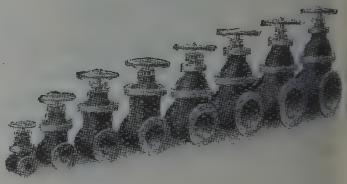
Machine Moulded Wheels



Grooved Pulleys



Pipe Lines



Valves for all purposes

A few of the productions of **Messrs. SWINNEY BROS. LTD.**, *Engineers & Ironfounders*
Wansbeck Ironworks, Morpeth, NORTHUMBERLAND
Telegrams: Civoil, Morpeth. *Telephone:* 92 Morpeth (2 lines)

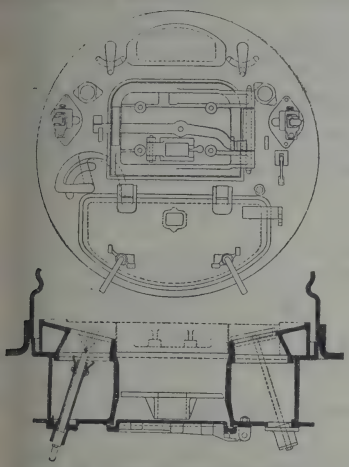


FIG. 35.—Patent Forced-Draught Side-Firing Furnace Front.

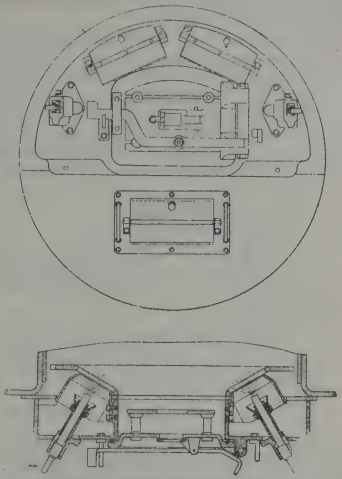


FIG. 36.—Patent Natural-Draught Side-Firing Furnace Front.

SMITH'S PATENT
FUEL BURNING SYSTEM.

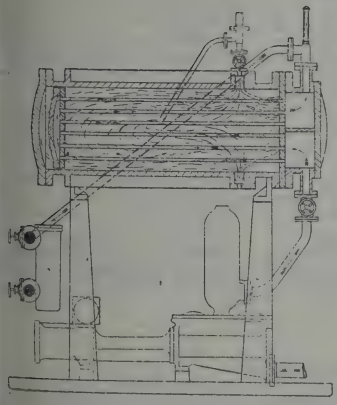


FIG. 37.—Section of Heating Unit: Single Type.

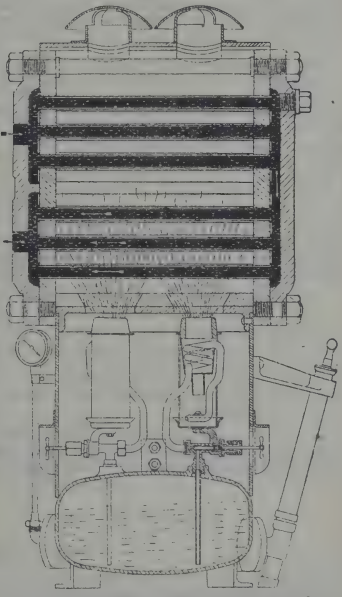


FIG. 38.—Lighting up Heater for starting up Boilers from cold without the use of steam or outside power.

of the tubes to take place, and prevents all possibility of 'working' of the tubes in the tube pla which would cause leakage.

A very important point in this design of heater is that as there are no coils or bends in tubes, they can be cleaned at once of any oil deposits which may lodge on the tube walls wh using heavy oils, such as Mexican flux, or pitch and creosote mixtures.

Each tube is fitted internally with a withdrawable retarder which allows only a flat spi ribbon of oil to come in contact with the tube walls, thereby ensuring the highest efficiency.

The 'delivery filter' is made on exactly similar lines to the suction filter except that t strainers are perforated with much smaller holes, and are able to collect the very fine partic of grit and foreign matter which may pass through the suction filter and pump.

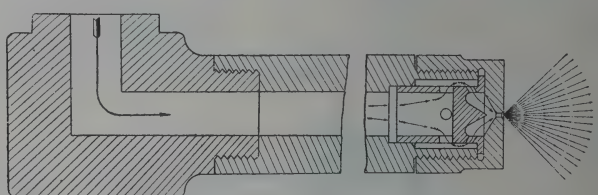


FIG. 39.—Thompson Patent Oil Fuel Atomiser.

The 'burner,' fig. 39, is of extremely simple design, there being only three component par *i.e.* the body, the nozzle, and the diaphragm. The atomising of the oil is obtained solely by t pump pressure forcing the heated oil through the tangential orifices in the diaphragm into the sw chamber, where a rotary motion of exceedingly high velocity is attained; this breaks up the so finely that on issuing from the nozzle it forms a hollow cone of oil mist or vapour which ligl up without noise or explosion when a lighted torch is applied. This burner is highly efficie and on actual service test has given results equal to 85 per cent. boiler efficiency.

For 'lighting up' boilers from cold without the use of steam or any outside source of power 'lighting up heater,' fig. 38, is used; this consists of a small straight tube heater made on the sar principle as the larger steam heaters, but the necessary heat is obtained by two self-heati paraffin lamps which are fixed below the heating tubes, and are also attached to a tank belo which contains the supply of paraffin. The tank is also provided with an air pump for putti air pressure on the paraffin to force the same through the lamps. The flame from these paraf lamps passes through and over the nest of tubes in the heater, thereby heating the fuel oil, whi is circulated through the same by means of a special valveless rotary hand pump; the hot is then led back through connections to the main oil supply lines in order to distribute it any of the furnaces of the boilers. With this apparatus it is possible to start up the fires in abo five minutes from the time of opening out the connections. The whole arrangement is specia designed for safety, and for this reason is connected up in a permanent manner to the oil-delive lines, so that the use of portable pipes and connections is avoided, which prevents any oil bei spilt about the stokehold floor plates, with the consequent danger of fire.

The steam that has been used for heating the oil in the main fuel heaters is drained off throu a 'collector,' which prevents the passing of live steam, and then to a 'filtering observation tan which is specially designed to prevent oil which may be contained in the drain water being pass back into the boiler as feed; as this tank works under atmospheric pressure, the contents a open to observation at any moment. An arrangement of division plates causes an under-wat circulation and allows the oil to float to the top of the various compartments. A filter chamb is provided near the outlet end, and is usually fitted with coke breeze, which can be removed any time for cleaning.

In cases where an extremely small amount of oil is to be consumed, as in small heating boile galley ranges, rivet-heating furnaces, etc., a steam or air jet burner is often advisable, and Smith installations of these types have been specially adapted for this class of work.

FILMA OIL-BURNING SYSTEM.

The Filma oil burners are distinct from marine oil-burning equipment, being intended primari for industrial application for manufacturing and steam-raising processes.

The burners are of three types, but all operate on the system of low pressure atomisation b means of multiple converging steam or air streams.

The oil before atomisation is spread out into a wide continuous flowing film, and is allowed o fall into the paths of atomising streams, which converge in one plane and diverge in the other.

The oil is therefore atomised between the opposing streams as they collide in one plane, and is ıen diffused by their divergence in the other.

Illustrations of this action are shown below.

The collision of the atomising streams causes them to give up the major part of their velocity, ıd the consequent oil mist resulting from the impact drifts forward and outwards at a rate hich permits perfect combustion with a soft flame; thus avoiding the local overheating or ıtting action which results from high velocity flames of concentrated energy.

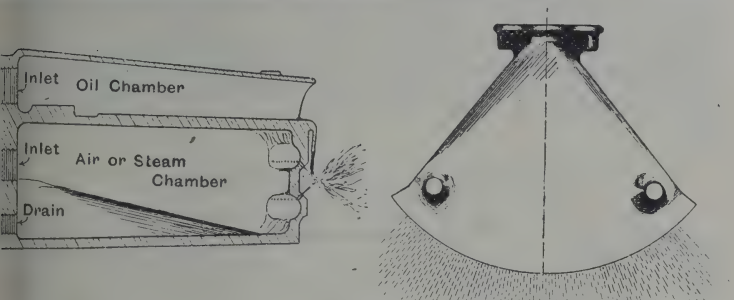


FIG. 39A.

The application of this system of atomisation is made in burners with fan blast, low-pressure and steam for horizontal, vertical, and downward firing.

The same system is also in extensive use for domestic heating appliances, quite apart from ınace and boiler work.

With these burners the quantity of atomising agent for power generation, calculated on ver available for steam generation, is with fan air about ½ per cent., with compressed air 2 per ıt., and with steam 4 per cent.

THE PRIOR OIL FUEL SYSTEM.

The burner in this system (which has been introduced by the Akt. Ges. Prior, of Lugano) has ough-like form and the oil flows into it by gravity. Air for burning the fuel is supplied through 's of holes drilled in the hollow walls. By varying the positions of these air apertures and the pe of the trough the burner can be adapted, it is claimed, for widely different services.

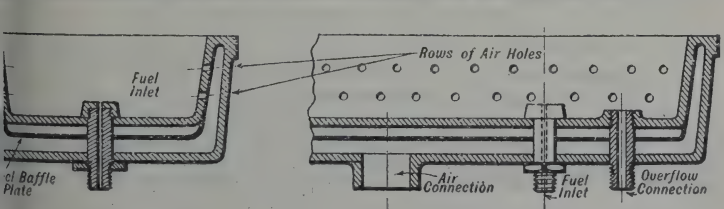


FIG. 39B.

The oil to be burned is fed by gravity, and an air pressure of about 8 in. water column is ided by a fan. The burner itself (fig. 39B) consists of an open cast-iron trough with hollow ls which serve as air-heating spaces. The oil is delivered at the bottom of the trough through or more inlet connections with approximately a $\frac{3}{16}$ in. aperture, terminating about ½ in. ve the bottom of the trough. There is also an oil overflow connection, which is lower. Air

to support the combustion of the oil is supplied through two rows of staggered holes which are arranged in the sides of the trough, and are given such an angle that the air jets tend to pick up the gasified fuel from the bottom of the burner. Below the bottom of the trough a steel baffle plate is welded on to the inner wall for the purpose of preventing undue heat from penetrating down to the air preheating spaces.

The burner is lighted by placing a piece of oily waste in the trough and turning on the fuel supply with a reduced quantity of air. Starting from cold the time taken may be only four to five minutes before the flame is brought up to a normal working height. If the burner has been previously in use the lighting-up period will be still shorter, while with a thoroughly hot burner the flame can be shut off and instantaneously re-ignited. A feature of the burner is the way in which the height of the flame can be regulated from only a few inches or about the height of the trough, to its full height of about 3 ft. Under varying loads a bright and smokeless flame can be maintained. An indexed fuel cock enables a constant flame height to be maintained without any attention on the part of the attendant.

A wide variety of oil fuels has been tested with the arrangement, and it has been found possible to burn heavy Mexican oils without trouble. With such oils there is a slight asphaltic deposit on the inner surfaces of the burners, which, however, can be easily removed. When using ordinary furnace oils the deposit is of a sooty nature and is dispersed automatically by the action of the flame.

Air Required for Oil Fuel Combustion.

The amount of air required in practice at normal atmospheric temperature for the combustion of 1 lb. of oil fuel, is from 250 to 450 cub. ft.; this is 1·6 to 2·5 times the theoretical amount.

British Admiralty Specification for Oil Fuel for the Navy.

(*Abstract.*)

'The oil fuel supplied shall consist of liquid hydrocarbons, and may be either (*a*) shale oil or (*b*) petroleum, as may be required, or (*c*) a distillate or a residual product of petroleum, and shall comply with the Admiralty requirements as regards flash-point, fluidity at low temperatures percentage of sulphur, presence of water, acidity, and freedom from impurities.

'The flash-point shall not be lower than 175° Fahr., close test (Abel or Pensky-Martens). 'The proportion of sulphur contained in the oil shall not exceed 3·00 per cent. The oil fuel supplied shall be as free as possible from acid, and in any case the quantity of acid must not exceed 0·03 per cent., calculated as oleic acid when tested by shaking up the oil with distilled water, and determining by titration with decinormal alkali the amount of acid extracted by the water methyl orange being used as indicator. The quantity of water delivered with the oil shall not exceed 0·5 per cent.

'The vicosity of the oil supplied shall not exceed 2,000 secs. for an outflow of 50 cubic centimetres at a temperature of 32° Fahr., as determined by Sir Boverton Redwood's standard viscometer (Admiralty type for testing oil fuel). The oil supplied shall be free from earthy carbonaceous, or fibrous matter, or other impurities which are likely to choke the burners.'

British Admiralty Specification for Oil Fuel for use in Diesel Engines.

'Quality :—The oil fuel supplied shall consist of liquid hydrocarbons, and may be either (*a*) shale oil, or (*b*) petroleum, as may be required, or (*c*) a distillate, or a residual product of petroleum, and shall comply with the Admiralty requirements as regards flash-point, fluidity at low temperatures, percentage of sulphur, presence of water, acidity and freedom from impurities.

'The flash-point shall not be lower than 175° Fahr., close test (Abel or Pensky-Martens). (This compares with a flash-point of 200° Fahr. in 1910.)

'The proportion of sulphur contained in the oil shall not exceed 3·00 per cent. (as against 0·75 in 1910).

'The oil fuel supplied shall be as free as possible from acid, and in any case the quantity of acid must not exceed 0·05 per cent., calculated as oleic acid when tested by shaking up the oil with distilled water, and determining by titration with decinormal alkali the amount of acid

extracted by the water, methyl orange being used as indicator. (In 1910 it was required that the oil should be free from acidity.)

'The quantity of water delivered with the oil shall not exceed 0·5 per cent.

'The viscosity of the oil supplied shall not exceed 2,000 secs. for an outflow of 50 cubic centimetres at a temperature of 32° Fahr., as determined by Sir Boverton Redwood's standard viscometer (Admiralty type for testing oil fuel).

'The oil supplied shall be free from earthy, carbonaceous, or fibrous matter, or other impurities which are likely to choke the burners.

'The oil shall, if required by the inspecting officer, be strained by being pumped on discharge from the tanks, or tank steamer, through filters of wire gauze having 16 meshes to the inch.

'The quality and kind of oil supplied shall be fully described. The original source from which the oil has been obtained shall be stated in detail, as well as the treatment to which it has been subjected and the place at which it has been treated. The ratio which the oil supplied bears to the original crude oil should also be stated as a percentage.'

Special Oil Mixtures used for External Combustion.

Pitch-Creosote Mixtures.

Recently the use of mixtures of pitch and coal tar creosote has become common for furnace firing.

The pitch creosote oils are marketed in three grades containing 25 per cent., 50 per cent., and 75 per cent. pitch respectively. As pitch is but little lower than creosote in heat value, and generally commands about half the price, there is a pronounced economic advantage in burning pitch mixtures wherever possible.

Petroleum-Tar Mixtures.

The addition of tar or tar products to heavy petroleum oils causes a thick semi-solid deposit of pitch to separate, and this has till recently prevented the use of such mixtures. This difficulty has recently been overcome by the use of emulsifying agents which are capable of maintaining the constituents in a state of emulsion for prolonged periods.

Coal Dust-Petroleum Mixtures.

The U.S. Navy authorities have met with success in preparing fuel mixtures from very fine coal dust mixed with petroleum fuel oil. The coal is prevented from settling by the action of emulsifying agents. Such oils are claimed to have given satisfaction for boiler firing on the U.S. warships.

Safety in Use of Oil Burners.

Serious accidents to engineers and firemen have frequently occurred from the practice of improper methods of lighting and handling oil fires.

In starting a new fire the steam should be turned on and the bypass opened in order that the oil and steam passage may be cleaned out and warmed up. The bypass should then be closed and the steam shut off. Then the damper must be opened ; on no account try to start a fire with a damper closed. Next light a torch or bunch of oily waste and place about 10 ins. to 12 ins. in front of the burner, turn on a small amount of steam (just enough to carry the oil from the burner tip to the torch) and crack the oil control valve a little. As it generally takes some little time for the oil to fill the burner passage, do not turn on more fuel but wait until the passage is filled, when the fire will light easily.

The moment the fire is out, either intentionally or accidentally, the oil should be shut off and the door opened. After a few minutes the gases (which are violently explosive) will have passed off and the fire may be rekindled.

In regulating a fire the attendant should hold the door open just enough to enable him to watch the flame and be in a position to duck his head in case of a flare back. To increase the fire the oil valve should be operated first, then the steam turned on until the flame is clear. If

not enough steam is used, the flame will appear red and smoky ; too much steam will cause the fire to look ragged and will have a tendency to extinguish it. In reducing the flame the steam is throttled down first, then the oil is reduced.

Once the fires have been set, they may be regulated over quite a range by increasing or decreasing the pressure applied to the oil supply without opening the fire-door or changing the steam supply. This can be done by manipulating the pump throttle or a bypass valve between the suction and discharge lines.

When extinguishing a fire, the flame should be cut down as low as possible ; then by opening the bypass immediately after shutting the oil valve, the oil passage will be blown out without danger, as the flame will not be extinguished until the passage is clear.—*A. C. McHugh.*

Automatic Regulation of Oil Burners.

The operation of oil burners can be made completely automatic by using in steam boilers the steam pressure, in water boilers the water temperature, and in furnaces the furnace temperature, for controlling automatic oil and steam or air valves. When air from an independently driven compressor or blower is used for atomising, it is important to provide automatic means for shutting off oil in case of failure of air supply, in order to avoid explosions.

For automatic control, oil must be kept at a constant temperature by automatically controlling the steam coil or electric heater in an oil-heating tank, otherwise control on account of viscosity changing with temperature is rendered difficult.

The Drayton Regulator and Instrument Co., Ltd., West Drayton, supply complete automatic regulating outfits.

Notes on Oil Fuel.

At a large London factory at which some Lancashire boilers were converted from coal to fuel oil firing, the water evaporation per lb. of coal, having a calorific value of 11,451 B.Th.U., was 7·22, whereas when working with the pressure system of oil burning, using an oil having a calorific value of 18,750, the evaporation per lb. of oil reached 14·44 lbs. The quantity of water evaporated per sq. ft. of heating surface with coal was 3·3 lbs., whereas, according to Mr. A. F. Baillie in a paper read before the Manchester Association of Engineers, the quantity evaporated with oil was over 7 lbs., thereby increasing the boiler rating by over 100 per cent.

In most engines of the hot-bulb type, oil fuel commonly known as gas oil or residuum is employed, this having a specific gravity of between 0·86 and 0·9. In some motors Tarakan crude oil has been used with success, whilst the other Mexican fuel oil, in spite of its relatively high percentage of sulphur, has operated very successfully. Paraffin is, of course, also suitable for these motors, but owing to its high price it is not often made use of.

Oil fuel heaters should be opened up and cleaned out periodically. In the operation of the average plant this should be done at intervals of not less than three months. Deposits of carbonised oil and other impurities quickly lower the efficiency of the heater by preventing the passage of the heat from the steam through the heater walls to the oil.

The fuel oil of oil-fired boilers is often maintained at too high a temperature. The best results are obtained where the oil is at a temperature just sufficient to insure proper and complete atomization. If too hot, the oil tends to turn into vapour and the burners puff and feed irregularly.

GASEOUS FUELS.

The more important gaseous fuels used commercially are generally mixtures. The combustible gases found in such mixtures are hydrogen, carbon monoxide together with the three hydrocarbons—methane, ethylene, and acetylene—also higher hydrocarbons of the series of which these are examples, together with benzene vapour, and occasionally other hydrocarbons.

Calorific Values, etc., of Gaseous Fuels.

In the table, p. 2157, the calorific values per lb. of the usual fuels are given, together with the weight of the products of combustion, both when burnt in pure oxygen and also when burnt in dry air. The 'higher value' is that obtained when the water produced in the combustion is considered as having been condensed to the liquid condition, thus yielding up heat at the rate of about 970 B.Th.U. per lb. produced.

Usually in calculations relating to internal combustion engines it is found more convenient to deal with the volume rather than the mass of the gaseous mixture ; accordingly in the

Fuel. 1 lb. of :—	Sp. Gr. (H = 1).	Burnt to :—	Combustion per Lb. of Fuel.					Heat of Combustion in B.Th.U. per Lb.	
			Lbs. of Oxygen needed.	Lbs. of Air needed.	Weight of Products in Lbs.				
					Burnt in Oxygen.	Burnt in Air.	Lbs. of Nitrogen.	Higher Value.	Lower Value.
Column :—	1.	2.	3.	4.	5.	6.	7.	8.	9.
Hydrogen	1	H_2O	8·0	34·80	9·0	35·80	26·80	61,500	52,800
Marsh gas	8	H_2O & CO_2	4·0	17·40	2·75 CO_2 2·25 H_2O 5·00 Total	18·40	13·40	24,000	21,820
Carbon	—	CO	1·334	5·80	2·334	6·80	4·466	4,400	4,400
Carbon	—	CO_2	2·667	11·60	3·667	12·60	8·933	14,600	14,600
Acetylene	13	H_2O & CO_2	3·077	13·385	3·3846 CO_2 0·6924 H_2O 4·077 Total	14·385	10·308	21,850	21,180
Carbon monoxide	14	CO_2	0·571	2·484	1·571	3·484	1·913	4,370	4,370
Olefiant gas	14	H_2O & CO_2	3·4285	14·914	3·143 CO_2 1·285 H_2O 4·428 Total	15·914	11·486	21,900	20,660
Alcohol (abs.) (vapour)	23	H_2O & CO_2	2·087	9·078	1·913 CO_2 1·174 H_2O 3·087 Total	10·078	6·991	12,420	11,285
Normal benzene (vapour)	39	H_2O & CO_2	3·077	13·385	3·385 CO_2 0·692 H_2O 4·077 Total	14·385	10·308	18,000	17,330

following table the calorific value and weight per cubic foot at N.T.P. and also at 60° F. a atmospheric pressure are given for the usual fuels :—

CALORIFIC VALUES, AND WEIGHTS PER CUBIC FOOT.

1 Cubic Foot of Gas.	Weight in Lbs. per Cub. Ft.		Calorific Value; B.Th.U. per Cub. Ft.			
			At N.T.P.		At 60°F. & 1 Atm.	
	At N.T.P.	At 60°F. & 1 Atm.	Higher.	Lower.	Higher.	Lower.
Column :—	1.	2.	3.	4.	5.	6.
Hydrogen	·00559	·00529	344	295	325	279
Methane	·04472	·04231	1,073	976	1,015	924
Acetylene	·07267	·06875	1,588	1,539	1,502	1,456
Carbon monoxide	·07826	·07403	342	342	323·6	323·
Ethylene	·07826	·07403	1,714	1,617	1,621	1,529

One cubic foot of CO_2 at N.T.P. weighs ·12298 lb.; in its formation from free carbon an oxygen 490 B.Th.U. were evolved.

At 60°F. (15·5° C.) and 1 atm. one cubic foot of CO_2 weighs ·11634 lb., and in its formatio 463 B.Th.U. were evolved.

In the following table the volumes of oxygen and of air just necessary for the complete com bustion of one cubic foot of gas are given, together with the change of volume of the product of combustion and the heat evolved per cubic foot of the mixture of gas and air befor combustion :—

VOLUMES OF OXYGEN AND OF AIR NECESSARY PER CUBIC FOOT OF GAS, AND HEAT PER CUBIC FOOT.

One Cubic Foot of Gas.	Cubic Feet for Complete Combustion.		Vol. of Mixture before Combustion in Cub. Ft.		Cubic Feet of Nitrogen in Mixture.	Ratio of Vol. of Nitrogen to whole Volume.	Vol. of Mixture after Combustion in Cub. Ft.		Ratio of Final to Initial Volume.	B.Th.U evolved per Cub. Ft. of Initia Volume with Air at 60°F. & 1 Atm
	Of Oxygen.	Of Air.	With Oxygen.	With Air.			With Oxygen.	With Air.		
Column :—	1.	2.	3.	4.	5.	6.	7.	8.	9.†	10.*
Hydrogen	0·5	2·4	1·5	3·4	1·9	·56	1·0	2·9	·853	82
Methane	2·0	9·6	3·0	10·6	7·6	·716	3·0	10·6	1·000	87·2
Acetylene	2·5	12·0	3·5	13·0	9·5	·731	3·0	12·5	·962	112·0
Carbon monoxide	0·5	2·4	1·5	3·4	1·9	·56	1·0	2·9	·853	95·2
Ethylene	3·0	14·4	4·0	15·4	11·4	·740	4·0	10·6	1·00	99·3

† Of mixture with air. * Lower values.

Hydrogen.

From the above table it will be noted that a hydrogen-air mixture contracts after combustion to only ·853 of its initial volume, the pressure of the explosion being correspondingly reduced. Further, notwithstanding the very high calorific value of hydrogen *per pound*, its excessive bulkiness results in a heat evolution of only 82 B.Th.U. *per cubic foot* of its admixture with air at 60°F. and atmospheric pressure. Hydrogen-air mixtures are also very sharply explosive and trouble is experienced in engines from pre-ignition at the compression pressures usual in practice when hydrogen is present in large proportion in a gaseous fuel. Thus it is clear that hydrogen alone would be a comparatively poor and very troublesome fuel to employ for power purposes, though its presence is often beneficial in conferring sufficiently prompt inflammability upon dilute mixtures of other gases. For heating purposes a large hydrogen content is advantageous on account of the high temperature obtained in its combustion. Hydrogen constitutes about 45 per cent. by volume of modern coal gas, on the average.

Marsh Gas.

Marsh Gas (Methane) is an excellent fuel for power purposes; it has a greater heat value per cubic foot of air mixture than hydrogen, and the volume of the products of combustion is equal to that of the mixture before combustion.

The 'natural gas' so largely used in the United States consists principally of marsh gas at of Olean (N.Y.), for example, containing no less than 96½ per cent. of this constituent. In 08 more than 100,000 horse-power was developed by engines operated by natural gas in the nited States; the gas usually issues from the wells at high pressure, occasionally approaching 000 lbs. per sq. in. The Snow engine of the N.Y. & Penn. Traction Co. at Olean is supplied r natural gas issuing at a pressure of 200 lbs. per sq. in., which is reduced down to 1·8 lb. per in. before being admitted, mixed with air, to the engine. With natural gas compression essures of 150 lbs. per sq. in. are common, and mean effective pressures of 80 lbs. per sq. in. e often attained.

Acetylene.

Acetylene has so far been but little used as a fuel for internal combustion engines. It is very olently explosive when mixed with air, and owing to its endothermic nature the pressure veloped is unusually high.

The range of explosive mixtures with air is also considerable; Grover found that at atmoheric pressure explosive mixtures were produced with one volume of acetylene to from 4 to volumes of air; at a compression of three atmospheres even a 30 : 1 air-acetylene mixture as found to be explosive.

Acetylene is soluble in water to the extent of 1·1 volume; in alcohol to about 6 volumes : nile acetone at 60°F. and atmospheric pressure absorbs about twenty-five times its volume the gas, and at a pressure of about 180 lbs. per sq. in., about 300 volumes. A solution of etylene in acetone contained in a porous matrix under a pressure of 150 lbs. per sq. in., is sold mmercially as dissolved acetylene ('D. A.'); the 'D. A.' cylinders contain 100 times their vn volume of acetylene at 60°F. and ten atmospheres. Commercial calcium carbide on ldition of water usually yields about 4½ cubic feet of acetylene per lb.

If bubbled through petrol, acetylene gas becomes heavily 'carburetted'; 100 cubic feet acetylene thus treated will produce about 150 cubic feet of 'carburetted' acetylene. ccording to Dr. Caro, as a heating agent this exceeds pure acetylene about in the ratio of 3 : 2.

Used as a fuel for internal combustion engines some remarkable results have been obtained ith acetylene. Some early tests on a 2 h.p. engine showed that only 8¾ cub. ft. of the gas were quired per b.h.p. hour, as against 35 cub. ft. of coal gas. In another case 6·35 cub. ft. of acetyne yielded 1 b.h.p. hour. And with a 6 h.p. engine using a 20 : 1 mixture, and a compression essure of 115 lbs. per sq. in., Cuinat found that only 6·26 cub. ft. of acetylene were consumed r b.h.p. hour, the consumption by volume of coal gas being about three times as great. Specially signed acetylene engines of from 1 to 10 b.h.p. are built; these are mainly employed in pumpg water for the generators of large village installations. The average consumption is about cub. ft. of acetylene per b.h.p. hour, costing about 2½*d.*; it is thus an expensive fuel for power rposes, as at present produced.

Several types of acetylene self-starting devices for the engines of motor vehicles have appeared ring recent years, but unless caution be exercised in their use the extreme suddenness and olence of the starting explosion may result in damage to piston or cylinder.

See also Index.

Carbon Monoxide.

Carbon Monoxide yields the large return of 95·2 B.Th.U. per cubic foot of mixture with r, notwithstanding its low calorific value per lb.; this results from its weight being fourteen mes that of hydrogen. The products of combustion occupy, however, only 0·835 of the volume the original mixture; it is the principal combustible constituent of producer and blast furnace as. Carbon monoxide is extremely poisonous, forming with the red corpuscles of the blood a able chemical compound of a bright red colour termed carboxyhæmoglobin; care must always e taken to prevent any leakage of the gas into the atmosphere, and all engine and producer ouses should be freely ventilated.

Olefiant Gas.

Olefiant Gas (Ethylene) is usually present to a small extent (up to about 4 per cent. by olume) in coal gas, and is a valuable producer of heat.

Owing to Government restrictions on the use of petrol during the war, many trials were made n the use of coal gas as a fuel for motors designed for the use of liquid fuels. Large gas-proof ags have been attached to the roofs of taxi-cabs, or placed underneath motor buses, and good nning obtained by filling up with coal gas at frequent stopping stations. Needless to say, the ileage of such an arrangement is very limited; otherwise its performance is quite satisfactory, nd, at present prices, considerably more economical than the use of petrol.

GASEOUS FUELS EMPLOYED IN GAS ENGINES.

1. Natural Gas.
2. Coal Gas. (See p. 2160.)
3. Coke-oven Gas. (See p. 2161.)
4. Acetylene Gas. (See p. 2161.)
5. Producer Gas. (See p. 2161.)
6. Blast Furnace Gas. (See p. 2177.)

1. NATURAL GAS.

Natural Gas.—Large quantities of natural gas are evolved in most petroleum oilfields. The composition of the gas varies in different localities, but it always contains a high percentage f methane. The net calorific power is usually 750 to 950 B.Th.U. per cubic foot. It is used n gas engines and for heating and illuminating purposes.

2. COAL GAS.

Coal Gas is still almost exclusively used in the smaller sized stationary gas engines, especially in towns ; it is an admirable fuel for internal combustion engines of any size, however large but its use for considerable powers is usually precluded by its relatively high cost. The introduction of the Welsbach mantle, and the largely increased use of gas for domestic heating and cooking, has enabled the gas companies within recent years to supply a gas of lower intrinsic calorific power than formerly at less cost to the consumer, and this reduction in cost has done much to encourage its use for power purposes.

Calorific Power of Coal Gas.

Since the introduction of the Gas Regulation Act in 1920 the gas undertakings in Great Britain ceased to operate on official standards of candle power and are now subject to penalties in default of maintaining their respective standards of calorific power. The choice of calorific power of the gas which is distributed is left in the hands of individual undertakings, thus a wide range of quality is found throughout the country. When utilised in gas engines the factor of calorific power plays an important part, so that the operating data and adjustment of the engine must depend largely on the quality of the gas supply in any particular district. In general, it may be said that the calorific power of the gas supplied by undertakings in the country varies between 470 and 500 B.Th.U. per cubic foot, but there are a few outstanding exceptions, as, for example, the South Metropolitan Gas Company of London which distributes a gas of 560 B.Th.U. per cubic foot, and the Nuneaton Gas Company whose standard is 280 B.Th.U.

CALORIFIC STANDARDS.

	Calorific value of gas.
London (Gaslight & Coke Company)	500 B.Th.U. per cu. ft.
,, (South Metropolitan Gas Company)	560 ,, ,, ,,
,, (Commercial Gas Company)	500 ,, ,, ,,
,, (Wandsworth Gas Company)	470 ,, ,, ,,
,, (South Suburban Gas Company)	500 ,, ,, ,,
,, (Tottenham Gas Company)	500 ,, ,, ,,
Manchester	450 ,, ,, ,,
Liverpool	475 ,, ,, ,,
Birmingham	500 ,, ,, ,,
Bristol	480 ,, ,, ,,

So far as the composition of towns' gas is concerned, it is not possible to lay down any arbitrary figures for the reason that the ultimate analysis varies not only in different localities, but it varies to some degree even in the same locality in accordance with the proportion of water-gas which is added to the mixture of coal-gas and water-gas distributed. As a general guide, however, the analysis given below represents the composition of a normal straight coal-gas having a calorific power of 520 B.Th.U. per cubic foot.

Composition of 520 B.Th.U. Coal-Gas.

	Per cent. by Volume.
Hydrogen	47·0
Methane	27·5
Unsaturated hydrocarbons	3·5
Carbon monoxide	7·75
Carbon dioxide	3·5
Nitrogen	10·5
Oxygen	0·25
	100·00

The gas supplied to-day by nearly all the principal undertakings consists, however, of a mixture of from 75 to 80 per cent. of straight coal-gas (of above analysis) and 20 to 25 per cent. of either blue or carburetted water-gas. In this case the typical composition will be represented by the following analysis :—

Composition of Mixed Gas consisting of 80 per cent. Straight Coal-Gas and 20 per cent. Blue Water-Gas. (480 B.Th.U.)

	Per cent. by Volume.
Hydrogen	48·0
Methane	22·2
Unsaturated hydrocarbons	2·8
Carbon monoxide	13·8
Carbon dioxide	3·7
Nitrogen	9·3
Oxygen	0·2
	100·0

It is important for the gas-engine user to bear in mind that in recent years it has been established at one B.Th.U. will always give the same service irrespective of the quality or concentration of a mixture. In other words, from the point of view of efficiency a poorer mixture (say, 400 Th.U.) can be utilised as efficiently as a rich one (say, 550 B.Th.U.) so long, of course, that combustion is always complete. Proper adjustment depends, therefore, on the variation of the air supply in accordance with the quality of the gas in any particular locality. The volume of air theoretically just necessary for complete combustion may be estimated by aid of the second table page 2158.

Increased economy in consumption is obtained by using mixtures of gas with such excess air, or other gases, that only about 50 B.Th.U. are introduced per cub. ft. of piston displacement for cylinders up to about 20 ins. diameter, while for larger cylinders (30 ins. dia. and above) the figure must be reduced to 40 or even 35 B.Th.U. in order to avoid overheating troubles.

When excess of oxygen is present in the mixture, practically no carbon monoxide is found in the exhaust; with deficiency of oxygen, or irregularity in the mixture, the contrary is to be expected.

Usually in practice the volume ratio of mixture employed is from 7 to 10 of air to 1 of coal gas; the richer mixture gives a greater power output, the more dilute a greater economy in consumption of gas per horse-power hour.

3. COKE-OVEN GAS.

Coke Oven Gas is produced in large quantities at many collieries in the process of manufacture of coke for metallurgical purposes; its composition varies somewhat widely, but it is usually specially characterised by its large content of hydrogen; this renders it peculiarly liable to pre-ignite on compression, and lower compression pressures than usual are generally adopted (to 100 lbs. per sq. in. only) on this account when coke-oven gas is used for power purposes.

Recently, however, the pre-ignition difficulty has been entirely overcome by Sir Dugald Clerk's patented process of introducing from 10 per cent. to 20 per cent. by volume of cooled *exhaust gas* into the inlet pipe; the addition of this inert gas reduces inflammability by diminishing the quantity of oxygen present, and diluting the charge without reduction of its mass. The application is very simple and easily made, and the maximum practicable power of the engine is materially increased.

An average characteristic composition by volume of coke-oven gas may be taken as:—

H, 50 per cent.; CH_4, 25 per cent.; CO, 5 per cent.; $CO_2 + N + O$, 20 per cent.

Such a gas has a lower calorific value per cub. ft. at 60° F. (15·5° C.) and 1 atm. of about 390 B.Th.U., and requires, roundly, 3¾ cub. ft. of air for complete combustion; the heat evolved per cubic foot of this maximum mixture is accordingly $\frac{390}{4{\cdot}75} = 82$ B.Th.U. Actually, the calorific value varies from 350 to 450 B.Th.U. per cub. ft. at 60° F. and 1 atm., and requires from 3 to 4 cub. ft. of air for complete combustion.

In a test by Prof. E. Meyer of a 500 h.p. two-stroke Borsig-Oechelhauser engine of 26½ ins. bore and 37½ ins. stroke (of each piston), running at about 106 revolutions per minute, and driven by coke-oven gas of 395 B.Th.U. (lower) value per cub. ft., the heat consumption per b.h.p. hour deduced from the blower driven by the engine amounted to 9,070 B.Th.U. corresponding to $\frac{9070}{395} = 23$ cub. ft. of coke-oven gas per b.h.p. hour only; the mean effective pressure averaged 70 lbs. per sq. in.

4. ACETYLENE GAS.

Experiments carried out in Germany with acetylene gas for internal combustion engines showed that the proportion of air to gas should be in the ratio of 12·02 to 1 to avoid the formation of soot. The maximum compression which may be used for a mixture of acetylene and air is about three atmospheres, compared with 4–5 atmospheres for petrol and 7 atmospheres for coal gas. One ton of carbide is sufficient to produce 10,000 cubic feet of acetylene.

5. PRODUCER GAS.

In normal combustion, when an excess of air is present in the combustion space, the carbon of the fuel is burnt to form carbon dioxide according to the reaction

$$C + O_2 \rightarrow CO_2.$$

Nitrogen from the air passes through the combustion space into the resulting gas without entering into the reaction. By this reaction one pound of carbon generates 14,647 B.Th.U.

By restricting the air supply and arranging to maintain a comparatively great depth of fuel on the grate the carbon may be burnt into carbon monoxide according to the reaction

$$2C + O_2 \rightarrow 2CO,$$

Nitrogen again passing through the grate without being affected.

By this latter reaction, 4,400 B.Th.U. are generated for each pound of carbon gasified the residual heat value obtainable from the carbon by complete combustion, *i.e* 14,647 − 4,400 = 10,247 B.Th.U., remaining in the resultant gas.

The greatest quantity of heat obtainable in the form of cool carbon monoxide from the air-carbon reaction is therefore only $\frac{10,247}{14,647} = 70$ per cent. of the heat originally available in the carbon.

Of the 30 per cent. of heat given out during the reaction, a large portion leaves the producer in the form of sensible heat.

The heat generated in the producer is sufficient to cause a temperature too high for satisfactory working.

In order to cool the producer and to utilise this excess of heat, steam is introduced into the combustion space, when, if conditions are favourable, the following reaction takes place:

$$C + H_2O \rightarrow CO + H_2$$

For each pound of fuel entering into the reaction 4,320 B.Th.U. *are absorbed* from the heated fuel.

By the use of air and steam in certain proportions, it is possible to absorb the excess heat generated by the air reaction and maintain a practically constant temperature in the producer.

By alternately blowing the producer with an excess of air and raising its temperature by the combustion of carbon, either to the monoxide or to the dioxide, and then cutting off the air supply and passing steam into the hot fuel until the producer temperature has again fallen, it is possible to generate water gas (the result of the steam-carbon reaction) which may be collected separately.

Water gas in conjunction with oil gas (generated by the cracking of heavy petroleum distillates) is largely used for the preparation of illuminating gas in normal times.

As the fuel used is not pure carbon, other considerations than those mentioned in the above theoretical outline affect producer design and working. As coals undergo a destructive distillation in the producers it is necessary to make use of special devices for the removal of tar from the producer gas. The recovery of ammonia generated from the nitrogen of the coal is also of the greatest importance in the economics of producer gas plants. These particulars are treated in greater detail in the following descriptions of various types of plant.

(*a*) Pressure producer gas from anthracite (Dowson).
(*b*) " " " " coke (")
(*c*) Suction and suction-pressure producer gas from anthracite (Dowson).
(*d*) " " " " wood, sawdust, chips (Dowson).
(*e*) " " " " charcoal (Dowson).
(*f*) " " " " coke and anthracite (Dowson).
(*g*) " " " " coke (Dowson).
(*h*) " " " " bituminous coal (Dowson).
(*i*) Pressure producer gas from bituminous coal (Mond).
(*j*) Suction and suction-pressure producer gas from anthracite (Mond).
(*k*) " " " " coke (")
(*l*) " " " " charcoal (")
(*m*) Suction-pressure producer gas from wood, semi-bituminous (")
(*n*) Suction producer gas from bituminous coal (Farnham).
(*o*) Producer gas from other substances, as colliery refuse, sawdust, wood chips, cocoanut shells, belt pickings, lignite, and peat.

In the table on page 2163 some results of analyses are given of producer gas from anthracite coke, and bituminous coal. The number of cu. ft. of air necessary for just complete combustion is obtained by aid of table on page 2158 from the formula :—

$$\text{Cu. ft. of air} = \frac{4{\cdot}8}{100}\left\{\tfrac{1}{2}(H + CO) + 2\,CH_4 - O\right\}$$

Gas Producers and Producer Gas.

Some account of producers and producer gases from material supplied by manufacturers of gas plant is given hereunder :—

Dowson Gas.

The Dowson gas is made by passing a mixture of superheated steam and air through incandescent fuel. There is no external fire, as in ordinary gas retorts, and no skilled labour is required to work the apparatus.

The original type of Dowson plant included a small steam boiler, to give the steam required and to work an air injector. Excellent results have been obtained in this way, and for some purposes it is still the best plant to use. It is now known as the 'Dowson Steam-jet Pressure Plant,' and is used when gas is required from one apparatus to serve several gas engines or one or more engines and heating appliances.

COMPOSITION OF PRODUCER GASES WITH HEAT VALUES, ETC

Description of Producer Gas.	Kind of Fuel used.	Per Cent. Composition by Volume.						B.Th.U. per Cub. Ft. (lower) at 60° F. (15·5° C.) and 1 Atm.	Cub. Ft. of Gas made per Ton of Fuel.	Cub. Ft. of Air required per Cub. Ft. of Gas.	B.Th.U. evolved per Cub. Ft. of Mixture.	Per Cent. Thermal Efficiency of Producer on lower value of Gas.
		H.	CH_4.	CO.	N.	CO_2.	O.					
Column :—	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Dowson Pressure	Anthracite	19·8	1·3	23·8	48·8	6·3	0·0	150·7	171,500	1·41	60·0	82
Dowson Suction	Anthracite	15·7	1·8	22·0	54·5	6·0	0·0	137·5	180,000	1·02	61·8	80
Dowson Suction	Gas Coke	13·0	0·55	25·4	55·65	5·4	0·0	130·0	168,000	0·95	63·3	75
Mond 1. Pressure	Non-Caking Bituminous Coal	22·65	3·5	16·05	44·55	13·25	0·0	147·3	147,500	1·26	65·2	60·4*
Mond 2. Pressure	Ditto	16·60	3·35	27·3	47·5	5·25	0·0	165·4	138,250	1·38	69·6	71·5*
Mond 3. Pressure	Ditto	17·36	1·20	25·55	49·82	5·77	0·30	142	190,000	1·13	66·7	—

* Including steam for blowing engine and washers.

1. With ammonia recovery and steam saturation temp. 175° F. (79·4° C.). 2. Ditto, and 140° F. (60·0° C.). 3. Without ammonia recovery.

Another type of Dowson gas-making plant is the 'Dowson Suction Plant,' which has been installed in large numbers in this and many other countries. This type of apparatus requires no boiler or gas-holder, and the engine itself draws the air required through the fire in the gas generator: the engine, therefore, governs the rate of producing the gas to suit its varying consumption, and there can be no waste of gas. Moreover, the dry steam required is produced by waste heat, and the fuel which is to be converted into gas is also heated by waste heat before it reaches the combustion zone. Throughout the apparatus the loss of heat is therefore reduced to a minimum, and the efficiency is exceptionally high. Sir Dugald Clerk's 'James Forrest Lecture,' delivered in 1904 to the Institution of Civil Engineers, refers to exhaustive tests made by him with this suction plant, the heat efficiency being proved to be about 90 per cent.

In both types of the Dowson apparatus anthracite peas or nuts, charcoal, or coke can be used. The consumption depends somewhat on the type of plant and the kind of fuel used. With the suction plant the Dowson Company guarantee that the consumption of small coke of good quality will not exceed 1¼ lb. per b.h.p. per hour, at full load, with any good gas engine suitably adjusted for working with the plant.

If anthracite peas (from ⅜ in. to ¾ in. cube) are used, the consumption is guaranteed not to exceed 0·9 to 1 lb. per b.h.p. per hour.

As regards stand-by losses careful independent investigations have shown that at four different places Dowson gas generators, ranging from 100 to 375 b.h.p. each, during long stand-by hours, consumed an average of only 3 lbs. per generator per hour, while gas of good quality could be ready for use in about ten minutes. With steam power the stand-by loss is far greater.

A further important advantage of the gas is that it does not condense or lose power on its way to the engine; on the contrary, the more the gas is cooled the better it is for the engine, as each charge of gas which enters the cylinder is more dense, and has consequently greater energy. With steam the condensation in the pipes, etc., is considerable; with gas there is no such loss. It is easy to prevent leaks of gas from the piping, owing to the low pressure of the gas, whereas with steam there is often much loss and inconvenience on this account.

With the suction plant there cannot be a leak of gas when the engine is working, but piping, scrubbers, etc., must be absolutely tight to avoid air leaks.

The wages of firemen are about the same for the gas plant as for a steam boiler of equal power.

The quantity of water per b.h.p. per hour in the gas plant is about 1 gall.; with steam power it is usually two or three times as great. The cost of repairs (pre-war period) is approximately as follows:—

For 100 b.h.p.	£4 per annum.	For 400 b.h.p.	£12 per annum.
„ 200 „	6 „ „	„ 500 „	15 „ „
„ 300 „	9 „ „		

As regards labour, with the suction plant the usual allowance is one man for about an hour each day to start the fire, clean, etc., and about one hour per day to put fuel in the generator. When the plant is worked with a boiler the labour required is greater, but not more than for steam power of equal size.

Although about four volumes of Dowson gas are required to do the same work in a gas engine as one volume of town gas, yet Dowson gas is produced so cheaply that the equivalent of 1,000 cubic feet of ordinary town gas costs only seven to twelve pence, according to the scale of working and price of fuel.

With Dowson gas 1 lb. of coal will produce ·70 cubic feet of gas, and 1 cubic foot of this gas requires only 1·1 cubic foot of air for complete combustion, against 6 to 8 cubic feet for ordinary gas.

A complete Dowson apparatus does not occupy more space than that required for the boiler of a steam engine of the same power.

Dowson gas is used for heating and furnace work of all kinds, as it is a cheap and cleanly fuel, under perfect control.

Their latest plant for heating is known as the high pressure type wherein the gas can be boosted to any pressure up to 100 ins. w.g., delivering the gas clean and steady to the burners. The producer is of the open-hearth type similar to the producer used on their latest suction plant. Space will not permit giving varied examples of the performance of plant and the splendid results with the gas obtained, even for delicate work such as singeing.

The following comparative estimates (pre-war period), for 25 and 50 b.h.p., show that it is much cheaper to use gas power than electricity, even where the latter is sold at 2*d.* per unit:—

25 B.H.P.	Per week. £ *s.* *d.*	Per annum. £ *s.* *d.*
Electricity—25 B.H.P.=18¾ B.Th. units×50 hours =937½ units at 2*d.*	7 16 3	390 12 6
Town Gas Power.—25 B.H.P.×20 cubic ft.×50 hours=22,500 cubic ft. at 2*s.* 6*d.*	2 16 3	140 12 6
Dowson Gas Power.—25 B.H.P.×85 cubic ft.×50 hours=106,000 cubic ft. at 3*d.*	1 6 6	66 5 0

50 B.H.P.	Per week. £ s. d.	Per annum. £ s. d.
Electricity.—50 B.H.P. = 37½ B.Th.units × 50 hours = 1,875 units at 2*d.*	15 12 6	781 5 0
Town Gas Power.—50 B.H.P. × 20 cubic ft. × 50 hours = 45,000 cubic ft. at 2*s.* 6*d.* . . .	5 12 6	281 5 0
Dowson Gas Power.—50 B.H.P. × 85 cubic ft. × 50 hours = 212,000 cubic ft. at 3*d.*	2 13 0	132 10 0

More recently Mr. Dowson has introduced a new type of producer, to work with bituminous al, which is a new departure in several respects. In producers which are worked with bitumin- s coal the tarry vapours from the hydrocarbons in the fuel mix with the gas, and the tar is ually afterwards extracted in separate apparatus. Mr. Dowson has always held the opinion at the tar should be got rid of in the producer itself, and he has succeeded in doing this.

The producer is double-acting—*i.e.* air is drawn in through the top and through the bottom the fuel column. The coal is put in at the top, and the upper part of the fire burns down- ards. The hydrocarbons are distilled off and various reactions occur, the coke which remains aks downwards into the lower part of the producer. The coke is there converted into ordinary oducer gas by the upward current of air (accompanied by steam), which is drawn in at the ttom. The mixture of gases leaves the producer through an outlet about halfway between e top and bottom. There is no external fire, and the gas is made as quickly as it can be con- med, as in the other types of Dowson gas plant.

When working with ordinary bituminous coal, or with lignite and several other varieties of el, there is no tar; it is removed altogether in the producer, and no mechanical or other tar ttractor is required. After leaving the producer the hot gas passes through a vaporiser to ol the gas, and to raise the steam required for making the gas. It then passes through suitable rubbers and is ready for use in the engine to be worked with it.

This bituminous plant is worked by suction, and consequently there is no escape of gas; is also easy to work, and the cost of labour is about the same as with an ordinary plant orking with anthracite or coke.

When the plant is to be worked by the suction of an engine as in the smaller powers, viz., up to 100 h.p., there is a fan to start it, as in ordinary suction plants, and this is stopped when ne engine is running. For powers 100 h.p. and upwards there is a fan or blower to draw the as from the plant and deliver it to the various engines or heating apparatus requiring gas. ach fan or blower produces the suction on the plant and governs the make of gas. Of course ith all heating work and where there is more than one engine requiring gas, even for the small owers, a fan or blower is always installed to deliver the gas under pressure.

The quality of the gas made in this plant is about the same as that of gas made with coke ordinary suction plants. The heat efficiency of the new plant is exceptionally high, and with good engine under full load the consumption of fuel is little over 1 lb. per b.h.p. hour. The and-by losses are small, and after standing over-night or during meal hours, good gas can be eady for the engines in a few minutes.

Many plants of this description have been installed both at home and abroad for industrial nd municipal undertakings with splendid results, and in the case of the foreign installations the eal in some cases being much inferior to our British standard. These plants can be made in ny size from 25 to 500 b.h.p.

The Kerpely Revolving Grate Gas Producer.

The Kerpely Gas Producer, with its mechanical ash discharge and mechanical feed and gitators, is entirely mechanical in operation. It effectively gasifies good or bad fuels, even aste fuels containing nearly 50 per cent. ash. As an example of the latter fuel, mention is ade of an installation of Kerpely gas producers at a colliery in Scotland for gas-firing colliery oilers. The fuel gasified is unsaleable from the colliery and consists of 'parrot' and 'belt ickings of the following approximate analysis:—

Parrot and Belt Pickings Mixed.

Fixed carbon (by difference)	24·50
Volatile matter	23·22
Ash	48·10
Moisture	4·18
	100·00
Calorific value	6,580 B.Th.U. per lb.

It will be noted that the fuel contains *nearly* 50 *per cent. of ash.*

The following is an average analysis of the gas produced from this fuel by the Kerpely producers, viz.:

CO_2	5·80
O	0·58
CO	23·21
H	11·50
CH_4	2·85
N	56·06
	100·00

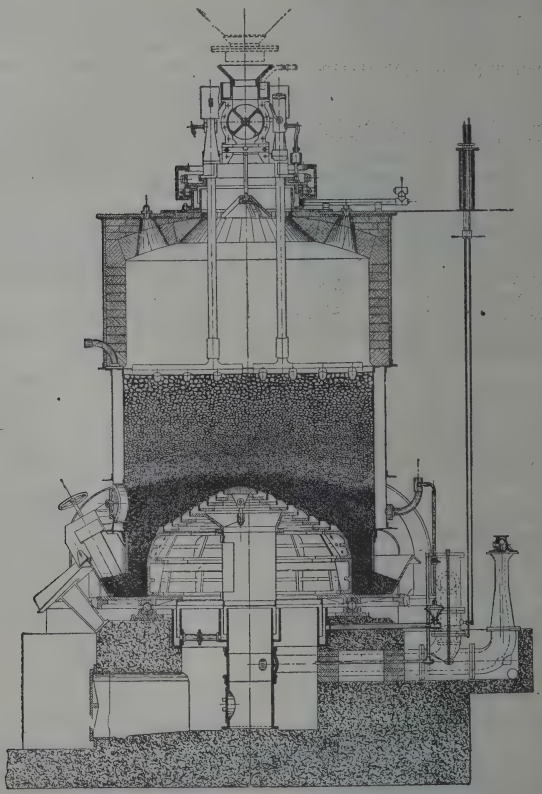


FIG. 40.—The Kerpely Revolving Grate Gas Producer.

The Kerpely grate, a sectional view of which (dimensioned for the standard 3-metre diameter producer) is shown by fig. 40, is of polygonal shape and is placed eccentrically on the water trough. It has a continuous and not an intermittent action in crushing any formation of clinker that may occur. The water-cooled jacket in the fire zone prevents the formation of clinker on the walls of the producer. The clinker, when entering the ash zone, is caught by the numerous edges of the revolving grate and pressed horizontally sideways against the seal apron, and is consequently broken or crushed into small fragments, which, dropping into the water trough, are removed by the ash scraper. The latter automatically discharges the ash and clinker accumulating in

he bottom of the producer, and, being constructed to suit the shape of the ash trough, the ash is ot only pushed aside, but is piled up and continuously discharged into an ash shoot. The auto- iatic discharge of the ash and clinker from the Kerpely producer results in considerable saving f labour in the removal of ash, and ensures continuous working of the producer and gas of uniform uality. Labour is saved in poking, a small amount only of steam is required, and a dry gas is btained, which ensures a prolonged life of the furnace linings. The supply of air and steam to he Kerpely producer is separately conveyed to the inner and outer sections of the grate, and, eing transmitted through spaces between the plates of the revolving grate, ensures uniform ombustion over the whole grate area, the maximum gasification capacity per square foot of grate rea, and effective control of the fuel bed.

The Kerpely producer can be fitted with the Appleby-Bentley Patent Mechanical Rotary uel Feed and Distributor, or this mechanical feed combined with patent balanced and adjust- ble fuel agitators and levellers, as the fuel conditions may determine.

These mechanical feeds and agitators are claimed to ensure greatly increased gasification 0 to 100 per cent., according to type of producer), constant high-value gas, saving of labour nd fuel, and greater production from furnaces. The following table gives daily working results aken over a period of one month with a Kerpely gas producer fitted with the Appleby-Bentley echanical feed and agitator:—

KERPELY PRODUCER WITH MECHANICAL FEED AND AGITATORS (BENTLEY'S SYSTEM).

Gas Analysis Monthly Report, June 1922.

Day.	Saturation °C.	Steam Press at Blowers.		Gas Analysis.					Total Combusts. per Cent.	B.Th.U.	Kind of Coal.
		Outer.	Inner.	CO_2 per Cent.	CO per Cent.	CH_4 per Cent.	H_2 per Cent.	N_2 per Cent.			
1	59	25	45	3·4	28·0	3·43	13·10	52·07	44·53	167	A
2*	61	20	40	5·4	24·6	3·74	12·46	53·86	40·86	157	A
3	61	20	40	3·2	28·2	3·66	14·18	50·76	46·04	174	A
6	56	25	50	3·2	28·4	4·11	13·39	50·90	45·90	177	A
7	57	25	50	2·8	29·6	3·63	13·30	50·67	46·53	176	A
8	57	25	50	2·6	29·0	3·86	13·93	50·61	46·79	178	A
9	57	25	50	3·2	29·0	3·63	13·01	51·16	45·64	173	A
10	57	25	50	3·6	28·0	3·45	12·28	52·67	43·73	165	A
12	60	20	45	3·8	28·0	3·41	13·50	51·29	44·91	165	A
13	62	27	50	2·4	29·2	3·88	13·09	51·43	46·17	176	A
14	63	25	50	3·2	28·4	3·42	14·29	50·69	46·11	173	A
19	62	25	50	4·0	27·2	3·21	13·46	52·13	43·87	165	A
20†	62	33	60	4·4	25·2	3·70	13·88	51·82	42·78	154	A
21	62	30	40	2·4	29·0	3·66	12·81	52·13	45·47	172	A
22	62	30	40	2·8	29·0	4·38	12·73	51·19	46·11	179	A, B
23	60	30	40	3·2	29·0	3·63	12·69	51·46	45·32	173	C
26	61	30	50	3·8	27·0	3·45	15·28	50·47	45·73	172	D
27	61	23	45	3·2	27·8	3·71	13·80	51·49	45·31	172	D
28	60	30	50	3·6	28·6	3·18	13·01	51·61	44·79	167	E
29	60	30	50	3·4	27·6	3·45	14·12	51·42	45·17	170	E
30	63	35	60	4·0	27·4	4·14	14·92	49·94	46·06	173	E

Comments.—Carbon in ash (sample taken 9th inst.), 2·77 per cent.

* Residue from bunkers, mostly dust.

† Day of stoppage for burning out.

A = Mansfield. B = Cannock. C = Great Wyrley. D = Cresswell. E = Langwith.

APPLEBY-BENTLEY PATENT MECHANICAL GAS PRODUCER.

This producer is mechanical in its action, as regards fuel feeding, agitating and levelling, ash evelling and discharge. The fuel is carbonised, then gasified, producing high or low temperature as as desired from the same producer. The apparatus has an improved blast distribution, ffecting perfect combustion with high gasification. Cheap fuels can be effectively gasified y its means.

CAMPBELL GAS PRODUCERS.

The Campbell Gas Engine Co. are makers of several types of suction producers. They were among the pioneers of the enclosed type, which is still their standard for anthracite or coke and—with certain modifications—for charcoal.

Another type, first introduced by the Campbell Gas Engine Co., is the open-hearth suction gas plant, which is particularly suitable for inferior anthracite, collie coal, and small coke. It also works successfully with locomotive smoke-box char, and plants to use this fuel have been supplied to the leading British railways and to railways abroad.

A third type of gas plant built by this company is designed for working with bituminous non-caking coal, lignite, etc. This plant works on the double draught principle in order to convert a considerable proportion of the tarry matter from the fuel into a fixed gas in the producer, and thus dispense with complicated scrubbing and cooling apparatus.

A fourth type of suction gas producer with which this firm have achieved success is their refuse fuel plant. This as its name indicates is used for gasifying all descriptions of vegetable refuse in such forms as wood chips, sawdust, olive refuse, cotton seed, rice husks, etc. Plants of this type have been operated for considerable periods on sawdust alone with entirely satisfactory results. The consumption of such fuel varies considerably according to its quality, but averages about 3 lbs. per b.h.p. per hour.

These gas plants are supplied from 28 to 640 h.p. Several large plants have been supplied to leading British railway companies in conjunction with vertical gas engines and run entirely on the refuse produced in the wood-working shops, developing more than sufficient power to drive the whole of the machinery in these shops.

Ample 'scrubbing' capacity is provided in all types, and careful provision is made for easy access to all parts for cleaning, thus keeping running costs at a low level.

The 'Crossley' Suction Gas Plants.

Messrs. Crossley Brothers, Ltd., build several types of suction gas plants, each specially designed to suit the various classes of mineral and refuse fuels.

The producer manufactured by them to work on anthracite, coke, or charcoal is of the open-hearth type shown by fig. 41.

With this type of producer the fire is always in full view of the operator, the firegrate consisting of a number of annular cast iron plates arranged in the form of steps and so disposed that the outside edge of each succeeding lower plate lies beyond the angle of repose of the fuel which falls through the opening in the plate above. These grate plates are supported on cast iron legs which also support the producer itself, comprising a simple steel shell internally lined with firebricks.

The grates are cooled by water which is supplied by small drip pipes to the top plate, from whence it overflows on to each succeeding plate in turn; a certain amount of steam is thus generated which assists in the gas production.

As will be seen from the fig. the lower part of the fuel bed can at all times be readily cleaned of ash and clinker without interfering with the process of gas making or necessitating shutting down of the plant, indeed, numbers of these plants have worked continuously for over 12 months without the fire having to be withdrawn for any purpose whatever.

The absence of a vaporiser in the top of the producer enables the operator to use a poker in a direction parallel to the firebrick lining, the clinkers being thus very easily broken away, without injury to the brickwork, and allowed to drop on to the grate plates, from whence they can be removed at will.

From the producer the hot gas passes into an external vaporiser consisting of a casing supporting a cast iron box divided into compartments, to the under side of which a number of water tubes are fixed.

With the exception of the first and the last in the series, the tubes are provided with internal circulating tubes of the 'Field' type.

The water to be vaporised is carried to the bottom of the first tube through an internal feed pipe and then rises into the first compartment, from which it passes in through each succeeding compartment and tube in turn, until finally it is flashed into steam in the last tube, which also forms the steam connections between the vaporiser and the producer. The steam is taken from the vaporiser into an annular box-shaped casting situated at the base of the producer, from which it is distributed to the fuel bed through a number of small holes drilled around the inside edge.

In this design of plant the gas is external to the water to be heated, so that both the cooling of the gas and heating of the water are effectually provided for.

Leaving the producer, the partially cooled gas passes through two cascades of water produced by the overflow from the cooler and scrubber; these remove the heavier impurities from the gas. It is next passed through a cooler and scrubber consisting of two coke charged compartments, each

tted with separate cleaning and charging doors, so arranged that the coke in the lower compart-ent (which is the first to become fouled) can be removed without interfering with that in the

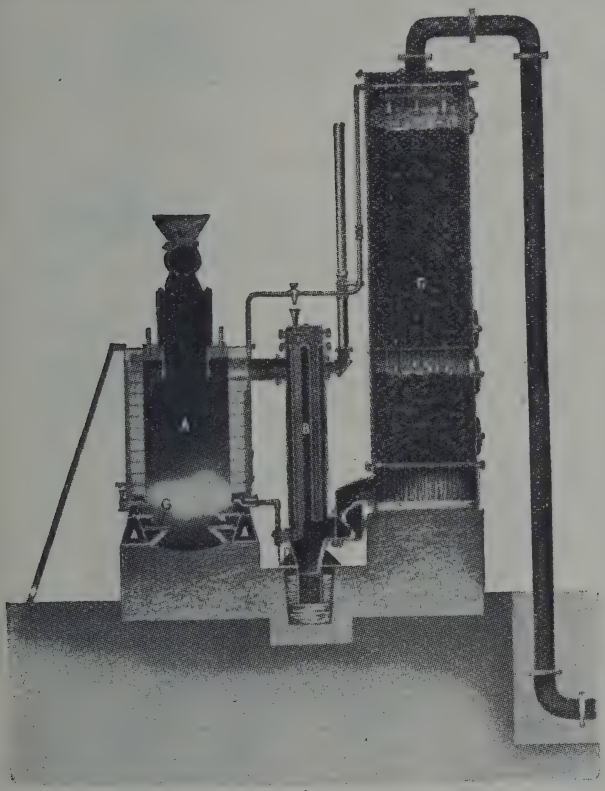


FIG. 41.—'Crossley' Suction Gas Plant.

pper compartment. During its passage through the coke the gas is thoroughly cooled by streams f water supplied by the spray situated above the top layer.

Leaving the scrubber the gas passes into a combined drier and expansion box and from thence o the engine.

'CROSSLEY' REFUSE FUEL PLANTS.

'Crossley' refuse fuel plants are designed to work on a variety of fuels, including waste wood f all kinds, spent tan, rice husks, olive refuse, sugar cane refuse, cocoanut shells, coir dust, cocoa nd coffee refuse, etc. Particular attention has been given by the designers to the removal of mpurities from the gas and to allow of continuous working of the plant by unskilled labour. A ectional view of a 'Crossley' Refuse Plant is shown by fig. 42.

The lower part of the producer is similar in design to that of the anthracite plant previously lescribed, with the exception that the grate is shielded by carrying the external shell to the oundation block.

Access to each section of the grate for removal of ash is provided for by large cleaning doors

CROSSLEY REFUSE FUEL PLANT.

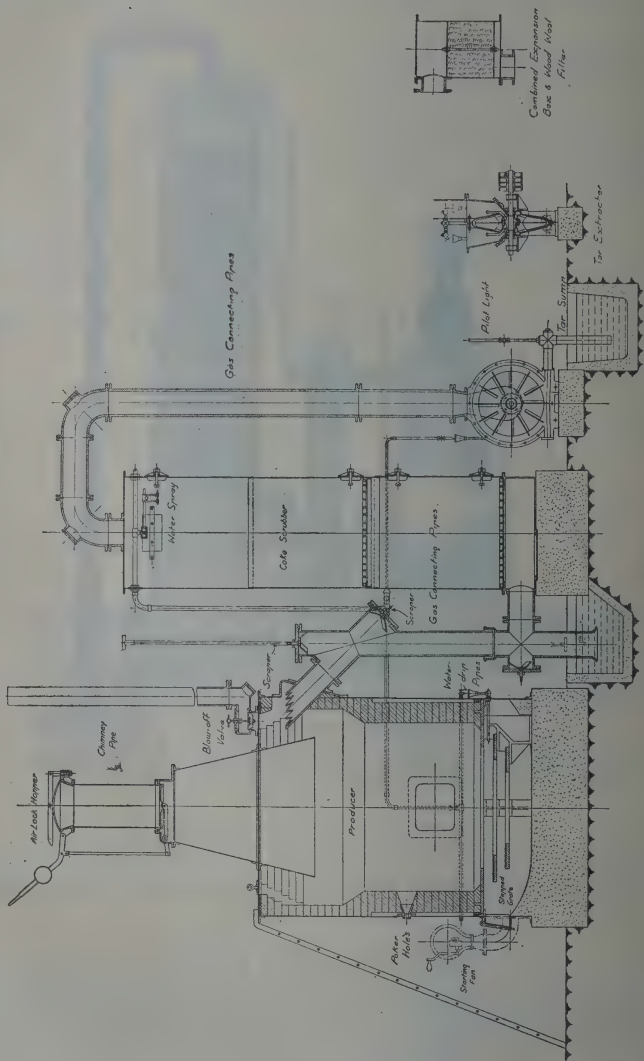


FIG. 42.

olted to the producer shell; these doors can be opened at any time whilst the plant is at work ithout disturbing the process of gas production.

Owing to the comparatively high moisture content of nearly all classes of waste fuels, little or o steam is required for gasification purposes, but when necessary, provision is made for generating supply of steam by feeding water on to the stepped grate plates.

One of the features of this plant is the provision of an Airlock fuel feeding hopper of large apacity and special design to allow of the plant being used for all classes of fuel without the lightest fear of explosion or interruption of gas supply when charging.

Other features of this producer are as follows:

(1) Provision for storing a large quantity of fuel in the producer itself, thus obviating the necessity of frequent charging.

(2) Exceptional facilities for spreading the fuel, thus ensuring a constant fuel depth and gas of constant calorific value.

(3) An effective design of mouthpiece for the gas outlet pipe, to reduce to a minimum any tendency for fine fuels, such as sawdust, to be drawn over with the gas.

(4) Gas outlet pipes from producer to scrubber are provided with scrapers for removing tarry deposit and dust whilst the plant is in operation. This device prevents the pipes from becoming choked and thus enables the installation to work continuously for long periods.

For cooling and washing the gas (preparatory to the removal of tar) a coke scrubber (of similar lesign and construction to that previously described) is provided.

Leaving the top of the scrubber and cooler, the gas is passed through a mechanically driven entrifugal tar extractor, where it is subjected to a combined heating and centrifugal action which hrows out the tar on to the inside of the casing, from whence it is washed into the tar collecting ump by a continuous spray of water.

Before the gas reaches the engine it is passed through a combined expansion box and wood ool filter which acts as a final drier.

Messrs. Crossley Brothers also manufacture suction plants for bituminous coal, lignite or peat; hese being of different design to suit the characteristics of the fuel to be gasified. The bituminous uel plant is provided with a central cone plate grate which allows of a continuous water lute around he base of the producer for the removal of ash and clinker.

All steam required for gasification purposes is generated in an annular steel boiler, situated near he base of the producer, the smooth surface of which prevents clinker from adhering. The steam nd air supply to the producer is controlled by a single valve, and the saturation temperature of he air can be regulated to a degree.

This design admits of free use of pokers through both the top and side poking holes.

For feeding the fuel a rotary barrel hopper is provided. The gas cleaning apparatus is very imilar to that supplied with the 'Crossley' Refuse Plant.

Mond Gas.

The Mond Gas-Producer Plant was originally developed by the late Dr. Ludwig Mond for the onversion of bituminous fuels into power and heating gas, along with the simultaneous recovery f the nitrogen in the form of sulphate of ammonia.

Plants of both the recovery and non-recovery type are constructed for power and for heating urposes, but considerations of economy rarely justify the installation of the recovery type n units of less than 2,000 h.p. or equivalent capacity. The non-recovery type, however, is nstalled in much smaller units.

Both types of plant can be adapted for utilising inferior fuel, such as the waste products from ollieries and coke ovens, and the gas used for gas-engine driving, industrial furnace heating r boiler firing, and in such cases with the recovery plant the return from the sulphate of mmonia will go a good way towards meeting the running expense of the plant.

The Mond Non-recovery Water-cooled Gas-Producer Plant.

(Mond and Lymn System.)

The modern type of Non-recovery Water-cooled Gas-Producer Plant, as installed for generating as from bituminous producer coal of suitable grading, quality, and condition for use in gas ngines or for other purposes where cleanliness equal to gas-engine practice is required, may be onsidered as composed of two sections: the 'Gas Generating Section'—comprising the pro- ucer and its accessories—and the 'Gas Cooling and Cleaning Section'—comprising vertical atic cooler and washer, centrifugal cleaners, and sawdust scrubber.

The producer is of the central blast type, with steel casing designed to sit on concrete foundations (provided by purchasers) and dip into a water-lute, formed in the foundations, and from which the ashes can be removed evenly all round without interrupting the working of the producer. The grate is conical in form, built up of two or more C.I. sections, and provided with air slots. It is located concentrically with the producer shell, and is connected up to the blast pipe which passes through the foundations to the outside of the producer. The lining of the producer is built of special quality firebricks and fireclay. The producer is fitted with a series of horizontal poke holes about the level of the air slots in the grate, and also with poke holes on the top giving access to the whole of the fuel bed, these top poke holes being fitted with spherical closers.

A fuel hopper is fitted on the top of the producer, with sliding cover and inner cone valve operated by lever and balance weight. The fuel in the hopper is discharged into a fuel container or inner bell, the top of which is provided with suitable poke holes, and from this container automatically on to the fuel bed; this method of charging ensuring a more constant quality of gas. The gas outlet branch is fitted on the side of the producer casing close to the top.

A steel chequer plate operating platform is arranged at the level of the top of the producer shell with suitable protecting handrailing and ladder giving access from ground level.

Fuel handling plant is frequently included, and the type usually recommended comprises a power-driven enclosed bucket type elevator, lifting the fuel from a boot at ground level into a bunker, which is mounted on substantial supports over the producer and fitted with a shute furnished with lever-operated discharge valve leading down to the producer hopper.

The air-blast for the producer is provided by a blower of the steam-jet type, arranged so as to ensure a thorough intermixture of air and steam before the blast reaches the grate, but in some installations a steam-driven Roots or turbo-type blower is included, the exhaust steam from the blower engine or turbine being led into the blast pipe.

Leaving the producer, the gas enters the cooler and washer, which is of patented design, and provides an effective means of gas washing by the employment of a novel and efficient method of utilising the momentum of upward flowing gases to atomise liquid falling in thin sheets, with a resultant intimate contact between gases and liquid without the use of any mechanical spraying device.

The apparatus consists of a cylindrical casing of mild steel, fitted with top and bottom plates, gas inlet and liquid outlet at the bottom, and with gas outlet and liquid inlet at the top. When desirable, the bottom of the casing can be arranged for water-luting.

A vertical stationary shaft is located in the centre of the apparatus, extending the height of the casing. At suitable distances from each other, a series of discs or distributing devices for the liquid are fixed on this shaft, and attached to the casing are a corresponding series of inverted truncated cones which serve as collecting devices, the design of these internal parts being varied to suit particular requirements.

Falling by gravity alternately from the distributors to the collectors and *vice versa*, the thin sheets of liquid are atomised, and in the form of fine spray actually driven by the gas—itself flowing in zigzag path in the opposite direction—on to the collectors and distributors, where the spray again forms into thin sheets of descending liquid. Each particle of gas is thus brought into contact with the liquid many times before it leaves the apparatus.

The distributors are constructed with diameters considerably smaller than the lower diameter of the collectors, and thus the gas passage is not restricted, and the loss of pressure occasioned is very small.

Packing or filling materials, such as coke, earthenware tiles, or wooden boards, which baffle the passage of the gas, are dispensed with, and the troubles of stoppage and renewals attendant upon such materials getting choked with tar and dust are thus eliminated.

This type of washer is of established efficiency, and the absence of moving parts, together with the freedom from possibilities of blockage, which is a feature of the design, make it a thoroughly reliable apparatus requiring a minimum of attention, with no upkeep charges for labour and material for packing or filling renewals such as have to be met with in other types of washer.

From the washer the gas passes to the first of two centrifugal cleaners. These two cleaners are normally arranged to work in series, but where desired, the requisite cross connections and valves can be added to enable either cleaner to be cut out of operation and by-passed for purposes of overhauling should such be necessary. Each cleaner has a tar drain water-sealed in a lute in the foundations, and the gas delivery branch of the second cleaner is joined up to a sawdust scrubber, to the outlet of which the gas main leading to the gas engines, etc., is connected.

The scrubber is a rectangular cast-iron box fitted with wooden grids, on which are spread layers of wood chips, shavings, and sawdust. The gas enters at the bottom, and passing up through these layers receives its final drying and purification.

The scrubber requires very little attention, only needing to be cleaned out and refilled a few es per year, according to the load on the plant. A special lifting arrangement is provided to ilitate the removal of the cover, and all the spent material taken out can be burnt under the ler which provides the steam for the plant.

The drains from the various parts of the plant are run to the settling tank, which takes the m of a concrete pit with iron or reinforced concrete partition plates, so arranged as to keep ck the tar and allow only the water to run to the drains. The tar is then scooped or run off d disposed of in the most convenient manner, either being sold, used for boiler-firing purposes, ydrated, or distilled, according to the quality and quantity available and local conditions.

The auxiliaries of the plant—elevator and centrifugal cleaners—can generally be most vantageously and economically driven by electric motors if electric supply is available, a ect or continuous current being preferable to an alternating current supply.

Where requirements call for a minimum fluctuation in the gas supply pressure, an automatic vernor can be added to plants in which a power-driven blower is installed. Such a governor uld be of the gas-holder type, but of small capacity, and hence of negligible storage value. ie bell of the holder would be so arranged that as it approaches its top position it actuates a lief valve connected to the air-blast main, reducing the blast supply to the producer when the s make is in excess of the requirements, and thus automatically controlling the gas production.

In installations where the gas generated is used to supply gas engines and also to fire furnaces, is advisable that a non-return valve should be provided in the gas main to the furnaces.

A suitable and sufficient supply of steam is required for blast saturation purposes, also suitable and sufficient supply of cold water to the washer, cleaners, and producer lute. Where ld water is scarce, water-cooling and circulating plant may be installed, and a considerable rtion of the water required can be used over and over again. Suitable motive power for the xiliaries is also required, in the form of electricity or steam.

This description is typical of units up to about 1,100 b.h.p. capacity, larger units being nerally similar but having two or more producers, gas main connections between producers d washer, to suit, and additional scrubber units.

Low Temperature By-product Recovery Gas-Producer Plant.

(Mond and Lymn System.)

Under normal circumstances, the installation of this type of plant is not, generally speaking, stified in units smaller than 2,000 b.h.p. in capacity, and local conditions and values may en require a larger unit, to afford an economical proposition. Thus, the usual plant of this pe comprises more than one producer unit with corresponding superheaters, etc., but, except plants of unusually large capacity, the washing, etc., vessels are installed in single units, th the scrubbers in multiple units, according to requirements.

This plant is made up to a certain extent of similar parts to the non-recovery type, but the sign of several of these parts is modified to suit the different working conditions, and additional paratus is included.

The plant may be considered as composed of four sections :—

(1) The Gas Generating Section, comprising producers.
(2) The Gas Washing and Cooling Section, comprising dust washer, ammonia absorber gas cooler, and in particular cases air saturator.
(3) The Gas Cleaning Section, comprising gas cleaners and scrubbers.
(4) The By-Product Recovery Section, comprising :—
    (*a*) Sulphate of ammonia, evaporating and drying plant.
    (*b*) Tar dehydration and/or distillation plant.

If the gas from the plant is required only for heating purposes, then Section (3), or, in some ses, the scrubber portion of this section, is not required.

The producers are generally similar to the non-recovery type, but with increased depth and her constructional modifications.

A steel chequer-plate operating platform common to the battery of producers is arranged the level of the top of the producer shells, with suitable protecting handrailing and ladder ving access from ground level.

Fuel-handling plant is generally included, and the type usually recommended comprises a ower-driven enclosed bucket type elevator, lifting the fuel from a boot at ground level into an erhead bunker, together with push-plate conveyor. The bunker, constructed of steel, is nerally of parabolic section, extending over the whole of the battery and suspended from ubstantial supports, which also carry the producer platform. The bunker is provided with scharge shutes leading down to the fuel hoppers of the producers, each shute being provided ith a lever-operated discharge valve. When required, a light iron framing and corrugated eet-iron covering is supplied to cover in the coal conveyor and bunker top. For large in-allations, fuel-handling plant of the travelling overhead crane and grab type offers advantages hich merit its adoption.

The air blast for the producers is provided by blower or blowers of either the turbo or Roots type, and after the necessary exhaust steam has been added to it to supply the vapour for blast saturation, it is passed into the producers. In certain cases some of the vapour required for blast saturation purposes is provided by means of an air saturator working in conjunction with the gas-washing plant.

The gas from each producer passes into a gas collecting main which joins up the various producer units and from which it enters the dust washer, where intimate contact with falling sprays of water wash out a large proportion of the dust. From this vessel the gas passes on to the ammonia absorber, which is the same type of patented vessel as used for the washer in the non-recovery gas producer plant.

From the absorber the gas passes to the final cooler, which again is a vessel of the patented washer type.

For certain heating purposes the gas may be taken off for use from the exit of this cooler but if further cleaning is required, it next passes forward to the first of two centrifugal cleaners which in detail and arrangement are exactly similar to those described as part of the non-recovery plant.

Where the gas is required to be of gas-engine cleanliness, the delivery branch of the second cleaner is connected to a bus-pipe joining up to the inlets of the scrubbers, the outlets of these vessels being connected with a bus-pipe, from which the main for the gas engines may be taken.

Where for special purposes the final cleaning in scrubbers is not required, then the gas may be taken off from the exit of the second centrifugal cleaner.

The scrubbers are formed in separate sections in a rectangular cast-iron box, each section being provided with wooden grids on which are spread layers of wood chips, shavings, and saw dust. The gas enters at the bottom, the various sections working in parallel, and the operation etc., being generally similar to this portion of the non-recovery plant.

The fourth section of the plant, in which the sulphate of ammonia is made in crystal form from the liquor obtained from the absorber, is generally housed in a building to itself.

The plant comprises stock liquor tanks, into which the liquor at suitable saturation is withdrawn from the circulating system of the absorber and stored. From these tanks the liquor is pumped up to overhead feed tanks, from which it is fed into the vacuum evaporator, which operates in conjunction with a condenser of the ejector-jet type. Here the liquor is evaporated and the crystals discharged from the base into a specially designed aspirator, and from thence passed on for final drying in power-driven hydro-extractor. The dry salt is then delivered into the store, usually arranged in the basement of the building, where it is packed in bags ready for distribution or shipment.

A steel circulating tank is provided for use in connection with the absorber, and located closely adjacent thereto, to contain the weak sulphuric acid solution which is used as the circulating liquor in this vessel, and a pump, constructed of acid-resisting metal, is provided for circulating this liquor, with the requisite connections between the tank, pump, and absorber and from the tank to the stock liquor tanks.

It is necessary for purchasers to provide acid and water supply pipes to this tank, to supply the make-up for the liquor withdrawn from circulation.

Suitable pumps are also provided for supplying the circulating water to the dust washer but it is usually left for purchasers to supply the cold water supply and pipe-line to the top of the final cooler, to the centrifugal gas cleaners, and to the jet condenser, as also the requisite drain connections for the disposal of the waste water from condenser and settling tanks.

The tar produced is collected from the various circulating tanks into a common settling tank. From this tank it is pumped to an overhead storage tank and dehydrated either by steam or by mechanical means. The dehydrated tar can either be sold as such or pumped forward to a distillation plant to yield oils suitable for fuel, disinfectants, wood preservatives, etc., and pitch.

The auxiliaries of the plant—elevator and conveyor, centrifugal cleaners, pumps, and hydro-extractor—can generally be most advantageously and economically driven by electric motors if electric supply is available, a direct or continuous current being preferable to an alternating current supply, but it is the usual practice to couple up the blowers to steam prime movers, the exhaust from which, as before mentioned, is utilised for blast saturation.

Automatic governor and non-return valve are provided when required to meet the same conditions as in the non-recovery type of plant, while steam, water, and motive power supplies will similarly be required.

Bituminous Suction Producers.

The production of a satisfactory suction plant using bituminous fuel has proved a problem of very great difficulty, but several types of such plant have recently appeared, and they are now built commercially by Messrs. Dowson, Messrs. Crossley, and others. In these the leading idea is to destroy any tar produced by distillation of the fuel *in the producer* before the crude gas enters the coolers and scrubbers. This is usually accomplished by taking the gas from the

t zone of the producer, and arranging the supply of air and steam from both above and below; e fuel enters from a hopper on top, and the gases coming off from the fresh coal pass down gether with some air and steam to the hot zone where reactions take place which destroy the r by converting it into useful gases. The fuel, now largely carbonised, passes slowly down- rds towards the grate supporting the whole mass, and being traversed by a current of mixed r and steam passing upwards yields carbonic oxide and hydrogen as usual.

Engines driven by these plants frequently require only about 1·2 lb. of slack to the producer r b.h.p. hour.

The 'Hornsby-Stockport' Suction Gas Plant for Anthracite, Coke, Charcoal, etc.

The outstanding features of this producer, fig. 43, are simplicity of design, ease in handling, d reliability under working conditions. Shaker grates to prevent the formation of clinker are ted on all producers of 37 b.h.p. and upwards. The blow-off pipe of the larger sized producers

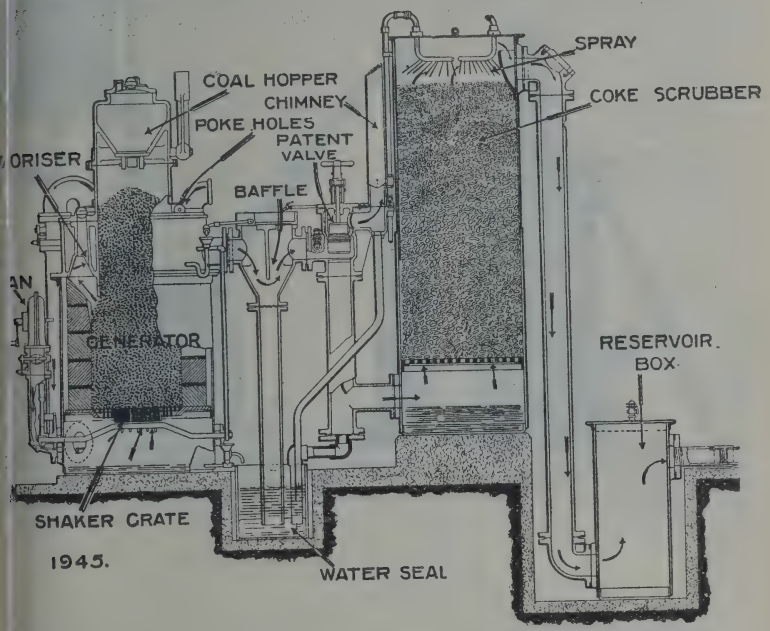


Fig. 43.—Hornsby-Stockport Improved Suction Gas Plant.

s fitted with a patented valve, closing the coke scrubber to the atmosphere when the generator s open to the blow-off pipe, thus keeping air from entering the coke scrubber.

Gas can be raised from cold in about 20 minutes.

The 'Ruston' Wood-Refuse Suction Gas Producer

This gas producer (*Ruston and Hornsby, Ltd.*), fig. 44, is for the purpose of dealing with wood refuse, non-caking bituminous coal, lignite, brown coal, anthracite, etc.

The chief endeavour has been to obviate the stoppages for cleaning usually necessary when working on such fuels. The little cleaning that is required is at the gas outlets from the generator, and this can be easily performed in a few minutes while the plant is in operation by means of special scrapers, so that the usual week-end cleaning is done away with, and the plant can be worked continuously if required.

A special feature of the producer is the multiple gas outlet pipes from the top of the generator, which ensure an evenly burning fire.

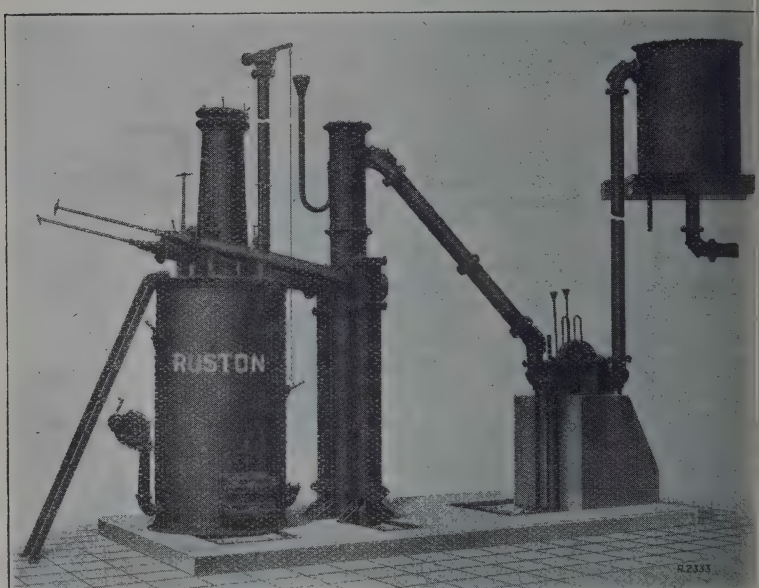


FIG. 44.—'Ruston' Wood-Refuse Gas Producer.

Other advantages claimed are as follows:—small space occupied, very little attention required, no coke scrubber to become clogged with tar, simple in design and construction, and gas free from grit, dust, or tar. The consumption of wood refuse is from $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. per b.h.p., according to the amount of moisture in the fuel, and the plant will produce four or five times the power as when the fuel is burned for direct steam raising.

When bituminous coal, lignite, anthracite, or coke is required to be used, solely or alternatively with refuse fuel, the details of the producer are somewhat modified. An annular steel vaporiser is arranged around the upper part of the generator, and an air lock feeding hopper is fitted. Poking holes are provided to give access to all parts of the fuel bed, and special facilities are given for the quick removal of ash and clinker.

A large number of these producers have been supplied at home and abroad, for a variety of refuse fuels, and for bituminous coals.

Water Gas.*

In 'Water Gas' producers the action is intermittent, the fuel being alternately raised to incandescence by an air blast which is then shut off and steam alone passed through the glowing mass; the steam is dissociated into free hydrogen and oxygen, and the oxygen combines with the carbon present in excess and forms CO; thus :—

$$H_2O + C = H_2 + CO$$
2 vols. + 1 vol. = 2 vols. + 2 vols.

In theory, therefore, water gas should contain 50 per cent. by volume each of hydrogen and carbon monoxide; practically a small quantity of CO_2, N and O generally appears, as shown by the analysis given below. The passage of the steam through the mass of incandescent coke soon cools it down, when the steam is cut off and the air blast again turned on; the cycle of operations is then repeated.

Water gas plants are frequently installed in gas works, and the water gas is often enriched or 'carburetted' by admixture of heavy hydrocarbon vapours and in this condition used either alone or mixed with coal gas for lighting, heating, and power purposes.

The following results of analyses suffice to give a general idea of the characteristic constitution of water gas, carburetted water gas, mixed gas (i.e. mixed water gas and coal gas), and normal coal gas :—

	H.	CH_4.	CO.	Heavy Hydrocarbons.	CO_2.	O.	N.
Water gas	48·6	0·4	44·0	—	3·3	—	3·7
Carburetted water gas	29·35	20·48	33·19	11·32	—	—	5·66
Mixed gas	46·73	24·57	14·46	4·91	1·45	0·73	7·15
Normal coal gas	45	33	10	5·3	0·5	0·3	5·9

6. BLAST FURNACE GAS.

In 1895 the late Mr. B. H. Thwaite showed that the hitherto waste gases from blast furnaces could be used in gas engines, and his discovery has stimulated the construction of the very large gas engines now becoming common.

The gas is taken from the gas main and forced by a blower through a scrubber into a holder regulator, and then to the engine. About 180,000 cubic feet of gas are produced per ton of fuel consumed in the furnace, and about 124 cubic feet of gas are used in the engine for each horse-power hour.

From tests made on Mr. Thwaite's first plant at Wishaw by Mr. W. H. Booth, it is estimated that for each ton of fuel used per week in a blast furnace, 10 horse-power may be continuously obtained by gas engines.

It is proposed to thus utilise the gases of all blast furnaces and so produce several millions of horse-power for distribution for railway, lighting, canal, traction, and general power purposes.

Table I. gives the analyses of blast furnace gas in two cases where the Thwaite system is in use, and a comparison with producer gas, while Table II. gives results of a volumetric analysis of the Wishaw gas.

* See also Section XXXVII, p. 2467.

TABLE I.

	Coal Fuel. *Wishaw.*	Coke Fuel. *Frodingham.*	A Dowson Gas Producer.
Carbonic oxide	24·75	27·3	23·8
„ acid	5·75	6·0	6·3
Hydrogen	2·33	1·5	19·8
Marsh gas	0·75	—	1·3
Nitrogen	66·42	65·2	48·8
	100·00	100·00	100·00
Heat units per cubic foot	97·8	96·7	164·0
Calculated cubic feet per H.P.	79·44	80·34	70·0
Percentage combustible	27·83	28·8	44·9

TABLE II.

Gas.	Per Cent. Vols.	Weight per cub. ft.	Lbs. Wt. per 100 cub. ft. of Mixed Gas.	Actual Weight of Elements per 100 cubic feet of Gas.			
				C	O	H	N
Carbonic oxide, CO	24·75	·0784	1·9404	·8316	1·1088	—	—
Hydrogen, H	2·33	·0056	0·0130	—	—	·0130	—
Marsh gas, CH_4	0·75	·0448	0·0336	·0252	—	·0084	—
Nitrogen, N	66·42	·0784	5·2073	—	—	—	5·2073
Carbonic acid, CO_2	5·75	·1234	0·7095	·1935	·5160	—	—
	100·00	·079038	7·9038	1·0503	1·6248	0·0214	5·2073
				7·9038			

From 80 to 100 cubic feet of gas are obtained from each pound of fuel used. The foregoing table shows about 98 cubic feet of gas per pound of carbon, but some of the carbon comes from the limestone flux and from the ore, and even from the blast itself. In the gas engine, with the necessary enlargement of the gas inlet as compared with that necessary for town gas, and with a fair amount of initial compression, the action of blast-furnace gas is perfect, and no misfires are found to occur. The poverty of the gas is, in fact, no bar to its employment for power purposes. In fact the blast furnace is described in Mr. W. H. Booth's report as an ideal gas-producer. The employment of blast-furnace gas for power purposes enables cold-blast iron to be made, for with a sale for gas the economy of fuel per ton of iron ceases to be of importance.

Approximately each pound of carbon in the fuel used will produce about 98 cubic feet of gas and each 100 cubic feet of gas produced weighs nearly 8 lbs. The tests on the small engine at Wishaw showed only about 1½ lb. of coal per electrical horse-power, or 1·12 per i.h.p., assuming an efficiency of 75 per cent. between the cylinder and the terminals of the dynamo and allowing for temperature. Approximately each ton of fuel used per week in a furnace would give continuously 10 horse-power.

There has been a very considerable extension of the use of blast-furnace gas in Germany, where full advantage was promptly taken of Thwaite's teachings, and after a period of attempting to work with uncleaned gas Thwaite's method of cleaning was practically adopted. It is very important that the gas should be cleaned of its dust. Failure has occurred at an American iron works where the engine valves became heavily loaded with dust. Fans may be employed through which the gas is circulated, jets of water being entered at the side of the fan casing. Rotating gas washers also are employed, and washer boxes in which the gas is passed under diaphragms which project an inch or two below water and compel the gas to bubble up through the water

ge scrubbers with cellular work of light athwork with water trickling over them will arrest ch dust. Thwaite employed a sawdust filter as a final catcher, arranged so that the sawdust ld be rapidly changed. Thwaite relied much on sawdust for removal of the tar, of which it ifficult to get rid. Though blast-furnace gas may contain as little as 27 per cent. of combustible it presents no ignition difficulties when electrically fired in a state of compression in the nder. A. Witz has shown that the average calorific value of the gas from twenty-seven Belgian naces was 111 B.Th.U. per cubic foot, while nineteen Luxembourg samples showed 114 B.Th.U., nty-three German furnaces showed 108 B.Th.U., and nine French and Spanish furnaces B.Th.U. He takes a general average of 110, but the value may fall to 97 with an acid flux. h poor gas will bear high compression, and will safely bear 7 to 9 atmospheres. No matter y poor a gas it will ignite if sufficiently compressed, and at Seraing as high as 11 atmospheres e employed in 1901. Hence the excellent efficiency that is obtained with blast-furnace gas.

Blast-furnace gas contains but little hydrogen, as no steam is used in the blast furnace; it proximates, in fact, closely to the gas that would be given by an ordinary producer supplied h air only. The small hydrogen content enables very high compression pressures to be used hout danger of pre-ignition; when well cleaned, this gas is an excellent fuel for large engines, heat evolved per cubic foot of maximum mixture at 60° F. and 1 atm. being about 57 B.Th.U. an average lower value; as already pointed out in an earlier part of this section, with cylinders 30 ins. in diameter and over, in order to avoid overheating troubles it is found desirable in ctice to introduce only from 35 to 40 B.Th.U. per cubic foot of piston displacement; thus, ough low in comparison with most other gaseous fuels, the heat evolution per cubic foot blast-furnace gas mixture is fully adequate to the needs of large gas engines.

Some average results for the principal gaseous fuels used at the present day are given in following table :—

HEAT VALUE AND COMBUSTION OF USUAL GASEOUS FUELS.

(*From Sir Dugald Clerk.*)

Nature of Gaseous Fuel.	B.Th.U. per Cub. Ft. (Lower Value) at 60°F. and 1 Atm.	Cub. Ft. of Air Necessary for Complete Combustion.	B.Th.U.(Lower) per Cub. Ft. of Max. Mixture at 60°F. and 1 Atm.	B.Th.U. as in Col. 3 × a Volumetric Eff. of 0·85.
Column :—	1	2	3	4
Coal gas	500	5·0	83·3	71·0
Coke oven gas . .	400	4·0	80·0	68·0
Pond gas	150	1·1	71·0	60·3
Pressure producer gas from anthracite . .	150	1·1	71·0	60·3
Pressure producer gas from coke . . .	130	0·95	67·0	57·0
Suction producer gas from anthracite . .	130	0·93	67·0	57·0
Suction producer gas from coke . . .	130	0·92	68·0	57·8
Blast furnace gas . .	100	0·75	57·0	48·4

60° F. = 15·5° C.

THE KIRKE PATENT GAS-FIRED BOILER.

The Kirke Patent Gas-fired Boiler, invented by Mr. P. St. G. Kirke, M.A., A.M.I.C.E., M.I.M.E., etc., is manufactured by *Spencer-Bonecourt, Ltd., Parliament Mansions, Victoria Street, London, S.W.* 1.

Fig. 45 shows a Kirke Patent Gas-fired Steam Boiler. The design is based on the discovery that, if such gases as coal gas, coke-oven gas, blue water gas, producer gas, and natural gas are induced into empty tubes of great length relative to their bore, together with the air theoretically required for combustion, or some 10 per cent. in excess thereof, they can be completely burnt in the tubes without being previously mixed, and the resulting products of combustion reduced to 70° C., or less, above the temperature of the water in the boiler. Further, that this can be done either with natural draft or with high induced draft of 4 ins. of water and over, provided that the length of the tubes is greater relative to their bore the higher the draft adopted.

The Kirke Patent Gas-fired Boiler in its simplest form consists of a drum traversed by a number of long tubes with nothing in them, which function as combustion chambers, as mixing chambers, and as extractors of the sensible heat remaining in the resulting products of combustion

KIRKE PATENT GAS-FIRED BOILER. (Patents No. 134,938, etc.)

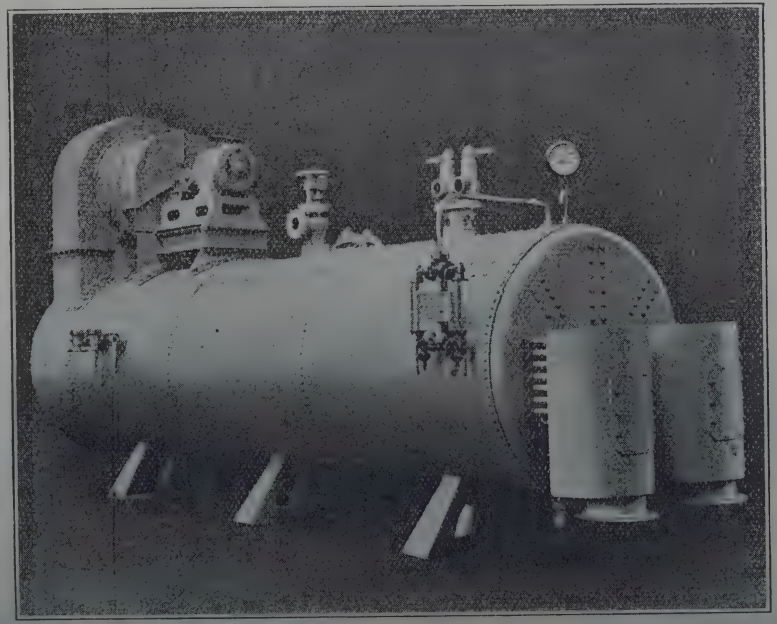
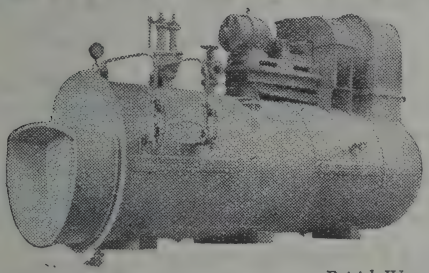


FIG. 45

STEAM for NOTHING!



British Waste Heat Boiler
Patents Nos. 130234, 140851, 172752, 186801, 193895, etc.

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At the inlet end of the tube is a patent gas burner or distributor which discharges a jet of s into each tube, the amount of which is determined by the size of the holes from which the s issues and the pressure of the gas in the burner, the latter being controlled by the large gas et valve at the bottom of the burner. The requisite air for combustion enters each tube m the atmosphere, the quantity being controlled by the amount of draft which is varied to it the load.

The following are figures obtained from a single tube evaporating water in an open wood nk lined with zinc :—

Gas burnt in cubic feet per hour	230
Steam raised from and at 212° F. in lbs. per hour	104
Cubic feet of gas per lb. of steam from and at 212° F.	2·21
Temperature of gases leaving the boiler	188° C.
Suction in inches of water	8
Gas pressure in inches of water	4
Evaporation per sq. ft. of heating surface in lbs. from and at 212° F. per hour	18
Net calorific value of the gas in B.Th.U.'s.	480
Thermal efficiency without economiser	91 per cent.

A single drum boiler of this type 7 ft. diameter by 21 ft. long, fired with coke-oven gas, will vaporate 21,000 lbs. of steam per hour with a suction of 4 ins. ; 16,000 lbs. with a suction of s ins. ; and 10,500 lbs. with a suction of 1 in. The radiation loss from the shell when completely gged (except for the front tube plate) is only ¼ per cent. at full load and under 3 per cent. when lagged.

The following table gives the power required by the fan, assuming 15½ lbs. of steam from nd at 212° F. are required to generate 1 b.h.p.

Nature of Fuel burnt in Kirke Patent Fuel-fired Boilers.	Draft.	Percentage of Boiler Output required to create 4 in. suction.	Approximate B.H.P. required by the Exhauster for an Evaporation of 10,000 lbs. of steam from and at 212° F. per hour.
	Ins.	Per Cent.	
Water gas	4	0·93	6
Coke oven gas	4	1·00	6½
Producer gas	4	1·25	8
Crude oil	4	1·35	8¾
Coal	4	1·71	11
Blast-furnace gas	4	2·00	13

When the floor space is very restricted, it is easy to put one drum on the top of another. n this way, for a given evaporation only one-fifteenth of the floor space required by Lancashire oilers for the same evaporation is required.

The cleaning of the tubes on the water side is made easy by division of the tubes into two ests. A man can enter the boiler through the manhole and walk along the whole length of the oiler between the two nests, so that he can scrape the surface of all the tubes for their entire ength, the distance between the tube centres being sufficiently great to enable him to get a uitably shaped scraper to all the tubes. This, however, is better avoided by softening the water r using a suitable boiler fluid. An internal scale-separating device is also fitted.

For superheating the steam a separate chamber containing fire tubes fired in the same way, ut with natural draft, is used, the temperature being kept constant by a thermostat operating he gas valve.

The following are the approximate fuel consumptions per lb. of steam raised from and at 212° F. for various fuels burnt in Kirke patent boilers without economisers :—

Producer gas	8 cubic ft.	Poor coal gas	2·7 cubic ft.
Coke oven gas	2½ ,,	Natural gas	1·2 ,,
Water gas	3⅝ ,,	Crude oil	$\frac{1}{17}$th lb.
Rich coal gas	2·2 ,,		

Kirke Patent Fire-Tube Boiler.

This boiler, fig. 46 (Patents numbered 140,851, 209,878, etc.), consists of one or more drums having inlet products chambers at one end and outlet products chambers at the other, connected together by a number of empty and straight fire tubes of great length relative to their bore through which the hot gases are drawn at a high vocity by means of an induced draught fan.

The high velocity enables large volumes to be handled in a boiler of comparatively small dimensions, and prevents most of the dust from lodging on, and insulating, the heating surface. It also reduces the cost of the boiler, and increases the return on the capital expenditure.

Notwithstanding the high velocity at which the gases flow over the heating surfaces, the great length of the tubes relative to their bore enables the temperature of the hot products to be reduced to about 30° C. above the temperature of the water in the boiler, before they enter the fan impeller. Consequently an economiser—although sometimes a good investment—is not essential, and higher thermal efficiencies can be obtained than have ever been obtained before.

Cleaning.—The fire tubes are arranged in two or more nests, between which it is possible for a man to enter, so that the tubes are exposed for cleaning on the water side over the whole of their length.

As the interior of the fire tubes is smooth, round, and straight, and the induced draught causes the hot products to travel through them at a high velocity, without changing their direction, there is nothing to catch the dust, which consequently is carried straight through to the outlet products chamber, from which it can be easily removed from time to time. To deal with dirty gases containing very large quantities of dust—such as are obtained from cement kilns—an arrangement (Patent No. 186,801) for enabling these boilers to be cleaned while they are running is now being fitted to all these boilers. The fan is arranged at the top or at the side of the boiler so as to leave the cover plate of the outlet products chamber unobstructed. In this cover plate small holes are drilled large enough to pass a tube brush or steam lance through for pushing through the whole length of tubes. One of these little holes will allow some air tubes to be cleaned, and, while leakage of air into several of the holes is not sufficient to reduce the draught, it is not necessary to open more than one at a time for cleaning purposes.

Circulation.—The circulation in the Kirke boilers is particularly good. About 70 per cent. of the evaporation occurs in the first third of the tubes, and only about 10 per cent. in the last third. Consequently there are strong convection currents upwards at the front end and downward at the rear end.

Dry Steam.—By taking the steam off at the back end of the boiler, where the circulation is downward, and by the use of an efficient anti-primer, the steam is rendered remarkably dry. In an independent test on a boiler of this type unlagged, the steam was found to be 99·3 per cent. dry. In a second independent test carried out on a lagged boiler of this type, the moisture in the steam was so small that it could not be measured and was reported to be 'practically quite dry.' In a third case, where water-tube boilers were giving trouble with priming, it was found impossible to make a boiler of this type prime even under conditions which no boiler would be put to in practice—namely, when supplying steam to a number of colliery winding engines, all of which were purposely started up at once.

Combustion Chamber.—The combustion chamber is very simple and may be supplied with mechanical stoker, grate for hand-firing, or gas burners, as shown. Pulverised fuel, wood, and blast-furnace gas may also be used.

Even when the drop of water gauge through the boiler tubes is raised to 4 ins. of water, that through the combustion chamber is a fraction of an inch, so that there is little chance of air leakages through the brickwork. Further, as the combustion chamber is comparatively small for the duty it is not a costly matter to encase it completely in metal.

The provisional patented superheater is arranged out of the path of flow of hot gases from the grate, but can receive radiant heat from the combustion chamber walls, which can be limited to any desired extent by armouring or screening the coils. Low-grade heat, if any, from the industrial furnace, may, however, pass over the coils.

Loss due to Radiation.—In Kirke boilers the radiation loss is extremely small, owing to the fact that, except for the front tube plate, the whole of the shell may be lagged. With air at 72° F., the heat loss from uncovered steam pipes carrying steam at 100 pounds per sq. in. is 1,170 B.Th.U.'s per sq. ft., and this is reduced to 100·2 B.Th.U.'s when 2 ins. of magnesia lagging is used to cover them (see 'Mechanical Engineers' Handbook,' by S. Marks). In the case of a large standard pattern Kirke gas-fired boiler, 6½ ft. diameter, evaporating 18,000 lbs. of steam

KIRKE PATENT FIRE-TUBE BOILER FOR WASTE HEAT, COAL, BLAST-FURNACE GAS, OR PULVERISED FUEL. (Patents No. 140,851, etc.)

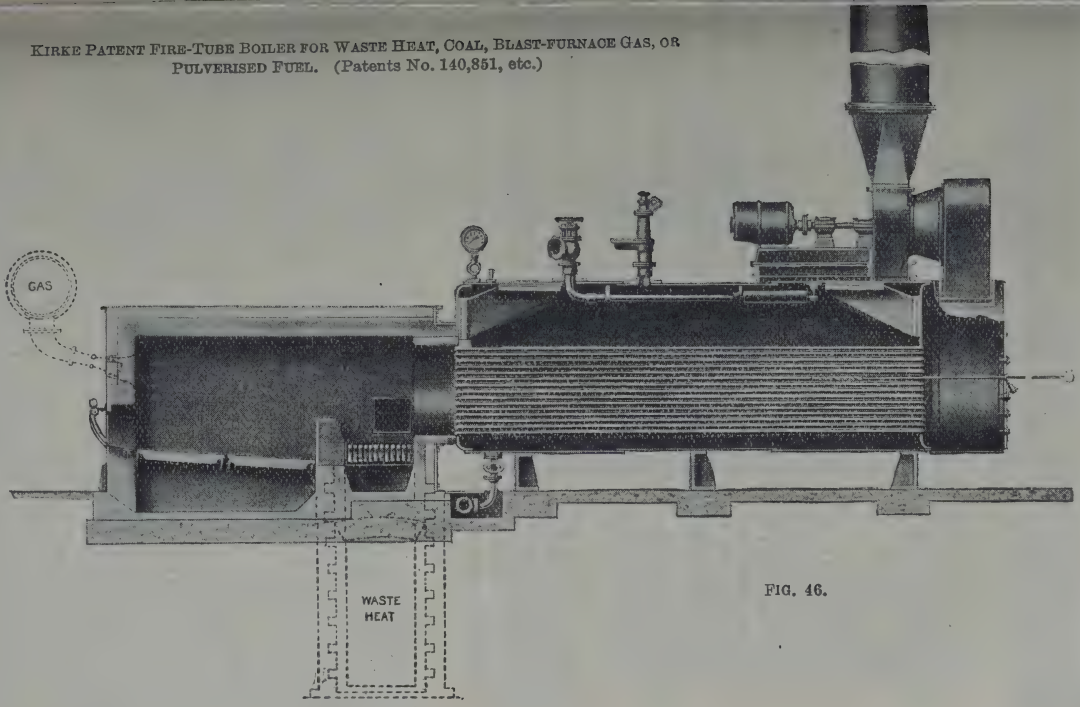

FIG. 46.

from and at 212° F. per hour with 4 ins. induced draught, the loss of steam due to radiation is however, only 2¾ per cent. before the boiler is lagged and about ½ per cent. after the boiler i lagged.

Efficiency.—Two Spencer-Bonecourt Kirke patent waste heat boilers which are generatin steam from the waste heat discharged from 10 settings of Glover-West retorts at the Stratfor works of the Gas Light and Coke Co., gave the following figures when tested by the staff of th Gas Light and Coke Co. :—

Date of test, November 19, 1923.

Duration of test, 24 hours.

Temperature of the products entering the boilers	689° C.
Temperature of the products leaving the boilers	225° C.
Steam pressure in lbs. per sq. in.	115
*Mean tube efficiency of the boilers	90·3 per cen
Suction in the outlet products chamber of the boiler in inches of water	1·4 ins.
Suction in the inlet products chamber available for the settings and collecting flues	1·4 ins.
B.H.P. consumed by the motor for the retorts	11½
B.H.P. consumed by the motor for the boilers	24½
Water evaporated per hour in lbs. actual	16,783
Water evaporated from and at 212° F. per hour in lbs.	18,500
Percentage of power absorbed by the draught for boiler (assuming 15 lbs. of steam from and at 212° F.) per b.h.p. hour	2 per cent.
Percentage of power developed absorbed by the draught for collecting flues and settings (assuming 15 lbs. of steam from and at 212° F. per b.h.p. hour)	0·93 per cen
Estimated saving in small coke and breeze per annum of 300 days freed for market in tons (assuming 6 lbs. of steam from and at 212° F. per lb. of this fuel)	10,000 tons
Steam produced from and at 212° F. per lb. of coke used in the producers	5·8
Steam produced from and at 212° F. per lb. of coal carbonised	0·9 lb.
Heat loss between the outlet of the settings and the inlet of the boiler due to radiation from the steel flues	4·9 per cent

One of these boilers fitted to a Talbot steel furnace at another works brought down th consumption of coal per ton of steel to 3½ cwts. Before the Kirke boiler was installed the co consumption was 5 cwts. per ton of steel.

These waste heat boilers have been successfully installed on horizontal retort benches, incline retort benches, vertical retort benches, open hearth steel furnaces, soaking pits, cement kiln water gas plants, puddling furnaces, etc.

The boilers have also been installed in Europe, Asia, Africa, America, and Australia.

THE CLARKSON BOILER.

(*The Clarkson Thimble Tube Boiler Co., Ltd.*, 613 *Australia House, Strand, London, W.C.* 2.)

The 'Clarkson Thimble Tube Boiler' has been evolved to meet the requirements of stea users who require all the advantages that an ordinary quick steaming water-tube boiler provide and for whom other considerations render inadvisable the use of such a boiler.

The boiler can be used for many duties and with various fuels, although the most suitable u for it is the extraction of the waste heat from engine exhaust gases. The makers claim that f this duty the boiler is the most serviceable on the market from almost every point of vie Installations on engines of all sizes from 30 b.h.p. to 5,000 b.h.p. have been successfully carri out.

The Clarkson Thimble Tube Boiler is of the vertical water-tube type, the general constructi of which is shown in fig. 47, page 2185. The tubes, being thimble shaped, are expanded into cylindrical shell sheet at one end only, so that the troubles caused by the expansion and co traction of water-tubes in ordinary boilers do not exist for the Clarkson Boiler, whilst at the san time quick steaming properties and other advantages of water-tube boilers are retained.

The boiler unit consists of two cylindrical shell plates, through the centre of which the fl gases pass. Several hundred thimble tubes are expanded into holes in the inner plate, ea successive ring being staggered. A centre core fills up the cylindrical space between the tu ends and compels the exhaust gases to travel tortuously through the nest of tubes which compri the heating surface (see page 2185). The water space is thus annular in shape with projectio inside each thimble.

The usual boiler or heater fittings are mounted on the shell. A combustion chamber and burners are added to the boiler unit, and make a highly efficient steam generator.

* To obtain tube efficiency, divide difference between the temperature of the gases enteri and leaving the tubes by the difference between the temperature of gases entering the tubes a that of the water in the boiler.

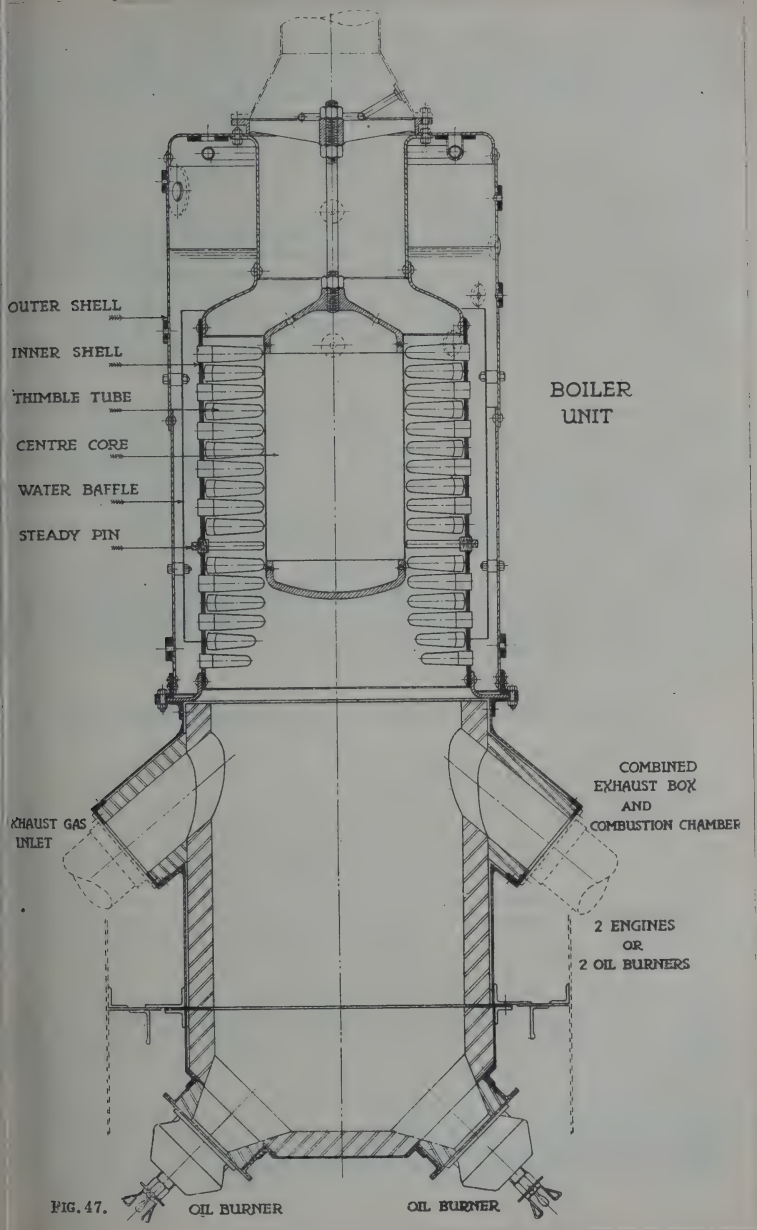
OUTER SHELL
INNER SHELL
THIMBLE TUBE
CENTRE CORE
WATER BAFFLE
STEADY PIN
BOILER UNIT
COMBINED EXHAUST BOX AND COMBUSTION CHAMBER
XHAUST GAS INLET
2 ENGINES OR 2 OIL BURNERS
OIL BURNER
OIL BURNER

FIG. 47.

Non-Scaling.—It will be realised that steam is generated inside the thimbles, and therefore when a certain amount of steam is generated it blows the water back out of the mouth of the tube. The water then returns into the tube when the steam has escaped. The pulsating action thus set up has a frequency of the order of 90 to 160 per minute, and effectively scours the tube of scale. The scale-forming matter is then directed to the foot of the boiler by the cylindrical baffle plate which also prevents the cold feed water from impinging direct on to the tube ends, and helps an effective circulation.

Thimble Tubes.—There are 272 tubes, 1 in. diameter by 2 $\frac{3}{8}$ ins. long on the smallest heater of 10 sq. ft. heating surface, and about 1,150 tubes, 3$\frac{1}{4}$ in. diameter by 12 ins. long on the largest boiler, which has a heating surface of about 700 sq. ft. Each tube is tested to a pressure of 1,000 lbs. per sq. in. before leaving the Works.

Soot Cleaning.—Should the outside of the thimble tubes foul, as may happen when running off a dirty engine exhaust, the boiler can be emptied, a wad of oil-soaked waste ignited and put at the foot of the tube nest, and the impurities burnt off with no danger of damage occurring.

Accessibility.—The tubes are easily accessible on the steam side, by raising the outer shell, and on the inner side, by removing the centre core.

Centre Core.—The centre core or gas baffle, of the best fire-resisting material, forces the exhaust gases to travel tortuously through the nest of tubes, and is suspended from the uptake, being steadied by three to six steady pins, screwed into the inner shell.

Exhaust Heat Extraction.

Silencing.—The Clarkson Boiler is an efficient exhaust silencer, and when run off, exhaust gases may be allowed to run dry, with no ill effects, and can be put on to steaming load at short notice.

No Back Pressure.—In estimating the size of boiler required for extracting heat from exhaust gases, the main consideration is the avoidance of any extra back pressure on the engine. The contraction of the gases as they cool in the boiler assists the exhaust from the engine cylinders, tending to reduce back pressure.

Boilers of this type have been fitted by the British Admiralty to provide steam for evaporators on submarines, and have given efficient and satisfactory service.

Fuel Firing.

Owing to the quick steaming properties and strong design of the Clarkson Boiler, it was found necessary to adapt the unit for coal or oil firing, and a range of thimble tube boilers with water legs has been built and have given satisfactory service as donkey boilers, galley boilers, and dredging duties. Types of these boilers, used on steam waggons, have withstood successfully for many years the rough treatment that is often met with in road work.

The makers claim the following advantages for this boiler:

1. A smaller size of thimble tube boiler will do the work of steam generation more efficiently and at less cost than is possible with any other type of boiler, especially other vertical boilers.
2. In consequence of low size and weight, it can be fitted in the place of silencers, in the exhaust pipe run above the engine room.
3. Silencer boilers may be fitted with alternative oil firing, for use in port.
4. Ample accessibility for cleaning and inspection of all internal parts.

Summary of Test Results when Oil Firing.

Clarkson Silencer Boiler: Type Begatoo-400.

Boiler.—Clarkson Patent Vertical Thimble Tube, 5 ft. diam. by 17 ft. high; 100 lbs. per sq. in. working pressure.

Heating Surface.—402 sq. ft., 2 oil burners, Todd's pressure system.

Utility.—Silencer for 2 main engines, total 4,500 h.p. or oil-fired donkey boiler.

Oil used.—Shell Mex. Spec. grav. 0·936 at 60° F.; calorific value, 18,600 B.Th.U.

Guaranteed Evaporation.—4,000 lbs. of water from and at 212° F. with oil of above calorific value

Evaporation per hour from and at 212° F.	4,273 lbs
Total evaporation in 2 hours' test at 100 lbs. per sq. in.	7,130 „
Total evaporation per hour at 100 lbs. per sq. in.	3,565 „
Oil consumed per hour	327 „
Water evaporated at 100 lbs. per sq. in. per hour per lb. of oil	10·9 „
Water evaporated from and at 212° F. per hour per lb. of oil	13·0 „
Water evaporated from and at 212° F. per sq. ft. of heating surface per hour	10·2 „
Thermal efficiency of boiler—unlagged	65·9%

WASTE HEAT RECOVERY.

(Contributed by Chas. F. Wade, A.M.I.Mech.E., A.M.I.E.E.)

The directions in which profitable recovery of waste heat must be looked for are

(i) Waste heat from various metallurgical and other furnaces

(Ii) Waste gases from internal combustion engines;

(iii) Exhaust steam from non-condensing engines, steam hammers, steam-hydraulic intensifiers, etc.

Waste heat from high temperature metallurgical operations, such as open-hearth melting rnaces, consists of the sensible heat of the waste gases and the heat carried away by radiation id convection from the furnace walls. The latter is permitted deliberately in order to prevent necessarily rapid burning of the walls. The heat of the waste gases is generally utilised for e purpose of preheating the incoming air and gas by means of regenerators and reversing lves. By jacketing the furnace walls and utilising the heat formerly wasted in radiation r air preheating, thus releasing approximately 50 per cent. of the heat of the waste gases for eam-raising in a waste heat boiler, a very substantial saving of fuel will result. The loss of at by radiation and convection from unjacketed furnaces is certainly not less than 25 per nt. of the total heat of the fuel used. Even in a reheating furnace working at 1000° C., jacketing the furnaces instead of regeneration in chequer chambers will often give an air temperature over 300° C.

Small reheating furnaces for light forgings and similar work air-jacketed at the sides only ll often give a temperature of over 150° C. in the air supplied for combustion. In all cases e result will be that the final temperature of the gases will be sufficient to make a waste heat iler a profitable investment.

In metallurgical furnaces wherein the process requires a densely smoky atmosphere and the r supply is deliberately restricted, the use of a waste heat boiler for the products of combustion gether with a supplementary coal fire, through which an excess of air is passed, will not only ad to large recovery of heat in the form of steam, but will also furnish a solution to the smoke-atement problem. Without the supplementary fire-grate a supply of highly preheated air ought through ducts on the furnace settings will usually ensure reignition of the combustible atter in the smoky gases. Cold air will not do this owing to the low temperature of the gases begin with, thus keeping the products below ignition point.

For ordinary waste heat boiler work without supplementary firing a temperature of at least)0° C. is needed to make the proposition profitable. With tubular boilers of the Cochran pe the usual evaporation per pound of coal consumed in the furnace is:—

Temperature of Waste Gases.	1500° F.	1800° F.	2000° F.
Lbs. water per lb. of coal from water at 62° F.	3·08	4·25	5·00

Using boilers of the 'Bonecourt' type, in its more modern developments, wherein gas at a gh velocity, aided by mechanical draught, is in use, gases with an initial temperature of 350° C. ay be used profitably.

Gases from internal combustion engines usually allowed to expand in a silencer, with corre-ponding fall of temperature, are maintained at smaller volume and part with their heat to the ater in the boiler with a final temperature of about 75° C.

This system is of considerable value also in dealing with the waste heat from gas retort rnaces.

Where low-temperature furnaces are in use only the waste gases may be used for heating water for shop and office heating by means of economisers, and where both high- and low-mperature furnaces are worked, the hot water from the latter should be used for feed to the gh-temperature waste heat boilers. An interchange of heat and power from waste sources etween adjoining establishments is often a practicable proposition where the means of power id heat generation and utilisation are collectively equal.

The heat wasted in exhaust steam can be applied to the drive of low or mixed pressure rbines, which latter will have the additional economical effect of levelling out the load on ie boiler plant, in that a falling-off of the supply of exhaust steam will cause the turbine to raw on the boilers directly for a high pressure supply. Other important advantages are the sturning of soft water to the boilers for feeding purposes, either with or without preliminary ectrolytic treatment for oil elimination.

Other applications of the heat of exhaust steam are for heating processes in manufacture heating of buildings, etc., all of which permit of the return of the condensate for boiler fee purposes.

All proposals for the utilisation of waste heat of any kind require to be dealt with individuall on their merits, the conditions being so variable that no hard and fast rules can be laid dow which will be universally applicable.

Generation of Electricity in Great Britain by Waste Heat.

In the Annual Report of the Electricity Commission * it is stated that the total units generate by waste heat during the year ending March 31, 1926, was 178,159,230 (from 17 stations), a against 186,289,858 (from 19 stations) in 1925.

* Generation of Electricity in Great Britain, year ending March 31, 1926. H.M. Stationer Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.

SECTION XXXV

ELECTRICAL ENGINEERING

UNITS — RESISTIVITIES — FUSES — CONDUCTORS — PORCELAIN INSULATORS — ELECTRICAL EQUIPMENT OF SHIPS AND BUILDINGS — TESTING ELECTRIC SUPPLY MAINS — EARTH DETECTORS — WIRING SYSTEMS — COST OF ELECTRICAL ENERGY — ELECTRO-CHEMISTRY — BATTERIES — GENERATORS — CONVERTERS — MOTORS — CONTROL GEAR — TRANSFORMERS — STATIC BALANCERS — POWER FACTOR IMPROVEMENT — INSTRUMENTS — METERS — LAMPS — ELECTRIC CLOCKS — LIGHTNING CONDUCTORS — ELECTRIC HEATING AND COOKING — ELECTRICITY IN AGRICULTURE — TELEGRAPHY AND TELEPHONY — THERMIONIC VALVES — INSULATING MATERIALS — X-RAYS IN INDUSTRY.

(Revised and amplified by Prof. S. Parker Smith, D.Sc., Assoc.M.Inst.C.E., M.I.E.E.)

THE SEACOMBE FLOATING BRIDGE

Sea and Sand

THE opening of the Floating Roadway at Seacombe, and its subsequent operation, marked the success of an enterprising scheme. The roadway forms part of the Seacombe Ferry Improvements rendered necessary by the great increase in traffic across the Mersey. It is 600 ft. long and 56 ft. wide, carrying three roads. Five floating spans rest on pontoons which rise and fall with the tide, grounding at low tide. So far as is known this bridge is the largest of its type yet constructed. The photograph shows the brilliant lighting of the bridge by night. The cables for supplying the current were run under the roadway on wooden battens and taken up the inside of each pillar. Thus the cables have no protection and are washed twice daily for considerable periods by the sea and by the sand which comes under the roadway at each side. For this reason "Maconite" Insulated Cables were chosen. They were chosen by reason of their known ability to withstand such conditions, proved by exhaustive tests and by long experience of actual installations in the most exacting situations.

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Seacombe Floating Bridge, *Engineers:* Messrs. Wilton, Bell & Ramsbotham, MM.Inst.C.E. Westminster. *Electrical Contractors:* Western Engineering Co., Liverpool. *General Manager Wallasey Corporation Ferries,* Lt.-Com. W. H. Fry, R.N.R.

SECTION XXXV

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(Revised and amplified by Prof. S. Parker Smith, D.Sc., Assoc.M.Inst.C.E., M.I.E.E.)

Electrical Units.

Unit.	Symbol.	Name.	Value in C.G.S. Units.	Dimensions in terms of Length Time Mass.	Dimensions in terms of Length Time Force Velocity.
Electromotive force	E	Volt	10^8	$L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-2}$	$V\sqrt{F}$
Current	I	Ampere	10^{-1}	$L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$	$\sqrt{F}$
Quantity	Q	Coulomb	10^{-1}	$L^{\frac{1}{2}}M^{\frac{1}{2}}$	$T\sqrt{F}$
Resistance	R	Ohm	10^9	LT^{-1}	V
Capacity	C	Farad	10^{-9}	$L^{-1}T^2$	TV^{-1}
Inductance	L	Henry	10^9	L	L
Power or rate of working	P	Watt	10^7	L^2MT^{-3}	VF
Energy	W	Joule	10^7	L^2MT^{-2}	LF

The values of these units are as follows:—

One Ampere (international) is the unvarying electric current which, when passed through a olution of nitrate of silver in water, deposits silver at the rate of 0·001118 gramme per Second.

One Coulomb is the quantity of electricity represented by 1 Ampere passing for 1 Second.

One Ohm (international) is the resistance to an unvarying electric current of a column of ercury of uniform cross-section and length equal to 106·3 cm. whose mass is 14·4521 grammes t the temperature of melting ice.

One Volt (international) is the electrical pressure which, when steadily applied to a conductor hose resistance is one international Ohm, will produce a current of one international Ampere.

One Farad is that capacity which is charged to a potential of 1 Volt by a current of 1 Ampere owing for 1 Second.

One Henry is the inductance of a circuit in which an E.M.F. of 1 Volt is induced by a current ariation of 1 Ampere per Second.

One Watt is the power, or the rate at which work is being done, when a current of 1 Ampere asses through a resistance of 1 Ohm.

One Joule is the amount of work done, or heat generated, by 1 Ampere flowing for 1 Second hrough a resistance of 1 Ohm.

The following multiples and sub-multiples of these units are in common use :—

One millivolt = one-thousandth of a volt.
One milliampere = one-thousandth of an ampere.
One megohm = one million ohms.
One microhm = one-millionth of an ohm.
One microfarad = one-millionth of a farad.
One millihenry = one-thousandth of a henry.
One kilowatt = one thousand watts.

The following relations will be found useful :—

One horse-power is equal to 746 watts.

One foot-pound is equal to 1·356 joules = 0·323 calorie.

One joule is equal to 0·238 calorie.

One (gm.) calorie is the work done in raising 1 gramme of water 1° C., = 4·2 joules.

One (kg.) calorie = 1000 (gm.) calorie.

One joule is equal to 0·7373 foot-pound.

One dyne is the force which, acting on a mass of 1 gramme for 1 second, will give it a velocity of 1 cm. per second.

One erg is the work done by 1 dyne acting through 1 centimetre.

One watt = 0·00134 horse-power = 0·7373 ft.-lb. per second = 44·24 ft. lb. per minute = 0·057 British thermal unit per minute = 1 joule per second.

One kilowatt-hour = 1,000 watt-hours = one Board of Trade Unit = 1·34 horse-power-hour = 2,656,400 ft.-lb. = 3,415* British thermal units = 860,600 calories.

The practical standard of electromotive force is the Weston Normal cell, which has an E.M.F. of 1·0185 volts at 15° C., decreasing by 0·00004 volt per degree C. rise of temperature.

Laws of Currents in Conductors.

Ohm's law states that: Voltage = Current × Resistance, or V = I × R.

Kirchhoff's first law states that : The algebraic sum of the currents meeting at any point of a network of conductors is zero.

Kirchhoff's second law states that: The algebraic sum of all the products of resistances and currents in all the wires forming a closed network equals the algebraic sum of all the electromotive forces in the network.

RESISTIVITY OF PURE ANNEALED METALS, AND ALLOYS, AT 0° C. (32° F.).

(*Fleming & Dewar.*)

Metal.	Microhms per cm. cube.	Microhms per inch cube.	Ratio to Copper.	Temp. Coefft. F. per cent.	Temp. Coefft. C. per cent.
Aluminium	2·665	1·048	1·68	0·342	0·435
Antimony	36·0	14·17	22·7	0·217	0·39
Arsenic	33·3	13·1	21	—	—
Bismuth	111·0	43·7	69·6	0·195	0·35
Copper	1·588	0 6252	1	0 237	0·426
Gold	2·20	0·866	1·38	0·209	0·377
Iron	9·07	3·57	5·71	0·347	0·625
Lead	20·4	8·03	12·8	0·228	0·411
Mercury	94·07	37·04	59·2	0·040	0·072
Nickel	12·3	4·84	7·75	0·345	0·62
Platinum	10·92	4·299	6·88	0·204	0·367
Silver	1·47	0·579	0·926	0·222	0·40
Tin	13·05	5·138	8·22	0 244	0·44
Zinc	5·75	2·26	3·62	0·226	0·406
Constantan	51	20	32	±0·0005	±0·001
German Silver	30	11·8	19	0·0152	0·0273
Manganin	46·7	8·4	29·4	0·0008	0·0015
Nichrome	95	37·5	60	0·0239	0·043
Platinoid	38	15	24	0·0122	0·022

* British Engineering Standards Association, 'Glossary of Terms used in Electrical Engineering' (Publication No. 205—1926). The Electricity Commissioners have adopted the value '341' which takes the *mean* British thermal unit to be $\frac{1}{180}$ of the quantity of heat required to raise the temperature of 1 lb. of water from 32° F. to 212° F. See also p. 1593.

Lenz's law states that : The current induced in a conductor flows in such a direction that its action opposes the change of position or state by which it is produced.

The power represented by a current of I amperes flowing under a difference of potential of volts through a conductor of resistance R ohms $= I \times V = I^2R = V^2/R$ watts.

The heat energy generated by a current of I amperes flowing through a conductor of resistance R ohms for t seconds $= I^2Rt$ in joules.

Effect of Temperature on Resistance.

The resistance of metals increases with the temperature in accordance with the approximate formula

$$R_t = R_o (1 + kt)$$

where k is the coefficient given in col. 5 or 6 (according to the temperature scale employed) divided by 100.

If the resistance R_1 at temperature t in ° C. be known, then for copper the resistance R_2 at temperature t_2 in ° C. will be :—

$$R_2 = R_1 \left(\frac{234{\cdot}5 + t_2}{234{\cdot}5 + t_1}\right)$$

Metallic Resistance Materials.

Metallic resistance materials are classified by the British Engineering Standards Association for maximum temperatures of 60, 200, 300, 700, and 1,000° C. respectively. According to Report No. 115—1924, the resistivity at 20° C. is not to differ more than 5 per cent. from that declared by the supplier, and the material must be uniform in resistance within 5 per cent. ; the temperature coefficents in the two low-temperature classes must not exceed 0·00002 and 0·00004 respectively for ten hours without the resistance changing more than 0·01 per cent. Lists of standard sizes of wires, sheets, and tapes are given in the Report.

Copper Conductors.

COMPARATIVE TABLE OF OLD AND NEW STANDARD SIZES.

New Standard.		Old Standard.		New Standard.		Old Standard.	
New Nominal Area in Sq. Inches.	Number and Diameter in inches of Wires.	Number and Gauge of Diameter in inches of Wires.	Old Nominal Area in Sq. Inches.	New Nominal Area in Sq. Inches.	Number and Diameter in inches of Wires.	Number and Gauge or Diameter in inches of Wires.	Old Nominal Area in Sq. Inches.
0·001	1/·036	1/20 S.W.G.	0·0010	—	—	7/14 S.W.G.	0·0346
0·0015	1/·044	—	—	0·04	19/·052	—	—
—	—	1/18 ,,	0·0018	—	—	19/17 ,,	0·0459
—	—	3/22 ,,	0·0018	0·06	19/·064	19/16 ,,	0·0600
0·002	3/·029	—	—	0·075	19/·072	19/15 ,,	0·0750
—	—	7/25 ,,	0·0022	—	—	19/14 ,,	0·0937
0·003	3/·036	3/20 ,,	0·0030	0·1	19/·083	—	—
—	—	7/23 ,,	0·0031	0·12	37/·064	37/16 ,,	0·1168
0·003	1/·064	1/16 ,,	0·0032	—	—	19/13 ,,	0·1250
—	—	7/22 ,,	0·0042	0·15	37/·072	37/15 ,,	0·1500
0·0045	7/·029	—	—	—	—	37/14 ,,	0·1824
—	—	7/21½ ,,	0·0049	0·2	37/·083	37/·083″	0·2000
0·007	7/·036	7/20 ,,	0·0070	0·25	37/·093	37/·092″	0·2500
—	—	7/19 ,,	0·0086	0·3	37/·103	37/·104″	0·3000
0·01	7/·044	—	—	0·4	61/·093	61/·092″	0·4000
—	—	7/18 ,,	0·0125	0·5	61/·103	61/·104″	0·5000
0·0145	7/·052	—	—	0·6	91/·093	61/·112″	0·6000
—	—	7/17 ,,	0·0170	0·75	91/·103	91/·101″	0·7500
0·0225	7/·064	7/16 ,,	0·0220	0·85	127/·093	—	—
0·03	19/·044	—	—	1·0	127/·103	127/·101″	1·0000
—	—	19/18 ,,	0·0338				

Fuses.

Approximate Fusing Currents of Copper Wires in Free Air.

Diameter of Wire.	Equivalent S.W.G. Size.	Fusing Current.	Maximum Safe Working Current.
In.		Amps.	Amps.
0·0092	34	8·6	4·3
0·01	33	9·8	4·9
0·0108	32	11·0	5·5
0·012	—	12·8	6·4
0·0124	30	13·5	6·8
0·0148	28	17	8·6
0·018	26	22	11
0·022	24	30	15
0·028	22	41	21
0·029	—	43	22
0·036	20	62	31
0·040	19	73	37
0·044	—	86	13
0·048	18	98	49
0·052	—	111	56
0·056	17	125	63
0·064	16	156	78
0·072	15	191	96
0·080	14	229	115

Approximate Fusing Currents of Lead-Tin Alloy (Lead 75 per Cent, Tin 25 Per Cent. Wires in Free Air.

Diameter of Wire.	Equivalent S.W.G. Size.	Fusing Current.	Maximum Safe Working Current.
In.		Amps	Amps.
0·02	25	3	2·0
0·022	24	3·5	2·3
0·024	23	4	2·6
0·028	22	5	3·3
0·032	21	6	4·1
0·036	20	7	4·8
0·048	18	10	7·0
0·064	16	16	11·0

Note on Fusing Currents.

The fusing currents in the tables may be taken to be correct where the fuse wire passes through an asbestos tube and does not closely touch the tube, but they do not apply where a substantial length of the wire is in contact with a porcelain holder. With the latter, more current is needed to melt the fuse.

For copper wires, the values of the current given are those necessary to fuse the wire in one minute, and are not appreciably different for other periods. For the lead-tin alloys, the fusing time is two minutes. Under normal running conditions, the actual temperature-rise at the hottest part of the fuse wire will be 100 to 150° C. for copper and 50 to 75° C. for the lead-tin alloy.

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BRITISH STANDARDS FOR DIMENSIONS, WEIGHT, AND RESISTANCE OF SOLID AND STRANDED CIRCULAR CONDUCTORS.
(Standard Annealed Copper.)

Standard Sizes.		Number and Diameter of Wires.	Weight per 1,000 yards.	Resistance per 1,000 yards at 60° F.			Overall Diameter of Conductor.
Nominal Area.	Calculated Area.			Standard.	Maximum for Plain Wires.	Maximum for Tinned Wires.	
Sq. in.	Sq. in.	Inch.	Lbs.	Ohms.	Ohms.	Ohms.	Inch.
0·0010	0·001018	1/·036	11·77	23·59	24·29	24·53	0·036
0·0015	0·001521	1/·044	17·58	15·79	16·26	16·42	0·044
0·0020	0·001943	3/·029	23·37	12·36	12·61	12·85	0·062
0·0030	0·002994	3/·036	36·02	8·019	3·180	8·260	0·078
0·0030	0·003217	1/·064	37·20	7·463	7·687	7·761	0·064
0·0045	0·004546	7/·029	54·39	5·281	5·387	5·493	0·087
0·0070	0·007005	7/·036	83·81	3·427	3·496	3·530	0·108
0·0100	0·01046	7/·044	125·2	2·294	2·340	2·363	0·132
0·0145	0·01462	7/·052	174·9	1·643	1·675	1·692	0·156
0·0225	0·02214	7/·064	264·9	1·084	1·106	1·117	0·192
0·0300	0·02840	19/·044	340·4	0·8468	0·8637	0·8721	0·220
0·0400	0·03960	19/·052	475·5	0·6063	0·6184	0·6244	0·260
0·0600	0·05999	19/·064	720·3	0·4002	0·4082	0·4122	0·320
0·0750	0·07592	19/·072	911·6	0·3162	0·3225	0·3257	0·360
0·1000	0·1009	19/·083	1211	0·2380	0·2427	0·2451	0·415
0·1200	0·1168	37/·064	1403	0·2056	0·2097	0·2118	0·448
0·1500	0·1478	37/·072	1776	0·1625	0·1657	0·1673	0·504
0·2000	0·1964	37/·083	2360	0·1223	0·1247	0·1259	0·581
0·2500	0·2465	37/·093	2963	0·09738	0·09933	0·1003	0·651
0·3000	0·3024	37/·103	3635	0·07939	0·08098	0·08177	0·721
0·4000	0·4064	61/·093	4886	0·05908	0·06026	0·06085	0·837
0·5000	0·4985	61/·103	5994	0·04816	0·04913	0·04961	0·927
0·6000	0·6062	91/·093	7290	0·03961	0·04040	0·04079	1·023
0·7500	0·7435	91/·103	8942	0·03229	0·03294	0·03326	1·133
0·8500	0·8459	127/·093	10175	0·02838	0·02895	0·02923	1·209
1·0000	1·0376	127/·103	12481	0·02314	0·02360	0·02383	1·339

British Standards for Insulated Annealed Copper Conductors for Electric Power and Light.*

No. 7—1926—(*Abstract.*)

The International Standards of Resistance for Copper are as follows:—At 20° C. (68° F.), th resistance of a wire of standard annealed copper 1 metre long and of 1 sq. millimetre cros section is $\frac{1}{58}$ (0·017241) ohm. The density of such copper at 20° C. is 8·89 grams per cub. centi metre, and the temperature coefficient of resistance is 0·00393 per degree C. At 60° F. (15·56° C. the resistance of a solid conductor of standard annealed copper 1,000 yards long and of 1 sq. in cross-section is 0·0240079 ohm; the density is 8·892015, and the temperature coefficient c resistance is 0·0022221 per degree F.

At 15·5° C. (60° F.), the resistance of a copper conductor is accurately given by th expression:

Resistance in microhms = 8 × length in feet/cross section in square inches.

For the purposes of the specification an increase of 2 per cent. in the length of each wire in th stranded conductor has been assumed, and the area of the stranded conductor has been taken t be that of the solid wire which has the same resistance. In the case of multicore cables, a increase of 2 per cent. has been taken, to allow for the laying-up of the cores.

Tolerances allowed on solid conductors are, in weight, 3 per cent.; in resistance, 3 per cent plain, 4 per cent. tinned (0·036 in. diameter upwards), 5 per cent. (below 0·036 in.). On strande wires, in weight 2 per cent.; in resistance, 2 per cent. plain, 3 per cent. tinned (0·036 in. diamete upwards), 4 per cent. (below 0·036 in.).

The resistance of hard-drawn copper is about 3 per cent. higher than that of annealed coppe conductors.

This specification also gives tables of sizes, resistances and weights of standard solid an stranded circular copper conductors, flexible cords and cables. Details of standard thickness c dielectric for paper, rubber and vulcanised bitumen insulated cables, the sizes and thickness c lead and tough rubber coverings, galvanised steel wire and tape for armouring are tabulated fc cables up to 11,000 volts. Pressure tests are specified together with the method of procedur An appendix contains diagrams showing sections of single and multicore cables and an extrac from the British Standard Glossary of Electrical Terms and Definitions.

Flexible Cables.

A flexible cable is one in which the conductor (or conductors) exceeds 0·007 sq. in. in cross section, and comprises a number of wires, the diameter of the wires and the material of the dielectri being such as to ensure flexibility.

Dimensions and Resistance of Flexible Cables.†

Nominal Area in sq. in.	Number and Diameter of Wires comprising Conductor. Diameter. 0·010 in.	0·012 in.	0·018 in.	0·029 in.	Resistance in Ohms per 1000 yards at 60° F. (15·6° C.) Standard	Maximum for Plain Wires.	Maximum for Tinned Wires.
0·01	140/·010	97/·012‡	—	—	2·29	2·34	2·39
0·0145	195/·010	—	60/·018‡	—	1·64	1·68	1·71
0·0225	296/·010	—	91/·018‡	—	1·08	1·11	1·13
0·03	—	266/·012	117/·018‡	—	0·847	0·864	0·881
0·04	—	368/·012	163/·018‡	—	0·606	0·618	0·631
0·06	—	557/·012	248/·018‡	—	0·400	0·408	0·416
0·075	—	705/·012	313/·018	121/·029‡	0·316	0·323	0·329
0·1	—	—	416/·018	160/·029‡	0·238	0·243	0·247
0·12	—	—	482/·018	186/·029‡	0·206	0·210	0·214
0·15	—	—	610/·018	235/·029‡	0·163	0·166	0·169
0·2	—	—	810/·018	312/·029‡	0·122	0·125	0·127
0·25	—	—	1017/·018	392/·029‡	0·0974	0·0993	0·101
0·3	—	—	—	481/·029	0·0794	0·0810	0·0826
0·4	—	—	—	646/·029	0·0591	0·0603	0·0614
0·5	—	—	—	792/·029	0·0482	0·0491	0·0501

* For 'Bare Annealed Copper Wire for Electrical Machinery and Apparatus,' see p. 225 For 'Enamelled Plain Copper Wire for Electrical Instruments and Apparatus,' see p. 2303.

† For current-carrying capacity, see p. 2200. ‡ For trailing cables and similar purpose

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F. 2197

Flexible Cords.

A flexible cord is a flexible cable of cross-section not exceeding 0·007 sq. in.

Dimensions and Resistance of Flexible Cords.

Nominal Area.	Ordinary Flexible Cords.				Flexible Cords with Tough Rubber Sheathing.		
	Number of 0·0076-in. Diameter Wires comprising Conductor.	Resistance in Ohms per 1,000 Yards at 60° F. (15·6° C.)			Number of 0·012-in. Diameter Wires comprising Conductor.	Resistance in Ohms per 1,000 Yards at 60° F. (15·6° C.)	
		Standard.	Maximum for			Standard.	Maximum.
			Plain Wires.	Tinned Wires.			
Sq. in.	Inch.	Ohms.	Ohms.	Ohms.	In.	Ohms.	Ohms.
0·0006	14/·0076	39·7	40·5	41·3	7/·012	40·5	41·3
0·0010	23/·0076	24·2	24·6	25·1	11/·012	24·6	25·1
0·0017	40/·0076	13·9	14·2	14·4	16/·012	14·2	14·4
0·0030	70/·0076	7·94	8·10	8·26	28/·012	8·10	8·26
0·0048	110/·0076	5·05	5·15	5·25	44/·012	5·15	5·25
0·0070	162/·0076	3·43	3·50	3·57	65/·012	3·50	3·57

Thickness of Insulation and Current-carrying Capacity of Flexible Cords.*

Nominal Area of Conductor. Sq. In.	Minimum Thickness of Dielectric in Inches (Ordinary Flexible Cords).				Flexible Cords with Tough Rubber Sheathing.			Maximum Currents in Amps. (subject to Voltage Drop).
	High Insulation, Kind 1.		Medium Insulation, Kind 2.		Thickness of Tough Rubber.	Overall Diameter in Inches.		
	Pure Rubber.	Pure and Vulcanising Rubber.	Pure Rubber.	Vulcanising Rubber.		250 Volts.	600 Volts.	
0·0006	0·02	0·033	0·015	0·028	0·05	0·200	0·244	1·8
0·001	0·02	0·034	0·015	0·029	0·05	0·214	0·255	3·0
0·0017	0·02	0·035	0·015	0·030	0·05	0·227	0·267	5·0
0·003	0·02	0·036	0·015	0·031	0·05	0·248	0·290	8·5
0·0048	0·02	0·038	0·015	0·032	0·05	0·268	0·308	13·0
0·007	0·02	0·039	—	—	0·05	0·288	0·328	17·0

* A flexible earth wire is not regarded as a conductor for the purpose of this table.

Vulcanised Rubber Cables.

Current-carrying Capacity of Copper Conductors.

Nominal Area of Conductor.	Number and Diameter (In.) of Wires.	Single Cables Run in Pairs.	Concentric or Twin Cable.	Three-core Cable.	Length of Lead and Return for 1-Volt Drop.
Sq. In.		Amps.	Amps.	Amps.	Feet.
0·001	1/·036	4·1	3·5	—	30
0·0015	1/·044	6·1	5·2	—	30
0·002	3/·029	7·8	6·7	—	30
0·003	3/·036	12·0	10·3	—	29
0·003	1/·064	12·9	11·1	—	29
0·0045	7/·029	18·2	15·7	13·6	28
0·007	7/·036	24·0	20·6	18·0	33
0·01	7/·044	31·0	26·6	23·2	39
0·0145	7/·052	37·0	32·0	27·8	45
0·0225	7/·064	46·0	39·0	34·0	55
0·03	19/·044	53·0	46·0	40·0	61
0·04	19/·052	64·0	55·0	47·0	71
0·06	19/·064	83·0	71·0	59·0	83
0·075	19/·072	97·0	83·0	69·0	90
0·1	19/·083	118·0	100·0	83·0	98
0·12	37/·064	130·0	118·0	90·0	103
0·15	37/·072	152·0	126·0	105·0	112
0·2	37/·083	184·0	149·0	126·0	123
0·25	37/·093	214·0	170·0	146·0	132
0·3	37/·103	240·0	188·0	—	145
0·4	61/·093	288·0	220·0	—	162
0·5	61/·103	332·0	249·0	—	172
0·6	91/·093	384·0	—	—	181
0·75	91/·103	461·0	—	—	185
0·85	107/·093	512·0	—	—	190
1·0	127/·103	595·0	—	—	200

The figures for vulcanised rubber cables apply to single cables run in pairs in iron conduits o in wood casing, and to single cables sheathed with tough rubber compound, and to concentri twin, and three-core cables of any finish run singly.

The maximum permissible currents (subject to voltage drop) given in the table for conducto up to 1 square inch in area allow for a rise in temperature of 20° F. (11·1° C.) For sizes belo 0·007 square inch the table is based on a current density of 4,000 amperes per square inch. Th length of lead and return given in the last column is based on the figures in the third column.

Where the temperature of the air exceeds 80° F. (26·6° C.), the current should be reduced s that the normal maximum running temperature does not exceed 100° F. (37·7° C.). Rubbe insulated cables should not be allowed to attain a temperature higher than 120° F. (48·8° C for long periods.

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IMPREGNATED-PAPER AND LEAD-COVERED CABLES.

CURRENT-CARRYING CAPACITY OF COPPER CONDUCTORS.

ominal Area of Conductor.	Number and Diameter (In.) of Wires.	Single Cables run in Pairs.	Concentric or Twin Cable.	Three-core Cable.	Length of Lead and Return for 1-volt. drop.
Sq. In.		Amps.	Amps.	Amps.	Ft.
0·001	1/·036	4·1	3·5	—	30
0·0015	1/·044	6·1	5·2	—	30
0·002	3/·029	7·8	6·7	—	30
0·003	3/·036	12·0	10·3	—	29
0·003	1/·064	12·9	11·1	—	29
0·0045	7/·029	18·2	15·7	13·6	28
0·007	7/·036	28·0	24·0	21·0	27
0·01	7/·044	42·0	36·0	31·0	27
0·0145	7/·052	57·0	49·0	43·0	28
0·0225	7/·064	75·0	65·0	56·0	32
0·03	19/·044	87·0	76·0	66·0	35
0·04	19/·052	104·0	89·0	76·0	41
0·06	19/·064	135·0	116·0	97·0	48
0·075	19/·072	157·0	135·0	111·0	52
0·1	19/·083	191·0	162·0	134·0	57
0·12	37/·064	210·0	177·0	146·0	60
0·15	37/·072	246·0	204·0	170·0	65
0·2	37/·083	296·0	240·0	203·0	72
0·25	37/·093	343·0	265·0	233·0	78
0·3	37/·103	385·0	302·0	258·0	85
0·4	61/·093	464·0	354·0	—	95
0·5	61/·103	540·0	405·0	—	100
0·6	91/·093	624·0	—	—	105
0·75	91/·103	738·0	—	—	109
0·85	127/·093	815·0	—	—	116
1·0	127/·103	932·0	—	—	121

The figures for impregnated-paper and rubber-insulated cables apply to single cables run in airs, and to concentric, twin, and three-core cables run singly.

The maximum permissible currents (subject to voltage drop) given in the table for conductor p to 1 square inch in area allow for a rise in temperature of 50° F. (27·7° C.). For sizes elow 0·007 square inch, the table is based on a current density of 4,000 amperes per square inch. The length of lead and return given in the last column is based on the figures in the third column.

Where the temperature of the air exceeds 80° F. (26·6° C.), the current should be reduced so hat the normal maximum running temperature does not exceed 130° F. (54·4° C.). Impregnated-aper lead-covered cables, for pressures not exceeding 660 volts, should not be allowed to attain , permanent temperature higher than 176° F. (80° C.).

Rubber-Insulated Flexible Cables.*

Current-carrying Capacity of Rubber-Insulated Flexible Cables for use with Portable Appliances.

Nominal Area of Conductor.	Maximum Current in Amps. (subject to Voltage Drop).	
	Two Conductor.	Three Conductor.
Sq. In.		
0·01	20	17
0·0145	24	20
0·0225	30	25
0·03	35	30
0·04	42	35

SIZES, WEIGHT, AND INSULATION RESISTANCE OF CABLES INSULATED WITH VULCANISED RUBBER.

Association Cables, 600-Megohm Grade.

(Abstract from Silvertown List.)

Nominal Area of Conductor.	Number and Diameter of Wires.	Minimum Thickness of Dielectric.	Minimum Insulation Resistance for a Mile.	Grade S. Taped, Braided and covered preservative Compound.		Grade RL. Taped and Lead covered.	
				Approximate Overall Diameter.	Approximate Weight per 1,000 yds.	Approximate Overall Diameter.	Approximate Weight pe 1,000 yds
Sq. Inch.	Inch.	Inch.	Megohms.	Inch.	Cwt.	Inch.	Cwt.
0·0010	1/·036	0·034	2000	0·165	0·43	0·200	3·01
0·0015	1/·044	0·034	,,	0·173	0·5	0·208	3·2
0·0020	3/·029	0·036	1250	0·195	0·64	0·230	3·64
0·0030	1/·064	0·036	2000	0·197	0·75	0·232	3·76
0·0030	3/·036	0·038	1250	0·215	0·83	0·250	4·13
0·0045	7/·029	0·039	,,	0·226	1·02	0·261	4·49
0·0070	7/·036	0·041	900	0·259	1·44	0·314	6·49
0·0100	7/·044	0·043	,,	0·287	1·92	0·342	7·53
0·0145	7/·052	0·046	900	0·317	2·53	0·392	10·28
0·0225	7/·064	0·049	,,	0·359	3·56	0·434	12·30
0·0300	19/·044	0·052	750	0·393	4·48	0·468	13·82
0·0400	19/·052	0·056	,,	0·441	6·11	0·516	16·53
0·0600	19/·064	0·062	,,	0·513	8·82	0·608	23·33

* A flexible wire is not regarded as a conductor for the purpose of this table.

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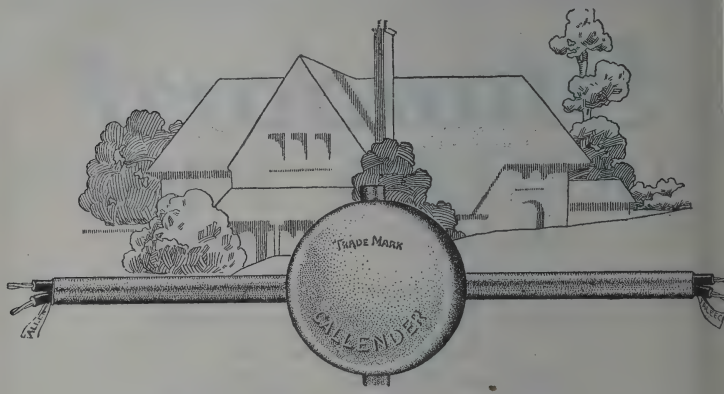

THE CALLENDER KALEECO WIRING SYSTEM is specially designed to eliminate the possibility of damage or interference with existing structure. Its adaptability is such that Castles, Churches, Mansions and Houses of all sizes and periods have been equipped efficiently at a reasonable cost and without disturbance. The wires employed in this system are rubber covered, taped and metal sheathed. These are clipped to wall surfaces, and although stiff enough to prevent sagging are easily bent round mouldings. When enamelled or distempered to tone with the decorative scheme the wires are practically invisible.

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THE CALLENDER KALEECO WIRING SYSTEM

CALLENDER'S CABLE & CONSTRUCTION CO., LTD., HAMILTON HOUSE, LONDON, E.

F. 220

SIZES, WEIGHT, AND INSULATION RESISTANCE OF CABLES INSULATED WITH VULCANISED RUBBER—(*cont.*)

Nominal Area of Conductor.	Number and Diameter of Wires.	Minimum Thickness of Dielectric.	Minimum Insulation Resistance for a Mile.	Grade S. Taped, Braided and covered preservative Compound.		Grade RL. Taped and Lead covered.	
				Approximate Overall Diameter.	Approximate Weight per 1,000 yds.	Approximate Overall Diameter.	Approximate Weight per 1,000 yds.
Sq. Inch.	Inch.	Inch.	Megohms.	Inch.	Cwt.	Inch.	Cwt.
0·0750	19/·072	0·066	600	0·596	10·96	0·656	26·73
0·1000	19/·083	0·072	,,	0·663	14·25	0·723	31·79
0·1200	37/·064	0·075	,,	0·702	16·25	0·762	34·82
0·1500	37/·072	0·080	,,	0·768	20·16	0·848	43·94
0·2000	37/·083	0·088	600	0·889	26·17	0·949	52·94
0·2500	37/·093	0·095	,,	0·973	33·12	1·053	66·02
0·3000	37/·103	0·102	,,	1·057	40·13	1·137	75·96
0·4000	61/·093	0·114	,,	1·197	53·44	1·297	99·96
0·5000	61/·103	0·121	600	1·301	64·72	1·421	121·13
0·6000	91/·093	0·125	,,	1·425	77·42	1·525	138·3
0·7500	91/·103	0·131	,,	1·547	93·78	1·667	166·77
0·8500	127/·093	0·135	,,	1·631	106·09	1·751	183·05
1·0000	127/·103	0·141	,,	1·773	128·63	1·893	212·29

ASSOCIATION CABLES, 2,500-MEGOHM GRADE.

Nominal Area of Conductor.	Number and Diameter of Wires.	Minimum Thickness of Dielectric.	Minimum Insulation Resistance for a Mile.	Grade C. Taped, Braided and covered preservative Compound.		Grade CL. Taped and Lead covered.	
				Approximate Overall Diameter.	Approximate Weight per 1,000 yds.	Approximate Overall Diameter.	Approximate Weight per 1,000 yds.
Sq. Inch.	Inch.	Inch.	Megohms.	Inch.	Cwt.	Inch.	Cwt.
0·0010	1/·036	0·034	5000	0·165	0·43	0·200	3·01
0·0015	1/·044	0·034	,,	0·173	0·50	0·208	3·2
0·0020	3/·029	0·036	4500	0·195	0·64	0·230	3·64
0·0030	1/·064	0·036	5000	0·197	0·75	0·232	3·76
0·0030	3/·036	0·038	4500	0·215	0·83	0·250	4·13
0·0045	7/·029	0·039	,,	0·226	1·02	0·261	4·49
0·0070	7/·036	0·041	4000	0·259	1·44	0·314	6·49
0·0100	7/·044	0·042	,,	0·287	1·92	0·342	7·53
0·0145	7/·052	0·046	4000	0·317	2·53	0·392	10·28
0·0225	7/·064	0·049	3500	0·359	3·56	0·434	12·30
0·0300	19/·044	0·052	,,	0·393	4·48	0·468	13·82
0·0400	19/·052	0·056	3000	0·441	6·11	0·516	16·53
0·0600	19/·064	0·062	,,	0·513	8·82	0·608	23·33
0·0750	19/·072	0·066	3000	0·596	10·96	0·656	26·73
0·1000	19/·083	0·072	,,	0·663	14·25	0·723	31·79
0·1200	37/·064	0·075	,,	0·702	16·25	0·762	34·82
0·1500	37/·072	0·080	,,	0·768	20·16	0·848	43·94
0·2000	37/·083	0·088	2500	0·889	26·17	0·949	52·94
0·2500	37/·093	0·095	,,	0·973	33·12	1·053	66·02
0·3000	37/·103	0·102	,,	1·057	40·13	1·137	75·96
0·4000	61/·093	0·114	,,	1·197	53·44	1·297	99·96
0·5000	61/·103	0·121	2500	1·301	64·72	1·421	121·13
0·6000	91/·093	0·125	,,	1·425	77·42	1·525	138·3
0·7500	91/·103	0·131	,,	1·547	93·78	1·667	166·77
0·8500	127/·093	0·135	,,	1·631	106·09	1·751	183·05
1·0000	127/·103	0·141	,,	1·773	128·63	1·893	212·29

ALUMINIUM CONDUCTORS.*

Conductivity.

The conductivity of aluminium depends upon the purity, and, to a less extent, upon t amount of work put upon the metal in its evolution from billet to the finished wire or bar. T British standard of resistance for hard copper is 2 per cent. higher than that of soft, and t difference also applies to hard and soft aluminium. The conductivity of all materials is norma compared with that of the International Standard for annealed copper, and on this basis ha drawn aluminium will have a minimum conductivity of 60 per cent. Hard-drawn copper w have a conductivity of about 98 per cent. and hence compared with hard-drawn copper, ha drawn aluminium will have a conductivity of 61·3 per cent.

Weight.

The specific gravity of aluminium wire is about 2·71. As the specific gravity of copper w is about 8·89, the relative weight of a given volume of each metal is in the ratio of 8·89 to 2·71 3·3. In other words, a copper wire of any given size and length will weigh 3·3 times as much an aluminium wire of the same size and length. Aluminium, therefore, having a conductivity 61 per cent. of that of copper, will have a sectional area 1·642 times as great as a copper conduc of the same resistance and length, and the ratio of the weights will be 3·3 to 1·642 = 2·01; th is to say, a copper conductor of any given resistance and length will weigh approximately tw as much as an aluminium conductor of the same resistance and length.

The ratios are therefore as follows :—

	Copper.	Aluminium.
Conductance for equal section	1	0·61
Section for equal conductance	1	1·642
Diameter for equal conductance	1	1·28
Weight for equal bulk	3·3	1
Weight for equal conductance	2·0	1

Tensile Strength.

Although the tensile strength of aluminium in the annealed state is low, the strength aluminium in the form of wire is greatly increased owing to the work put upon it during roll and drawing. The strength can be increased more than 100 per cent. without making elongation too small for engineering purposes.

Durability.

Aluminium has withstood the test of varying and severe climatic conditions. Lines h been in operation for over twenty years in exposed positions on the sea coast which show li signs of deterioration. The metal is less affected by sulphurous and sulphuric fumes than copp and shows less deterioration in the presence of any of the commoner acids. On the other ha aluminium is attacked by strong alkalies, and should not be used in such circumstances with efficient painting.

Increase of Resistance with Temperature.

The coefficient of increase of resistance with temperature varies somewhat with the ext and nature of the impurities present and the temperature range over which it is taken. 20° C. the value for aluminium may be taken at 0·0040 per degree C.

Coefficient of Linear Expansion.

The coefficient of linear expansion being somewhat greater with aluminium than with copp due allowance should be made for this when installing long lines of solid feeders or bars.

Action of Acids.

Aluminium is not acted upon by any of the common acids in a cold state, with the except of hydrochloric acid, and withstands the effects of sea-water better than either copper or ir but galvanic action is set up between aluminium and any of the common metals in the prese

* See also B.E.S.A. Report No. 215—1925.

noisture, and for this reason, if iron and copper joints must be used, they should be thoroughly tected from moisture by taping or painting with bituminous paint. It is found that galvanised n parts can be used with aluminium owing to their closer proximity in the electro-chemical ies, and the hardware employed with aluminium overhead lines is usually of galvanised lleable iron.

PHYSICAL PROPERTIES OF ALUMINIUM AND COPPER.

Property.	Aluminium.	Copper.
hemical symbol	Al	Cu
tomic weight (oxygen = 16)	27·1	63·57
osition in electro-chemical series	14	33
elting point degrees Cent.	658·7	1,083
,, ,, degrees Fahr.	1,217·7	1,981
pecific heat (water = 1) at 20° C. cals.	0·214	0·095
pecific thermal conductivity cals. per degree C. per sq. cm. per cm. per sec.	0·504	0·895
pproximate relative heat conductivity (silver = 100 per cent.)	51·8	90
oefficient of linear expansion, per degree C.	0·00002268	0·0000166
oefficient of linear expansion, per degree F.	0·0000126	0·00000922
pecific gravity, rolled or drawn	2·705	8·89
ensile strength of hard drawn wires /lbs. per sq. in.		
0·0935–0·211 ins. diam.	28,000–23,000	—
0·104–0·400 ins. diam.	—	65,000–51,000
odulus of elasticity, lbs. per sq. in.	$9{\cdot}6 \times 10^6$	$18{\cdot}0 \times 10^6$
lastic limit as percentage of tensile strength (minimum value)	60 per cent.	75 per cent.
pecific resistance in microhms per cm. cube at 20° C. (68° F.) — Annealed	2·82	1·7241
pecific resistance in microhms per cm. cube at 20° C. (68° F.) — Hard drawn	2·86	1·7585
hms per metre-gr. at 20° C. (68° F.) — Annealed	1·1107	0·6788
hms per metre-gr. at 20° C. (68° F.) — Hard drawn	1·1230	0·6924
hms per metre-gr. at 20° C. (68° F.) — Annealed	0·0763	0·1533
hms per metre-gr. at 20° C. (68° F.) — Hard drawn	0·0774	0·1564
oefficient of increase of resistance with temperature at 20° C. — Per degree C.	0·00400	0·00393
oefficient of increase of resistance with temperature at 20° C. — Per degree F.	0·00222	0·00218
eight per 1,000 yds. by 1 sq. in. cross section, lbs.	3,510	11,541
or H.D. conductors of equal resistance—		
Ratio of diameters	1·28	1·0
Ratio of sectional areas	1·64	1·0
Ratio of weight	0·50	1·0
or H.D. conductors of equal temperature rise—		
Ratio of diameters	1·18	1·0
Ratio of sectional areas	1·39	1·0
Ratio of weight	0·424	1·0

Sulphur has no effect upon aluminium at ordinary temperatures, and consequently aluminium hstands the action of smoke and fog much better than either silver or copper. A thin trans-ent film of insoluble oxide forms immediately on the surface of aluminium when it is exposed the atmosphere, protecting it from further oxidisation or corrosion. This film of oxide is a od insulator and will withstand the application of considerable electrical pressure before aking down. Advantage is being taken of this feature in the manufacture of magnet ndings, etc., which are otherwise uninsulated.

Capacity and Inductance.

Aluminium being a non-magnetic material, the inductance or capacity of the line can only affected by the increased diameter. This increased diameter may decrease the inductance d increase the capacity by some 5 per cent., but as all transmission lines possess more inductance an capacity, this difference is in favour of aluminium, tending to improve the power factor the system and to reduce the pressure drop due to inductance.

Heating Effect.

Aluminium, having a larger surface than copper of equal conductance, is more easily a to get rid of its heat, and when transmitting a given current with a given I^2R loss, alumini will remain the cooler. This is a considerable advantage when installing electric apparatus a hot atmosphere, or where current-carrying capacity is of more importance than the permiss pressure drop. In any case aluminium will have a higher overload capacity, from a heat point of view, than copper of equal resistance. In consequence of this aluminium is being larg used for busbars and solid rod battery connections. Erection on site is facilitated by the e with which bends and joints can be made.

Corona Losses.—With a high voltage overhead line a serious loss of energy may occur in form of a luminous discharge due to the breakdown of the air surrounding the conductors. point at which corona begins is a function of the conductor diameter, and the use of alumini or, better still, steel-cored aluminium, both of which involve a larger diameter than that of equivalent copper, will safely enable a higher working voltage to be employed.

ALUMINIUM CABLE, STEEL-CORED.

After the introduction of aluminium for electrical conductors it became apparent that conductor could be obtained, combining the advantages of lightness of aluminium with strength of high-grade steel now obtainable on the market, the highest efficiency would res Cables of this character were made up and have now been in service in such a variety of locali and conditions that their efficiency has been thoroughly demonstrated.

The cables consist of a steel core about which the aluminium is stranded. The steel for smaller size cables consists of a single strand, while for the larger sizes several strands are u These are composed of patent steel, having an ultimate strength of 160,000 lbs. per square i to 200,000 lbs. per square inch, according to the diameter, an elastic limit of 70 per cent. of ultimate strength, and an elongation of 4 to 6 per cent. on 10 inches. The wires are hea galvanised, and after the aluminium strands are in place over the steel, around which they closely by reason of the stress resulting from the load on the cable, the steel is to a large ext protected from corrosive action. This protection is due to the almost complete exclusion moisture from the steel core by the aluminium envelope, and further on account of the insula oxide film on the aluminium, which tends to prevent the flow of small local electric curre Another feature which adds to this desirable condition is the fact that zinc and aluminium closer together in the electro-chemical series than any other two metals in common use.

The following table shows at a glance the superiority in mechanical characteristics of st cored conductors over all-aluminium, or copper of equivalent conductance.

Size.	—	Aluminium.	Steel-cored Aluminium.	Copper.
0·025 sq. ins. copper area	Weight	1·0	1·48	2·04
	Diameter	1·0	0·98	0·79
	Ultimate load	1·0	2·19	1·52
0·10 sq. ins. copper area	Weight	1·0	1·37	2·04
	Diameter	1·0	1·07	0·79
	Ultimate load	1·0	1·95	1·55
0·40 sq. ins. copper area	Weight	1·0	1·68	2·04
	Diameter	1·0	1·11	0·79
	Ultimate load	1·0	2·58	1·58

PHYSICAL PROPERTIES OF STEEL-CORED ALUMINIUM CONDUCTORS.

The strength of a steel-cored aluminium conductor is somewhat less than the sum of strengths of the component wires, owing to the fact that the aluminium wires will break before

el wire reaches its ultimate stress. The strength of the composite conductor may be taken 35 per cent. of the strength of the steel core plus 98 per cent. of the strength of the aluminium res.

The stress is not distributed uniformly over the different wires, and the stress in the steel l normally be about three times the stress in the aluminium.

The coefficient of expansion and modulus of elasticity of the composite conductor are culated upon the assumption that there will be no relative movement between the aluminium l steel wires. This is found to be the case in practice, and calculations based on 'virtual' ues of the constants as so determined are found to conform with sensible accuracy to observed ues. The constants depend upon the ratio of steel section to aluminium section in the con- ction, and the following values apply to standard forms:

No. of Wires.	Coefficient of linear expansion per F°.	Modulus of elasticity, lbs. per square inch.
7	$10{\cdot}55 \times 10^{-6}$	$12{\cdot}51 \times 10^{6}$
37	$10{\cdot}02 \times 10^{-6}$	$13{\cdot}45 \times 10^{6}$
61	$10{\cdot}90 \times 10^{-6}$	$11{\cdot}95 \times 10^{6}$

Splicing.

Small sizes of aluminium and steel-cored aluminium conductors are joined by aluminium Intyre Joints of the same form as commonly employed with copper. For larger sizes of steel- ed aluminium conductors different systems are employed, in all of which the aluminium and steel are joined separately. Among the methods employed may be mentioned the 'Pairard' at, which employs the principle of wedging cones, and the compression joint, in which the steel es are joined by a steel McIntyre joint, which is enclosed in an aluminium sleeve pressed on the aluminium wires.

Aluminium Overhead Lines.

Span Length.

With short spans where a large cross section is required, all-aluminium conductors have a g differing but little from that of copper, while in the case of a small cross section steel-cored uminium may be installed with a smaller sag and lower poles. In the case of long spans steel- ed aluminium is also employed, but in this case the span length may be increased. This leads a reduction of capital outlay and upkeep expenses owing to the reduced number of insulators.

Span Length (Ft.).		150	200	300	400	500	600	700	800	900	1000
Conductors having the conductivity of 0·6 sq. in. copper.	All aluminium	1·8	2·7	4·8	7·5	10·7	—	—	—	—	—
	Copper.	0·87	1·5	3·2	5·3	8·1	—	—	—	—	—
0·4 copper.	Steel - cored Aluminium	—	—	—	3·4	5·4	7·7	10·5	13·7	17·3	21·3
	Copper.	—	—	—	5·7	8·5	12·0	16·1	20·7	26·0	31·8
0 075 copper	Steel - cored Aluminium	—	—	—	7·7	12·7	18·8	25·9	34·5	43·6	54·0
	Copper.	—	—	—	11·2	18·0	25·9	35·6	46·7	59·2	73·4

STRANDED ALUMINIUM CONDUCTORS. (B.E.S.A. STANDARDS.)

Equivalent Section of Solid Copper.	Sectional Area of Aluminium.	Number of Wires.	Diameter of each Wire.	Overall Diam. of Conductor.	Resistance at 60° F.		Weight.		Tensile Strength of Wires.	Approximate Tensile Strength of whole Conductor.
					Ohms per 1,000 Yds.	Ohms per mile.	Lbs. per 1,000 Yds.	Lbs. per Mile.		
Sq. In.	Sq. Ins.		In.	Ins.					Lbs./Sq. In.	Lbs.
0·02	0·0328	3	0·118	0·254	1·24	2·18	118	207	27,000	859
0·025	0·0410	3	0·132	0·284	0·987	1·74	147	259	25,000	996
0·03	0·0488	3	0·144	0·310	0·829	1·46	175	309	25,000	1,185
0·04	0·0664	7	0·110	0·330	0·608	1·07	238	419	27,000	1,724
0·05	0·0817	7	0·122	0·366	0·494	0·870	292	515	26,000	2,042
0·06	0·0985	7	0·134	0·402	0·409	0·720	353	622	25,000	2,369
0·07	0·114	7	0·144	0·432	0·354	0·624	408	718	25,000	2,736
0·075	0·122	7	0·149	0·447	0·331	0·582	437	769	25,000	2,929
0·08	0·130	7	0·154	0·462	0·310	0·545	467	821	24,500	3,067
0·09	0·148	7	0·164	0·492	0·273	0·480	529	931	24,500	3,478
0·1	0·164	7	0·173	0·519	0·245	0·432	589	1,036	24,000	3,791
0·125	0·205	7	0·193	0·579	0·197	0·347	733	1,290	23,500	4,620
0·15	0·244	7	0·211	0·633	0·165	0·290	876	1,542	23,000	5,404
0·175	0·288	19	0·139	0·695	0·140	0·247	1,034	1,819	25,000	6,775
0·2	0·331	19	0·149	0·745	0·122	0·215	1,188	2,090	25,000	7,785
0·225	0·368	19	0·157	0·785	0·110	0·194	1,319	2,321	24,500	8,471
0·25	0·411	19	0·166	0·830	0·0984	0·173	1,474	2,594	24,500	9,470
0·3	0·499	19	0·183	0·915	0·0809	0·142	1,791	3,153	23,750	11,156
0·35	0·579	19	0·197	0·985	0·0698	0·123	2,076	3,654	23,500	12,793
0·4	0·664	19	0·211	1·055	0·0608	0·107	2,382	4,192	23,000	14,364
0·45	0·753	37	0·161	1·127	0·0537	0·0946	2,702	4,755	24,500	16,609
0·5	0·820	37	0·168	1·176	0·0494	0·0869	2,942	5,177	24,500	18,085
0·6	0·973	37	0·183	1·281	0·0416	0·0731	3,490	6,143	23,750	20,802
0·75	1·232	37	0·206	1·442	0·0328	0·0577	4,423	7,784	23,250	25,804

The above figures are subject to the usual tolerances.

(The British Aluminium Co., Ltd., London.)

Equivalent Sections of Solid Copper.	Sectional Area of Aluminium.	Stranding.				Overall Diam. of Conductor.	Resistance.		Weight per 1,000 Yds.			Weight per Mile.			Ultimate Stress of individual Wires in lbs. per sq. in.		Approximate Strength of Whole Conductor.	
		Aluminium.		Steel.			Ohms per 1,000 Yds.	Ohms per Mile.	Aluminium.	Steel.	Total	Aluminium.	Steel.	Total.	Alum.	Steel.		
		No. of Wires.	Diam.	No. of Wires.	Diam.													
Sq. In.	Sq. In.	In.	In.		In.	Ins.			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.				Lbs./ Sq. In.	Lbs.
0·025	0·0412	6	0·0935	1	0·0935	0·281	0·986	1·74	148	69·8	218	261	122	383	28,000	180,000	45,400	2,181
0·03	0·0490	6	0·102	1	0·102	0·306	0·828	1·46	176	83·0	259	309	147	456	27,000	180,000	44,500	2,548
0·04	0·0656	6	0·118	1	0·118	0·354	0·619	1·09	236	111	347	414	197	611	27,000	180,000	44,500	3,409
0·05	0·0821	6	0·132	1	0·132	0·396	0·493	0·869	295	139	434	518	246	764	25,000	180,000	42,800	4,106
0·06	0·0976	6	0·144	1	0·144	0·432	0·415	0·730	351	166	517	617	292	909	25,000	180,000	42,800	4,886
0·07	0·116	6	0·157	1	0·157	0·471	0·349	0·614	417	197	614	734	347	1,081	24,500	170,000	41,200	5,586
0·075	0·122	6	0·161	1	0·161	0·483	0·332	0·584	438	208	646	771	366	1,137	24,500	170,000	41,200	5,874
0·08	0·130	6	0·166	1	0·166	0·498	0·312	0·549	466	221	687	820	389	1,209	24,500	160,000	40,000	6,061
0·09	0·148	6	0·177	1	0·177	0·531	0·274	0·483	530	251	781	933	441	1,374	24,000	160,000	39,600	6,819
0·10	0·163	6	0·186	7	0·062	0·558	0·248	0·437	585	219	804	1,030	385	1,415	23,750	200,000	40,400	7,387
0·125	0·204	6	0·208	7	0·069	0·624	0·198	0·349	731	273	1,005	1,288	482	1,770	23,250	200,000	39,700	9,134
0·15	0·245	30	0·102	7	0·102	0·714	0·166	0·292	880	593	1,473	1,550	1,042	2,592	27,000	180,000	50,400	15,238
0·175	0·285	30	0·110	7	0·110	0·770	0·142	0·251	1,023	690	1,713	1,802	1,213	3,015	27,000	180,000	50,400	17,721
0·20	0·328	30	0·118	7	0·118	0·826	0·124	0·218	1,178	793	1,971	2,073	1,396	3,469	27,000	180,000	50,400	20,394
0·225	0·368	30	0·125	7	0·125	0·875	0·110	0·194	1,321	891	2,212	2,320	1,573	3,893	26,000	180,000	49,600	22,524
0·25	0·410	30	0·132	7	0·132	0·924	0·0987	0·174	1,472	995	2,467	2,593	1,748	4,341	25,000	180,000	48,800	24,715
0·3	0·502	30	0·146	7	0·146	1·022	0·0807	0·142	1,802	1,216	3,018	3,173	2,138	5,311	25,000	180,000	48,800	30,236
0·35	0·580	30	0·157	7	0·157	1·099	0·0697	0·123	2,083	1,407	3,490	3,670	2,472	6,142	24,500	170,000	46,800	33,525
0·4	0·665	30	0·168	7	0·168	1·176	0·0609	0·107	2,386	1,610	3,996	4,200	2,832	7,032	24,500	160,000	45,200	37,070
0·45	0·740	30	0·177	7	0·177	1·239	0·0548	0·0965	2,650	1,785	4,435	4,670	3,136	7,806	24,000	160 000	44 700	40,787
0·5	0·820	54	0·139	7	0·139	1·251	0·0495	0·0870	2,940	1,102	4,042	5,170	1,944	7,114	25,000	180,000	39,200	36,329
0·6	0·928	54	0·152	7	0·152	1·368	0·0413	0·0727	3,518	1,316	4,834	6,190	2,317	8,507	24,500	170,000	36,900	41,881
0·75	1·225	54	0·170	7	0·170	1·530	0·0331	0·0582	4,390	1,656	6,046	7,730	2,911	10,641	24,500	160,000	36,900	51,038

The above figures are subject to the usual tolerances. (*The British Aluminium Co., Ltd., London.*)

Sag.

Various countries have regulations governing the erection of overhead lines, in which th factors of safety in the various components are fixed under certain specified weather conditions Under the British Regulations the spans must be such that the stress does not exceed one-half o the ultimate load when the conductors are loaded with a ½ in. radial thickness of ice and a simu taneous wind pressure of 8 lbs. per sq. ft., on the projected area of the ice-loaded conductors at temperature of 22° F. The fulfilment of these conditions necessitates that during the erectin the conductors shall be pulled up with a definite sag which will depend upon the temperature a the time. The maximum sag usually occurs at the maximum summer temperature, and it i upon this maximum sag that the height of the supports above ground depends. The table o p. 2205 gives the maximum summer sags, calculated at 122° F., for copper, aluminium, an steel-cored aluminium conductors of exactly equivalent conductivity:

Steel Overhead Lines.

The Pacific Companies are giving considerable attention to the use of steel in place c copper for transmission lines. Steel conductors not only effect a saving due to reduced cost pe unit of length, but also because of the longer spans permissible. Standard spans of 350 ft. t 450 ft. have been used extensively in the past; with the introduction of steel a 700-ft. span wa selected as standard, and many miles of line have been built with spans of this length. The span necessitate large sags, and the old style triangular construction, with pole-top pin, has bee adopted, to give greater clearances between conductors.

Owing to the greater strains, more careful guying is required at corners, and at sharp corne four to six anchors to the pole are occasionally required. The San Diego Co. has installed i main or branch lines, wire of ¼-in., $\frac{5}{16}$-in. or ⅜-in. standard steel, and of ¼-in. steel in constant current series circuits. Most of the constant pressure circuits are at 11,000 volts, though a fe are at 2,300 volts.

The world's longest span of overhead h.t. transmission wires has recently been built in Norway by the Stavanger Electric Power Company. It was required to transmit 12,000 h.p. from th power station at Lysefjord across Hoegsfjord to a transforming station at Oltedal, and from th station over 50,000 volt-lines to Stavanger. The three wires of the transmission line are supporte from three steel towers 7 m. high on each side of the fjord. The total free span is 1,384 m., th sag is 80 m., and the distance to the water surface 40 m. at the centre of the fjord and 80 m. at or side. The biggest span previously built was 1,350 m. across the Strait of Carquinez, in Americ The steel cable has 19 strands and a diameter of 16 mm., the breaking strength being 15 kg. p sq. mm. When no wind is blowing the total stress in the cables is 4 tons, but with maximu wind pressure the stress is 7 tons.

Copper Overhead Lines.

British Standard Specification for Hard-Drawn Copper Solid and Stranded Circul Conductors for Overhead Power Transmission Lines. No. 125—1924.*

The resistance of hard-drawn copper at 60° F. (15·6° C.) is based upon the resistance Standard Annealed Copper at 60° F. (see p. 2081). Weight 554·98232 lb. per cubic ft. C efficient of linear expansion between 32° F. (0° C.) and 86° F. (30° C.) = $9 \cdot 222 \times 10^{-6}$ p degree F. ($16 \cdot 6 \times 10^{-6}$ per degree C.).

Samples for mechanical tests to be taken on component wires of stranded conductors, and te sile strength of any wire must not differ from values in Tables I. and II. by more than 10 per cent average of all wires by not more than 8 per cent. Wires of less than 0·204 in. diameter sh withstand being closely lapped six times round wire of its own diameter, unlapped and similar lapped in same direction without breaking. Joints in wires before stranding must comply wi all requirements of specification. No joints permitted except before stranding in any wire of stranded conductor containing 7 wires or less. Joints (other than before stranding) in co ductors of more than 7 wires must not be closer together than 50 ft. The wires in strand conductors before stranding must fulfil requirements for solid wires. The primary standa sizes in Tables I. and II. (pp. 2209, 2210) are recommended to be used wherever possible.

* By permission of the British Engineering Standards Association.

Hard-Drawn Copper Conductors for Overhead Lines.

BRITISH ENGINEERING STANDARDS ASSOCIATION.

(No. 125—1924.) (*Abbreviated.*)

TABLE I.—PRIMARY STANDARD SOLID CONDUCTORS.

Standard Nominal Area. Sq. in.	Calculated Area. Sq. In.	Diameter, Inches.			Weight per 1,000 Yds. Lbs.			Weight per Mile. Lbs.			Resistance per 1,000 yds. at 60° F.		Resistance per mile at 60° F.		Ultimate Tensile.		Minimum Elongation on 10 in. %
		Standard	Max.	Min.	Standard	Max.	Min.	Standard	Max.	Min.	Standard	Max.	Standard	Max.	Strength. Lbs.	Stress. Tons per Sq. In.	
·00850†	·00849487	·104	·1050	·1030	98·22	100·2	96·25	172·9	176·3	169·4	2·908	2·937	5·118	5·169	550	28·9	—
·01629	·01628602	·144	·1454	·1426	188·3	192·1	184·5	331·4	338·0	324·8	1·515	1·530	2·667	2·693	1016	27·9	—
·01697	·01697167	·147	·1485	·1455	196·2	200·2	192·3	345·4	352·3	338·5	1·454	1·468	2·559	2·584	1056	27·8	—
·02061	·02061199	·162	·1636	·1604	238·3	243·1	233·6	419·4	427·8	411·1	1·197	1·209	2·106	2·127	1266	27·4	—
·02164	·02164243	·166	·1677	·1643	250·2	255·2	245·2	440·4	449·2	431·6	1·140	1·151	2·006	2·026	1324	27·3	—
·02545	·02544690	·180	·1818	·1782	294·2	300·1	288·3	517·8	528·2	507·5	0·9689	0·9786	1·705	1·722	1540	27·0	—
·02688	·02688025	·185	·1868	·1831	310·8	317·0	304·6	547·0	557·9	536·1	0·9172	0·9264	1·614	1·630	1621	26·9	—
·03269	·03268513	·204	·2060	·2019	377·9	385·5	370·4	665·1	678·4	651·8	0·7540	0·7616	1·327	1·340	1943	26·5	1·81
·03631	·03630503	·215	·2171	·2128	419·8	428·2	411·4	738·8	753·6	724·0	0·6787	0·6855	1·195	1·206	2142	26·3	1·85
·0825	·08244796	·324	·3272	·3207	953·3	972·3	934·2	1678	1711	1644	0·2983	0·3012	0·5249	0·5302	4488	24·3	2·27
·095	·09511486	·348	·3515	·3445	1100	1122	1078	1936	1975	1897	0·2584	0·2610	0·4548	0·4594	5078	23·8	2·37
·126	·1256637	·400	·4040	·3960	1453	1482	1424	2557	2608	2506	0·1954	0·1974	0·3440	0·3474	6461	22·9	2·55

† Single conductors of a cross-sectional area of less than 0·0098 square inch are not permitted by the Electricity Commissioners under their Regulations for Overhead Lines. The conductor marked with an obelus in the above table is, therefore, to be used in the make-up of stranded conductors only.

TABLE II.—PRIMARY STANDARD STRANDED CONDUCTORS.
(*Abbreviated.*)

Standard Nominal Area. Sq. In.	Calculated Area Sq. In.	Strands and Diameter.	Approximate over-all Diameter. Ins.	Weight per 1,000 Yds. Lbs.			Weight per Mile. Lbs.			Resistance per 1,000 Yds. at 60° F.		Resistance per Mile at 60° F.		Ultimate Strength of Wire before Stranding. Lbs.
				Standard	Max.	Min.	Standard	Max.	Min.	Standard	Max.	Standard	Max.	
·025	·0249849	3/·104	·224	300·6	306·6	294·5	529·0	539·5	518·4	0·9887	0·9985	1·740	1·757	550
·075	·0748439	3/·180	·388	900·3	918·3	882·3	1585	1616	1553	0·3294	0·3327	0·5798	0·5856	1540
·100	·0999780	7/·136	·408	1196	1220	1172	2105	2147	2063	0·2469	0·2493	0·4345	0·4388	912
·15	·148951	7/·166	·498	1782	1817	1746	3136	3198	3073	0·1656	0·1672	0·2914	0·2943	1324
·175	·175134	7/·180	·540	2095	2137	2053	3687	3761	3613	0·1408	0·1422	0·2478	0·2503	1540
·225	·224951	7/·204	·612	2691	2745	2637	4736	4830	4641	0·1096	0·1107	0·1928	0·1947	1943
·25	·249864	7/·215	·645	2989	3049	2929	5260	5365	5155	0·09861	0·09960	0·1736	0·1753	2142
·4	·403569	19/·166	·830	4845	4941	4748	8526	8697	8356	0·06111	0·06173	0·1076	0·1086	1324
·5	·501239	19/·185	·925	6017	6137	5897	10590	10802	10378	0·04919	0·04968	0·08657	0·08743	1621
·75	·748094	37/·162	1·134	8989	9169	8810	15821	16138	15505	0·03297	0·03330	0·05803	0·05861	1266

Standard Nominal Area. Sq. In.	Calculated Area. Sq. In.	Diameter, Inches.			Weight per 1,000 Yards. Lbs.			Weight per Mile. Lbs.			Resistance per 1,000 Yds. at 60° F.		Resistance per Mile at 60° F.		Ultimate Tensile	
		Standard.	Max.	Min.	Standard.	Max.	Min.	Standard.	Max.	Min.	Standard.	Max.	Standard.	Max.	Strength Lbs.	Stress. Tons per Sq. In.
·003217†	·00321699	·064	·06464	·06336	37·20	37·94	36·45	65·46	66·77	64·15	7·683	7·760	13·52	13·66	213	29·5
·006648†	·00664761	·092	·09292	·09108	76·86	78·40	75·32	135·3	138·0	132·6	3·717	3·754	6·541	6·607	434	29·1
·008012†	·00801185	·101	·1020	·09998	92·63	94·49	90·78	163·0	166·3	159·8	3·083	3·114	5·427	5·481	520	29·0
·01057	·01056832	·116	·1172	·1148	122·2	124·6	119·7	215·1	219·4	210·8	2·337	2·360	4·112	4·154	676	28·6
·01208	·01207628	·124	·1252	·1228	139·6	142·4	136·8	245·7	250·7	240·8	2·045	2·065	3·598	3·634	769	28·4
·01348	·01347822	·131	·1323	·1297	155·8	159·0	152·7	274·3	279·8	268·8	1·832	1·850	3·223	3·256	852	28·2

† See note to Table I., p. 2209.

TABLE IV.—SECONDARY STANDARD STRANDED CONDUCTORS. (Abbreviated.)

Standard Nominal Area. Sq. In.	Calculated Area. Sq. In.	Strands and Diameter In.	Approximate over-all Diameter. In.	Weight per 1,000 Yards. Lbs.			Weight per Mile. Lbs.			Resistance per 1,000 Yds. at 60° F.		Resistance per Mile at 60° F.		Ultimate Strength of Wire before Stranding. Lbs.
				Standard	Max.	Min.	Standard	Max.	Min.	Standard	Max.	Standard	Max.	
·022	·0221405	7/·064	·192	264·8	270·1	259·5	466·1	475·4	456·8	1·116	1·128	1·965	1·984	213
·046	·0457512	7/·092	·276	547·2	558·2	536·3	963·2	982·4	943·9	0·5400	0·5454	0·9505	0·9600	434
·058	·0584647	7/·104	·312	699·3	713·3	685·3	1231	1255	1206	0·4225	0·4267	0·7436	0·7510	550
·094	·0937306	19/·080	·400	1125	1148	1103	1980	2020	1941	0·2637	0·2663	0·4640	0·4687	330
·125	·123959	19/·092	·460	1488	1518	1458	2619	2671	2567	0·1993	0·2013	0·3508	0·3543	434
·175	·174002	19/·109	·545	2089	2131	2047	3676	3750	3603	0·1419	0·1434	0·2498	0·2523	602
·20	·197069	19/·116	·580	2366	2413	2318	4164	4247	4080	0·1253	0·1266	0·2205	0·2227	676
·25	·251330	19/·131	·655	3017	3077	2957	5310	5416	5204	0·09822	0·09920	0·1729	0·1746	852

Porcelain Insulators for Overhead Lines.

BRITISH STANDARD SPECIFICATION FOR PORCELAIN INSULATORS FOR OVERHEAD POWER LINE (3,000–150,000 VOLTS). No. 137—1922.*

The porcelain must be white, sound, completely vitrified, with insulation independent of the glazing, which must cover all exposed parts. The electrical design must conform to requirements in Table I., and when of more than one part the voltage drop across the assembled part shall be proportional to their thickness. Mechanical factor of safety to be not less than 2. The porcelain must not engage directly with a metal screw, and must be unaffected by stresses set up by temperature changes. Every insulator shall be impressed with the manufacturer's mark before fixing, and, when conforming to this specification, bear the Association's brand. Type tests to be carried out on not less than three samples completely fitted in the following order. In tests 1 to 4, failure shall not occur below the appropriate values in Table I.

1. *Inherent Stresses.*—Insulator and glaze to withstand test voltages in columns 2, 3, or 4 of Table I. (applied as for Test 2) after being heated in water at 50° C. for one hour and immediately immersed in ice and water for one hour, the test being repeated three times.

2. *Dry Spark-over Tests.*—Testing pressure to be applied between the support and a wire of 0·4 inch diameter attached to insulator. Test to begin at one-third full voltage, and increased at 1 k.v. per second until spark-over occurs.

3. *Rain Tests.*—Insulator to be tested as in Test 2, but subjected to artificial rain at 15° of 1 inch in 5 minutes directed downwards at 45° from vertical. Specific resistance of the water to be not more than 20,000 ohms per cm. cube.

4. *Puncture Test.*—Insulator to be tested as in Test 2 while immersed in oil.

TABLE I.—TEST VOLTAGES. (R.M.S. Values.)

1	2	3	4	5	6	7	8	9	10
	Dry Spark-over Test.			Rain Test.			Puncture Test.		
A. C. Delivered or Declared Voltage.	Supporting Insulator.		Tension-ing Insulator	Supporting Insulator.		Tension-ing Insulator	Supporting Insulator.		Tensio-ing Insulat
	Pin Type.	Sus-pension Type.		Pin Type.	Sus-pension Type.		Pin Type.	Sus-pension Type.	
Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo-volts.	Kilo volta
3	40	—	30	20	—	10	70	—	52
6	50	—	40	30	—	20	87	—	70
10	62	—	54	39	—	30	108	—	95
†20	95	90	90	62	57	57	166	158	158
30	125	125	125	84	84	84	220	220	220
†40	145	150	150	105	105	105	250	260	260
†50	158	175	175	125	125	125	275	310	310
60	165	200	200	140	142	142	290	350	350
†80	—	250	250	—	180	180	—	440	440
100	—	300	300	—	220	220	—	525	525
120	—	335	335	—	260	260	—	585	585
150	—	365	365	—	315	315	—	610	610

Note I.—The term 'Delivered Voltage' denotes the normal voltage between conductors at the delivery end.

For the purposes of this Specification the Working Voltage is assumed not to exceed the Delivered Voltage by more than 10 per cent.

Note II.—Test voltages for special insulators required for intermediate voltages may be ascertained from a curve prepared from the above figures.

Note III.—In cases where testing apparatus is not available for puncture tests at pressures exceeding 310 k.v., arrangements may be made to test the insulator units separately and to estimate the equivalent puncture test voltage of the complete insulator from these individual tests.

* By permission of the British Engineering Standards Association.

† These four voltages are not included in B.S. Specification No. 77—Standard Pressures for New Systems and Installations.

5. *Mechanical Test.*—Complete insulator with metal fittings must withstand loads in accord-e with Table II. For a pin insulator the tension is applied by a flexible wire rope placed round r, and for tensioning and suspension types the load is applied between metal connecting parts either side. Any permanent deformation constitutes failure.

3. *Porosity Test.*—The finished porcelain shall show no signs of impregnation when broken es free from external glaze are immersed for twenty-four hours in a 0·5 per cent. alcoholic tion of fuchsin under a pressure of 2,000 lbs. per sq. in.

Routine Tests.—Every complete pin insulator shall be inverted in water, and withstand, iout puncture, for five minutes the spark-over voltage between testing terminal and wire ched to neck groove. Every unit of a tension or suspension insulator must withstand for minutes the spark-over voltage of that unit without puncture, and the complete insulator a 20 per cent. above maximum working load applied vertically for one minute.

Appendices to specification give experimental methods of carrying out mechanical and trical tests.

TABLE II.

Maximum Working Load.	Test Loads. Supporting Insulators. Pin Type.		Suspension Type.		Tensioning Insulators.	
	Lbs.	Approx. Kgs.	Lbs.	Approx. Kgs.	Lbs.	Approx. Kgs.
to 400	1,000	454	1,000	454	1,000	454
,, 800	2,000	907	2,000	907	2,000	907
,, 1,400	—	—	3,500	1588	3,500	1588
,, 2,800	—	—	7,000	3175	7,000	3175

Electricity Supply.

The standard voltages of supply laid down by the British Engineering Standards Association port No. 77—1925) for new systems and installations are as follows (at consumers' terminals):—

Direct current, 230 and 460 volts; alternating current, 230 volts between neutral wire and of the principal conductors, 400 volts between any two of the principal conductors.

The standard high voltages for new systems and installations are: 3,000, 6,000, 10,000, 00, 60,000, 100,000, and 120,000 volts.

In each case the approximate station voltage is assumed to be 10 per cent. higher at full load.

Periods allowed by the Electricity Commissioners for Repayment of Loans.

d—	Years.		Years.
reehold	60*a*	Mains and services	25
easehold (subject to duration of lease)	30	Meters	10
stantial buildings	30	Wiring of premises	10
nt and machinery	20	Apparatus to be let on hire	7–10
P. trunk transmission mains	40*a*		

(*a*) Except in Scottish cases, for which the present maximum period is 30 years.

Generation of Electricity in Great Britain.*

The total units generated in Great Britain up to March 31, 1926, were 8,122,961,823. In 1925 total was 7,415,375,529. The total number of stations in 1926 was 584, which was also the l number for 1925.

The steam stations in 1926 generated 96·08 per cent. of the total; gas-producer stations, 5 per cent.; oil engine stations, 0·56 per cent.; waste heat, 2·19 per cent.; refuse destructors, 2 per cent.; gas engines using town's gas, 0·04 per cent.; water power, 0·56 per cent. In 5 the steam percentage was slightly less, viz. 95·63 per cent., water power slightly more, 0·69 per cent.

According to Mr. H. Quigley, Chief Economist of the British Electrical and Allied Manufac-ers' Association, during 1927 there has been a 25 per cent. increase in the output of electricity reat Britain, the total being 10,500,000,000 units, approximately.—*Times, Jan. 21st, 1928.*

* *Generation of Electricity in Great Britain, Year ending March* 31, 1926. Electricity Com-sion, H.M. Stationery Office, Adastral House, Kingsway, London, W.C. 2. Price 1*s.* 6*d.* net.

Ministry of Transport Regulations in reference to Overhead Electric Lines.

Every application for the consent of the Electricity Commissioners to the placing of electr lines above ground should be accompanied by the following particulars :—

1. Where the undertakers are a company, or a local authority supplying outside their ow area, evidence of consent of the local authority for the district.

2. A statement showing commercial or other considerations why underground cables shoul not be used.

3. A brief description of the proposed system, whether by continuous or by alternating current the working voltage ; the kind of wire, whether copper or aluminium ; whether solid or strandec the total sectional area ; tensile strength and elongation ; average and maximum length of span minimum height of wires from the ground ; name or description of automatic protective devic if any.

4. A statement whether the supply is to form (1) an extension of an existing system of unde ground cables, or (2) of an existing traction system, or (3) an independent system.

5. An ordnance map on a scale of 6 ins. to the mile, showing the proposed route of the ove head lines and any existing overhead lines. The sheets of these maps must be fastened togethe

6. In the case of high and extra high pressure, plans of construction of poles, etc., on a sca of about 1 in. to the ft., or a reference to previously deposited plans where these are identic with the proposed work.

Regulations of the Electricity Commissioners. (El.C. 38–1926).

Regulations for Securing the Safety of the Public.

1. Supply pressure shall not exceed the low-pressure limit of 250 volts, except for power or a lamps in series, when the medium pressure limit of 650 volts is permissible under the followi conditions. Machine frames must be earthed, motor leads enclosed in earthed metal casing wi enclosed fireproof and shockproof switches and fuses, switch when opened must completely c off motor and all auxiliary devices. Similar conditions apply to arc lamps and incandescent lam in series. Regulations 1 and 2 do not apply to a factory, workshop, mine, or quarry.

2. Where the voltage between the outer conductors of a 3-wire system exceeds 250 volts a is taken into premises, two pairs of terminals shall be provided and the wiring from these ke distinct.

3. The Commissioners reserve their consent to the supply of extra high pressure to consume premises.

4. Minimum area of conductor installed in street line to be 7/20 gauge except for lamp-p wiring.

5 Supply mains to be tested at at least 200 volts, and results of tests to be recorded before t supply is begun.

6. Insulation of every complete circuit used for supply of energy to be maintained so th leakage current never exceeds $\frac{1}{1000}$ part of maximum supply current. Measurements must made weekly, records kept, leakage remedied without delay, and means provided for indicati and localisation of leakage.

7. High-pressure circuits (650 to 3,000 volts) must not be brought into use until successfu tested for ½ hour at twice the maximum working pressure in the case of lines and 50 per ce excess of normal for machines and apparatus. Results to be recorded.

8. Every high-pressure main, etc., to be fitted with fuse or automatic circuit breaker, exc the outer earth conductor of a concentric main.

9. Automatic quick-acting device must be fitted on transformer circuits to prevent cont or leakage from high-pressure circuit to consumers' wires.

10. All metallic portions (except conductors) of high-pressure transformers to be earthed.

11. Exposed lines and their supports to be protected from injury by lightning.

12. The undertakers must inform Commissioners of all accidents.

Overhead Lines.

13. Overhead lines erected after this date (1926) to be in accordance with Commission Regulations.

Electric Lines other than Overhead.

14. Conduits, street boxes, etc., to be constructed of durable material, and where laid und ground to be unaffected by heavy traffic. Accumulation of gas must be prevented.

15. Precautions must be taken to prevent the charging of any metallic substance directly indirectly from any electric line.

16. All high-pressure conductors carrying conduits to be jointed, connected across street-box and efficiently earthed.

17. Bare conductors in conduit must not exceed 300 volts to earth, and must be secured position. Such conduits must be moisture proof and insulators so placed that they can inspected.

8. High-pressure lines on ground surface or public subway must either be enclosed in insulating embedded in brickwork, masonry or concrete, or in an earthed metal casing.
9. Means must be taken to prevent the ground surface or other conductors becoming charged eakage from a high-pressure line.
0. A high-pressure line must be properly laid, jointed, examined, and tested and in the sole ge of the undertakers before being used for supply of energy.

Sub-stations and Street Boxes.

1. To be in sole occupation and charge of the undertakers and placed above ground wherever sible: if underground, provision must be made for ventilation and drainage.
2. In addition to regulation 14, (*a*) covers of street boxes only to be opened by special liance; (*b*) covers of street boxes containing high-pressure apparatus other than cables must n connection with metal strips laid immediately underneath the street, and means taken to vent all exposed material, including the street surface, becoming charged by any means; treet boxes used as transformer chambers must not be subject to influx of water, and when of ater size than one cubic yard must be adequately ventilated; (*d*) street boxes must be regularly ected for the presence of gas, and notice of gas influx must be immediately given to the gas ority concerned; (*e*) mains at different pressures in the same street box must be readily inguishable.
3. Maximum power supplied to underground sub-station or street box containing one trans- er must not exceed 30 k.w., or 75 k.w., if with two or more transformers, without consent of mmissioners.

Consumers' Premises.

4. The undertakers shall be responsible for maintenance of their property on consumers' mises.
5. The undertakers must guard against fire risks in delivering energy to premises.
6. Fuse or automatic circuit breaker in fireproof, sealed receptacle to be fitted near entry of h service main if latter is unprotected by fuse in the street box. No fuse or circuit breaker st be inserted in intermediate conductor of a 3-wire system.
7. Service lines and apparatus on consumers' premises must be highly insulated, moisture- of and all exposed bare metal forming part of a circuit, efficiently earthed. Lines must be d and protected to prevent electrical discharge to nearby metal.
9. Consumers' wires must not be connected to undertaker's mains unless the resulting kage is not in excess of one ten-thousandth of maximum current supplied to the premises. tice of objection must be served upon the consumer.
0. Undertakers have the right, after giving notice to consumer, to test wires and fittings leakage and to discontinue supply if excessive leakage is found (see 29), or facilities for testing l inspection are refused.
1. Consumer may appeal for an independent test to an electrical inspector on payment of scribed fee. This regulation must be endorsed on every notice served under regulations 29 d 30.

Arc Lighting.

2 and 33 respectively fix the minimum height of any part of an arc lamp 10 feet above ground. l provide for the provision of arc lamp guards, forbidding the use of arc lamps where explosive t or gas may be present.

Connection of Circuits with Earth.

4. Where supply pressure between adjacent conductors of a 3-wire system of mains exceeds volts, the intermediate conductor for each distinct circuit shall be earthed at one point only, nely, at generating station, sub-station or transformer, the insulation being maintained else- ere. The earth current from intermediate conductor must be continually recorded and must exceed at any time one-thousandth of maximum supply current.
5. Penalties are provided for default of regulations 1 to 35.

Regulations for Ensuring a Proper and Sufficient Supply of Electrical Energy.

1. Supply must be constantly maintained, and in case of d.c. without change of polarity. tice of any interruption for testing purposes or polarity change must be given to consumer.
2. Distribution mains must be sectionalised on their respective feeders and connected only ough circuit breakers or fuses.
3. Variation from declared pressure of supply shall not exceed $\pm$ 4 per cent. Public notice th consent of Commissioners is required for any alteration of conditions.
4. The system and frequency of supply (in a.c. systems) must be declared. Variation of quency from declared value must not exceed $\pm$ 2½ per cent. Notice and consent required for eration (see 3).
5. Penalties are prescribed for default of regulations 1 to 5.

Regulations of Electricity Commissioners for Overhead Lines. (El.C. 39–1924).

General Regulations.

1. Conductors to be of copper, aluminium, or other approved material.

2. Conductors to conform to B.E.S.A. specification for elongation, breaking load, and elasticity If no specification be in force at time of erection, characteristics measured on a single wire sha not be less than :—

Material.	Elongation in length of 10 inches. Per cent.	Breaking Load. Tons per sq. in.	Young's Modulus of Elasticity. Lbs. per sq. in.
Copper	1	24	10×10^6
Aluminium	4	11	10×10^6

3. Minimum permissible size for copper and aluminium conductors must have an actu breaking load of not less than 650 lbs. Minimum areas for copper and aluminium : 0·0098 sq. i and 0·0237 sq. in. respectively.

4. Conductors must be rendered inaccessible to persons not having the use of appliance Regard must be paid to the normal use of his land or premises by the occupier. See 17.

5. Except in the case of contact between broken conductors and earth were on the same suppor precautions must be taken by the undertakers against contact between line conductor and an other overhead wire.

6. Line insulators to be carried on supports of wood, iron, steel, or reinforced concrete. Co rosion of metal work on or below ground surface to be prevented. Wooden supports must be red fir, except oak or hardwood cross arms.

7. Supports, in conjunction with any struts or stays, shall take all loads without damage movement in the ground. Strength in direction of line must not be less than one quarter transverse strength. Factor of safety for iron and steel 2·5, for wood and reinforced concrete 3· These factors to be calculated for 22° F. with ice covering specified in 11 and 14, and with a win pressure of 8 lbs. per sq. ft. on whole of the projected surface, corresponding to a velocity of m.p.h. at right angles to the line. Strength of foundations under these conditions to give factor of safety of 2·5 against overturning. Wind pressure on lee side members of lattice other compound structures, A and H poles, to be taken as one-half that on windward side, an factor of safety calculated on crippling load of struts and upon elastic limit of tension members.

8. Service lines to be connected only at a point of support, and fixed to insulators on consumer premises. Service lines (other than an earthed neutral conductor) which are accessible from building must be protected by insulating material or otherwise.

Service lines over carriage ways must not be lower than 20 ft. from the ground except wit consent of Commissioners.

9. The whole structure with all appliances must be regularly inspected and maintained.

10. Materials must conform at time of erection to B.E.S.A. specifications and to the Po Office Technical Instructions of Aerial Lines.

Specific Regulations.

A. For pressures not exceeding 650 volts d.c. and 325 volts a.c.

11. Factor of safety of line conductors, 2, based on breaking load at 22° F., with ½ in. radi thickness of ice and simultaneous wind pressure as in 7.

12. Minimum height of any wire (except service) not to be less than 20 ft. at temperatur below 122° F.

13. Where pressure to earth exceeds 250 volts d.c. or 125 volts a.c., precautions shall be tak to prevent danger

(*a*) from a broken conductor ; by earth wire suitably disposed or other approved metho

(*b*) from leakage : in cases of metal poles, by provision of earthed wire connecting t poles, or by supporting the insulators on insulated metallic frame connected neutral conductor. With wooden poles by a bonding wire connected to supporti metal of all insulators and terminating at lowest part thereof and not less th 10 ft. from ground. Other means may be approved.

Where lighting or uninsulated conductors are run down wooden poles to within 10 ft. of t ground, precautions against leakage must be as for metallic poles. Unearthed stay wires mu be insulated by insulator placed not less than 10 ft. above ground.

B. For pressures exceeding 650 volts d.c. and 325 volts a.c.

14. Factor of safety of conductors as in 11, except that for ½ in. ice, read ½ in.

15. Minimum heights of conductors above ground at temperatures below 122° F. are 20 ft. for ssures not exceeding 66,000 volts, 21 ft. exceeding 66,000 and below 110,000 volts, 22 ft. ,000 to 165,000 volts, and 23 ft. above 165,000 volts.
16. Means must be taken to render broken conductors dead. All other metal work to be thed by continuous earth wire earthed at four equidistant points per mile; alternatively tal shall be effectively earthed at each support. When earth contact is made by a line ductor, leakage current must be at least twice that required to operate safety devices.
17. At road, canal, or railway crossings, in addition to 15, there shall be provided (*a*) duplicate insulators with automatic earthing of a fallen conductor or (*b*) duplicate insulators tied at ervals not exceeding 5 ft.

Where line is erected along or within 50 ft. of road, canal, or railway, (*a*) duplicate insulators (*b*) automatic earthing for fallen conductor shall be provided. Other means may be approved.
18. Supports must be consecutively numbered, carry permanent danger notice, and guarded n unauthorised climbing.

Regulations Relating to Extra High Pressure. (El.C. 13–1920).

The following *additional* regulations relating to *extra high pressure* have been issued by the nmissioners.

A. *Regulations for Securing the Safety of the Public.*

3. An extra-high-pressure main before being brought into use shall be tested in position to hstand for half an hour continously a pressure of 10,000 volts in excess of the working voltage, en this exceeds 10,000 volts, or twice the working pressure when this is less than 10,000 volts. sults of tests must be recorded.
4. Suitable fuse or circuit breaker must be provided for every main, but not in earthed outer nductor of concentric mains.
8. Where leakage from 3-phase mains is prevented by a copper strip under the lead sheath of ble, this shall not be less that 0·016 in. thick, and where steel wires are thus employed outside a d sheath, each shall not be less than 0·1 in. in diameter. A lead sheath must be efficiently thed and not less than 0·1 in. thick.
9. Single-phase supply mains to consist of two concentric conductors or separate conductors. ters of concentrics to be earthed at one point: with separate conductors, leakage to be pre- ted as with 3-phase mains.

Street Mains.

11. These mains must be enclosed in strong metal casing where passing through street box with ier mains: boxes must not contain any other undertaker's electric mains, nor water or gas es. Telephone wires belonging to the undertakers are allowed.

Sub-stations.

12. Must be in sole or joint occupation of the undertakers or authorised distributor.
13. When constructed below streets, must contain no switches or apparatus other than nsformers.
14. The transforming apparatus must be arranged to avoid danger of excessive voltage on nected mains.
15. Precautions must be taken against fire risks.
17. Gives right of entry and examination to the Commissioners.

Connection of Circuits with Earth.

18. Earth connection to be made at only one point on a circuit, viz. generating station, sub- tion or transformer. Insulation must be maintained elsewhere.
19. When neutral star point of each distinct 3-phase circuit is earthed through a resistance, s must be low enough to ensure the action of the cut-out in the mains.
Separate electrostatic voltmeters must be connected in the generating station between each tinct circuit and earth to act as leakage indicators. Faulty circuit insulation must be mediately restored.
20. Penalties are prescribed against default which are not to affect liability of undertakers respect of damages caused by default.

B. *Regulations for Ensuring a Proper and Sufficient Supply of Electrical Energy.*

1. Undertakers must maintain sufficient and constant supply from the main to authorised stributors and consumers.
2. Maximum load on a main not to exceed 1,000 k.w. without consent of Commissioners, less provision is made for alternative supply in the event of breakdown.
3. Minimum pressure to be declared. Pressure at authorised distributors' terminals must t be less than this minimum, and not exceed it by more than 12½ per cent. Alteration of mini- um to be allowed only by consent of Commissioners after one month's public notice of such plication.

4. Frequency to be declared 50 or 25 cycles per second; 2½ per cent. variation allowed. Co
sent and notice of alteration as in 3.

5. Penalties are prescribed for default.

These regulations are in addition to any regulations relating to mines and factories made b
any Act, and also include regulations 9, 16, 18, 20, and 27 of El.C. 38, summarised above.

The Electrical Equipment of Buildings,

REGULATIONS ISSUED BY THE INSTITUTION OF ELECTRICAL ENGINEERS.

(Ninth Edition, 1927.)

(*Abbreviated.*)

SUPPLY PRESSURE.

These regulations provide for wiring based on the following pressures of supply :—

Medium pressure, i.e. above 250 volts and below 650 volts.
Low pressure, i.e. above 30 volts a.c or 100 volts d.c., but not exceeding 250 volts.
Extra low pressure, i.e. below 30 volts a.c. or 100 volts d.c.

GENERATING PLANT.

Generators must comply with the following :—

(*a*) They must be placed in well-ventilated rooms where inflammable dust or gases cann
accumulate.

(*b*) They must be protected from damp, dust, or mechanical injury.

(*c*) No unprotected woodwork or other combustible material shall be within a distance
12 ins. from them measured horizontally, or within 4 ft. measured vertically above them.

(*d*) When the supply is at medium pressure, the generating plant shall have its frame an
bedplate earthed.

SECONDARY BATTERIES.

(*a*) A p.d. exceeding 50 volts must not exist between adjacent cells without adequat
protection. Each cell shall be readily accessible from the top and at least from one side.

(*b*) In a lead-sulphuric acid battery with more than 33 cells, and in a nickel-iron alkalin
battery with more than 53 cells, the cells shall be supported on glass or vitreous porcelai
insulators. The stands shall also be insulated if there are more than 56 and 88 cells respectively

(*c*) When acid is used as an electrolyte for the cells, the battery-connecting bolts, unless
non-corrosive type, shall be kept covered with petroleum jelly.

(*d*) Cells having containers not sealed nor provided with screw-down covers shall have spra
arrestors.

(*e*) Celluloid shall not be employed for non-portable batteries.

(*f*) The battery-room shall be well ventilated.

(*g*) As a minimum, the gear controlling the current shall comprise an automatic cut-in an
cut-out switch and fusible cut-out, or a circuit breaker with overload and reverse-current trip

SWITCHBOARDS.

(*a*) Must be placed in dry and well-ventilated situations away from explosive dust or aci
fumes.

(*b*) Must be constructed wholly of durable, non-ignitable, non-absorbent materials.

(*c*) If marble or slate be used, all conducting parts shall be insulated with mica or othe
non-hygroscopic substance.

(*d*) Terminals must be provided for earth connection.

(*e*) Live parts must be spaced or shielded so that an arc cannot be maintained.

(*f*) All connections shall be readily traced.

(*g*) All parts shall be readily accessible, and no fuse shall be fixed at the back of the board.

(*h*) All nuts at back of board must be effectively locked.

(*i*) All circuits, instruments, etc., shall be clearly labelled.

(*j*) Connecting wires to every voltmeter and earth lamp must be protected by a fuse on eac
insulated pole.

(*k*) The moving parts of switch, in the ' off ' position, must be disconnected from the supply.

(*l*) With fuses and switches on same pole, the fuses must be disconnected from supply whe
their respective switches are in the ' off ' position.

MAIN SWITCHGEAR.

Every main switchboard must be fitted with the following switchgear as a minimum :—

1. *Two-wire Systems of Wiring.*

(*a*) When supply is obtained from one generator or a single service main, for these and fo
each outgoing circuit either a double pole overload circuit breaker or a linked switch with
fuse on each pole. (For earthed system, single pole on the insulated main.)

(*b*) With several generators not running in parallel or with duplicate service mains, changeer switches must be used, in addition, on each outgoing circuit.
(*c*) With generators in parallel, a double-pole circuit breaker (single-pole for earthed system) ted with overload and reverse-current trips. For compound-wound machines an additional igle-pole equaliser switch interlocked so that equaliser must be closed before and opened after e main circuit breaker.

2. Three-wire Systems of Wiring.

Each generator or each side of service mains and each two- or three-wire outgoing circuit ouble-pole apparatus as for two-wire system. No fuse or unlinked switch on neutral. When eutral is known to be directly earthed, a two-conductor earthed circuit may have single-pole verload circuit breaker or switch and fuse in outer conductor.

3. Two-phase Three-wire Systems of Wiring.

Each generator or service main and each outgoing three-conductor circuit a triple-pole circuit reaker with overload trips on each phase or a triple-pole linked switch with a fuse on each nductor except the neutral. Each outgoing two-wire circuit, double-pole circuit breaker ith overload trip on at least one conductor or double-pole switch and fuse.

4. Three-phase Three-wire Systems of Wiring.

For each generator or service main and each outgoing three-conductor circuit, either a triple-ole circuit breaker with overload trips on at least two phases, or a triple-pole linked switch with fuse on each conductor. For each two-wire outgoing circuit these to be double-pole.

5. Two-phase Four-wire Systems of Wiring.

Each generator or service main and each outgoing four-conductor circuit, either a four-pole rcuit breaker with overload trip coil on each phase or a four-pole linked switch with a fuse on ch conductor. For each two-wire outgoing circuit double-pole circuit breaker with overload ip on at least one conductor or double-pole switch and fuse.

6. Three-phase Four-wire Systems of Wiring.

For each generator or service main, a triple-pole circuit breaker with overload trips on each hase (at least on two phases for outgoing three-conductor circuit), or a triple-pole linked switch ith a fuse on each phase. For each outgoing two-wire circuit supplied from one phase and irectly earthed neutral, single-pole gear as above connected in the phase conductor. (Double-ole with unearthed neutral.) For four-wire outgoing circuits supplying a distribution board, iple-pole gear as above, but no fuse or unlinked switch in neutral conductor, except for testing.

INSTRUMENTS.

Every main switchboard not supplied from an external source must have the following inimum:—

Two-wire Systems of Wiring.

For a single generator an ammeter and voltmeter. For generators not to be run in parallel, ne ammeter for each machine and a voltmeter to be fitted with multiple-way switch or plug. For parallel running, an ammeter for each machine and two voltmeters, one being connected to us-bars and the other arranged for use on any generator. Alternators to have synchronising evice. The ammeter in the circuit of compound wound machines to be connected in opposite ole to equaliser connection.

Three-wire Systems of Wiring.

An additional voltmeter to be connected between neutral and each outer bus-bar and a entral-zero ammeter for d.c. or central-zero wattmeter for a.c. in main neutral conductor.

Two-phase and Three-phase Systems of Wiring.

For a single generator an ammeter on each phase and one voltmeter. For each generator running in parallel, an ammeter in each phase; one voltmeter on bus-bar and one on multiple-way switch, for use on one phase of any generator. A synchronising device.
Instruments should conform to British Standard Specification No. 89.

Earth Testing.

Except for extra low pressure plant of less than 5 kw. capacity, the switchboards of private installations must have suitable means for indication insulation.

Switches and Circuit Breakers.

(*a*) Must be able to carry working current continuously with a temperature rise above the air of not more than 36° F. (20° C.), if rated at less than 100 amperes, and 54° F. (30° C.), for ratings of 100 amperes or more.

(*b*) Must not arc over when breaking 50 per cent. excess current at a pressure 50 per cent. above that of the supply. Fuse switches and circuit breakers must fulfil regulations for fusible cut-outs. (See British Standard Specifications 109 and 110.)

(*c*) Accidental closing impossible.

(*d*) Provision for renewal of main arcing contacts.

(*e*) Handles must be robust and must not be operated through unprotected slots. Operator must be protected from live metal or any injury from adjacent apparatus.

(*f*) Bases to be of durable, fireproof, non-absorbent insulating material. Slates to be planed all over, free from metallic veins, and if of slate must be treated (including holes) with damp-proof medium after drying. All bolts fixing slate or marble slabs must be insulated from slab, and the latter similarly from metallic frame by non-hygroscopic insulating bushes and washers.

(*g*) The live parts of switches not mounted on a switchboard must be enclosed by metal or fireproof insulating covers, guarded from mechanical injury, and giving proper clearance from live parts and protection against arcing.

(*h*) When placed out of doors or in damp places, must have weather-proof cases and proper provision for leading-in cables. Suitable glands are given in British Standard Specification No. 94.

(*j*) Operating current must be adjustable on electromagnetic circuit breakers, and latter must be incapable of being held in against this current.

(*k*) Arrangements and position must avoid all risk of fire.

Fusible Cut-outs.

A. *For Extra Low Pressure.*

(*a*) Temperature rise of any part of the fitting above air not to be more than 54° F. (30° C.), with normal current continuously.

(*b*) Fusing current to be double the current capacity of the smallest cable controlled by the fuse when fusing time is one minute (two minutes for a lead-tin alloy fuse). No fuse to blow at less than 7 amperes need be inserted in final sub-circuits.

(*c*) The base to be of durable, fireproof, non-absorbent insulating material, and all construction must avoid arcing and scattering of metal.

(*d*) No fuse to be placed in ceiling roses, wall plugs, or sockets, or in switches other than fuse-switches of regulation patterns with metal covers. A fuse rated at not more than 5 amperes may be used in projecting wall socket adapters taking the pins of a smaller plug.

(*e*) Cut-outs not fixed on switchboard must be grouped on distribution boards or contained in regulation cases unless completely enclosed.

(*f*) Removable carriers to be used except where the covers provide against scattering of metal, and the maximum power in the building does not exceed 1000 watts.

B. *Low-pressure Cut-outs must in addition :*

(*a*) Be provided with safe insulating carrier for the fuse, with convenient contacts for the wire.

(*b*) Base contact to be unaffected by vibration.

(*c*) Risk of contact with any live metal to be avoided when handling a carrier.

(*d*) Cut-outs and carriers to be graded ' Ordinary Duty ' and ' Heavy Duty.'

Maximum working current.	Maximum short-circuit current for ' Ordinary Duty ' cut-outs.
10 amperes	1,000 amperes
30 ,,	2,000 ,,
60 ,,	4,000 ,,
100 ,,	6,500 ,,

' Heavy Duty ' cut-outs to be used where ' Ordinary Duty ' cut-outs are inadmissible.

C. *Medium-pressure cut-outs must fulfil conditions* A (*a*) *to* (*f*) *and* B (*a*) *to* (*e*).

(See British Standard Specification No. 88 for Low-pressure Electric Cut-outs.)

Section and Distribution Boards.

A. Must generally comply with all regulations for switchboard, circuit breakers, and fusible ıt-outs, except for final sub-circuits carrying less than 20 amperes.

B. Unless current-carrying parts of all accessories are permanently protected, they must ave a protecting case, which with earthed concentric wiring systems must provide, if of metal, or attachment to case of all external conductors; if of wood, an interposing metal sheet between and the support not less than $\frac{1}{16}$ in. thick, to which all external conductors are connected.

C. Arcing under short-circuit conditions must be impossible.

D. Cases of soft wood to have fire-proof insulating lining, and all boxes not provided with ıcks shall be so shielded from the supports. A glass front must have 1 in. (2·5 cm.) clearance om live parts.

E. When placed out of doors or in damp places, must be weatherproof with proper provision r leading-in.

F. Dimensions must allow of easy access for connecting.

G. Cut-outs must be grouped vertically with fire-proof insulating material between opposite ıles.

Conductors of Cables.

(*a*) All conductors, other than the outer conductors of earthed concentric systems, shall be of nnealed copper.

(*b*) The sizes of conductors set out in the table on p. 2193 are recognised as standard. The andard sizes and resistances of conductors for flexible cables and flexible cords are set out in ıbles on pp. 2196 and 2197.

(*c*) No cable having a conductor of nominal sectional area less than 0·0015 sq. in. (1/·044 in.) ıall be used except for wiring fittings.

(*d*) All conductors having a nominal sectional area exceeding 0·003 sq. in. (1/·064 in.) shall ə stranded.

(*e*) For lighting, the drop from the consumer's terminals to any and every point in the stallation shall not exceed 1 volt plus 3 per cent. of the pressure at the consumer's terminals hen the conductors are carrying the maximum demand under the practical conditions of service. he current shall not exceed that in tables on pp. 2198–2199. For flexible cables the permissible ırrents are given in tables on pp. 2197 and 2200.

Insulation and Protective Covering of Conductors.

The following types have been approved :—

A. *Vulcanised Rubber-insulated Cables*—(*a*) insulated with a layer of pure rubber, an inter- ıediate layer of vulcanising rubber, and an outer jacket of vulcanising rubber and compounded r, alternatively, a homogeneous dielectric of vulcanised rubber free from corrosion of tinning— the latter is used as protective covering it must conform to the requirements of the tough rubber ompound (see p. 2235); (*b*) taped as (*a*) and braided; (*c*) sheathed with a closely fitting seamless overing of commercially pure lead, having a smooth exterior surface and of uniform radial hickness; (*d*) lead-covered as above and bedded and armoured, with or without serving or raiding over the armour; (*e*) bedded and armoured with or without serving or braiding over ne armour; (*f*) encased in a closely fitting covering of brass, copper, or equally hard incorrodible ıetal: (*g*) sheathed with a closely fitting seamless covering containing not less than 95 per cent. f commercially pure lead; (*h*) covered with tough rubber compound.

B. *Paper-insulated Cables*: as (*c*), (*d*), (*f*), and (*g*).

C. Of the types in A, the following shall not be used for a.c. except in connection with an arthed concentric system in which the sheathing forms one conductor; single cables armoured rith steel wire or tape or encased in a ferrous sheath, or single, unarmoured, lead-covered cables aving a conductor of area exceeding 0·25 sq. in.; or brass, copper or equally hard incorrodible ıetal with conductor above 0·1 sq. in.

Twin Flexible Cords.

(*a*) Twin twisted flexible cords shall be used only for fixed wiring, fixed fittings and portable ımp standards; in all other positions and for all other purposes, flexible cords made up to a ircular or oval section shall be employed—the use of circular or oval section flexible cords is ecommended for all portable fittings.

(*b*) The maximum weight carried by a twin-twisted flexible cord shall be as follows :—

Number and diameter of wires in conductor.	Maximum weight.
14/·0076 ins.	3 lbs.
23/·0076 ,,	5 ,,
40/·0076 ,,	10 ,,

Installing and Fixing of Conductors and Cables.

Bare conductors may be used as collectors on trolley wires for cranes, etc., and for battery connections, supported on insulators and spaced so that risk of accidental contact is reduced to a minimum. At the ends of each conductor, straining gear with double insulation to be used. The supply circuit must be protected as for insulated conductors. Lightning arresters on each pole or phase to be used where necessary. Wall supports for span wires must not be within 12 ins. of any gas pipe. Except as above, bare conductors shall only be used in positions not ordinarily accessible to unauthorised persons and under conditions sanctioned by fire offices.

Taped and Braided Cables (Class L) may be used without conduit or casing provided that they are:—

(i) Open to view throughout their length and not installed under floors or buried in plaster.
(ii) Kept away from structural metal work.
(iii) They are protected where within 6 ft. above the floor or when liable to mechanical damage.
(iv) Kept away from gas and water pipes.
(v) Secured by porcelain cleats, clips, saddles, or clamps to prevent the cables coming into contact.
(vi) In damp situations, not less than ¼ in. away from wall.
(vii) Protected by non-absorbent, non-ignitable conduits when passing through floors, walls, or ceilings.
(viii) When passing through party walls or fireproof floors, the conduits to be close-fitting and holes plugged with non-ignitable material.

Metal-sheathed Cables (Class M1) may be used without conduit or casing provided they are in accordance with condition (iv) above and
(ix) Secured by clips, saddles, or clamps to prevent appreciable sagging or damage to cable.
(x) Vertical cables are fixed in the same way as horizontal. When inaccessible, 10 ft. allowed between supports.
(xi) All metallic envelopes of cables to be effectively earthed and made electrically continuous throughout by means of soldered joints or bonding clamps or joint boxes.
(xii) The resistance of the metallic envelope in a complete installation, between the main switch and any other point in the installation must not exceed 2 ohms.
(xiii) If liable to mechanical damage they are to be adequately protected.
(xiv) In damp and exposed situations, saddles and fixings to be of non-rusting material.
(xv) Bushed holes to be used when passing through steel or iron structures.
(xvi) Holes through party walls or fire-resisting floors to be plugged with non-ignitable material.
(xvii) When run under floors or behind partitions, all connections to be made in boxes of ample capacity and of non-absorbent, non-ignitable material.

Hard Metal-sheathed Cables (Class M2) may be used without conduit or casing provided they are in accordance with conditions (iv) and (ix) to (xvii) inclusive.

Armoured Cables (Class R) may be used without conduit or casing provided they are in accordance with conditions (iv), (ix), (x), (xiii), (xiv), (xvi), and (xvii). When lead sheathed, such sheathing shall comply with (xi) and (xii), and when not lead sheathed the armouring shall so comply.

Cables covered with Tough Rubber Compound (Class S) may be used without conduit or casing provided they are in accordance with conditions (iv), (ix), (x), and (xiii) to (xvii) inclusive.

Conduits Screwed (Class T1). All approved classes of cable may be enclosed in steel conduits provided that the conduits are in accordance with conditions (iv), (xiii), (xiv), (xvi), and (xvii), and in addition:

(xviii) The conduits and fittings are made in accordance with British Standard Specification No. 31, and if used on circuits of medium pressure are of heavy gauge. Metal bosses must be secured on both sides to conduit by screwing or nuts.
(xix) The conduits are mechanically and electrically continuous across all joints and are earthed.
(xx) The resistance of the conduit in a complete installation, between the main switch and any other point in the installation, does not exceed 2 ohms.
(xxi) Ventilating outlets are provided at the highest and lowest points of each circuit.
(xxii) The conduits of each circuit are erected complete before the cables are drawn in (see table on p. 2237).
(xxiii) Abrasion of covering of cables emerging from conduits must be prevented.
(xxiv) The end of conduits where terminating at accessories and fittings are screwed thereto or provided with lock-nuts, or are led into separate blocks, preferably of non-ignitable material.
(xxv) No elbows or tees, unless of the inspection type, are used except at the ends of conduits immediately behind fittings or accessories; and no bend has a radius less than 2½ times the outside diameter of the conduit.
(xxvi) In damp or exposed situations, the conduits are welded, brazed, or solid drawn.

Metal Conduits not Screwed (Class T2). All approved cables may be enclosed in conduits of eel or other metal provided that the conduits are in accordance with conditions (iv), (xiii), iv), (xvi), (xvii), (xix) to (xxiii), (xxv) and (xxvi), and (xxvii). The ends of the conduits where rminated at accessories and fittings are adequately clamped thereto, or are led into separate ocks, preferably of non-ignitable material.

NOTE.—Plain slip sockets do not comply with the above regulations—some form of screwed grip joint giving ample and permanent conductivity and rigidity throughout being necessary.

Non-metallic Conduits (Class T3). All approved cables may be enclosed in conduits of non-itable, non-absorbent damp-proof material, provided that such conduits are mechanically ntinuous and strong, and are in accordance with conditions (iv), (xiii), (xiv), (xvi), (xvii), (xxi) (xxiii), (xxv) and (xxvii).

Wood Casing (Class W). All approved cables may be enclosed in wood casing provided that

(xxviii) It is used in dry situations only.

(xxix) It is not buried in plaster or cement nor fixed in contact with gas or water pipes, nor mediately below water pipes.

(xxx) The capping is secured by screws.

(xxxi) If the casing forms part of ornamental woodwork, ready access to the cables is provided.

Flexible Cords (Class Z). High insulation twin or multicore flexible cords may, in addition being used for pendants and portable appliances, be used provided that conditions (iii) and r) are complied with, and in addition:

(xxxii) They are for low-pressure sub-circuits for currents not exceeding 6 amperes.

(xxxiii) If insulated with pure rubber, they are not used in damp situations.

(xxxiv) Insulating cleats not more than 3 ft. apart are used and placed so that the cords do ot come into contact with walls, ceilings, or structural metal work.

(xxxv) They are open to view.

(xxxvi) The premises do not come under the Factory and Workshop Acts and the Coal Mines egulation Acts.

(xxxvii) They are not used in shops, warehouses, or places of public resort.

(xxxviii) Where passing through walls or floors, they are protected by non-ignitable, damp-oof conduits.

(xxxix) Where issuing from fittings and unavoidably passing into ceilings they are enclosed . non-ignitable tubes terminating in non-ignitable junction boxes.

Bunching of Cables.—When installed in wooden casing, cables carrying direct or alternating rrent may, if desired, be bunched whatever their polarity, provided that the number of cables unched is not more than:

10	if the sectional area of each does not exceed				0·007	sq. in.
6	,,	,,	,,	,,	0·0025	,,
4	,,	,,	,,	,,	0·1	,,
3	,,	,,	,,	exceeds 0·1 sq. in.		

he size of the casing must not exceed that of the maximum number of cables permissible.

When installed in metal conduits, cables carrying direct current may, if desired, be bunched hatever their polarity; but if carrying alternating current, they shall always be bunched.

NOTE.—Where large cables are bunched, the rating should be reduced to prevent verheating.

Bell and Telephone Circuits in a building must not be run in casing or conduits used for the istribution of electricity supply throughout the building.

Cable Sockets and other Connections.—(*a*) The ends of all conductors exceeding 0·04 sq. in. hall be provided with a soldering socket.

(*b*) The dielectric shall not be removed farther than is necessary. Dielectric damaged by heat hall be cut away.

(*c*) The braid, lead, or other covering over the dielectric, including the tape, shall be cut back t least half an inch from the end of the dielectric.

(*d*) With paper-insulated cables, the exposed conductor and dielectric shall be protected from oisture by suitable sealing with insulating compound.

(*e*) The ends of stranded conductors unprovided with cable sockets shall be made solid by oldering in the case of paper insulation, and in the case of rubber when exposed to damp.

Connections between Cables other than flexible cords shall be made either by soldered joints r mechanical connectors.

(*a*) Every joint shall be easily accessible and mechanically and electrically sound.

(*b*) Every mechanical connector shall be enclosed in a non-ignitable box and made impervious o moisture.

(*c*) Connections between cables and flexible cords, or between lengths of flexible cords, shall e made by mechanical connectors shrouded in non-ignitable insulating material contained within uitable receptacles.

(*d*) Joint boxes shall be constructed wholly of durable, non-ignitable, non-absorbent materials.

Main Distribution.

Control of Main Supply.—Every installation shall be adequately protected by suitable controlling apparatus easily accessible to the consumer.

(*a*) If the normal current exceeds 100 amperes, there shall be provided, in addition to a fuse or circuit breaker with overload trip, an automatic device which shall operate in the event of a leakage to earth. The leakage current must not exceed 100 amperes.

(*b*) There shall be a circuit breaker or a switch and fuse on each insulated conductor, and all such poles shall be linked.

(*c*) No fuse or unlinked single-pole switch shall be inserted in a main circuit in that conductor which is direct earthed at the supply.

(*d*) The neutral conductor shall never be interrupted while the other conductors are closed.

(*e*) Wherever single-pole switches are required, they shall be on the same pole throughout the installation.

Subdivision of Circuits.—(*a*) The maximum number of points that may be connected in parallel to a final sub-circuit shall be as follows:

Where the total rating of the points supplied from the sub-circuit does not exceed

6	amperes	10	points
7	,,	6	,,
10	,,	4	,,
20	,,	2	,,

(*b*) Every final sub-circuit shall be connected to a sub-distribution board.

(*c*) Every sub-distribution board shall be connected to a separate way on a main distribution board.

Earthing.

Conditions where Earthing is Necessary.—(*a*) For all pressures of supply, earthing of metal objects other than the conductors shall be effected in the following cases:—In bathrooms, lift shafts, near running machinery, and in all places where even a slight shock might lead to serious accident, all exposed metal liable to become alive, or situated so that there is risk of contact with earthed metal, shall be earthed. The metal sheathings of cables shall be earthed.

(*b*) Where the pressure of supply exceeds the limits of extra low pressure, any damp plaster, concrete, or metal shall be earthed which is liable to become alive and touched by a person making contact with earth. All metal conduits shall be earthed.

Position of Metal in Bathrooms.—All exposed metal liable to become alive shall, in addition to being earthed, be placed out of reach of a person standing in the bath. Lampholders shall have their exposed metal parts efficiently earthed, or, alternatively, all parts liable to be handled when replacing a lamp shall be constructed of insulating material.

Earthing.—(*a*) The combined resistance of the earthing lead and system should be low enough to let enough current flow to operate the fuse or earth leakage trip.

(*b*) Water pipes used as an earthing system shall have metal joints throughout.

(*c*) Pipes conveying gas or an inflammable liquid shall not be used as an earthing system.

(*d*) An earthing lead shall be of high conductivity copper protected against mechanical injury and corrosion of not less than 0·0045 sq. in. (7/·029 in.). for the main connection. For flexible cords 0·0048 sq. in. and smaller, earth lead to be the same size as live conductors.

(*e*) All connections of the earthing lead shall be easily accessible.

(*f*) All domestic appliances, whether portable or fixed, for pressures exceeding 100 volts direct or 30 volts alternating current shall be provided with a terminal or other suitable means for earthing all exposed metal.

Fittings.

Portable Fittings which have to be earthed shall be connected to earth by means of a third conductor in the flexible cord.

Ceiling Roses shall not be used for pressures exceeding 250 volts, and not more than two pairs of flexible cords shall be attached to one ceiling rose, unless it be designed for multiple pendants.

Lampholders shall comply with the appropriate British Standard Specification. Switch lampholders shall be provided with further means of control in the same room. Lampholders in open-type portable fittings must be earthed as above or insulated from fitting.

Plugs and Sockets.—(*a*) Sockets shall be so constructed that they cannot be accidentally short-circuited whether the plug be in or out, and so that a pin of the plug cannot be made to earth either pole of the socket.

(*b*) Plugs connected to apparatus for currents between 1 and 10 amperes shall be constructed with (i) a hand shield, the entry for the flexible cable being at the side of the shield remote from the hand, and, if desired, a switch being fixed adjacent to the socket, or (ii) the plug so interlocked with a switch on the socket that it is impossible to insert or withdraw the plug when the

switch is in the 'on' position, provided that every socket, or group of sockets, carrying more than 300 watts shall have a switch in an accessible position.

(*c*) Plugs having a rated capacity exceeding 10 amperes shall, in addition to a hand shield, be provided with a switch immediately adjacent to the socket and preferably interlocked.

(*d*) The dimensions and clearances shall be in accordance with B.E.S.A. Report No. 73.

MOTORS.

Control of Motors.—(*a*) Every motor shall be protected by efficient means suitably placed and so connected that the motor and all apparatus in connection therewith may be isolated from the supply, except in the case of the earth point of an earthed system. For motors of less than 1 h.p. a plug and socket will be considered to be an efficient method of insulation from the supply.

(*b*) Every motor shall be provided with an efficient switch or switches for starting and stopping, so placed as to be easily operated by the person controlling the motor. Every motor rated over ½ h.p. shall also be provided with (i) means for automatically opening the circuit if the supply pressure falls sufficiently to cause the motor to stop; (ii) in the case of d.c. motors a starter or switch for limiting the current taken when starting and accelerating; (iii) in the case of a.c. motors, such starter or switch for limiting the current taken, when starting and accelerating, to the value (if any) required by the supply undertaking.

(*c*) In every place in which a machine is being driven by a motor there shall be means at hand for either switching off the motor or stopping the machine if necessary to prevent danger.

Electric Lifts.—Lifts to be operated from a circuit independent of lighting installation. Control and motor leads to be in separate conduit, and cables except trailing to be armoured or in metal conduits.

HEATING AND COOKING APPLIANCES.

Control of Heating and Cooking Appliances.—(*a*) Appliances shall be protected by a fuse on each insulated pole.

(*b*) Appliances, whether portable or fixed, shall be controlled as a whole by a switch, which in the cases of portable appliances shall be fitted on a wall.

(*c*) Where a switch or switches are fixed on the frame of a portable luminous heating appliance, at least one section of the heating element shall not be controlled by such switches, so that the luminous heating element is permanently connected to the wall-plug or similar device in order to indicate that the circuit is not broken and that the current is still flowing.

(*d*) The support and frame of every appliance shall be provided with a suitable terminal to which the earthing lead may be connected.

TESTING OF COMPLETED INSTALLATION.

NOTE.—The following tests are intended to ensure that the installation is in a satisfactory state at the time of completion.

The value of systematically inspecting and testing apparatus and circuits cannot be too strongly urged, and such periodical tests are essential if the installation is to be maintained in a sound condition and undue deterioration thereof detected.

All defects thus discovered should be made good without loss of time. The attention of consumers should be drawn to the importance of maintaining all apparatus and fittings in a clean and dry condition.

TESTS TO BE CARRIED OUT.

Before an installation is permanently put into service the following tests shall be carried out:—

Insulation Resistances.

(*a*) The insulation resistance shall be measured by applying a direct-current pressure of not less than twice the working pressure, between earth and the whole system of conductors or any section thereof with all fuses in place and all switches on. The working pressure is deemed to be that between outer or phase conductors and neutral, where latter is earthed.

(*b*) The insulation resistance of the lighting circuits measured as in (*a*) above shall not be less in megohms than 25 divided by the number of points on those circuits, except that the insulation resistance of any final lighting sub-circuit need not exceed 1 megohm.

(*c*) The insulation resistance between the case or framework and every live part of each individual dynamo, motor, heater, arc lamp, or other appliance complete with its switch and control gear, regulating resistance and similar accessories, shall not be less than half a megohm when measured as in (*a*) above.

(*d*) All lamps to be in place except on earthed concentric wiring systems. Heating and power circuits may be tested with appliances removed, but lamps (if any) in place.

NOTE.—In addition to the foregoing tests, it is advisable wherever practicable to take an insulation test between all the conductors connected to one pole or phase of a system and those on the other pole or phase.

Continuity of Metal Sheathing.

The metal conduits or metallic envelopes of cables in all cases where such methods are used for the mechanical protection of electrical conductors shall be tested for electrical continuity and the electrical resistance of such conduits or sheathing, measured between a point near the main switch and any other point of the completed installation, shall not exceed 2 ohms

The Electrical Equipment of Ships.

REGULATIONS ISSUED BY THE INSTITUTION OF ELECTRICAL ENGINEERS.
SECOND EDITION, JULY, 1926.

(*Abbreviated.*)

General.—These regulations apply to all sea-going ships except ships of war. They relate to the use of electrical energy for all purposes except the propulsion of ships, and comprise the main requirements for ensuring satisfactory results.

Nature of Supply.—Standard systems of distribution are two-wire d.c. or a.c., three-wire l.c. three-phase three- or four-wire. Standard pressures are 110, 220, 440 volts, and 650 volts for constant current series system 110 volts single-phase l.c. Standard pressures have not been fixed for polyphase currents, but must not exceed 150 volts for lighting and 250 volts for power and heating, except for oil ships. The standard frequency is 50 cycles per second.

Generating Plant.—Generators shall conform to the British Standardisation Rules, except that they shall be capable of sustaining an overload of 25 per cent. for two hours in temperate climates and cool situations on board ship. Generators shall be over-compounded 5 per cent.; they shall be placed where they do not affect the compasses, with their axis fore and aft, and the frames shall be efficiently earthed. Standard capacities for steam prime movers are 5, 10, 15, 20, 25, 30, 40, 50, 75, and 100 k.w. Steam pressures for single engines 100–120 and for compound engines 150 lb. per sq. in. Excluding turbines, the momentary and permanent speed regulations respectively must be within 10 and 5 per cent. for engines up to 50 k.w., and within 10 and 3 per cent. above 50 k.w. For internal combustion engines, these figures are 10 and 3 per cent. up to 10 k.w. and 10 and 2½ per cent. above 10 k.w. Standard capacities are 2, 3, 5, 7½, 10, 15, 20, 25, and 30 k.w.

Switchboards.—The requirements for switchboards, conductors, and distribution are in general those specified in the Regulations for the Electric Equipment of Buildings—see p. 2218. Where the load on a conductor is intermittent, the size of cables for such ratings is given in the following table:—

Rating of Conductors Intermittently Loaded.

Nominal Area of Conductor.	Permissible Current in Amperes.					
	Rubber Cables.			Paper Cables.		
Rating:	Half-hour.	One-hour.	Continuous.	Half-hour.	One-hour.	Continuous.
0·0145	38	37	37	60	57	57
0·0225	47	46	46	79	75	75
0·03	56	54	53	94	89	87
0·04	68	65	64	113	105	104
0·06	92	85	83	151	138	135
0·075	113	101	97	180	162	157
0·1	142	124	118	225	199	191
0·12	160	138	130	252	220	210
0·15	191	164	152	303	261	246
0·2	247	204	184	376	320	296
0·25	295	244	214	453	377	343
0·3	315	283	240	523	435	385
0·4	452	357	288	663	543	464
0·5	534	422	332	804	648	540
0·6	641	499	384	960	767	624
0·75	774	604	461	1,180	930	738
0·85	900	680	512	1,325	1,045	815
1·0	1,036	803	595	1,548	1,211	932

Cables in machinery spaces or exposed to weather or the action of salt water shall be lead overed and may be armoured in addition, with or without braiding over the armour. Cables n cold-storage chambers shall pass normally through the walls or lagging with continuous lead tube anged at each end. Such cables must be lead covered in full view throughout their length and upported by porcelain, hard wood, or other non-metallic, non-hygroscopic material.

Cables passing through decks or watertight bulkheads shall be provided with suitable glands r deck tubes—see B.E.S.A. Specification No. 94. Where unarmoured cables pass through eams and non-watertight partitions, the holes must be bushed with lead or other soft non-ferrous etal. Flexible cords with silk or cotton covering must not be used in crew or cargo spaces, or here exposed to mechanical damage.

Maximum Spacing of Clips securing Lead-covered or Armoured Cables.

Overall Diameter of Cable.	Lead-covered.	Armoured.
Under 0·3 inch . . .	8 inches	10 inches
0·3 to 0·5 inch . .	10 ,,	12 ,,
0·5 to 0·75 inch . .	12 ,,	14 ,,
0·75 to 1·25 inch . .	14 ,,	16 ,,
Over 1·25 inch . .	16 ,,	18 ,,

Earth Connections.—Only steel ships shall be wired on the single-conductor system. Earthing onnections carrying current shall be of the same size as the corresponding insulated conductor. Earthing connections not normally carrying current shall be of copper of the same size as the orking conductor (but not less than 0·003 sq. in.) up to 0·007 sq. in., and above that size not ss than 0·007 sq. in. for every 50 amperes of working current or part thereof, but need not exceed ·1 sq. in. Earth connections shall be accessible and secured by screws not less than $\frac{3}{8}$ in. in iameter.

Interference with Compasses.—Dynamos, batteries, and all apparatus producing an external agnetic field shall be fixed at such a distance from the compass that the magnetic field produced hereat has a negligible value. No single-conductor cable carrying continuous current shall be tted within 30 ft. of standard and steering compasses. Conductors in the vicinity of the compass hall be twin, or as close together as possible. Incandescent lamps used for lighting the compass hall not consume more than 0·6 ampere, and no live part shall be less than 7 ins. from any part f the magnetic system. Effect of switching must be noted during adjustment of compass.

Navigation Lamps.—Each navigation lamp is to be separately wired and controlled by a eparate switch and fuses, and to have an automatic indicator in circuit to give warning of the ailure of the light. Metal filament bayonet cap vacuum lamps fixed vertically of not less than 0 watts to be employed.

Storage Batteries.—The cells shall be so constructed that the electrolyte cannot be spilled, ith strong containers (not celluloid). They should be in a single tier and mounted on oil nsulators. The deck must be lined with lead or other acid-resisting material, and all exposed netal protected with acid-resisting paint. The battery compartment must be well ventilated. witches and fuses must be fixed outside the battery room. All connections in the battery room re to be of bare metal or lead-covered cables.

Fittings.—Fittings are to be so designed and fixed that dust and moisture cannot accumulate ithin them, and are not to be mounted on surfaces liable to become damp. In exposed positions hey are to be weatherproof and waterproof; open type fittings must not be used near inflam-nable goods or where inflammable dust or gases can occur. Switches, etc., must not be installed n bunkers or where inflammable gases may be present. Weatherproof portable lamp fittings ith metal frames must have all metal parts connected to earth by a third conductor in the flexible ord, and must be provided with hooks to hang them up with. Lampholders in weatherproof ortable fittings must be earthed, and in open type fittings they must be insulated and pro-ected with insulating shields. Plugs and sockets must be so constructed that they cannot be eadily short-circuited or earthed or allow an arc to be maintained. Plugs must be provided ith hand-shields or interlocked with switches in the sockets. Weatherproof plugs and sockets nust be employed in exposed positions. See B.E.S.A. Specifications Nos. 97, 98, 67, 73.

Lamps.—Arc lamps must have the whole of their live parts insulated from the frame, and mus be provided with wired globes or other protection; they must not be fitted near combustibl goods or where gases can accumulate, and each circuit must be controlled by a switch and fus on each insulated pole.

Motors.—May be of any type enumerated in B.E.S.A. Specification No. 168, or of submersibl type. When larger than 1 b.h.p. they must strictly conform. Working parts must be accessible and construction must allow of dismantling in space where fitted, unless readily removable. Th carbon brush gear must be adjustable. For brushes see p. 2290 and B.E.S.A. Specificatio No. 96 for standard terminals. Lubrication must be automatic. Motors should be placed i well-ventilated compartments, with axis of rotation in a fore and aft direction and clear of in flammable material: otherwise they must be of flame-proof or forced-draught type with pipe taken outside compartment. Where temperature exceeds 120° F. motors to be pipe-ventilatec induced- or forced-draught type connected to inlet air at less than 120° F. Motor starters abov 3 b.h.p. must have no volt-release and replaceable resistance elements.

Control Gear.—Regulators and controllers are to be of incombustible materials and guarde or enclosed in incombustible cases; contacts shall be renewable, and all live parts enclosed b metal covers, and so designed that they cannot be touched by the operator. Resistances sha not rise to an excessive temperature, and no accessible part of the apparatus may rise abov 130° F. Internal connections shall not be soldered. Control gear shall not be placed wher inflammable gases can accumulate, unless it is flameproof; in exposed situations it shall b totally enclosed. Resistances shall be placed in well-ventilated compartments and away fror combustible material.

Heating and Cooking Apparatus.—Appliances shall be so constructed that parts which ar handled cannot exceed a temperature of 130° F. The elements shall be readily replaceable live and highly heated parts shall be guarded. Connections between the elements and switche or external leads shall be made without solder, and their temperature shall not exceed 200° F All appliances for pressures exceeding 150 volts shall be efficiently earthed. Whether portabl or fixed, appliances shall be controlled by fixed switches; portable appliances shall have at leas one section of the elements controlled only on the live side of the wall plug or other connectio with the fixed portion of the circuit.

Internal Communications.—Transforming apparatus and batteries shall conform with the rule for lighting and power plant. If the working pressure exceeds 25 volts, all parts of the apparatu shall be made and fitted in accordance with the rules for lighting and power circuits. Com munication cables shall be made and fixed in accordance with the rules for light and powe cables, and shall be kept as far as possible separate from the latter, with separate groove when run in wood casing. Fuses need not be fitted in branch circuits for pressures not exceedin 25 volts, or in circuits supplied from primary batteries.

Lightning Conductors.—Conductors shall be fitted to all vessels having wooden masts, c copper tape or rope having not less than 0·15 sq. in. sectional area. When in dry dock, ship lightning conductors shall be connected to an efficient earth on shore.

Oil ships.—On oil ships the pressure for all purposes shall not exceed 110 volts with a.c. with d.c., for power 220 volts, for lighting and heating 110 volts. No part of the system sha be earthed, and double-pole linked switches shall be used on every circuit or sub-circuit. A cables shall be lead-covered, with or without armour. Distribution shall be on the two-wir two-conductor system. No wiring shall be taken into oil-holds or coffer-dams, which must b lighted by lamps entirely outside the space and separated from it by an airtight glass bow Lamps in dangerous spaces shall be in gas-tight fittings, and the switches shall be outside th spaces; no portable lamps other than self-contained battery-fed lamps (mining type) may b used in dangerous spaces.

Constant-current Series System.—Special requirements include automatic circuit closer fc short-circuiting generator in the event of an open circuit anywhere in the system, and forbid th use of open-type machines. All bare conductors (including heating elements) to be totall enclosed in metal cases with conductors accessible only when disconnected, and no part of th system shall be earthed.

Trials.—The insulation of the whole system, with all lamps and fuses in place, is to be teste before putting into service with direct current at twice the working pressure between the syster of conductors and earth, and shall not be less in megohms than 10 divided by the number of lamp (on lighting circuits), but the insulation resistance of any final lighting sub-circuit need not exceed one megohm. The insulation resistance of every piece of apparatus, with switch or contrc gear, etc., shall not be less than half a megohm. The installation shall be run for six hours an all the apparatus operated, not necessarily simultaneously.

Wall Plugs and Sockets.

British Standard Specification for 5-, 15-, and 30-ampere, 2-pin wall plugs and sockets for lomestic purposes (without earthing connection), No. 73—1927, gives details of materials to be used, sizes and spacing of all insulating, current-carrying, protecting, and fixing parts, toegther vith gauges and tables of dimensions.

Directions for Making Joints in Electric-Light Conductors.

(*Silvertown Instructions.*)

Preparing Ends and Making Metal Joints.

The braiding should first be removed, the tapes unlapped, and the conductor exposed for a ength of not less than eight to ten times its diameter (for small wires the length should not in ny case be less than 2 ins.). With vulcanised or similar cables the rubber should then be cut ff at a right angle, care being taken not to nick the wires. With pure rubber cables the pure ubber should be unwrapped, not cut.

In making all joints resin should be used, either raw, or a little powdered resin dissolved in pirits of wine to a thin paste.

The soldering-bit should always be kept clean. This is best done by dipping it into a satu- ated solution of sal ammoniac and water.

The copper conductor to be jointed should always be carefully cleaned ; and when the joint is inished, all rough points should be removed by means of a file so that the surface may be smooth or insulating.

For a Single-conductor Wire.—The ends of the copper should be filed to a long bevel—i.e. carfed—and the two ends so filed laid one on the other, the object being to get a long surface of ontact. The scarf should then be carefully soldered and whipped with small binding-wire, and he whole again soldered and cleaned up with emery cloth or a file ; the finished diameter should ow not greatly exceed the original diameter of the conductor.

For a 7-Strand Cable.—The whole of the strand should first be soldered up solid ; then scarfed nd jointed as a solid wire, in the same way as above.

For a 19-Strand Cable.—The conductor should be bared to a suitable length, and a small binder ied round the ends next to the rubber to keep the strand in place. The 12 outside wires should hen be unstranded and turned back. The central 7-strand should then be soldered up and ointed as a solid conductor. To joint the 12 wires over this, every alternate wire should be cut ff short, and the two sets of 12 married—that is, the long wire from the one end jointed to the hort wire on the other, and so on round the central strand ; thus half the joints on the single wires vill be on the one side of the joint in the central strand, the other half being on the other side. The joints in these single wires need not be scarfed, but only butted together at each end of the oint, where the long and short wires are soldered together. A narrow whipping of binding-wire hould be put on at each end and soldered, the whole being then filed down smooth.

For a 37-strand Cable.—If flexibility is required, the same method is followed out, with the ddition that the 18 wires surrounding the 19-strand joint are married in the same way.

If flexibility is not essential, the 19-strand should be scarfed and jointed in the same way as he 7-strand, and the 18 remaining wires only are to be married.

For a 61-strand Cable.—The joint should be made the same as the 37-strand, with the addition hat the remaining 24 wires surrounding the 37-strand should be married in the way previously lescribed.

Directions for Making T-Joints in Conductors.

To Joint a Single Wire to another Single Wire.—The smaller wire should be scarfed and laid long the surface of the other wire, and then whipped with binding-wire and soldered and finished mooth ; the binding should, however, not be continued up to the point where the smaller wire is ent.

To Joint a Single Wire to a Strand.—The surfaces should be carefully cleaned, and the single vire wound spirally round the strand at the end, but lying flat with the strand at the point of unction ; this flat part should be whipped, and the whole soldered.

To Joint a 7-strand on to a larger Cable.—The 7-strand should be unstranded, and, after clean ing the wires separately, the wires should be twisted round the larger cable, three being twiste parallel in the one direction and four in the reverse direction, and on the other side of the T, an a light whipping of copper wire round each end ; and the whole should then be carefully soldere together.

For Large T-Joints.—Each conductor should be soldered up solid. The smaller one shoul then be scarfed and a recess filled in the other, about halfway through, the shape of the scarf the whole should then be soldered together, and whipped with binding-wire, and soldered again Where the joints are heavy strong binding-wire should be used.

Directions for Insulating Joints.

Vulcanised Rubber Joints.—When the conductor joint is finished the rubber should be care fully trimmed and cut with as long a bevel as possible, according to the thickness of the rubber the copper conductor and the bevelled ends should then be rubbed with pure benzol and slightl heated with a spirit lamp. The conductor and the bevelled edges of the rubber should then b lapped with a pure rubber strip laid on as tightly as possible in one or two layers according t size : this pure rubber should then be covered with special rubber solution, rubbed in so as t exclude air as much as possible ; the joint should then stand until thoroughly dry. When th solution is sufficiently dry, and will not adhere to the fingers, a special rubber strip should b lapped on spirally, forming a uniform covering over the first coat of pure rubber, care bein taken, by lapping tightly and evenly, to exclude all air. This rubber should be put on in two o more layers, until the diameter is equal to that of the original insulation, and over this a layer c proofed tape should then be applied, the whole joint so made slightly exceeding in diameter tha of the original insulation. When so completed the next process is that of vulcanisation. To d this it is necessary to cover the joint with special sheeting cut to the whole width of the join and firmly rolled round it, making a longitudinal seam, binding the sheeting over all by a stron cotton selvedge tape applied spirally, and as tightly as possible by hand. The sheeting thus wi serve as a mould to keep the joint together during the process. The joint should then be fixed i the 'cure' (a cast-iron box) and the cover bolted on ; and, to prevent damage to the origina insulation and to make the box tight, the insulation on each side of the joint, for the proper dis tance to fit the cure, should be lapped with two or more coats of tape, to cover the original in sulation down to the point of junction. When the cure has thus been made tight molten sulphu compound, previously melted in a suitable pot, should be poured into the cure round the join through the small hole in the top of the cure, and a suitable thermometer afterwards inserted i this hole, to enable the temperature of the sulphur compound to be noted. This temperatur should be kept as constant as possible between 290° and 300° F. by means of spirit lamps.

After the joint has been kept at the full temperature for about half an hour the molten sulphu is run out and the cure-cover unbolted. The joint should then be taken out, the wrapping stripped off, and it will then be found to be vulcanised. A rough test of the degree of vulcanisa tion may be made by trying with the thumb nail (when the joint is cool) to indent it. If th mark of the nail remains in the rubber, or if the rubber is too hard, the joint is a failure, an should be cut out and remade. If the joint thus examined is found to be in good order, it shoul be finished off by lapping over all special tapes, extending, say, over about 2 ins. each side c the braiding ; this taping to be then painted with shellac varnish.

When insulating with rubber the hands should be kept dry and perfectly clean. When solu tion is used, it should only be used in small quantities, and the spirit allowed to evaporate befor the whole is again covered up. The spirit used should be of the best quality, so that it evaporate quickly and leaves little or no residue behind. Special care should be taken that the rubbe applied be brought into immediate contact with the prepared ends, and that no tapes of th original insulation, or foreign material which would conduct moisture, should intervene betwee the two surfaces to be joined. Unless everything used is perfectly clean, and all air exclude by careful and tight lapping, the joint may be found to have blown, even though the rubber i properly vulcanised. Special attention, therefore, is required to these points.

If, during vulcanisation, the temperature should drop below 290°, the heat will require to b maintained for a longer time ; say, if at 280°, the cure would last for about three-quarters of a hour instead of thirty minutes ; but it is important that the temperature should be kept a constant as possible between the limits of 290° and 300° F.

If the pure rubber appears hard and brittle it should be slightly warmed before using. Shoul the compound tape become dirty or too hard, it can be softened by wiping with benzoline.

The Electrical Testing of Electric-Supply Mains.

The accurate testing of electric-light mains before and after laying, and periodically durin use, is a matter of great importance if the efficient working of a system is to be obtained an maintained. For the purpose of accurate testing each station should be provided with a sensitiv

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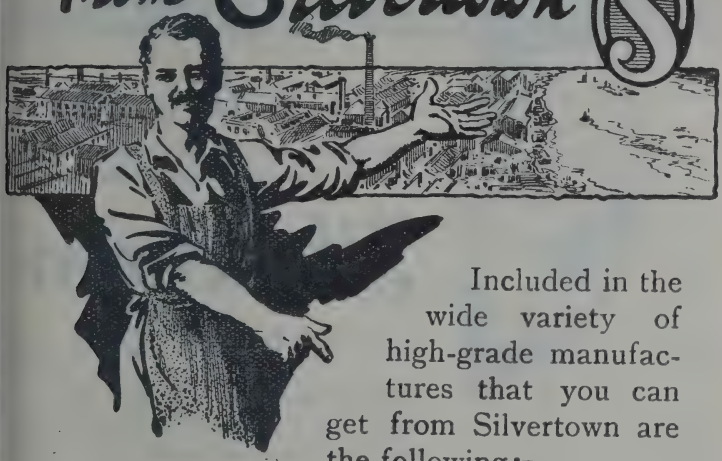

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F. 2231

gh-resistance mirror galvanometer, a shunt box, a resistance coil of not less than 10,000 ohms f possible, a megohm), a condenser, keys, and a battery of not less than 100 Leclanché cells. or tests during laying this battery should consist of 400 to 600 cells. It is often possible, how- ver, to use the current from the mains at the normal supply voltage on a direct-current system.

The shunt boxes usually supplied with the mirror galvanometers are fitted with shunts having r that particular galvanometer multiplying powers of 10, 100, and 1,000. For the varying insu- tion resistances which have to be measured in electric-light testing a resistance box having oils of units, tens, hundreds, and thousands is most convenient for use as a galvanometer shunt ox, as it enables work to be done between very wide limits, and the obtaining of the deflection pon any part of the galvanometer scale. The Ayrton-Mather 'Universal' shunt-box can be sed with advantage, as the multiplying powers are independent of the resistance of the

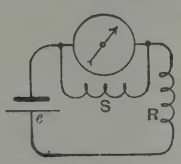

FIG. 2.

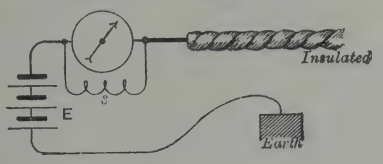

FIG. 3.

alvanometer. The instruments should be erected and adjusted before the work of laying or alling is commenced, so that tests may be taken on the arrival of the drums of cable and the pecified insulation resistance assured.

The test should be taken with the drums of cable immersed in water wherever possible; but here this cannot be done they must be well wetted, except in the case of lead-sheathed cable.

The preparation of both ends of the cable is of the utmost importance if the real insulation esistance of the dielectric is to be obtained, the difference in the results given with properly and mproperly prepared ends being very great. For vulcanised rubber cables the tapes, braiding, or ther covering should be removed for at least 6 inches from the ends. The tape next the rubber hould then be carefully removed, the surface of the rubber washed with naphtha, and well scraped o remove any fragments of the tape. The rubber should be tapered off with a pair of clean, bent cissors, the length of the taper being 1 to 2 inches. Next the whole of the prepared end is horoughly dried by means of a spirit lamp, allowing the flame to play round the rubber, but aking care not to burn it. If the test cannot be taken immediately, the prepared end should e well warmed and lapped with clean, warm, pure indiarubber tape, well stretched.

The most accurate method of obtaining the insulation resistance of a highly insulated cable the direct deflection method—i.e. by a comparison of the deflection of the galvanometer needle roduced by a given battery power working through a known high resistance with the deflection roduced by the same battery power working through the insulation of the cable. This method is s follows :—

A small battery (usually 1 cell) is first connected up, as shown by fig. 2, with the galvano- eter and with a resistance, R. of 10,000 ohms, the galvanometer being shunted by a shunt, S sually the $\frac{1}{1000}$th shunt), so that a convenient deflection, D, is obtained; this is called taking the onstant. The connections are then altered as shown by fig. 3, a large battery, E (about 100 more cells), being used, and the wire whose insulation is to be measured being joined up as nown. Let the deflection be d, and the shunt s on the galvanometer be the $\frac{1}{n}$th (usually $\frac{1}{10}$th, $\frac{1}{100}$th or $\frac{1}{1000}$th—i.e. $n = 10$, 100, or 1,000); also let the shunt used when the constant is taken e the $\frac{1}{N}$th shunt; then

$$\text{Insulation resistance of wire in megohms} = \left(\frac{D \times N}{n} + K \times R\right) \div \left(d \times 10^{s}\right),$$

here K is the ratio between the number of cells used in taking D and in taking the constant; us, if d is given by 100 cells and D by 1 cell, then K = 100. When great accuracy is required the xact ratio of the electromotive force of the large to the small battery has to be determined, for it is ldom that 100 cells have exactly 100 times the E.M.F. of 1 cell, though in a large number of cases is sufficient to consider it as such, care being taken that the cells are all in good condition. If a egohm resistance (1,000,000 ohms) is available, the constant may be taken with the same battery s is used for testing the insulated wire, the megohm being used in the place of the 10,000 ohms; this case K=1. A short-circuit key must be connected across the galvanometer terminals, nd must always be closed so as to short-circuit the galvanometer at the beginning of each test, therwise the rush of current from a high battery power will probably demagnetise the needle. or testing short lengths of highly insulated cable a battery of at least 400 Leclanché cells should

by used. If the battery is kept on for fifteen minutes, during which readings are taken eve minute, it will be noted that the deflection falls rapidly the first two or three minutes, the fa per minute becoming gradually less, till, at the end of fifteen minutes, the deflection is falling ver slowly. It would thus appear as if the insulation resistance rises during the test; but the chi reason is, that when the battery is first connected, and after the first rush of current, the dielectr

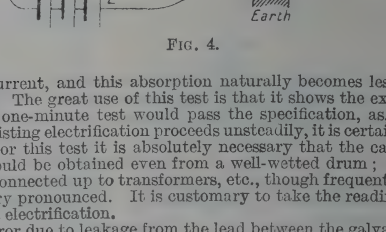

FIG. 4.

electrifies or absorbs current, and this absorption naturally becomes less and less as the cab becomes fully charged. The great use of this test is that it shows the existence of minute faul in a cable which on a one-minute test would pass the specification, as, if there is little or r electrification, or the existing electrification proceeds unsteadily, it is certain the dielectric contai undeveloped faults. For this test it is absolutely necessary that the cable should be in wate as no reliable results could be obtained even from a well-wetted drum; and of course it cann be taken on a system connected up to transformers, etc., though frequently before connecting u the electrification is very pronounced. It is customary to take the reading of the deflection *d* a the end of one minute's electrification.

In order to avoid error due to leakage from the lead between the galvanometer and the cabl the galvanometer key should be depressed before the lead is connected to the cable; any deflectic that may be observed is to be deducted from the deflection *d* before calculating the insulatic resistance. The leads should also be tested for continuity. Further, to prevent error due t leakage over the surface of the insulating covering of the cable, which is often of considerab importance, especially when the length of cable under test is short and the insulation resistanc very high, a 'guard wire' should be connected at one end to the junction between the batter and the galvanometer, the other end being wrapped round the prepared insulating surface at eac end of the cable (if both ends are accessible): this device (fig. 4) by-passes round the galvan meter any current due to surface leakage, and greatly improves the conditions of testing.

All insulated conductors should be tested after at least twenty-four hours' immersion in wat and none but those giving the specified insulation resistance should be accepted. When laid drawn in, but before jointing, the section having one end in the station should have its en prepared, the distant end being well warmed and lapped, and a careful test taken; if all righ prepare section 2, and having by means of a short piece of fine wire connected it to section test both sections together. If the insulation resistance per mile is found to be correct, the tw sections may be jointed, after which they should be again tested, and if not up to the previo tests the joint must be remade. Sections 1 and 2 being jointed and passed, section 3 may b temporarily connected and tested, jointed, and the three sections tested, and so on till the enti system is jointed and the final test taken. If this method is carried out the engineer in charg will have a record of tests—1st, upon each section in water; 2nd, upon each section after laying 3rd, upon the system as each length is jointed on—and he will feel satisfied that the cables ar up to the specification, that they have not been damaged in laying, and that the joints are a well made.

With vulcanised indiarubber joints in a vulcanised indiarubber insulated cable there is n difficulty in keeping th completed system up to the specified insulation resistance per mile c the cable. It is manifestly absurd to lay down high-class mains and, by means of inferior joint reduce the insulation resistance to a few thousand ohms. If a section cannot be tested from th station, or if the jointing cannot be commenced at the station end of the mains, a portable testin set should be employed; and when all the sections are jointed up a final test should be taken wit the station instruments.

With portable testing apparatus it is not possible to attain the same degree of accuracy a by the method outlined above; but, on the other hand, the insulation resistance of cables an wires when laid or installed in position is usually very much lower than in the former case, an therefore does not call for equally refined methods of testing. The most convenient portabl instrument for testing insulation resistance is the 'Ohm-meter,' of which several patterns ar obtainable, each combined with a generator which gives the necessary testing pressure withou the aid of a battery. These instruments are capable of applying a testing pressure of 500 c even 1,000 volts, and of measuring to a sufficient degree of accuracy insulation resistances up t 2,000 megohms.

Testing sets are also made for carrying out tests of insulation resistance by the direct de flection method, using a galvanometer of the pivoted type, and a battery; these instrument in some cases are so designed as to be capable of being applied also to the measurement of direc currents and pressures, low resistances, etc., and for localising faults on cable network. Th Evershed ohm-meters are described on p. 2310.

Earth Detectors.

Earth Detectors are required in mining work in stations covered by the following extract om the Home Office Rules :—

> ' In every completely insulated circuit, earth or ground detectors shall be kept connected up in every generating and transforming station, to show immediately any defect in the insulating of the system.'

Generally Earth Detectors are either one or other of two kinds, depending upon the pressure the circuit on which they are used :—

(a) For circuits not exceeding 750 volts a milli-ammeter is used. This consists of a voltmeter, e scale of which is calibrated to read milli-amperes. This instrument is used in conjunction ith resistances which are so proportioned that in the case of a bad fault giving full line voltage earth, the needle would indicate the maximum reading marked on the scale.

For three-phase circuits one instrument with resistance is used as shown in fig. 5, illustrating Westinghouse Earth Detectors.' One pole of the instrument is connected to earth, the other ole being connected to the centre point of a special three-way key switch. Under normal orking conditions the instrument is connected through the three-way key switch and the three sistances shown on the diagram to the three phases, the three keys being locked in the closed osition, thus ensuring that the leakage detector is kept in circuit permanently.

If a fault occurs on one of the mains, a deflection is obtained on the milli-ammeter, and to termine upon which phase the fault exists it is only necessary first to release all three keys and

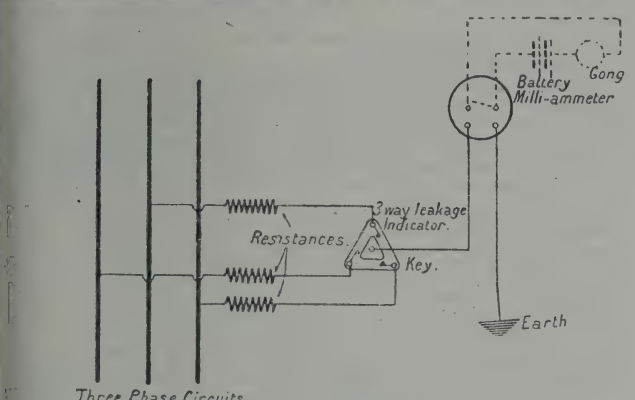

FIG. 5.

en to depress them one at a time. The faulty phase will give the smallest deflection. As dicated in the diagram, a bell and battery can be included and the milli-ammeter can be prooded with special contacts so that in the event of a serious fault occurring on the mains the ell would sound an alarm.

(b) For circuits having pressures greater than 750 volts, it is customary to use a Static Earth etector. In this instrument, the indicating pointer carries a large black disc, which under ormal conditions appears in the centre of the scale. This disc and pointer are electrically conected to the case of the instrument, which in turn is earthed. The live portion of the instrument onsists of two metal plates embedded in the porcelain base of the instrument to the right and ft respectively of the central position normally taken up by the black disc on the pointer. When he condition of the system is healthy, the pointer retains the central position, since the ull between the disc and each one of the live pieces of metal is equal. As soon as a fault occurs n one main, however, the attraction between the centre disc and the particular stem to which he faulty main is connected becomes less and the disc is consequently attracted towards the ther stem. The scale is calibrated so that the deflection is an approximate measure of the actual onditions. Since the two stems must be connected one to each phase in the case of a three-phase ircuit it is necessary to employ two instruments.

Electrostatic Earth Detectors can only be used on circuits having an insulated neutral. In he case of systems where the neutral is earthed, it is customary for an ammeter to be placed in he earthed connection.

Cable Soldering Sockets.

Specification No. 91—1926 of the British Engineering Standards Association gives the standa dimensions of cast and wrought lug sockets, clamp sockets, and clamps, for cables from 0·0 to 1·000 sq. in. sectional area. Cast lug sockets are of brass containing 70 per cent. of copp and tubular lug sockets are of solid-drawn copper tubing; clamp sockets are of brass or oth suitable non-ferrous metal. Sweating surfaces are to be drilled and tinned, and contact surfac machined.

Cables for Installation Work.

As far as electrical installation work, and particularly conduit work, is concerned, the type cable with which the contractor has mostly to deal is that known as a rubber insulated cable. T real properties of rubber insulated cables are more or less obscure, and the question as to wh constitutes a good cable is almost impossible to answer with any degree of accuracy. To gi some indication as to the quality of the rubber compound covering, a careful chemical test required, and this combined with a stretching test will give a distinct clue as to the possible du bility of the material.

Government Department Specification for Rubber-Covered Cables J, K and L Class for Power and Light.

Designation.—Cables shall be designated by the nominal sectional area of the conductor a a letter prefix as follows: 'J Low' and 'J Low Twin,' 'J Medium' and 'J Medium Twin' f 250-volt and 660-volt respectively for V.I.R. taped and braided. 'K' and 'K Twin' for V.I. taped, and lead sheathed (660-volt) and 'L' and 'L Twin' for V.I.R. taped, lead-sheathed a armoured (660 volts).

Material.—The conductor shall comply in all respects with B.E.S.A. specification No. 7 (s p. 2196), and be free from all mechanical defects.

Tinning.—Each wire shall be tinned uniformly with pure tin free from lead in a bath free fr contamination with copper. Before stranding, a sample shall be bent into a loop of radius n less than 12 and not more than 15 times its diameter, cleaned to remove grease and immers for 1 minute in hydrochloric acid specific gravity 1·088 at 60° F., washed and examined unde lens for blackening. Average number of times of immersion to produce visible blackening sh not be less than 8 times for wire 0·029 to 0·048 inches diameter, 7 times for diameters abo 0·048 up to 0·0808, and 5 times for diameters over 0·0808 inches. A further sample to wrapped round a rod of diameter four times that of the wire and submitted to the above for o cycle.

Jointing.—Not more than one joint to be allowed in any wire forming 1000 yards of conduct nor a joint to be within 12 inches of another in same layer, nor in conductor after strandi Joints shall be brazed, silver soldered or electrically welded.

Stranding.—To be uniform throughout length. 3-stranded wires to have a left-hand heli lay, 7 strand to have straight centre wire with six left-hand helically laid wires, the strandi for other numbers of wires to have alternate left-hand and right-hand lays.

Resistance of Conductors.—To conform to B.E.S.A. specification No. 7. Compensation the laying up of twisted twin cables to be agreed between contractor and inspector.

Dielectric.—Conductor shall be covered with one layer of British plantation pure rubb applied helically or longitudinally, then a covering and jacket of vulcanised rubber consisting of pu rubber mixed with sulphur, non-hydroscopic mineral matter and wax if required. The dielect shall contain not less than 45 per cent. by weight of pure rubber. After vulcanisation the aceto extract shall not exceed 5 per cent. by weight, of which rubber-resins are not greater than 2 p cent. and free sulphur 0·75 per cent. Maximum amount of organic matter in residue after aceto extraction not to exceed 1·0 per cent. of total dielectric. Sulphur content in rubber not to less than 1·25 or greater than 1·75 per cent. of total dielectric. No re-manufactured rubb or rubber substitutes to be used. Cable to be rejected if blackening is shown on pure rubb or tin, or if pure rubber adheres to conductor.

Thickness.—To be in accordance with B.E.S.A. specification No. 7.

Taping and Vulcanising.—To consist of helical binding of fine cotton tape (red and black blue for twin cables) of specified thickness, rubber proofed. The whole to be vulcanised in homogeneous body, after which rubber layers shall be inseparable but tape removable witho tearing rubber.

Mechanical Tests.—After removal of the conductor, an outer covering a length of 2 inch marked on the dielectric shall be maintained stretched to 6 inches for 24 hours at an ordin temperature not exceeding 65° F. After release, the length shall not be greater than 2½ inch no signs having been shown of the rubber cracking or elongating irregularly. Tensile streng not to be less than 800 lb. per sq. in.

Heat Tests.—Separate samples after removal of conductor shall withstand without mater deterioration a dry heat of 270° F. for 1 hr. and a moist heat of 320° F. for 3 hrs. After th days interval samples to be stretched as above from 2 ins. to 5 ins. for 6 hrs., the distance becom not greater than 2½ ins. on release.

Electrical Tests.—(*a*) High voltage test as B.E.S.A. Specification No. 7 after vulcanising a before outer protective coverings are put on. (*b*) Insulation resistance shall not be less than th given in tables and to be measured immediately after test (*a*). Cable to be immersed in wa

ıd measurement made with not less than 500-volt direct current after 1 minute negative electrifi-
ıtion. The electrification must proceed regularly.

Twinning.—For circular twin, the complete cores shall be twisted with a right-hand lay,
ɔrmed with tanned jute and wrapped to approximate circular section with rubber-proofed
ttton tape. For flat twin, the two cores side by side are tape-wrapped to form symmetrical
ble.

Mechanical Protection.—The specification gives particulars for braiding, identification cotton,
ad sheathing, bedding and serving, galvanised steel wire and steel tape armouring, tests on
ıished cables and packing, together with tabulated data and a temperature correction table
r insulation resistance.

The foregoing details give some indication of the main features which are to be looked for in
high-class rubber insulated cable. As regards the conductors, the conductivity question is
ıe of considerable importance, but it should be mentioned that trouble in this direction very
ldom arises, because there is little difficulty in maintaining a standard purity in electrolytically
fined copper. The phrase 'to show no sign of sulphide of copper after vulcanising' refers to
ıe appearance of the wire when it is stripped of its insulating covering. It should then present
clean, bright appearance, free from blackening.

The building up of the rubber dielectric in three layers represents the usual English practice,
ıd the wording of the specification is designed to exclude the use of adulterants and deleterious
ıbstances, these being practically synonymous so far as the life of the rubber insulation is
ɔncerned.

The specifying of a minimum percentage of rubber in addition practically leaves no room for
ıything but legitimate compounding ingredients, the choice of which is left to the experience
ıd skill of the cable manufacturer.

There is, perhaps, no industry so greatly dependent on detailed experience and skill in apply-
g that experience as that of the manufacture of rubber, and when electrical conditions are
.volved this is doubly true.

Generally speaking, therefore, where considerations of quality and durability are paramount
will always be best to purchase rubber-insulated cables, either to a specification such as that
stanced above, or to agreed standards such as those of the Cable Makers' Association.

The provision of suitable outer coverings for rubber-insulated wires and cables which are
ɔposed to abnormal conditions is a point which should not be overlooked. Conversely, in a
ven situation, a certain method of installing may be unsuitable. For instance, condensation
fects, which occur in tubes and pipes, are notoriously bad for rubber cables, and in such situa-
ons either the method of installing should be varied or special coverings, such as a bitumen
eath, should be applied to the cables. Many cable makers are prepared to advise as to the
ɛst type of covering and method of running or fixing cables under abnormal surrounding
ɔnditions.

A second quality of vulcanised rubber cable has been placed on the market to meet the demand
those users who are satisfied with a cheaper grade of cable. Such cable, known as 'non-
ɛsociation' cable, is quite satisfactory when properly manufactured, and may be safely used in
ıses where only a moderate length of life combined with good mechanical properties, is required,
ıd where the conditions do not require a permanent maintenance of high elasticity of the di-
ectric.

Revised Specification for Cab Tyre Sheathed Cable.*

The following specification for this class of cable is based on the British Admiralty Specifica-
on Tests for Cab Tyre Sheathing :—

The cab tyre sheathing shall contain not less than 35 per cent. and not more than 40 per
ınt. of first-grade plantation rubber or other rubber of not less good quality.

The surface of the sheathing shall not be treated or dressed without the consent of the
dmiralty Overseer.

The acetone extract of the vulcanised sheathing shall not exceed 5 per cent. calculated on the
eight of the complete sheathing as manufactured.

Bending Test.—A test length of the complete cable containing the conductor shall be bent
ınd a hard rod having the same diameter as the external diameter of the cable to form a loop.
he unbent portions of the test piece shall be bound together so that the two parts touch one
ıother closely throughout their length from their ends up to the beginning of the loop.

In cables of large size when this method is not practicable the test piece shall be bent in a
·op so that the maximum extension of the external surface at the curvature at the bend
ɛaches 50 per cent.

The sample in either case shall be left untouched for a period of 48 hours and at the termina-
on of this time shall show no signs of cracking.

Immersion Tests. (*a*) *Chemical.*—Test pieces 6 ins. long shall be prepared, and after the
ɔnductor and dielectric have been removed they shall be dried at a temperature of 100° C. for
ne hour in an air oven; they shall then be cooled in a desiccator for two hours, and at the end
f this period shall be weighed. The ends of the test pieces shall be plugged with rubber bungs
ıd sealed with paraffin wax for a length of half an inch from each end. The test pieces thus
repared shall be completely immersed in a vertical position in the following solutions for a

* Referred to in I.E.E. Rules under 'Tough Rubber Compound' Covering, p. 2221.

period of 48 hours at normal temperature; they shall then be removed and washed in runnin water for a period of two hours, afterwards being wiped dry and the wax and plugs remove The samples shall then be dried in an air oven for one hour at a temperature of 100° C. and sha be cooled for two hours in a desiccator; they shall then be reweighed. The difference i weights before and after immersion shall be calculated as grammes per 100 sq. ins. of surfa exposed to the solution.

(1) *Acid Test.*—The solution shall be hydrochloric acid having a specific gravity of 1·04 The figure calculated as stated above shall not exceed 1·0.

(2) *Alkali Test.*—The solution shall be sodium hydrate having a specific gravity of 1·11 The figure calculated as stated above shall not exceed 1·5.

(*b*) *Oil Test.*—A test piece shall be prepared 6 ins. long; one end shall be sealed so efficiently to prevent access of oil to the interior. The test pieces shall be immersed in pure ra oil of the best quality to such a depth that not less than 2 ins. of sheathing is exposed to t action of the oil. The immersion shall be continued for six hours, the oil during that time bei maintained at a temperature of 100° C. After immersion the sample shall be removed and roll dry between blotting paper; the seal shall then be removed and the sample re-weighed.

The difference in weights shall be calculated as grammes per 100 sq. ins. of surface expose and the figures so obtained shall not exceed 15.

The cable should be generally in accordance with *St. Helens Cable & Rubber Company's* origin Patent No. 3996/1911.

Cab Tyre Sheathed Cables are now made in C.M.A. 'Nonazo' (non-Association) quality, well as in C.M.A. Association grade.

WIRING SYSTEMS.

Conduits and Fittings for Electrical Installations.

Conduits, with the exception of the seamless or drawn varieties, are generally made fro specially selected steel strip, varying in gauge according to the diameter of the tube. T strips are rolled to a circular section of exact external and internal diameter, by a method whi ensures freedom from internal roughness and an even surface to facilitate the drawing of t wires into the conduit, thus preventing injury to their insulation. Exact sizes are essential order to obtain a tight junction between the conduit and fittings with both socket and screw junctions.

The conduits are made in two different types, viz. Light Gauge, for socket and continuit junctions, and Heavy Gauge for screwed junctions.

Conduits are usually supplied in two standard finishes, as follows:—

(1) Stove enamelled (black); (2) Galvanised.

For all ordinary installation work in the interior of buildings, enamelled conduits will found satisfactory in working.

The enamel employed should be flexible, acid-resisting, insulating, and durable.

The conduits must be well cleaned before being enamelled, and subsequently stored at even temperature until the enamel is set, so that it is not liable to flake or break away wh the conduit is bent. The enamel should resist any chemical action which is likely to be found the plaster of buildings.

Where conduits are subjected to excessive chemical action, especially when buried in cind fill concrete, quick-drying chemical plasters, and the like, a more efficient protection is require and this is afforded by galvanising.

BRITISH STANDARD SPECIFICATION FOR STEEL CONDUITS FOR ELECTRICAL WIRING.*

(No. 31—1923.) (*Abstract.*)

Steel conduits shall be either close-joint, brazed, welded or solid drawn as ordered, and sh be of mild steel and free from burrs and internal roughness. The conduit fittings shall be ma of steel or malleable iron. All steel shall have a tensile strength of not less than 18 tons nor mo than 24 tons per square inch of section, and an elongation of not less than 15 per cent. in a leng of 8 inches. Malleable castings shall be well annealed and free from internal projections.

The conduit shall be manufactured in straight lengths of ten to fifteen feet.

For all fittings made out of *tube*, the minimum thickness of the fittings shall be equal to th of the corresponding conduit with which they are used. In no case shall 'close joint' tube used for these fittings.

Two classes of steel conduit for electrical wiring are recognised as Standard:

Class A.—Plain.
Class B.—Screwed.

Class A consists of light gauge conduit of the thickness and dimensions given in the Ta (p. 2237). Class A conduit is either close-joint, brazed, welded or solid drawn. The coup joining the lengths of tubing is a sleeve, and neither the ends of the conduit nor the coupler screwed.

* By permission of the British Engineering Standards Association.

Specify

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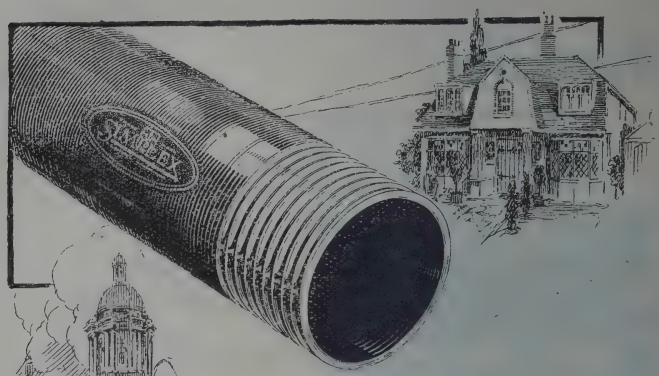
F. 2236



Electric Wiring

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SIMPLEX products also include Switch and Distribution Gear, Watertight Fittings, Lighting Fixtures, Illuminated Signs, Electrical Accessories, and all kinds of equipment for industrial, street, colliery and general lighting.

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F. 2237.

In the close-joint tubes, the edges of the steel strip, though brought tightly together in the ocess of manufacture, are not metallically joined in any way.

Class B consists of heavy gauge conduit of the thicknesses and dimensions given in the Table. ass B conduit is either brazed, welded or solid drawn. Both ends of the conduit are screwed.

Unless otherwise specified with the order, all conduits and fittings shall be stove enamelled jet ack or galvanised by the hot process both inside and out.

TABLE OF STANDARD DIMENSIONS OF STEEL CONDUITS.

Conduit outside Diameter in ins.		½	⅝	¾	1	1¼	1½	2	2½
Threads per inch		18	18	16	16	16	14	14	14
Depth of thread (ins.)		·0356	·0356	·0400	·0400	·0400	·0457	·0457	·0457
Maximum length of thread on ends (ins.)		7/16	½	9/16	11/16	¾	13/16	15/16	1 1/16
Minimum length of thread on ends (ins.)		⅜	7/16	½	⅝	11/16	¾	⅞	1
Nom. thickness—Class A (plain) (ins.)		·040	·040	·048	·048	·056	·064	·064	·072
Min. thickness—Class A (plain) (ins.)		·036	·036	·044	·044	·052	·060	·060	·068
Nom. thickness—Class B (screwed) (ins.)		·056	·064	·072	·072	·072	·080	·092	·092
Min. thickness—Class B (screwed) (ins.)		·052	·060	·068	·068	·068	·076	·088	·088
Calculated weight per 100 ft., in lb., unenamelled and not including couplers	Class A (plain)	20	26	37	50	73	100	135	191
	Class B (screwed)	27	39	53	73	93	124	192	242

TABLE OF CAPACITY OF CONDUITS.

(Type B, Screwed, B.S.S. No. 31, for the Drawing-in of Conductors.)

(From I.E.E. Rules.)

Size of Conduit (ins.)		½	⅝	¾	1	1¼	1½	2	2½
Internal Diameter (ins.)		0·388	0·498	0·606	0·856	1·106	1·34	1·816	2·316
Nominal Area of Conductor. Sq. In.	Number and Diameter (In.) of Wires.	Approximate Overall Diameter. Inch.	Maximum Number of Conductors.							
0·0015	1/·044	0·173	2	3	5	8	—	—	—	—
0·002	3/·029	0·195	—	3	4	8	—	—	—	—
0·003	3/·036	0·215	—	2	4	8	—	—	—	—
0·003	1/·064	0·197	—	2	4	8	—	—	—	—
0·0045	7/·029	0·226	—	—	3	5	7	—	—	—
0·007	7/·036	0·259	—	—	2	5	7	—	—	—
0·01	7/·044	0·287	—	—	2	4	7	—	—	—
0·0145	7/·052	0·317	—	—	—	2	5	7	—	—
0·0225	7/·064	0·359	—	—	—	2	4	7	—	—
0·03	19/·044	0·393	—	—	—	—	3	5	7	8
0·04	19/·052	0·441	—	—	—	—	2	4	7	8
0·06	19/·064	0·513	—	—	—	—	—	3	5	6
0·075	19/·072	0·596	—	—	—	—	—	—	4	4
0·1	19/·083	0·663	—	—	—	—	—	—	3	4
0·12	37/·064	0·702	—	—	—	—	—	—	2	3
0·15	37/·072	0·768	—	—	—	—	—	—	2	2

The Henley Wiring System.

(W. T. Henley's Telegraph Works Co., Ltd.)

In this system the cables carry their own metallic protection, which is of a flexible nature it is consequently very easily and speedily erected. The wires and cables are of very small dimensions, and when painted, distempered, or stained and varnished to match existing decorations they are to all intents and purposes indistinguishable. If desired, the cables may be buried in plaster and concealed generally. The cables may be run under floorboards, in lofts or cupboards and dropped down between the faces of lath-and-plaster partition walls. The chasing of walls or cutting away of joists is very much less than is required with tubing.

The cables employed are of flat section of one, two, or three conductors, each conductor composed of tinned copper wires, insulated with pure and vulcanised rubber, taped with proofed tape of a distinctive colour for each core, the whole then vulcanised together, cores laid side by side, sheathed with a solid drawn tube of special alloy to protect the cores from mechanical damage. These cables may be used on either direct or alternating current.

TABLE OF SINGLE-CORE, TWIN, AND TRIPLE CABLES.

Nominal Area.	Conductor.	Minimum Insulation Resistance per Mile at 60° F.	Amperes at I.E.E. Standard.	Approximate Overall Dimensions.	Approximate Weight per 1,000 Yards
Sq. In.	In.	Meg.		In.	Cwts.
		SINGLE CORE—CLASS ZM.			
0·0015	1/·044	2,000	6·1	0·208	3·2
0·002	3/·029	1,250	7·8	0·230	3·64
0·003	1/·064	2,000	12·9	0·232	3·76
0·003	3/·036	1,250	12·0	0·250	4·13
		TWIN—CLASS ZZMF.			
0·0015	1/·044	2,000	6·1	0·232 × 0·360	5·01
0·002	3/·029	1,250	7·8	0·254 × 0·404	5·78
0·003	1/·064	2,000	12·9	0·256 × 0·408	6·02
0·003	3/·036	1,250	12·0	0·274 × 0·444	6·66
0·0045	7/·029	1,250	17·5	0·305 × 0·486	8·93
0·007	7/·036	900	22·0	0·338 × 0·552	10·51
0·010	7/·044	900	26·0	0·366 × 0·608	12·38
0·0145	7/·052	900	31·0	0·416 × 0·688	16·82
0·0225	7/·064	900	38·5	0·458 × 0·772	20·49
0·030	19/·044	750	45·0	0·512 × 0·860	25·65
0·040	19/·052	750	53·0	0·580 × 0·976	34·85
		TRIPLE—CLASS TZMF.			
0·0015	1/·044	2,000	6·1	0·252 × 0·508	8·71
0·002	3/·029	1,250	7·8	0·274 × 0·574	10·00
0·003	1/·064	2,000	12·9	0·276 × 0·580	10·36
0·003	3/·036	1,250	12·0	0·294 × 0·634	11·43

Test Pressure.—1,000 volts alternating for 15 minutes after 24 hours' immersion in water at 60° F. (15·5° C.).

For the purpose of bonding the sheathing at switch and light points the Universal Bonding Clamp is provided. This clamp, fig. 7, has been designed so that one clamp only, instead of several, may be used at any point, thereby reducing to a minimum the necessity for stocking various sizes of clamps for various numbers and sizes of wires, etc.

When erecting it will be found more economical in many instances to run both switch and light feeds to a three-plate ceiling rose, looping from there to the next light. In the case of electroliers controlled by two switches, in many instances it will be found economical to use a four-plate ceiling rose, taking both switch and light feeds to this rose, the switches being connected by means of a triple cable. This three-core cable can be used to advantage in many other instances which will be readily apparent when the work is planned out.

Straight through and tee joints, etc., are made by means of the boxes provided under ne system.

For fixing the cables, the 'Link' clip, fig 8, is specially convenient. These clips are ade from tinned brass, and may be fixed either with nails or countersunk-headed screws.

Fig. shows a form of Tee Joint Box for ne twin system. These Boxes are manu- actured from brass heavily tinned; the ternal connectors are of the porcelain type, nd are made in various forms according o requirements. The continuity of the metal neathing of the cables is preserved by means f mechanical clamps that bond the lugs on ne boxes to the cables.

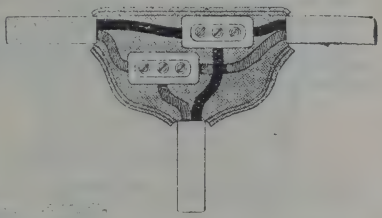


FIG. 6.

Another form of Tee Box—the 'Super' ox—is shown by fig. 9, p. 2241. In this Box ne loose bonding clamps used with the box lustrated in fig. 6 are dispensed with; the over is held in position by one unlosable self- entring nut which is fixed in the cover, and ne porcelain connectors are substituted by a ouded terminal block.

The latest addition to the system is a Box of the 'Universal' type, which is illustrated in g. 10, p. 2241. This Box works on the same principle as the Universal Bonding Clamp illustrated fig. 7, and can be used as a straight through, tee, or four-way box as required. As with the Super' Box, the cover is secured by one unlosable nut. The joint is made by means of porcelain onnectors.

The fixing of link clips, saddles, protective covering, or other articles, to plaster, brick, arble, slate, stone, etc., is best effected by the use of "Rawlplugs" (see p. 521).

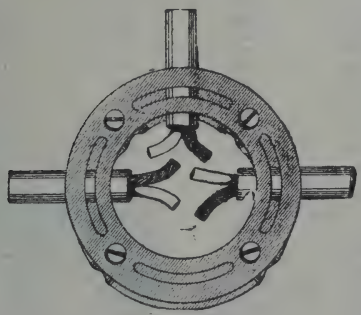


FIG. 7.

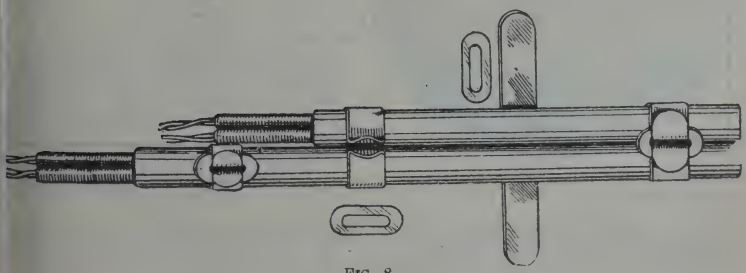


FIG. 8.

The Henley 'Nomet' (Regd.) Wiring System.

This system, whilst not new, employs Henley C.T.S. cables, and has been developed:

(*a*) To meet the wishes of customers who prefer a non-metal covered system.

(*b*) For use in abnormal situations where metal-covered wiring may be undesirable.

It is strongly recommended that, wherever possible, a metal-covered system be used, this being an economical and efficient means of electric wiring, and also a relatively safer method than any non-metal covered system.

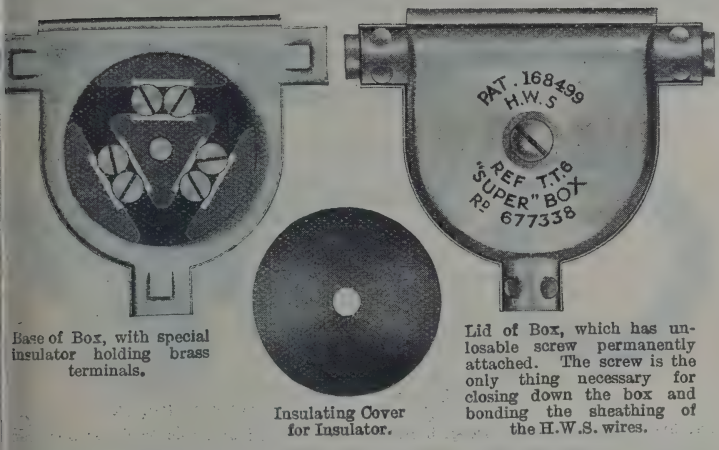
Table of Single-Core, Twin, and Triple Cables.

Nominal Area.	Conductor.	Minimum Insulation Resistance per Mile at 60° F.	Amperes at I.E.E. Standard.	Approximate Overall Dimensions.	Approximate Weight per 1,000 Yards.
Sq. in.	In.	Meg.		In.	Cwts.
		Single Core—Class S.R.X.			
0·0015	1/·044	2,000	6·1	0·212	0·86
0·002	3/·029	1,250	7·8	0·234	1·03
0·003	1/·064	2,000	12·9	0·236	1·14
0·003	3/·036	1,250	12·0	0·254	1·27
0·0045	7/·029	1,250	18·2	0·265	1·49
0·007	7/·036	900	24·0	0·290	1·91
0·010	7/·044	900	31·0	0·318	2·48
0·0145	7/·052	900	37·0	0·348	3·14
0·0225	7/·064	900	46·0	0·410	4·51
0·030	19/·044	750	53·0	0·444	5·42
0·040	19/·052	750	64·0	0·492	7·03
0·060	19/·064	750	83·0	0·564	9·89
		Two Core—Class F.S.R.X. 2.			
0·0015	1/·044	2,000	6·1	0·212 × 0·324	1·48
0·002	3/·029	1,250	7·8	0·254 × 0·388	2·05
0·003	1/·064	2,000	12·9	0·256 × 0·392	2·27
0·003	3/·036	1,250	12·0	0·274 × 0·428	2·54
0·0045	7/·029	1,250	17·5	0·285 × 0·450	2·99
0·007	7/·036	900	22·0	0·310 × 0·500	3·88
0·010	7/·044	900	26·0	0·338 × 0·556	5·05
0·0145	7/·052	900	31·0	0·368 × 0·616	6·44
0·0225	7/·064	900	38·5	0·450 × 0·740	9·54
		Three Core—Class F.S.R.X. 3.			
0·0015	1/·044	2,000	6·1	0·236 × 0·468	2·17
0·002	3/·029	1,250	7·8	0·255 × 0·525	2·67
0·003	1/·064	2,000	12·9	0·256 × 0·528	3·01
0·003	3/·036	1,250	12·0	0·274 × 0·582	3·30

Test Pressure.—1,000 volts alternating for 15 minutes after 24 hours' immersion in water at 60° F. (15·6° C.).

The 'Nomet' Wiring System cables, like the Henley Wiring System cables, are small in dimensions and carry their own mechanical protection. The cables can be easily erected, painted or otherwise treated, and the complete range of accessories (which are stocked) facilitate the wireman's work and enable a neat and satisfactory installation to be made.

THE HENLEY WIRING SYSTEM.



Base of Box, with special insulator holding brass terminals.

Insulating Cover for Insulator.

Lid of Box, which has unlosable screw permanently attached. The screw is the only thing necessary for closing down the box and bonding the sheathing of the H.W.S. wires.

FIG. 9.

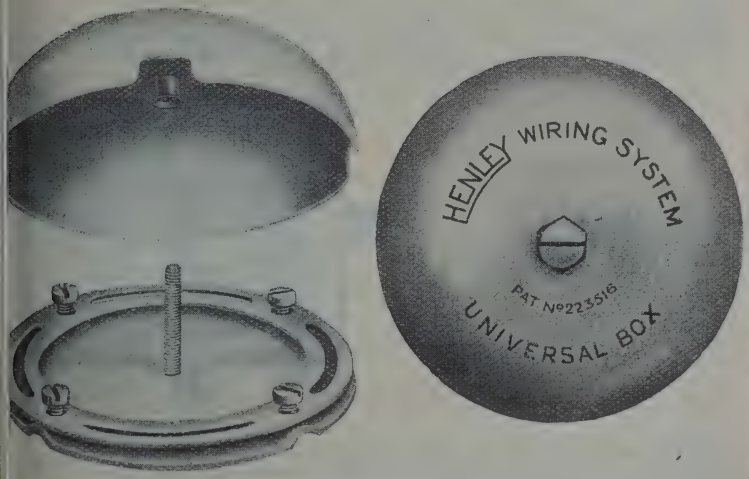


FIG. 10.

The J. and P. Wiring System.

(Johnson and Phillips Ltd.)

This system consists of single, twin (fig. 11), or three-core (fig. 12) rubber-insulated cal protected by a metallic sheathing of a special lead alloy. The cables are of flat section, and a intended for the wiring of domestic and other building interiors without further protecti

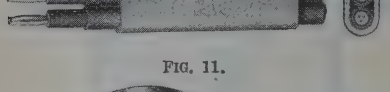


FIG. 11.

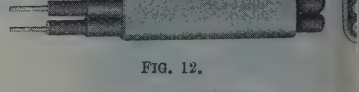


FIG. 12.

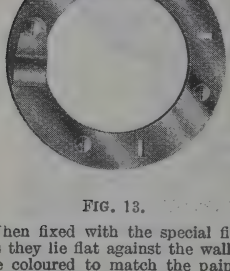


FIG. 13.

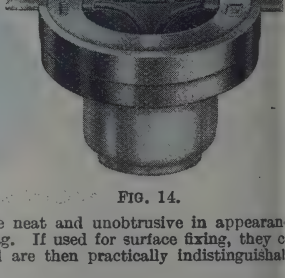


FIG. 14.

When fixed with the special fittings provided, they are neat and unobtrusive in appearan as they lie flat against the wall or ceiling and do not sag. If used for surface fixing, they c be coloured to match the paintwork or distemper, and are then practically indistinguishal from their surroundings.

The system fully complies with the I.E.E. Wiring Rules, and with the requirements of f insurance companies and electricity supply authorities.

The bonding fixtures are a special feature of the J. & P. wiring system. By means bonding and bonding clips a perfect bond can be secured with the greatest ease.

The bonding ring (fig. 13) is fixed behind a wooden pattrass (fig. 14), where connectio are made to switch points, etc. The ring is supplied with four ways, one or more of which m be used as required, suitable for cables up to 3/·036 twin core.

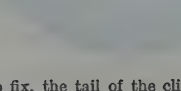


FIG. 15.

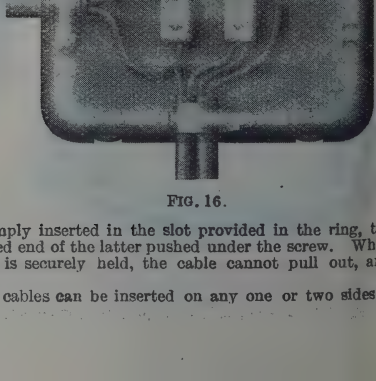
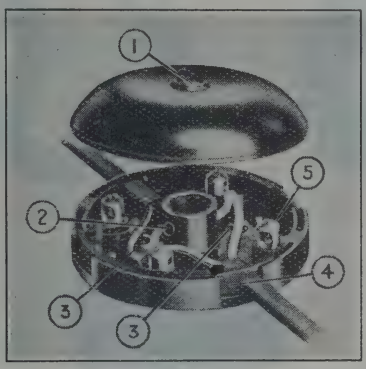


FIG. 16.

To fix, the tail of the clip, fig. 15, is simply inserted in the slot provided in the ring, t cable is placed under the clip and the notched end of the latter pushed under the screw. Wh this is tightened up, the metal cable sheath is securely held, the cable cannot pull out, a absolute electrical continuity is attained.

Fig. 16 shows a joint box in which twin cables can be inserted on any one or two sides it is desired to do so.

The J. and P. 'Non-Metal Sheathed System,' designed to supplement the Metal Sheathed system scribed, uses C.T.S. cables which are of the same overall size as the corresponding metal-sheathed bles, and the same fixing clips and saddles, protective steel covering, etc., can be employed. T.S. cable is more flexible than the metal sheathed cable, and although this extra flexibility luces the risk of kinking the cable during installation, a little more care is needed to avoid gging on long straight runs. An ornamental wood moulding, designed to cover the cable and ps, and shaped so that it cannot be misused as a picture rail, is available for use where the pearance of a moulding would harmonise better with the decorations.



1. Blanked hole for flex.
2. Hole in pillar for flex.
3. Blanked holes for back entry cable.
4. Sliding Shutter.
5. Terminal post.

FIG. 17.

Only one size and type of Joint Box (fig. 17) is used with this system. It is hot moulded in kelite, and has a very fine finish. Four apertures are provided for side entry cables, the apertures ng reduced in size to fit any cable used for domestic installations, or closed completely by means sliding shutters. Two blanked holes in the base can be knocked out cleanly and easily to accom- date back entry cables, and by knocking out another blanked hole in the cover the box can be ed as a neat ceiling rose. The flex is passed through the central pillar, and is gripped firmly en the cover is screwed down. Loose connectors are not required with this box, four terminal lars being moulded into the base.

The 'Kaleeco' Wiring System.

(Callender's Cable and Construction Co., Ltd.)

The conductors for this system, which are supplied either single, twin, or three-core, consist of h conductivity tinned copper wires, insulated with two layers of vulcanised india-rubber, then ed with a proofed tape of a distinctive colour, the whole being vulcanised into a homogeneous ly. The cores are sheathed under heavy hydraulic pressure with a tube of metal possessing siderable strength and flexibility, thus ensuring an effective mechanical protection for the lectric.

Before despatch from the works, each length of insulated core is immersed in water for at least hours, then subjected for a period of 15 minutes to a pressure test of 1,000 volts alternating, erwards being tested for insulation resistance with a battery having a pressure of not less than) volts.

'Kaleeco' metal sheathed wires, although stiff enough to prevent sagging between fixing clips perly spaced, are easily bent round mouldings and cornices, and being of small dimensions have articularly neat appearance when in position.

By the use of 'braided' 'Kaleeco' wire, which is made in various styles of decoration, a arrangement of the electrical equipment of a room may be made at any time without spoiling effect of an artistic scheme of decoration, or losing the wiring efficiency.

A special feature of the system is the 'C-B" Kaleeco" Universal Junction Box,' fig. 18, which designed on engineering principles and is of sound and substantial construction. It consists of ir component parts, accurately finished, neat in appearance and easily assembled. The box is ple to erect, accommodating without special adjustment any width and thickness of meta - ered wire and any direction of entry. It is universal throughout, and alterations can be made h perfect ease, without dismantling the box or employing additional component parts. By

the introduction of a lamina of tinned copper strip, which is termed the bonding ring, the effectiv ness of the continuity is ensured. The wires can be brought into the junction box at any positio and provision is made for bonding up to eight cables. All the jointing of the wires is effected l porcelain sheathed connectors.

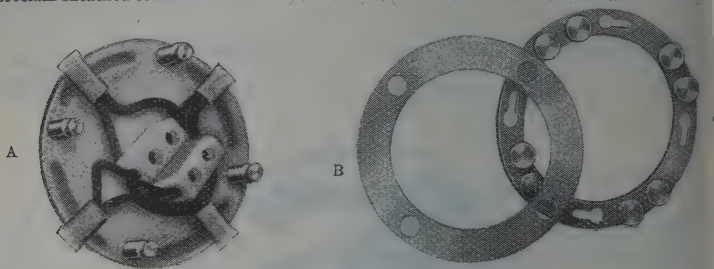


FIG. 18.

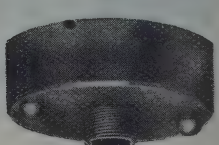


FIG. 19.

The fig. shows—(A) backplate of tinned brass on which the connection is made; (B) bo ing ring of tinned copper strip; (C) underside view of tinned steel bridge ring showing br mushroom tailed bonding screws.

Fig. 19 shows the special cord grip cover of a C-B 'Kaleeco' loop-in box. The box l been designed to obviate the use of ceiling roses mounted separately on wood blocks; t arrangement is a particularly desirable one in situations where head room is limited. The co is provided with a screwed nipple which will take either cord grip or standard $\frac{3}{8}$-in. lamp holde the whole fitting being fixed to the loop-in box by means of two screws.

The C.T.S. Wiring System.

This well-known type of protected cable was originated by The St. Helen's Cable & Rub Co. Ltd., Slough. It is generally known as C.T.S. It was designed for use in positions wh ordinary protected cables often give trouble, principally as trailing or portable cables, and since been found of value in all kinds of dangerous situations.

The conductors are usually insulated in accordance with the standards of the C.M.A., whole then being sheathed with the same tough rubber material as is used in the manufact of cab tyres. The principal characteristics of this rubber are durability, non-corrodibil and non-absorbence. This type of cable is, therefore, now used in the numerous places wh corrosion, moisture, hard wear, climatic or temperature changes are likely to be met with.

An advantage for some classes of work is that the elastic flexibility of the material preve it from being kinked.

This class of cable is being largely used for general wiring. Being a portable solid syst not needing any further protection, it is easily and cheaply run.

The use of C.T.S. without further protection of any kind is authorised by the Wiring R of the Institution of Electrical Engineers (see p. 2221, *re* 'Tough Rubber Compou Protection).

The Macintosh Wiring System.

(The Macintosh Cable Co., Ltd.)

The highly flexible properties, tough nature, and high permanent dielectric strength of this sulating material, known as ' Maconite,' have led to its adoption for nearly all classes of electrical nductors. The fact that twin cables of the now well-known 8 section can be mounted on the rfaces of walls, ceilings, etc., (either with or without the special wood fillet supplied) without ing conspicuous, and at low cost, renders it particularly suitable for the wiring of small houses, ats, and working-class dwellings. Many housing schemes have utilised it for this purpose. Its sulation resistance is equal to high quality vulcanised rubber, but in the case of ' Maconite ' it more constant and is unaffected by prolonged immersion in water or in a saturated solution of ustic soda. Resistance to breakdown pressure is also stated to be very high.

The following are details of tests to which Maconite has been satisfactorily subjected. Except here specifically mentioned, no tests of less duration than some thousands of hours are given :—

Extremes of temperature.—

(1) Freezing Maconite Cable in a block of ice for several days, and testing at 1,000 volts a.c. for 30 minutes. Then thawing out in running water and again testing at 1,000 volts a.c.

(2) Boiling in water and for 3 hours in a weak solution of caustic soda.

(3) Exposure for several months in temperature of 100° F. above boilers and brass furnaces.

In all these cases, not only did the cable withstand the tests, but its flexibility was found be absolutely unimpaired at the end.

Exposure to Chemical Action.—

(1) Immersion in dilute uric acid.
(2) ,, copper pickling acid.
(3) ,, 50 per cent. solution of sulphuric acid.
(4) ,, 5 per cent. solution of nitric acid.
(5) ,, 50 per cent. solution of hydrochloric acid.
(6) ,, slaked slag water.
(7) ,, two samples of corrosive pit waters.
(8) Immersion in saturated solution of caustic soda.
(9) ,, saturated solution of common soda.
(10) ,, 10 per cent. solution of ammonia.
(11) ,, saturated solution of common salt.
(12) ,, sea water.

In all cases the cables withstood the tests, the cables carrying direct current at 250 volts, vo cables being on test in each solution, and being connected to the positive and negative oles of the system respectively. This was done in order to be certain that the material would ithstand osmotic action.

The general results of the tests indicate that cables insulated with ' Maconite ' are particularly ited for installation in chemical works, steel works, dye works, long railway tunnels, etc., etc., here corrosive fumes or liquids are always present.

The material may prove to be suitable as a sheath for cables in the place of lead alloys or itumen. It is already being used as a sheath for a surface wiring system which requires no onding or earthing.

Failures only occur at the points where it is jointed to other apparatus, such as junction boxes, witches, lamp fittings, and distribution boards. *The Macintosh Cable Company* have therefore roduced a complete system embodying gas-tight fittings of the above nature, using patented Maconite ' glands which will ensure that no destructive gases or elements reach the metal fittings ecessary for junction purposes.

A further use for which ' Maconite ' has proved highly efficacious is in the construction of multi- ore cables for telephone and signalling purposes: its resilience and flexibility prevent destruction y the mechanical strains to which the cores of such cables are subjected. The same feature is lso leading to its adoption for trailing and similar cables for colliery work, etc.

Electro-chemistry.

A current of I amperes will, in T units of time, deposit from a solution of any salt of a metal under suitable conditions, ITa grammes of the metal (if time is reckoned in seconds), or IT grammes (if time is measured in hours), where a and b have the values given below, due account being taken of the valency of the metal in solution. One 'gramme-equivalent' of any substance is dissolved, deposited, or decomposed by the passage of 96,494 ampere-seconds (coulombs) or 26·80 ampere-hours; this quantity of electricity is known as the 'faraday.'

Element.	Atomic Weight.	Valency.	a Gm. per coulomb.	b Gm. per amp.-hr.	Element.	Atomic Weight.	Valency.	a Gm. per coulomb.	b Gm. per amp.-hr
Aluminium	27·1	3	0·00009362	0·3370	Mercury	200·6	2	0·001036	3·731
Arsenic	74·96	3	0·000259	0·9322	„	„	1	0·002073	7·462
Bismuth	208·0	3	0·0007185	2·587	Nickel	58·68	2	0·0003040	1·094
Calcium	40·07	2	0·0002077	0·7478	Nitrogen	14·01	3	0·00004840	0·1742
Chlorine	35·46	1	0·0003675	1·323	„	„	1	0·00014521	0·5227
Cobalt	58·97	2	0·0003056	1·100	Oxygen	16·00	2	0·0000829	0·2985
Copper	63·57	2	0·0003294	1·186	Platinum	195·2	4	0·0005057	1·821
„	„	1	0·0006588	2·372	Potassium	39·10	1	0·0004052	1·459
Gold	197·2	3	0·0006812	2·452	Silver	107·88	1	0·001118	4·025
Hydrogen	1·008	1	0·00001045	0·03762	Sodium	23·00	1	0·0002384	0·8387
Iron	55·84	3	0·0001929	0·6944	Tin	118·7	4	0·0003083	1·110
„	„	2	0·0002894	1·042	„	„	2	0·0006166	2·220
Lead	207·2	2	0·001073	3·863	Tungsten	184·0	2	0·0009535	3·432
Magnesium	24·32	2	0·0001260	0·4536	Zinc	65·37	2	0·0003388	1·220

In order to find the volume of gas evolved, multiply the weight in grammes by the volume occupied by one gramme of the gas at normal temperature and pressure. For the gases included in the table, the volumes in litres per gramme are as follows:—Chlorine, 0·3103; hydrogen, 11·12; nitrogen, 0·7990; oxygen, 0·6998.

Resistivity of Electrolytes.

Electrolyte.	Grammes in 100 of Solution.	Specific Gravity.	Resistivity.	Temperature Coefficient, C.	Gramme equivalent per litre.
H_2SO_4 at 18° C.	5	1·0331	4·82	0·00121	1·065
	10	1·0673	2·57	0·00128	2·182
	20	1·1414	1·54	0·00145	4·667
	30	1·2207	1·36	0·00162	7·487
	40	1·3056	1·48	0·00178	10·68
	50	1·3984	1·86	0·00193	14·30
KOH at 15° C.	4·2	1·0382	6·85	0·00188	0·619
	8·4	1·0777	3·69	0·00187	1·580
	12·6	1·1177	2·67	0·00189	2·515
	16·8	1·1588	2·20	0·00194	3·477
	21·0	1·2088	1·97	0·00200	4·534
	25·2	1·2439	1·86	0·00210	5·599
	29·4	1·2908	1·85	0·00222	6·778
	33·6	1·3332	1·92	0·00237	8·001
	37·8	1·3803	2·10	0·00258	9·319
$CuSO_4$ at 18° C.	2·5	1·0246	92·4	0·00214	0·322
	5	1·0513	53·2	0·00217	0·661
	10	1·1073	31·4	0·00219	1·393
	15	1·1675	23·8	0·00232	2·202
	17·5	1·2003	21·9	0·00237	2·642

(*Kohlrausch & Holborn.*)

PRIMARY BATTERIES.

'Siemens' Dry Cells.

These cells (*Siemens Bros. & Co. Ltd.*), originally known as the 'Obach,' have the exciting agent in the form of a damp paste. The following table gives the details of a few

he rectangular sizes. The outputs in ampere-hours are for continuous discharges through an xternal resistance of 10 ohms, until the P.D. across the terminals of the closed circuit has fallen o 0·75 volt.

Size.	Approximate Overall Dimensions (including terminal).	Approximate Weight.		E.M.F.	Initial Internal Resistance.	Output.
		Lb.	Oz.	about	about	Amp. Hours.
M	$4\frac{7}{16}$ ins. × $4\frac{7}{16}$ ins. × $8\frac{1}{8}$ ins. high	10	0	1·5 volt	0·15 ohm.	260
N	$3\frac{5}{16}$ „ × $3\frac{5}{16}$ „ × $7\frac{1}{2}$ „	5	4	1·5 „	0·15 „	110
O	$2\frac{15}{16}$ „ × $2\frac{15}{16}$ „ × $6\frac{5}{8}$ „	3	0	1·5 „	0·20 „	40
P	$2\frac{1}{4}$ „ × $2\frac{1}{4}$ „ × $6\frac{1}{8}$ „	1	14	1·5 „	0·25 „	25

An improved form of high-tension dry battery comprises large cells capable of giving satisfactory service with multi-valve wireless receiving apparatus at a normal anode current not exceeding 10 milliamperes. Three sizes only are standardized, viz., 18 volts, 36 volts, and 72 volts. Spring clip terminals are fitted and tappings provided at suitable intermediate voltages.

Siemens Inert Cells.

These cells, originally known as the 'Dura' cells, have the exciting agent in the form of an inert powder, which by the addition of ordinary clean drinking water becomes a paste, thereby giving a cell all the characteristics of a 'dry' cell, as described above.

Batteries and single cells are made up in this form, and the special utility of the construction is that the cells before being charged keep for an unlimited time in any climate, without deterioration, and may be converted at any time, as required, into a newly-made, so-called, 'dry' cell, with equivalent E.M.F. and output. This form is particularly suitable for use in those countries where it is essential to keep considerable stocks and where deterioration would be serious.

Siemens 'Sack' Leclanché Cells.

These cells are wet cells using sal-ammoniac as the exciting agent, and are modifications of the porous-pot form, the depolarising material being enclosed in fabric instead of a porous-pot. This enables a lower internal resistance and higher output in ampere-hours to be obtained.

Improved results can also be obtained by using Siemens 'Siebrosal' as the exciting agent in place of sal-ammoniac crystals.

G.E.C. 'Extra Sec' dry Cells.

The cell only requires to be filled with water, without any exciting element, and the excess of water emptied out. Specially suitable for use in tropical climates as the cell can be stocked for considerable periods without deteriorating, and only becomes active when charged with water.

G.E.C. 'Porous Pot' Leclanché Cells.

Specification.—Porous pot of high porosity, thoroughly tested and filled with a mixture of best selected peroxide of manganese and crushed carbon; positive plate of carbon throughout; without lead cap; well-amalgamated, solid drawn zinc rod of 98 per cent. purity; E.M.F., 1·5 volts.

Directions.—Place porous pot and zinc in glass jar and fill two-thirds full with solution of sal ammoniac, 2 ozs. to the pint of water.

G.E.C. 'Carsak' Leclanché Cells.

Specification.—Positive element consists of a porous sack which surrounds the carefully selected granules of carbon and manganese peroxide, which are very tightly packed. The 'pot' is practically unbreakable and its cylindrical form is maintained by a cap and base of hard material. The zinc is a semi-circular plate of ample dimensions, well amalgamated. 'Carsak' cells have a very low resistance, are thoroughly reliable and constant, and have a long life. They are particularly suited for telegraph, telephone, bell and signal circuits and for all positions where a low resistance Leclanché cell is required.

The 'Carsak' cell is designed to withstand severe transit conditions, and is therefore particularly suitable for export.

ACCUMULATORS.

Compiled from information supplied by the Hart Accumulator Co. and the Chloride Electrical Storage Co.

Storage cells should be placed in a well-ventilated room, preferably with louvres at the top to allow of the free escape of the gases evolved during charging; and the room should also be well lighted, both naturally and artificially, provision being always made for a hand inspection lamp to enable cells to be examined individually. The best working temperature is 50° to 80° F. Windows should face north to avoid direct sun rays. The room should not be exposed to undue draughts, as this promotes evaporation of the electrolyte, and it then becomes necessary to add an abnormal amount of water to keep the plates well covered with electrolyte.

Insulation.

Good insulation is essential. The cells should be mounted on insulators unless the boxes, if glass, are provided with feet. Above 100 volts the stands should be mounted on insulators also.

Assembly.

Cells with a capacity of less than 1,000 ampere-hours are assembled in glass boxes. The smaller sizes may be provided with feet or are mounted on separate insulators with lead discs, indiarubber washers or wood strips intervening. The larger sizes are mounted on wooden trays filled with sawdust. Above 1,000 ampere-hours capacity, cells are assembled in lead-lined wooden boxes.

The battery should be mounted on strong wooden racks or stillage protected with acid-proof paint with sufficient space between each cell to allow for insulation and cleaning.

The cells should be placed with the edges of the plates to view (if in glass boxes) and should only be arranged in double rows when they are accessible from each side.

Polarity.

The positive pole is painted red and is that to which the brown plates are connected: the negative pole is painted black and is that to which the grey plates are connected. The positive pole of each cell must be connected to the negative pole of the next cell throughout the battery, so that there will be a disconnected positive terminal at one end and a disconnected negative terminal at the other end of the battery. These are the battery terminals, which are connected to the dynamo as indicated in the diagram of connections in fig. 20. Cells should never be connected in parallel so as to form single cells of larger capacity; but if necessary they may be formed into batteries, and the batteries connected in parallel by coupling their ends.

Regulating cells should be at the negative end of the battery.

An automatic switch should be provided in the charging circuit.

Dynamo.

The dynamo used for charging should be shunt-wound, and the electromotive force required will be 2·6 volts for each cell in series. Before connecting up the dynamo it should be tested for polarity, which may be done as follows: Place two clean strips of sheet lead in a stone jar filled

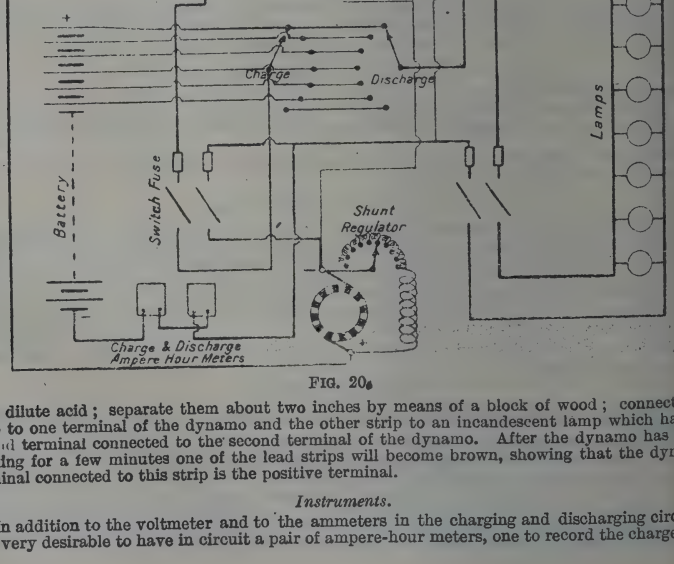


FIG. 20.

with dilute acid; separate them about two inches by means of a block of wood; connect one strip to one terminal of the dynamo and the other strip to an incandescent lamp which has its second terminal connected to the second terminal of the dynamo. After the dynamo has been running for a few minutes one of the lead strips will become brown, showing that the dynamo terminal connected to this strip is the positive terminal.

Instruments.

In addition to the voltmeter and to the ammeters in the charging and discharging circuits it is very desirable to have in circuit a pair of ampere-hour meters, one to record the charge and

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the other the discharge. These may be connected in series as shown in the diagram of connections, and fitted with pawls which will prevent backward running, so that there will be a continuous record of both charge and discharge.

Water.

The water used for the cells should be distilled, as this avoids any danger of impurities entering the cell.

Acid.

The electrolyte in all storage batteries—lead-acid type—is dilute sulphuric acid with a specific gravity of 1·200/1·215. The method of manufacture is immaterial provided the finished article when diluted does not contain more than 0·001 grammes per 100 c.c. of chlorine or copper, twice that amount of iron, or one-third that amount of arsenic.

On the continent, sulphuric acid prepared by the catalytic process is largely used, but as this acid is usually prepared from iron pyrites the iron contents are higher than that made from natural brimstone. In this country *Messrs. F. W. Berk & Co., Ltd.*, the manufacturers of the well-known B.A.A. Accumulator Acid, prepare it from distilled water and the best brimstone, producing thereby an acid of the highest purity and best quality.

Preparing Electrolyte.

To dilute concentrated sulphuric acid it must be mixed with about 4½ times its volume in a suitable acid-proof vessel. The acid must be added to the water, never the water to the acid on account of the heat generated. Careful stirring is necessary. Correction for temperature must be made when testing the specific gravity to the extent of one point added to the hydrometer reading for every 2·7° F. above 60° F. The mixture must be allowed to cool before using it.

Filling up.

When everything is ready for charging, the acid must be put into the cells to a height of not less than one inch above the plates. Charging must proceed as soon as possible afterwards.

Charging.

Before the battery is switched into circuit with the dynamo care should be taken that the field-magnets are properly excited and the proper E.M.F. generated. The initial charge should be continued for not less than 36-40 hours at the normal charge rate specified by the makers for the battery in use. It has been recommended that the first 12 hours' run be continuous. Some makers, *e.g.*, The Chloride Electrical Storage Company Limited, now supply their batteries in a short first charged condition, which entails only 15 hours' initial charge at a prescribed rate, or alternatively two runs of 8 hours each. During the early portion of the initial charge the specific gravity will drop 20 to 50 points, and the charge cannot be considered complete until the specific gravity has maintained a maximum stationary value for at least two hours in the case of short first charge batteries, or five hours in the case of ordinary batteries. As the plates absorb the acid slowly, the level of the electrolyte will fall at first, and to compensate for this, more acid should be added, but any subsequent evaporation should be made good by the addition of water only.

Discharge.

The permissible rate of discharge depends upon the number of hours for which the discharge is required—the longer the time the smaller the rate. The product of rate into time is, however, not constant, but is greater with low rates of discharge than with high. Thus in the Hart Accumulator, 25-plate Lighting Type, the rates of discharge for 5, 7 and 10 hours are 126, 99 and 75·6 amperes respectively, giving discharge capacities of 630, 693 and 756 ampere-hours. The discharge rates for different times are always given by the makers, and should never be exceeded, the ampere-hours taken out being recorded on the discharge ampere-hour meter. The accompanying tables have been prepared for users of batteries supplied by The Chloride Electrical Storage Company Limited, and may be considered applicable to all Planté batteries.

CAPACITIES OF PLANTÉ TYPE STATIONARY BATTERIES AT VARIOUS RATES OF DISCHARGE.

Capacity in Ampere-Hours (expressed as a percentage of the ampere-hours available at the 5-hour rate) When Discharging in									
1 Hour.	2 Hours.	3 Hours.	4 Hours.	5 Hours.	6 Hours.	7 Hours.	8 Hours.	9 Hours.	10 Hours.
60%	76%	86%	93·8%	100%	105·5%	110·1%	114%	117·5%	120%

Capacity in Amperes (expressed as a multiple of the amperes available at the 5-hour rate) When Discharging in									
$\frac{1}{60}$ Minute.	1 Minute.	3 Minutes.	5 Minutes.	10 Minutes.	15 Minutes.	20 Minutes.	30 Minutes.	45 Minutes.	60 Minutes.
7·5	6·0	5·91	5·82	5·61	5·35	5·10	4·47	3·58	3·0

Recharging.

To obtain longest life from a battery it should be recharged whenever the cells are about two-thirds discharged, determined by specific gravity and voltage, also by ampere-hours used (where ampere-hour meters are installed). A battery may be charged at any convenient rate between the conventional 'normal' specified by the maker, and half that value. In any case the charge should be completed at the lower rate. The ampere-hours put in should exceed the number taken out by about 10 per cent. ordinarily, but at least once a fortnight the battery should be brought up to a thorough healthy condition regardless of ampere-hour meter readings—all cells uniform and the extent of gassing, the specific gravity of the acid, the voltage, and the colour of the plates. Records should be kept on suitable forms of the individual voltage and specific gravity of each cell periodically and details of each charge and discharge.

Level of Electrolyte.

The level of the electrolyte must never be allowed to fall to less than half an inch above the top of the plates. Any loss due to evaporation must be made up by adding pure distilled water as above explained. Evaporation will be greatly retarded by the use of glass spray arresters covering the top of the plates or by an anti-spray oil film. Spray arresters must be so placed as to be easily removable for the purpose of examining the cells. Acid should not be added, except under the maker's advice.

Specific Gravity.

The specific gravity of each cell should be taken and recorded at least once a week, and if the consecutive readings so obtained are carefully compared, it is possible at once to detect a backward cell and take steps to remedy what is amiss. The hydrometer should be long enough to float in about two-thirds of the total depth of the electrolyte. The specific gravity varies to some extent with the temperature, and during the summer months will be rather lower than during the winter. The standard is taken at 60 deg. Fahr.; for every 2·7 degrees above this 1 degree of specific gravity may be added; for every 2·7 degrees below 1 degree of specific gravity may be deducted.

Weak Cells.

The indications of weak cells are bad colour of the plates, irregularity of gassing, or failure to gas, and a fall of specific gravity of electrolyte (obtained by the hydrometer), or voltage (obtained

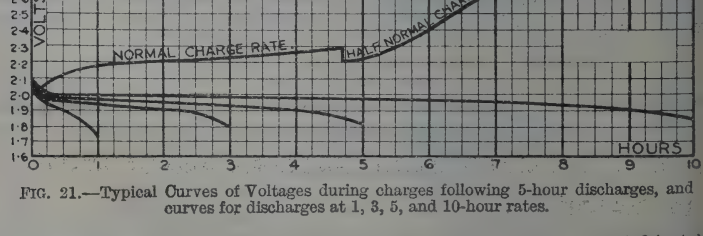

FIG. 21.—Typical Curves of Voltages during charges following 5-hour discharges, and curves for discharges at 1, 3, 5, and 10-hour rates.

by a cell-testing voltmeter) below that of other cells. Weak cells should be inspected for 'short circuits.' These may be caused by the lodgment of material between the plates or by the positive and negative plates touching each other. After removing the short circuit the weak cell should be cut out of circuit for a few discharges and put into circuit again for the following charge. Care must be taken not to allow the negative plates to dry out or heat by exposure to the atmosphere

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Voltage Characteristics.

Fig. 21 indicates the characteristic rise in voltage on charge, and fall in voltage during discharge ording to the rate of discharge in amperes. The curves are applicable to any modern Planté ttery.

Buckled Plates.

Buckled plates should be removed and straightened by pressing between thick boards. e positive plates are most easily straightened when fully charged, as they are then softer and t so liable to crack. The negative plates should be kept in dilute acid while the positives are ing overhauled, as otherwise they may get heated by oxidisation with the air.

Battery Rooms.

SIZE OF BATTERY ROOMS REQUIRED FOR 25, 50 AND 100-VOLT 'HART' BATTERIES.

apacity n Amp. Hours.	25 Volt.		50 Volt.		100 Volt.	
	Single Tier.	Two Tier.	Single Tier.	Two Tier.	Single Tier.	Two Tier.
	′ ′ ′ ′	′ ′ ′ ′	′ ′ ′ ′	′ ′ ′ ′	′ ′ ′ ′	′ ′ ′ ′
140	6 6×3 9	3 6×4 3	6 9×5 0	7 0×4 3	13 3× 5 0	13 3× 4 3
280	9 3×3 9	5 0×4 3	10 0×5 0	10 0×4 3	12 9× 8 9	9 9× 6 0
420	6 9×5 0	6 9×4 3	13 0×5 0	13 0×4 3	16 6× 8 9	12 6× 6 0
630	9 0×5 0	9 0×4 6	11 6×8 9	9 0×6 6	16 9×12 6	16 9× 6 6
770	10 6×5 0	10 6×4 6	13 3×8 9	10 6×6 6	19 6×12 6	13 3×11 0
1,050	13 3×5 0	13 3×4 6	17 0×8 9	13 3×6 6	25 3×12 6	17 0×11 0

In preparing this Schedule the number of cells is as follows: 25-volt circuit, 13 cells; 50-volt cuit, 27 cells; 100-volt circuit, 54 cells. The height of room in each case should not be less an 8 feet.

Idle Batteries.

When a battery is not required for several weeks it should be thoroughly charged and the ates well covered with electrolyte. The cables should then be disconnected at the ends of ch row to avoid any possibility of electrical leakage. Cells will remain in this condition for veral months. If a charge can be given once every six or eight weeks it is best to do so; this ould be given at 75 per cent. of the normal rate and continued until the full charge is com-ted, and the plates gas freely. If a battery is to be used at infrequent intervals, it should given an extended charge once every two weeks.

CARE OF STORAGE BATTERIES.

The essential instructions in condensed form are:—

(1) add nothing but pure distilled water to the cells, and do this often enough to keep the ates always covered.
(2) Give ordinary charges as frequently as the service demands, and extended charges periodi-ly.
(3) Avoid high temperatures at all times.
(4) Avoid excessive gassing at end of charge.
(5) Record readings of voltage and specific gravity of each cell at the end of extended charges.
(6) Attend to weak cells without delay.
(7) Keep the battery and surroundings dry and clean.
(8) Take voltage while normal charge or discharge current is flowing.
(9) Never discharge below 1·8 volts per cell.

TESTS FOR IMPURITIES.

Hydrochloric Acid (Chlorine).—To a small quantity of dilute electrolyte add a few drops of ric acid, then add 3 drops of silver nitrate. The formation of a white, cloudy precipitate icates the presence of chlorine in some form.

Nitric Acid.—Mix a solution of diphenylamine in concentrated sulphuric acid, and add it the sample under test. Nitric acid will be indicated by a blue colour.

Iron.—Fill a test-tube with dilute electrolyte and heat to boiling point; add several drops concentrated nitric acid and boil again. Repeat two or three times. When solution is cold d a few drops of potassium sulphocyanide, which will colour a deep red if iron is present.

Copper.—Add common ammonia until the resultant mixture gives an alkaline reaction; a p blue indicates the presence of copper.

Arsenic.—Add an equal quantity of hydrogen sulphide solution; a yellow precipitate indicates enic.

Chloride Sealed-in Batteries.

The most recent development in the lead-acid storage battery is the Chloride Company's sealed-in battery. The positives have a large surface area for rated capacity, the negatives have armoured frames enclosing adhesive, porous, and homogeneous active material. The plates are assembled in moulded glass containers with isolating ribs between each pair of plate lugs. The containers have fully sealed lids minimising evaporation and acid spray and enabling cells to be transported in a fully charged condition. Between the plates are fitted treated wood separators forming a complete diaphragm entirely preventing internal short circuits. The cells only require to be coupled up on site and be given a short freshening charge and they are then ready for service.

Signalling and Wireless Batteries.

Special lines of batteries are designed for wireless batteries, electric bells, telephones, fire alarms, clocks, and signalling circuits. The two types have a capacity of 20 and 45 amp.-hr. respectively. Each cell consists of one positive and one negative plate of unusual thickness and incorporating an extremely large mass of active material in proportion to the grid or frame. The plates are kept correctly spaced by grooves in the side and bottom of the moulded glass box, which is fitted with a sealed-in ebonite lid. These cells are supplied in a dry charged condition and only require the addition of acid to render them ready for service at any time within six months from date of manufacture.

Edison Nickel-Iron Accumulator.

The Edison storage cell, which is largely used for propelling vehicles, has a positive plate of iron and a negative plate of nickel, immersed in a solution of potassium hydrate. The E.M.F. when fully charged is 1·5 volts, falling to 1·0 volt, or less, at the end of discharge. The output is 14 to 16 watt-hours per lb. of complete cell.

Standardisation Rules for Electrical Machinery, issued by the British Engineering Standards Association.

The following eight specifications of the B.E.S.A. are devoted to the electrical performance of electric machinery :—

No. 170—1926 applies to fractional horse-power motors of any continuous rating less than 1 h.p. per 1,000 revs. per minute, but not to 'universal' motors (*i.e.* motors capable of operating on both a.c. or d.c. circuits).

No. 168—1926 applies to industrial motors and generators having rated outputs larger than in Spec. No. 170 and smaller than those in Spec. No. 169, and wound for voltages not exceeding 7,000 volts.

No. 169—1925 applies to large generators and motors permitting overloads and of such size that the rated load plus the sustained overload of 25 per cent. for 2 hours does not exceed 2·5 k.w. 2·5 k.v.a., or 2·5 h.p. per revolution per minute.

No. 226—1925 applies to large generators and motors with continuous maximum rating of sizes not exceeding 2·5 k.w., 2·5 k.v.a., or 2·5 h.p. per revolution per minute.

No. 225—1925 applies to steam-turbine driven alternators (turbo-alternators) and to alternators not steam-turbine driven if of similar high-speed construction.

No. 172—1927 applies to rotary converters (to be ready shortly).

No. 173—1923 applies to traction motors (see p. 2275), and is now under revision.

Sizes of Bare Copper Wire for Electrical Machinery.

The British Engineering Standards Association's Specification No. 128 (1922) gives the dimensions and resistances of bare annealed copper wires for winding electrical machinery and apparatus. The standards for resistance fixed by the International Electrotechnical Commission have been adopted (see p. 2193). The dimensions are expressed in decimals of an inch, and the sizes are divided into three classes : 29 sizes identical with the even numbers of the Standard Wire Gauge are classed as *primary* standards ; the remainder of the S.W.G. sizes are classed as *secondary* standards, and intermediate sizes are given but not recommended for general use. The total number of sizes for which data are tabulated is 110.

GENERATORS.

DIRECT-CURRENT GENERATORS.

The Metropolitan-Vickers Direct-Coupled Generator.

(The Metropolitan-Vickers Electrical Co., Ltd.)

A circular field yoke carries inwardly-projecting pole pieces of laminated soft steel. The field ring is divided horizontally or vertically to suit variable conditions of service. When the machine is coupled at one end of a high-speed engine, and there is sufficient overhead room, the

izontal position is adopted. But when overhead room is restricted or if the machine be ced between the cranks of a cross-compound engine, the field ring is split vertically, the two ves being set on a guide plate. This vertical division of the field affords facility for inspection removal of armature or field coils without the necessity of removing the outboard bearing or mantling the engine. The opening of the field in a horizontal direction is of convenience where id room is limited and cranes or other devices for handling heavy castings are not available.

The armature core consists of punchings of carefully annealed steel held together between d-plates. This core is built upon an iron spider, which also carries the commutator. The der is pressed and keyed upon the extended engine-shaft, and may be drawn off at will should at ever be necessary, without in any way interfering with the permanent arrangement of the mmutator and winding. Ventilating spaces through the spider and armature core are so anged as to give a constant circulation of air through the commutator and winding.

The generator field is over-compounded to compensate for drop of potential in the line. By ans of a shunt on the series coils, the compounding may be adjusted for different degrees of er-compounding. The shunt and series coils are separately wound and removable at will. e series coils are composed of forged copper conductors of rectangular section.

The periphery of the armature is slotted. The armature winding of all machines of 50 kw. d over is made from bars of drawn copper, forged into proper shape on cast-iron formers. ter being thus shaped, the bars are thoroughly insulated and baked to remove all moisture. e coils are held in slots by means of retaining wedges of hard fibre driven into notches near e top of the slots, parallel to the shaft. These fibre wedges may be pressed out should it become cessary to remove any armature coil.

The brush-holder mechanism is carried by brackets projecting from a ring concentric with, d supported by, the field. A hand-wheel rocker arrangement accomplishes the adjustment of the brushes simultaneously. The ring carrying the brush-holder brackets does not project er the commutator face ; the commutator face and brushes are therefore clear of obstructions, d may easily be inspected at any point. Carbon brushes are used in connection with all these achines.

A feature of importance in the Metropolitan-Vickers engine-type generators is that all brushes the same polarity are maintained at the same potential. Trouble has frequently been experi- ced in working with large multipolar direct-current machines owing to the difficulty of securing e same magnetic strength in all the poles ; the E.M.F. generated in conductors under one pole fered from that generated in conductors similarly situated under another pole of the same larity, the result being a slight difference of potential between brushes of similar polarity. is caused currents to flow from one brush to another, and from one section of the armature nding to another, an occurrence attended by wasteful heating and the sparking of brushes. ie difficulty is obviated in these generators by a particular method of electrical balancing. By e use of this method, the armature could be considerably out of centre and no injurious results cur, as the balancing currents flow, not through the brushes, but through specially provided nnections. The pull exerted by one side of the field on a large armature out of centre by even e small fraction of an inch may become as high as several tons ; this method of balancing events such an increased pull.

DIRECT-CURRENT GENERATORS DRIVEN THROUGH GEARING.

The Mather & Platt Direct-Current Geared Generator.

(Mather & Platt, Ltd.)

One of the latest phases of electrical engineering is the driving of large D.C. slow-speed nerators, through gearing, by steam turbines, and a considerable number of these plants ve been installed up and down the United Kingdom by Messrs. Mather & Platt, Ltd., of Park orks, Manchester.

A typical generator is shown in fig. 22. This machine is installed at the works of the lectro Bleach and By-Products, Ltd., Middlewich, Cheshire, and is driven by a steam turbine, the ' Howden-Zoelly ' Multi-Stage Impulse type, running at 3,000 r.p.m., manufactured by essrs. James Howden & Co., Ltd., Glasgow. The generator is driven through double helical aring and runs at a speed of 250 r.p.m. The substantial character and satisfactory operation the plant—which runs day and night—cannot be better exemplified than by the fact that a rther set of 1,000 kw., consisting of two 500 kw. machines in tandem, and a 1,250 kw. set ve recently been installed, and set to work.

The details of construction of this machine is as follows :—

Carcase.—The frame is a plain ring of high permeability cast steel ; the main poles consist steel stampings accurately punched and assembled, and are bolted to the frame. Magnetic mmetry is thus ensured.

Bearings.—The bearings are of the self-lubricating, parallel bush, pedestal type ; the bushes e of cast iron with white-metal lining, and all bushes and pedestals are split horizontally. ach bearing is lubricated automatically by means of two oil rings running in an oil well of rge capacity.

Commutator.—The commutator is designed with a very high factor of safety. The segments of hard-drawn copper, are insulated by megohmit, mounted on a strong cast-iron hub, and clamped between steel end rings. Before connection to the armature every commutator is subjected to an insulation flash test of 3,000 volts.

Armature Core.—The armature is built of thin steel slotted laminations of the highest electrical and magnetic quality, insulated from each other and clamped together under pressure on a strong cast-iron hub, an extension of which carries the commutator hub.

Armature Winding.—All wires and strips are thoroughly impregnated before winding, and the main insulation consists of mica sheet mechanically protected by leatheroid. The complete armature is finally dried and impregnated with varnish.

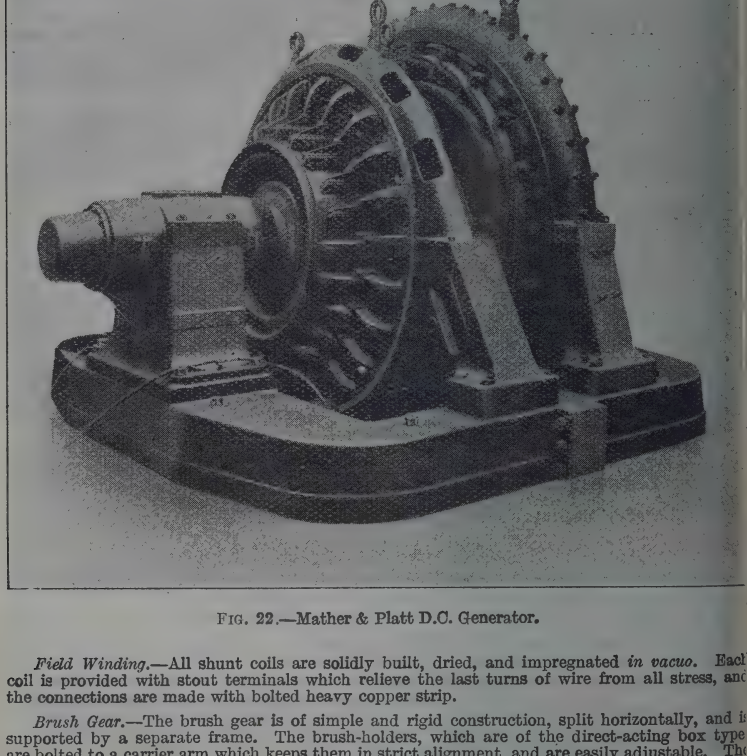

FIG. 22.—Mather & Platt D.C. Generator.

Field Winding.—All shunt coils are solidly built, dried, and impregnated *in vacuo*. Each coil is provided with stout terminals which relieve the last turns of wire from all stress, and the connections are made with bolted heavy copper strip.

Brush Gear.—The brush gear is of simple and rigid construction, split horizontally, and is supported by a separate frame. The brush-holders, which are of the direct-acting box type are bolted to a carrier arm which keeps them in strict alignment, and are easily adjustable. The insulation is micanite throughout. When the brush rocker has been once set in the working position, it remains fixed for all loads up to the maximum permissible overload.

G.E.C. 'WITTON' DIRECT-CURRENT GEARED GENERATOR.

(The General Electric Co., Ltd.)

Fig. 23 shows a 1,000 kw. direct-current generator, driven through gearing by a Fraser & Chalmers turbine, in a Scotch iron and steel works. This set delivers direct current at a pressure

240 volts, and runs at a speed of 600 r.p.m. with the turbine operating at 3,000 r.p.m. The aring is employed to enable the speed of the generator to be reduced to such a point that the

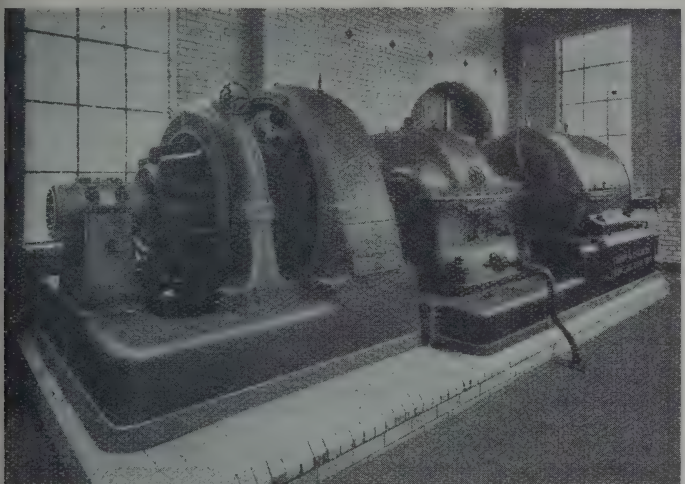

FIG. 23.—1,000 kw. G.E.C. 'Witton' Direct-Current Generator; 240 volts, 600 r.p.m.; turbine driven through gearing by Fraser & Chalmers turbine—3,000 r.p.m.

st commutation is obtained, and to enable the turbine speed to be raised to the point of highest ciency.

Care of Direct-Current Generators.

Steadiness.—It is important that the machine be firmly fixed to a good foundation. A machine y be run successfully on an upper floor, if supported on solid joists either of timber or iron. e machine will spark and the brushes and commutators wear unduly if there is vibration.

Commutator and Brushes.—These will always repay careful attention. If the brushes are t to wear unequally, and the commutator is not cleaned, the machine will soon commence spark badly, and both brushes and commutator will wear rapidly. If, however, these parts attended to in accordance with the following instructions, the wear and tear will be very small.

Adjustment of Brushes.—The brushes must be set truly on a diameter so that the point of is diametrically opposite the point of the other. Gauze and metal brushes as they wear must advanced to maintain the same distance, and consequently to bear the same angle on the face of the commutator. They must be advanced frequently, even though the wear may be y small, otherwise the brush will not bed properly on the surfaces of the commutator when vanced. Each brush must always bed equally well at the point, or toe, and at the heel. If ushes are allowed to wear too much before advancing (but this should not be), they must be ten out and filed to fit truly. In filing a brush, clamp it firmly, and file by taking long strokes th a file always in one direction. If it is the toe that requires filing, after filing to fit take the sharp edge, leaving the toe always $\frac{1}{16}$ inch thick. One brush often wears faster than fellow (or fellows), and must be set up accordingly. Moreover, sometimes a whole set of ushes on one side of the commutator will wear faster than those on the other side, and this ust be allowed for, or the brushes will cease to be on a diameter, and sparking and flatting of the mmutator may result.

Carbon Brushes are usually set radially to the commutator and therefore require no diagonal justment. They require periodical inspection, adjustment and cleaning, as the toes or heels ually burn away and a new surface giving the full contact area of the brush must be again tained. The best results with carbon brushes of ample contact area and good designs fitted th flexible tails are obtained by keeping the brushes absolutely clean and free from dust and e commutator true and polished with polishing paste.

Flats.—The most common source of the formation of little 'flats' upon the surface of the mmutator is the brushes being out of adjustment. Another cause is vibration of the brushes, e primarily to vibration of the machine, owing to improper foundations or a badly-jointed

belt. Flats are sometimes caused by the pressure of the brushes being reduced to too low limit.

Pressure.—It is well to have the pressure as light as possible, so long as no sparking and n vibration takes place at the brushes.

Oiling and Cleaning the Commutator.—In the case of metal brushes use a little good miner oil or vaseline, applied with a piece of rag. Do not on any account apply oil with a feeder, or o a piece of waste. A commutator well looked after will acquire in time a dark-coloured, smoot polish. When this takes place run a piece of No. 0 0 emery cloth on the commutator occasion ally before starting to work. In flour-mills and dusty places it is necessary to clean the com mutator with a little benzoline every day before starting, or, if run continuously, during the run taking care not to drench the commutator ; also to apply emery cloth about once a week as jus directed.

Belting.—Where practicable, the drive should be arranged so that the under side of the belt the tight or driving side. A flexible belt should always be used. Leather-linked belting, arche on the face next the pulleys and flat on the outside, is very suitable. Such a belt should *not* t taken off after working. Single belting with double edges makes a good cheap belt for ordinar use, and may be jointed with a butt joint, secured by belt fasteners. If an ordinary single be is used, it should be straight and of good quality. It should be jointed with a laced butt join until it has stretched, and then a proper spliced and cemented joint made. A dynamo belt mu run evenly. A belt which lashes either up and down, or from side to side, should not t tolerated.

Oiling the Bearings.—Adjust the sight-feed lubricator to give about 3 to 10 drops per minut The amount required varies with the quality of the oil used and the load on the machine. If th machine has been standing, give it a few extra drops before starting. It is well to use an o feeder made entirely of copper. Keep the machine clean—free from copper dust and waste oil.

Should the commutator wear out of truth or become very uneven (scored), take out th armature and turn up the commutator in a lathe, being careful to use a fine-pointed tool and no to take heavy cuts ; afterwards polish with emery cloth. If the commutator should be onl scored, it may be dressed in the machine with coarse, and afterwards fine, emery cloth, finishin with No. 0. Slight 'ringing' does not matter.

ALTERNATING-CURRENT GENERATORS.

THE CROMPTON ALTERNATOR.

Fig. 24 shows a type of alternator made by Messrs. Crompton & Co., Ltd. The

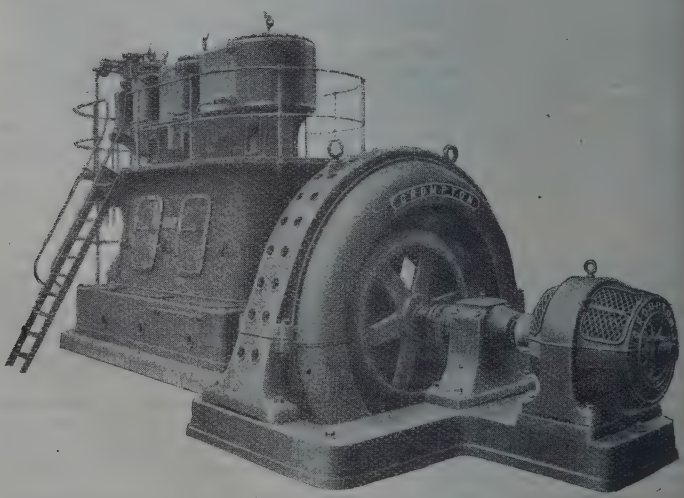

FIG. 24.—'Crompton' Alternator.

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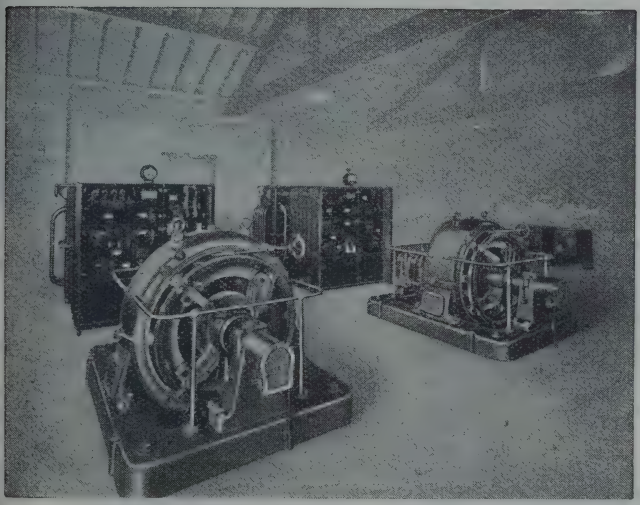

Fully automatic Sub-station, containing two 100 k.w. G.E.C. Rotary Converter equipments.

The G.E.C. manufacture within their organization complete equipments for all types of automatic sub-stations for lighting, power and traction, as follows :—

Fully Automatic.—Converter started up on fall of voltage and shut down on fall of load at pre-determined values.

Supervisory or Remote Control.—Converter started, controlled and shut down from a distant point by means of two pilot wires per sub-station only.

Operation by Time Switch.—Converter started and shut down by means of a time switch.

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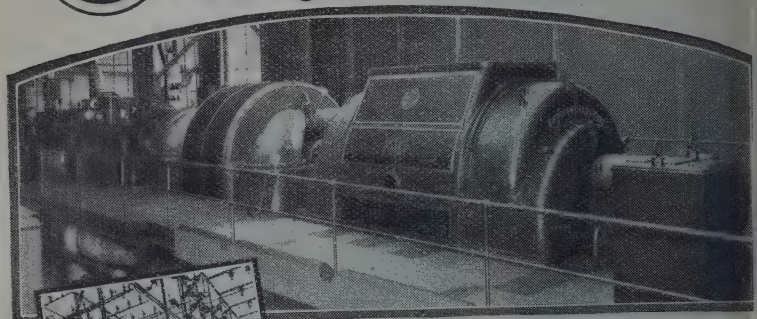
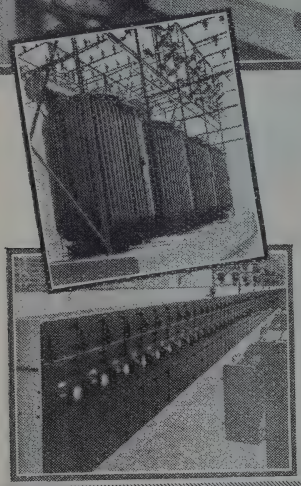
F. 2256

ELECTRICAL EQUIPMENT





The English Electric Company design and manufacture Electrical Equipment of the largest capacity for the Generation, Transmission, Conversion and Distribution of Electricity in all parts of the World. The upper illustration shows one of four 3,000 R.P.M. Turbo-Alternator Sets installed at Preston, Lancs, the total capacity is 50,000 K.W.; the centre view shows a 9,000 K.V.A. 33,000 Volt Outdoor Substation and the lower picture shows sixty 2,600 Volt Distribution Cubicles in a bulk supply substation.

Send us your Enquiries.

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F. 2257

ernators are supplied for mounting direct on the engine crankshaft, for coupling direct, or for t or rope driving. They are of the stationary armature type, with open parallel slots or semi-losed slots depending on the general design of the machine and the duty required. The coils held in position by hard wood or fibre wedges. The magnets are of the rotating radial pole e, with the poles and shoes laminated or cast solid, according to the design. The field coils und on insulated formers are held in position by the pole shoes.

When driven by slow-speed gas or oil engines, amortisseur or damping coils are often fitted.

The ventilation is a special feature of these machines. The armature coils are protected with tal covers, which assist in directing the air currents from the revolving field of the machine ially through the armature end windings to the back of the armature stampings, and thence ough the ventilating holes in the cast-iron frame of the machine.

In the larger size machines the stationary armature is divided on the horizontal centre to ilitate transport and erection.

The exciter is of the usual standard construction for direct-current machines, and is ally direct coupled to an extension of the alternator shaft, fitted with an outer bearing and unted on an extension of the alternator bed plate.

ALTERNATING-CURRENT GEARED GENERATORS.

While many D.C. machines nowadays are driven by steam turbines through gearing, a similar angement is adopted with alternators in spite of the fact that it is not very difficult, either n an electrical or a mechanical point of view, to construct medium-size high-speed turbo rnator sets. The geared alternator is adopted from motives of economy, as the steam turbine then be designed for speeds of over 3,000 r.p.m.

The Mather & Platt Geared Alternator.

(*Mather & Platt, Ltd.*)

Fig. 25 shows a 1,250 k.v.a. alternator, 2,200 volts, suitable for a speed of 500 r.p.m. and

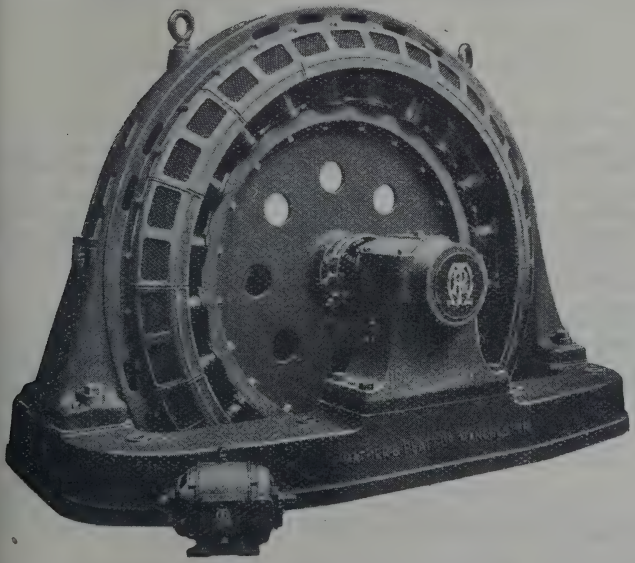


Fig. 25.—Mather & Platt 1,250 k.v.a. Alternator.

nged for gear driving from a steam turbine of over, say, 4,000 r.p.m. Such a machine is structed on the following lines:—

The stator consists of a cylindrical core, built up of thin steel laminations of the highest

electrical and magnetic quality, insulated from each other, and firmly clamped together in rigid cast-iron frame.

The windings are fully insulated before insertion in the slots, the latter being usually of th open type. High-tension coils are insulated with moulded mica, and low-tension coils wit standard mica sheet mechanically protected by leatheroid. In all cases the insulatio forms a complete sealed tube completely enclosing the straight part of each coil, and extendin for a considerable distance beyond the stator core at each end. The coils are held in positio by hard wood wedges.

In normal machines, the poles are completely laminated, the core and tip being stampe in one piece. The built-up poles are usually bolted to the rim of a cast-steel hub. In speci cases, however, the above construction may be modified.

For small machines with few poles, the field coils consist of cotton-covered wire or stri Each coil is provided with terminals which relieve the last turns of wire from all stress. Th coils are thoroughly dried and impregnated in vacuo with an oil- and moisture-resisting varnis For larger machines copper strip bend on edge is used in all cases where it is practicable.

The shaft is of mild steel of ample size and stiffness. Each bearing is of the pedestal typ with a cast-iron bush of large diameter and length, lined with white metal, and lubricated aut matically by two oil rings running in an oil well of large capacity. The oil channels and esca grooves are carefully designed to eliminate oil-flinging and creeping, and the overflow is arranged that frothing or churning of oil in the oil well does not cause any drip. The pedest and bearing bush are split horizontally.

The slip rings are of bronze, insulated entirely by mica. The brush-holders are of the direc acting box type, and the whole brush gear is simple and strong.

ALTERNATING-CURRENT TURBO-GENERATORS.

The G.E.C. Turbo-Alternator

(with combined axial and tangential ventilation).

(The General Electric Co., Ltd.)

The following is the specification of a G.E.C. turbo-alternator of the standard type :—

The alternator is of the enclosed type, with drum-type rotor and forced ventilation. Sh and exciter are included, but no bearings or coupling, excepting where this is specifically stat

Stator Frame.—The stator frame is a massive casting of box section, accurately bored accommodate and clamp tightly the laminations. Stout end-plates are used for this purpo and are secured in such a way that no bolts pass through the stampings, thereby avoidin considerable amount of iron loss. All longitudinal ribs are fitted with dovetailed keys to wh the stampings are secured. The casing rests on two feet, which are connected to the main bo by strong ribs to avoid flexure or vibration.

Laminations.—The laminations are accurate stampings of special low-loss iron, punched of large plates with carefully ground tools to avoid burrs. They are re-annealed after punchi and insulated as a last operation. No filing or scraping takes place after the laminations assembled, as this causes much higher iron losses due to eddies than in ordinary machines. the same reason, the insulation between plates is increased by sheets of strong paper placed suitable intervals.

Stator Winding.—The stator winding consists of a lap winding of the diamond coil type.

The coils are completely insulated before insertion in the slots, which are of the open ty The insulation of the coils is entirely class ' B ' insulation and consists of mica and micanite.

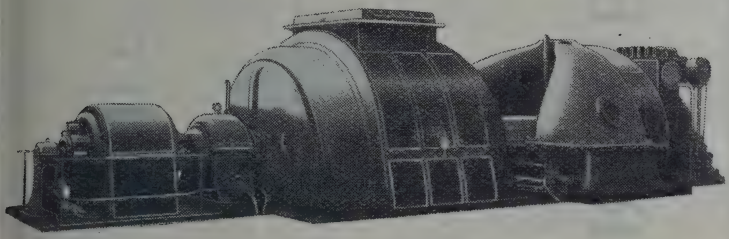
The insulation of the slot portion consists of a micanite tube carefully moulded on to coil by a special process, which eliminates the possibility of air spaces. The end turns are sulated by a suitable number of layers of mica silk tape wrapped round the coil, and the coi finally finished off with a layer of protective tape.

Clamping of Stator Windings.—The end windings are suitably braced, which prevents a possible movement of the coil under the severe stresses which accrue should a sudden sh circuit take place.

Ventilation of Stator.—Fans are arranged at both ends of the rotor, to draw air throu channels in the end shields from ducts in the foundations and force it into the space enclo

B T-H

Turbo-Alternators



High Pressure
Low Pressure
Mixed Pressure
Extraction and
Back Pressure
Steam Turbines

The illustration shows one of two 18,000 Kw. B.T.H. high pressure turbo-alternators installed in the Stourport Power Station of the Shropshire, Worcestershire and Staffordshire E.P. Company ; each machine has a continuous rating of 18,000 Kw. at 80% power factor, 5,500 volts, 3 phase, 25 cycles.

In addition to high pressure turbo-alternators, this Company manufactures machines operating on low pressure, mixed and back pressure as well as extraction types essential where process steam is required.

The British Thomson-Houston Co., Ltd.

ELECTRICAL ENGINEERS AND MANUFACTURERS.

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The

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The Editorial pages of the Review cover each week everything of interest and importance to the Electrical Industry—commercially, financially and technically. It is distributed all over the world, not only in the industry itself, but in all other industries and trades interested in the use and development of Electric Power. It has by far the largest circulation of any Electrical Journal in this country. Net Sales Certificate on Application.

THE ELECTRICAL REVIEW

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by the guards of the stator winding. From there, after cooling the overhanging parts of the stator coils, the air is pressed into pockets in the stator casing, and through the vent ducts of the stator core. It enters these vent ducts on the outer periphery of the core, and is guided by suitably shaped spacing pieces first inwards to the teeth and stator coils and then outwards to the outer periphery. The air escapes from the ducts through the stator casing to the outlet opening, a funnel-shaped orifice, through which the cooling air finally leaves the machine. This orifice can be arranged either at the top or below the machine, according to local requirements. The employment of an air-cooler is recommended, but a decision as to the type can only be arrived at in each particular case with a knowledge of the local conditions.

Rotor Winding.—The winding consists of coils which are completely shaped before they are embedded in the slots. Strong and ample insulation is provided between the winding and the rotor, as well as between the conductors themselves, particular care being taken to avoid crushing action due to centrifugal force. The insulation used is practically incombustible.

Clamping of Rotor.—The rotor windings are held in the slots by metal wedges. The overhanging end-connections are enclosed by steel shrouds of ample strength to withstand with safety the centrifugal stresses at maximum speed. These are put on with a moderate shrinkage. The shrouds are located at one end on a spigot provided in the core, at the other end on strong steel end plates carried from the shaft. Balancing grooves are provided at both ends of the rotor. The windings are entirely boxed in and protected from injury.

Ventilation of Rotor.—The cooling air enters the rotor at both ends through channels underneath the stator fans and passes under the rotor end winding into axial ducts arranged below the rotor coils. It escapes from these ducts through radial vent spaces, provided at intervals in the rotor core, into the air gap of the alternator, and leaves the machines through the stator core and casing.

Slip Rings.—The current is supplied to the winding through two steel slip rings shrunk on to an iron sleeve, and insulated therefrom by a moulded-on mica bush. Any danger of distortion or of getting out of truth of the rings is thereby avoided. Particular attention is paid to the leads connecting the rings to the windings. They are sunk into a groove in the shaft and protected by a key-shaped cover.

Terminals.—The terminals are usually arranged at the bottom of the shell, the cables being brought up to them from the basement. They are thus in a naturally protected position without necessitating unsightly boxes in the engine-room. The neutral point of each phase is brought out separately.

Rotor Construction.—The rotor is of the drum type, the winding being distributed in slots all round the periphery. The rotor body and shaft are one solid forging. This design has been adopted because a solid forging gives the strongest possible mechanical construction. The slots are milled out of the solid.

Journals.—The journals are of ample dimensions to run without overheating. They are finished off after the whole of the rotor is completed to ensure a true surface. Ample oil flirts are left at both sides, working in rings supplied with the bearings by the makers of the turbine.

Exciter.—The exciter is carried from the bearings at the slip-ring end. It is specially built for high speeds, and is usually compound wound.

Tests.—Numerous tests are carried out during the process of construction to see that the materials are satisfactory at all stages. Amongst these tests are the following :—

(*a*) Breakdown test for tubes after inserting them in the core.

(*b*) Test between adjacent conductors in a slot, not less than ten times the working voltage between conductors.

(*c*) Between finished coils and between any coil and earth, twice working voltage plus 1,000 volts, but in any case not less than 2,000 volts.

(*d*) Rotor winding tested to earth with 2,500 volts when all connections are made to the slip-rings and after balancing test.

(*e*) Static balancing on flat rails.

(*f*) Dynamic balancing at full-speed.

(*g*) Synchronous run at full speed to measure iron, windage and excitation losses. During this test the open-circuit curve and the short-circuit curve are obtained.

(*h*) Overspeed test at 15 per cent. above running speed.

(*i*) Oscillograph of wave-form on open circuit.

The G.E.C. Fraser & Chalmers Turbo-Alternator Set.

(The General Electric Co., Ltd.)

In fig. 26 is shown a G.E.C. Fraser & Chalmers Turbo-Alternator set for 6,000 k.v.a. a 6,600–7,200 volts, 50 cycles, 3,000 r.p.m.

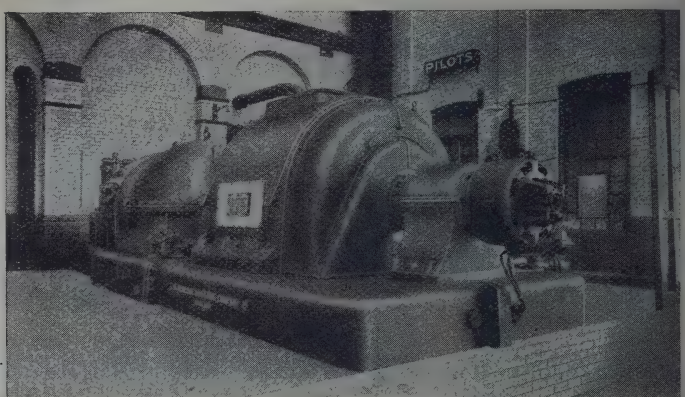


Fig. 26.—Fraser and Chalmers Turbo-Alternator Set.

The Tirrill Automatic Voltage Regulator.

(Messrs. British Thomson-Houston Co. Ltd.)

Fluctuation loads, and the time-lag inseparable from manual control of generator voltage, ma cause serious variation in a generating station voltage. This regulator (fig. 26A) automaticall

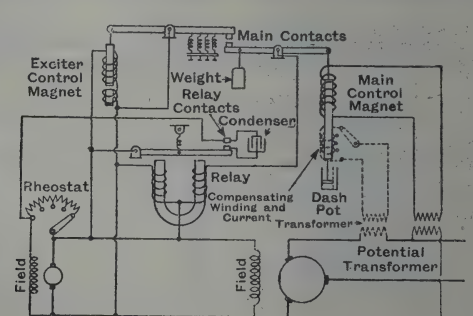


Fig. 26A.—Elementary Diagram of Type T A Regulator, connected to Three-Phase Alternator, showing (in dotted lines) Compensating Coil and Current Transformer.

and instantaneously regulates the voltage of either alternating- or direct-current generators In fig. 26A, the rheostat in the field circuit of the exciter results in the alternator generating onl about 60 per cent. of its normal P.D.; when it is short-circuited, the P.D. of the alternator greatl

xceeds the normal value. The action of the Tirrill regulator is to vary the duration of the periods f open- and of short-circuit of this exciter field resistance. In the diagram, the two main or float- ng contacts are fixed respectively to two pivoted levers. The top contact lever tends to be kept epressed by springs, which are opposed by the downward pull of the exciter control magnet. 'he bottom contact lever has a counterweight balancing a core which is acted upon by the main ontrol magnet energised from the alternator terminals. The pivoted armature of the relay carries ne of the rheostat short-circuiting contacts which the spring tends to keep closed. The middle oint of the relay winding is connected to an exciter terminal, one end to the other exciter terminal ermanently, and the other end intermittently through the main contacts. When these contacts re closed there is no magnetic effect in the relay, because the two portions of the winding eutralise each other and the exciter rheostat remains short-circuited. The rising generator oltage then increases the current in the main control magnet sufficiently for the core to rise and pen the main contacts. The relay magnet now becomes strongly excited, and, its armature being ttracted, opens the short-circuiting contacts across the exciter field rheostat terminals, the ondenser reducing sparking. The regulator is thus in a constant state of vibration and responds nstantaneously to changes in alternator P.D. The function of the compensating winding on the ontrol magnet (energised through a current transformer) is to eliminate circulating currents etween alternators in parallel by reducing the excitation of an over-excited generator and *vice ersa*.

Air Coolers.

The 'Heenan' Air Filter.

(*Heenan & Froude, Ltd.*)

The overload capacity of turbo-alternators and generators is dependent to a considerable xtent upon the supply of suitable volumes of cool air for carrying away the heat generated by lectrical loss. The usual method is to mount fans on the rotor shaft, arranged to extract air hrough a supply system in which a combined air filter and cooler is inserted.

The 'Heenan' Air Filter receives ordinary unfiltered air from the neighbourhood of the enerating station and brings it into very thorough and intimate contact with wet scrubbing urfaces. The arrangement of these surfaces has undergone a complete transformation ince the machine was last described in The Engineer's Year-Book. The rotary principle as been given up in favour of stationary air screens, the surfaces of which are kept horoughly wetted by water issuing from jets. After cleansing the scrubbing surfaces the water ravitates to a tank, from which it passes through strainers to a centrifugal circulating pump and hence to the distributing jets. The atomisation of water, forming part of certain air-filtering ystems, is entirely avoided. The air leaves the filter in an entirely natural condition, containing o trace of loose moisture.

The filtering efficiency of this apparatus is extremely high, both heavy and fine dust being liminated. The cooling effect in hot summer weather in temperate climates is often as high s 20° or 30° F. In tropical climates the latter figure is sometimes exceeded. The consequent eduction in air temperature is of great value in permitting the generation plant to run on heavy verloads without overheating.

The 'Heenan' Closed Circuit Air Cooler.

(*Heenan & Froude, Ltd.*)

This cooler, fig. 27, which is designed for the ventilation of turbo-alternators, comprises a tubular air cooler built generally on the lines of a surface condenser arranged in the alternator foundations and coupled up to the bottom discharge of the alternator by suitable ducting.

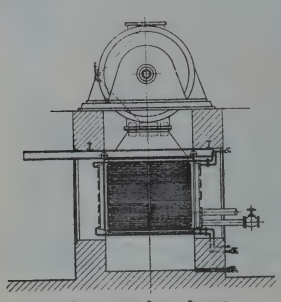
After passing through the cooler the air returns to the alternator *via* the end shields, the fans circulating the air being carried on the rotor.

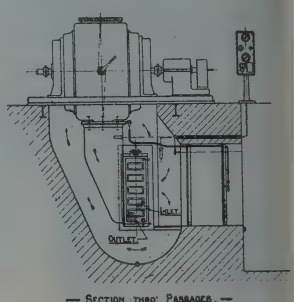
With this system the same air is continually recirculated through the windings of the alternator, so that the only dirt that can be deposited is that contained in the initial volume of air, thus the necessity for air filtration is obviated.

With an unfailing and clean supply of water the circuit can always remain a closed one, but under actual working conditions it has been found necessary to provide for cooling in the event of a failure of the water supply or other eventuality, and the arrangement, therefore, embodies a system of dampers and emergency air doors which cut out the air cooler and permit external air to enter the foundations, the hot air in this case being discharged direct to atmosphere from the top of the alternator.

Dampers are fitted to the top and bottom discharges of the alternator, which are inte connected and operated by one lever, and arranged so that if one set is closed the other set open. Connected to the same lever is the trip gear for the emergency air doors, which ar balanced and which open automatically, due to the difference in pressure, immediately the cate is released. As soon as the trouble has been diagnosed and rectified the emergency doors ar closed and the alternator dampers changed over for closed circuit running.

A thermostatic alarm device is fitted in conjunction with the system, which gives visib and audible warning to the attendant should the temperature of the air leaving the cooler reac a pre-determined figure. This alarm device consists of a dial type thermometer with a klaxo horn, red lamp and relay, arranged on a panel either for wall or floor fixing. The thermomete is connected to a bulb in the foundations, and as soon as the dial hand reaches a certain poin the relay brings into operation the klaxon horn and lights up the red lamp, so warning th attendant that the air temperature is rising.





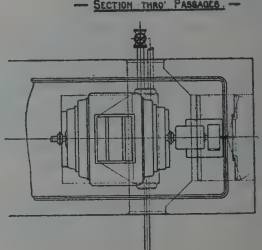


FIG. 27.—Arrangement of 'Heenan' Enclosed Circuit Air Cooler.

The arrows show the direction of the air.

In regard to the construction of the coolers, this follows condenser practice in as far as they consist of a nest of tubes held between tube plates, the joints being formed by screwed ferrule and packing. The water headers fitted with division plates and branches for inlet and outle water connections are also in line with condenser practice, but the tubes in these coolers ar gilled at close pitch, the gills being soldered to the tubes in one operation for each length of tube this construction giving the highest heat transference efficiency, which has, of course, been ascer tained chiefly by experimental work.

Another departure from an ordinary condenser is the addition of secondary tube plates i front of the main tube plates, so that a dead air chamber is formed at either end of the coole into which any leakage from the main tube plates would drain instead of being carried over wit the air into the windings. Rubber bushes are used in these secondary tube plates to form an air and water-tight joint with the tubes.

Air cocks are fitted to the top of the water headers and drain pipes to the dead air chambers

The tubes are of brass (Admiralty mixture), solid drawn and tested to an internal pressur of 2 tons per sq. in.

The tube plates are also brass, of ample thickness to allow for a suitable stuffing box an screwed gland. The water headers are of cast iron of ample thickness to withstand any pressur

ıey are likely to be subjected to, and are fitted with small inspection doors, so that the tubes ıd tube plates can be inspected from time to time without breaking the joints of the main ;ader.

The gills are of thin copper, and both gills and tubes are tinned in the process of soldering the lls to the tubes, so that the danger of corrosion is well catered for.

Fig. 27 shows the arrangement of a cooler in the foundation, from which it will be noted that ıe cooler itself is carried on rollers, which bear on the flanges of a steel joist, the latter being :tended and supported outside the foundations, so that the complete cooler unit can be removed r overhaul or cleaning when necessary, with a minimum amount of trouble.

Inspection doors are provided on either side of the foundations to permit the removal of the ›oler and also to give access to the foundations.

Portable Electric Blower.

(The Consolidated Pneumatic Tool Co., Ltd.)

This blower, fig. 28, is largely used for keeping the windings of motors and dynamos free from ıst. Weighing, complete, about 15 lbs., and suitable for use on either a direct or alternating

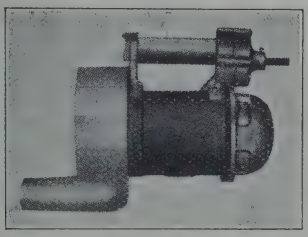


Fig. 28.

ırrent circuit, it will maintain a steady air blast through a 1¼-in. orifice, with a pressure of ›out 12 ins. of water. It is very convenient to handle, and can be attached to any ordinary mp socket.

Visco Air Filter.

(The Visco Engineering Co., Ltd.)

The Visco Air Filter (devised in 1916) is used in conjunction with turbo alternators, pipe ntilated motors, and general ventilating plants. It works on the principle that the air volume divided into a large number of thin streams which are passed through a layer of specially pre- ıred filter bodies, the surfaces placed irregularly to each other, so that the direction of the r flow is changed suddenly and a great number of times. The filter bodies are thin copper- ated steel rings $\frac{7}{16}$ in. diameter and $\frac{7}{16}$ in. long, coated with a thin film of viscinol, which is specially prepared blend of highly viscous mineral oils. When the direction of the air flow is ıanged, the dust particles continue in the original direction and are thrown against and retained ; the viscinol-coated surfaces.

The filter is standardised in units 20 by 20 ins. square and 3½ ins. deep, consisting of frame and ıll, which latter is simply hooked on the frame. The capacity per unit is 600 cu. ft. per minute. ressure loss is practically steady at $\frac{3}{8}$ in. water gauge. Average consumption of oil, 1 gallon per uit per annum. Cleaning is done by rinsing in hot soda water on the average every eight weeks epending on the original dust content and length of daily run. There are practically no other ınning costs.

The filter units are assembled in a convenient shape to make up any capacity, and are p ferably built into the alternator foundations (thus taking up no valuable space) or as self-contai units in any position.

The *advantages* claimed are: No moving or wearing parts, all metal, fireproof, no attenti foolproof, small space.

SYNCHRONOUS OR ROTARY CONVERTERS.

The G.E.C. Synchronous Converter.

(The General Electric Co., Ltd.)

The following is a specification of a Synchronous Converter of standard type:—

Frame.—The frame is constructed of cast iron or steel of high magnetic permeability. I split horizontally and bolted together by strong steel bolts. The construction permits the half to be readily removed for inspection or repair.

Main Pole-Pieces.—The main pole-pieces, which are bolted to the frame from the outsi are built up of laminations in order to reduce eddy-current losses in the pole faces to a minimu The design is such as to permit the removal of a field coil without disturbing the armature or yo In exceptional cases cast steel poles with laminated shoes may be employed.

Armature.—The armature is built up of best quality stampings of high permeability and l iron loss. They are mounted on a cast iron spider and held tightly in position by heavy en plates. The laminations are accurately punched before assembling and are covered with a spec insulating compound which is effective in reducing eddy-currents to a minimum. The core held together between the end-plates by means of bolts which, however, do not pass throu the active portion of the core and therefore introduce no local circuit for eddy-currents. Ven lating ducts, adequate in number and ample in dimensions, are provided at frequent interva Similar ducts are included at the two ends between the core and end-plates. The general c struction of the armature is such as to afford a current of air to the field coils for ventilation a cooling. The armature winding is composed of former wound coils, taped, varnished, and bak before assembly. The slots are lined with several layers of non-hygroscopic insulating mater Special care is taken to make the leakage surfaces as large as possible. The aperture at the of the slot is filled by strong wooden wedges driven in tightly. There are no binding bands the armature core itself, that part of the winding being retained in position by the wooden wedg The end windings are so shaped that the surface exposed for cooling is as large as possible. large number of equalising connections is provided. Prior to assembling in the frame the armat is balanced statically, and the final balancing is obtained dynamically.

Commutator.—The commutator is built up of hard-drawn copper segments, insulated by b mica insulation and held tightly between two V-shaped clamping rings in such a manner that inevitable expansion of the copper and iron on account of temperature rise may take pl without in any way affecting the commutator surface. During its construction the commuta is subjected to several baking processes, with the result that no binding varnish remains in mica insulation. When completed, the whole commutator gives a true ring, which indica that the entire mass has been formed into one rigid body. In addition, the construction is su that 'breathing' is reduced to a minimum and the possibility of moisture permeating the insu tion is eliminated. A considerable distance to the iron parts is allowed at the front and ba of the commutator in order to secure a high insulation resistance to earth, and to prevent a leakage to the iron. The radial depth of the segments is ample for the size of the commutat and varies somewhat with the size of the machines. Before leaving the works, the mica betw the segments is grooved to a suitable depth to promote good commutation. To assist in cooli the commutator lugs which connect the segments to the armature windings are given a consid able width, and thus provide a large cooling surface.

Field Coils.—Shunt field coils are wound upon spools composed of a material with h insulating properties, a former larger than the poles being employed in the winding proces ensure that no undue stresses are imposed upon the spool when in position. The wires insulated with a double cotton covering and after being wound are put into a heated impregnat chamber where they are dried for several hours under vacuum. Afterwards they are floo (while still under vacuum) with a heavy insulating compound. They are then subjected heavy pressure at the same temperature, the insulating compound being forced right thro the layers of the coils. Series coils are wound with bare copper strip and treated with an insulat compound. Ample leakage surfaces to the frame are provided.

Commutating Poles.—G.E.C. synchronous converters are fitted with commutating poles c design which permits sparkless collection of current at all loads with fixed brush position. coils are wound with bare copper strip and treated with an insulating compound. The m spools are moulded direct on the poles and ample leakage surfaces are provided.

Damping Winding.—A substantial damping winding is fitted to the field poles. This is instrumental in strongly opposing any tendency to hunt, whether from changes in load or from any low frequency oscillations originating in the generating plant. It consists of a pair of heavy copper rings bolted together by copper bolts between the poles and connected up by drawn copper rods passing through the pole faces and fixed at each end of the rings. In order that any pole winding may be removed, the rings are divided up between the poles and jointed in a manner which permits the joint to be readily unmade for the removal of the pole or winding, and at the same time in no way impairs the mechanical strength or the electrical conductivity of the rings. A damping winding of high conductivity and great rigidity is thus obtained which completely damps out all oscillations. The damping winding is also necessary for improving the starting characteristics of the converter when started from the alternating current side, from transformer tappings.

Booster.—When a booster is specified it takes the form of an alternating-current generator, with a stationary field. The booster armature is mounted on the main shaft side by side with the armature of the synchronous converter, and is constructed on the same principle as the latter. The current passes from the converter slip rings through the booster armature to the armature of the rotary. The booster field frame is split horizontally into two parts, and mounted on the bedplate by the side of the main frame. The booster field may be excited either by shunt or series windings, or both.

Six-phase and Four-phase Connections.—Synchronous converters intended to work on a three-phase supply are usually wound as six-phase machines, drawing a six-phase supply from three-phase transformers in order to take advantage of the greater output and more even heating of a six-phase armature as compared with a three-phase one. Similarly converters for operating on a two-phase supply are wound either four-phase or six-phase, the latter being made possible by the use of a double Scott-connected transformer.

D.C. Brush Gear.—The direct-current brush-holders are fixed to a strong cast-iron arm projecting radially from the brush rocker. The rocker is carried in a spigot in the yoke, or carried by a separate frame from the bedplate. The rocker is split across the horizontal diameter, so that the halves can be readily removed for inspection or repair. The rings connecting the brush sets of the same polarity are carried from the brush rocker on insulating supports; they are well insulated from the rocker and have ample clearances and cooling surfaces. Provision is made for separating the halves of the rings should it be desired to remove one-half of the brush gear for any reason. Each brush carbon is contained in a separate box-type holder to avoid rubbing, and a spiral clock spring exerts radial pressure on the brush. The pressure on the brush is adjustable by means of a steel lever, which engages in one of a large number of slots in a quadrant. The design of the brush holder is such that each brush mechanism is self-contained; the pressure of the brushes can therefore be adjusted when running, and one brush can be removed without in any way disturbing the others. The brush gear is of compact design, giving a maximum distance between adjacent brush sets, thereby assisting in the prevention of flashing-over.

A.-C. Brush Gear.—The alternating current brush holders are mounted on semi-circular arms which are carried on, and insulated from, two strong brackets projecting from the pedestal bearing on the slip-ring end of the converter. Each brush is contained in a separate box-type holder and a helical spring exerts radial pressure on the brush. This pressure is maintained by means of a lever terminating in a special pawl which wedges against corrugations on the inside of a brass tube. The pressure is adjusted by slightly canting the lever, moving it up or down the brass tube and releasing it, when the pawl will automatically engage in other corrugations. The terminals for the incoming cables are provided and are fixed direct on to the arms.

Slip-rings.—The slip-rings are of Admiralty gun-metal, and are so designed as to ensure efficient cooling. Each ring is so cast that the portion between the contact face and the internal diameter takes the form of a fan. A cast-iron sleeve which is securely keyed to the shaft forms the base for the slip-ring structure. This sleeve is insulated throughout its length with micanite wound to size, the slip-rings being shrunk on to it. The connections from the armature to the slip-rings consist of copper rods strongly bolted into the slip-rings at one end and supported at the other by a steel ring shrunk on to the sleeve, similarly to the slip-rings. These connecting bars are covered with insulating material and are efficiently protected from breakdown to the other slip-rings through which they have to pass. Ample clearances are provided for cleaning. Wherever possible, each tapping of the armature winding is brought to the rings separately in order to avoid unbalanced current. Thus the slip-rings themselves act as balancing rings.

Shaft.—The shaft is of such strength that it will carry the armature without undue flexure or vibration. It is supported by two main bearings lined with white metal and split in halves.

Bearings.—The bearings are of the self-oiling type, and have rings which dip into oil chambers of large dimensions. The bushes are of cast-iron lined with best quality white metal and are split horizontally. The length of the bearing is 2·5 times the diameter of the shaft in the bearing. A glass level gauge with draw-off tap is fitted to each bearing. The general design of the bearing is such as to preclude any oil flinging.

Bedplate.—A strong bedplate of box section is provided, having heavy ribs connecting sides at various points. Its general construction is substantial and ensures complete freed from vibration. The bedplate is fixed to the foundations by strong bolts and plates suppl with the machine.

Speed-Limiting Device.—All large G.E.C. Synchronous Converters (and small ones if desir are equipped with a speed-limiting device which will shut down the machine if by any chance normal speed should be exceeded by a predetermined amount. A weight, which tends to m under the action of centrifugal force, is mounted on a shaft and revolves with it. Under action of centrifugal force it tends to run outwards, against the compressive resistance of a spri At a predetermined speed the arm, to which the weight is attached, flies out and closes contact in a tripping circuit, thereby opening the direct-current circuit breaker. This devic usually fixed at the direct-current end of the shaft.

Oscillating Gear.—When specially ordered, an oscillating device can be supplied for mov the armature to and fro longitudinally while it is running. As the armature rotates, it is alt nately pushed out of the magnetic centre and then released, thus causing a smooth oscillatio

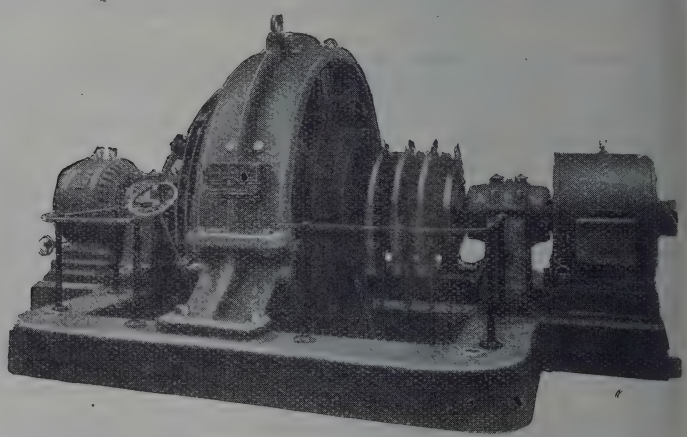


FIG. 29.—1,000 k.w. G.E.C. Synchronous Converter; 550–570 volts, 50 cycles, 750 r.p.m.

Temperature Rise.—The synchronous converter is capable of developing its full rated l continuously with a rise in temperature of 40° C. (72° F.).

Overload Capacity.—The synchronous converter will give an overload of 25 per cent. for t hours, and 50 per cent. for 15 minutes. It will also withstand overloads of 100 per ce momentarily.

Starting Motor.—If the synchronous converter be supplied with a starting motor, the latte mounted on an extension of the bedplate. The motor is of large capacity and is adequate in siz run the converter up to speed in a short time. The motor is either of the solid rotor or slip-r type, as circumstances demand. The starting torque is sufficient to permit rapid acceleration the first moments of starting, even though the supply voltage is below normal, as may be case after a shut-down at the main power station.

Tests.—All material is subjected to tests at various stages of its manufacture to ensure t no faults exist in the completed machine. Tests for static and dynamic balance are also carr out before the machine leaves the works. Excellence in this respect is assured. Standard fi tests on rotaries for 650 volts direct current or under include a 2,000 volt flash test with altern ing current for five minutes, and six hours run on full load to ascertain the efficiency and te perature rise.

A 1,000 k.w. G.E.C. Converter is shown in fig. 29. This machine is for 50 cycles, and 550– volts, D.C., at 750 r.p.m.

Starting, Self-Synchronising, and Controlling Rotary Converters.

G.E.C. Methods of Starting, Self-Synchronising and Controlling Synchronous Converters.

It is usually required that synchronous converters shall be of the self-synchronising type, as the ning of sub-stations is thereby facilitated. The practice can be considered standard. In the E.C. patented method of starting and self-synchronising, the starting current is not allowed to ss into the armature until the field is excited. Consequently, when the armature is switched through the choking coils, the current is not strong enough to reverse the field, so that the larity of the converter is always correct.

Fig. 30 shows the scheme of connections. The essential features are the synchronising switch d the choking coils. The rotary converter is provided with a starting motor, which is started closing the triple-pole circuit-breaker shown at the right of the figure. This brings the set to approximately synchronous speed. Meanwhile the switch shown in the figure is closed in starting position, where the blades make contact on the long synchronising contacts. Under ese conditions the slip-rings of the rotary are connected to the source of alternating-current pply through the choking coils, which limit the current taken by the machine. This current, wever, is sufficient to pull the set into synchronism. When this has happened, the synchronis- switch is pushed right home, so that the blades go into the full-on contacts. Mechanism is ovided which prevents the synchronising switch being pushed at once into its fully-closed sition. The device is so arranged that on slightly pulling the switch towards the ' off ' position pin releases a slotted bar, which falls under its own weight, allowing the pin to pass along the t and permitting the synchronising switch to be pushed right home. When this happens, an

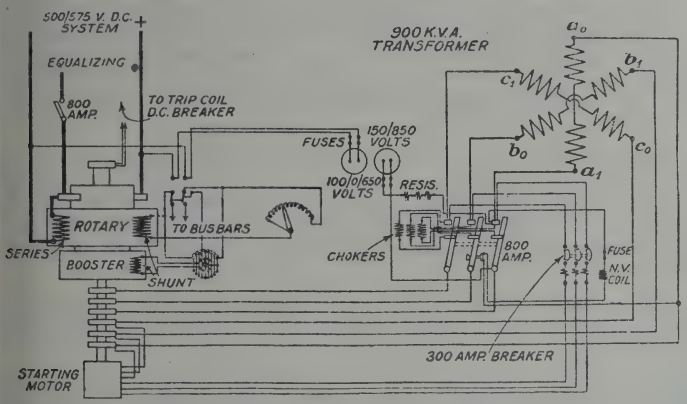


FIG. 30.—Diagram of Connections for Self-Synchronising Synchronous Converter.

erlocking contact is operated, which opens the no-volt coil of the starting-motor circuit-breaker pping the latter, so that the converter set is left in synchronism with the starting motor connected.

The standard starting motor used is provided with a solid rotor. The stator windings are justed once for all when the set is first put into use so as to give the best value of slip to the rting motor and so as to necessitate the minimum value of synchronising current.

MOTOR CONVERTERS.

The Motor Converter represents a compromise between the motor generator and the synchr nous converter, combining the best features of each type of converting plant. It consists of a se starting a.c. motor, the rotor of which is coupled both electrically and mechanically to the arm ture of a d.c. generator, about half the power supplied to the motor being transmitted to t generator by way of the shaft, and half by the electrical connections. The motor fulfils the du functions of a transformer and a motor, while the generator similarly acts both as a rotary co verter and a dynamo. The rotating parts—the rotor of the motor and the armature of t generator—run at half the speed corresponding to the frequency of supply. The motor convert is used to supply direct current when fed with alternating current, and *vice versa*, the ratio the a.c. and d.c. voltages being determined by the design.

Comparing the three methods of conversions, the motor-generator is more expensive, tak up more floor-space, and is much less efficient than its rivals, whilst it possesses no advantag comparable with these drawbacks, except under special circumstances, such as supplyi wide d.c. voltage regulation or an a.c. load at low power factor. The chief advantage of t rotary converter is that, including transformer losses, it is slightly more efficient than the mot converter at full load—about 1½ per cent. for 1,000 kilowatts. On the other hand, the mot converter has a high efficiency at half and quarter load, is not easily thrown out of step wi the generating plant by a heavy drop in voltage, and is practically immune from liability flash over on a short circuit occurring, while it can carry heavy overloads without sparkin The motor converter is very easily started up from the a.c. side and synchronised with the supp frequency, without risk of reversal of the d.c. polarity—a drawback to which the rotary convert is very subject ; it can equally well be started from the d.c. side, and it works with unity or les ing power factor, which varies very little when the d.c. voltage is varied over a wide range. T rotor of the motor converter is usually wound for 12 phases, conferring upon it very high sy chronising power and stability of running. The generator can be shunt or compound woun according to requirements, being capable of a variation of d.c. voltage of 40 per cent. ; th it can be used alternatively for supplying a light and power system at, say, 400 volts, or a tracti system at 550 volts, and like a rotary converter, it can be arranged for use in connection wi a three-wire system, automatically balancing the load. As the motor and generator togeth have the same total number of poles as the equivalent rotary converter, a 50-cycle motor co verter operates under as favourable conditions as a 25-cycle rotary converter, with correspondi advantages in respect of the wider spacing of poles (entailing less magnetic leakage) and brushes (with consequent freedom from flash-over). As the slip-rings of the motor-conver are only used for starting up, or for balancing a three-wire system, their maintenance is l onerous than that of the six slip-rings and brushes which carry the whole of the a.c. load ir rotary converter.

Owing to the stator of the motor being wound for the full supply pressure (up to 10,000 vol no transformers are necessary, and thus the floor-space occupied is a minimum ; the switch-g also is simple and compact. The air-gap on the a.c. side may be larger than in a correspondi induction motor, the advantage of this naturally being more apparent in the larger sizes. Wh exceptionally wide variations of d.c. voltage are required, the motor converter can be provid with a 'booster,' as in the case of a rotary converter, but as the booster carries only half t load, it is much smaller. The starting current is from 25 to 35 per cent. of the normal full-lo current.

Whilst the machine is usually required for converting from three-phase or two-phase curre it is also suitable for use on a single-phase supply, and in this case it offers special advantag its synchronising power being practically as good as on a polyphase supply, and its efficie being but little lower.

Motor converters run perfectly in parallel at either or both ends, and are not subject to hunti Whilst their good d.c. regulation is highly appreciated on lighting systems, their ability to co with heavy overloads and violent load fluctuations renders them particularly well suited supplying d.c. tramway and railway systems.

Power-factor correction can be obtained at a certain predetermined load and voltage ra The set can also be run with the d.c. side open, and the a.c excitation increased until the side supplies leading wattless current to the main.

Action of Motor Converter.

The motor converter consists of an induction motor directly coupled mechanically and e trically to a direct-current generator, and is a synchronous machine. Fig. 31 is a diagram connections of a three-phase motor converter.

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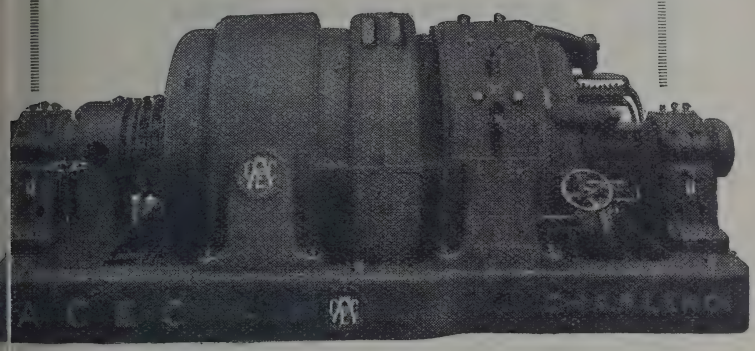

1000 k.w. A.C.E.C. La Cour Motor Converter.

A.C.E.C. LA COUR MOTOR CONVERTERS.

Among many other advantages, A.C.E.C. La Cour Motor Converters are provided with patent automatic starting and self-synchronising gear which enables them to be started and synchronised with perfect safety by an unskilled operator.

There is no High-tension current on any revolving part, and the machines automatically balance the two sides of a three-wire system within fine limits.

The obsolete three-bearing design has of course been abandoned, and all A.C.E.C. La Cour Motor Converters are of the latest two-bearing type.

We shall be glad to send an instructive booklet descriptive of these machines to anyone who is interested.

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(2) Rotary Converters with Transformers.

(3) Motor Generators.

The most suitable type of machine to adopt is determined by the conditions which obtain in each case.

As manufacturers of all three types we shall be glad to place our extensive experience at your disposal.

We not only manufacture the particular types of plant mentioned above, but also everything which is required for the complete electrical equipment of all kinds of works and factories, central and sub-stations, tramways and railways.

We also specialise in the manufacture of all types of paper and rubber insulated cables, centrifugal pumps, turbo alternators, electric winders, rolling-mill motors, electric cranes, transformers, etc. We shall be glad to supply full particulars of any or all of our products on request.

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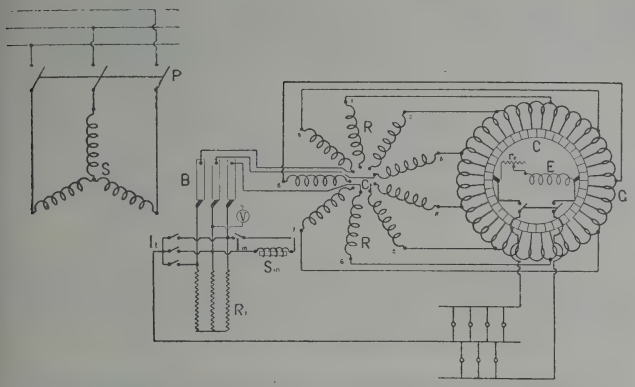

FIG. 31.—Diagram of Connections of Motor Converter.

The following gives the explanation of the letters used in the diagram:—

P Main three-pole high-tension switch.
S Stator winding of the a.c. machine, which is supplied with current direct from the three-phase system.
R Rotor winding, which is connected at symmetrically arranged points with the armature winding of the direct-current machine.
Rt Fixed three-phase starting resistance, which is connected with the rotor through the slip rings *B*.
B Rotor slip rings.
G Direct-current machine.
C Commutator of the direct-current machine.
E Field winding of the direct-current machine.
re Field rheostat of the direct-current machine.
Sm Self-synchronising coil.
Im Switch for self-synchronising coil.
V Synchronising voltmeter.
It Three-pole short-circuiting switch.
Ct Slip-ring short-circuiting device.

Assuming, for the sake of simplicity, that both machines have the same number of poles, the mber of revolutions of the set will be half of the number which corresponds to the synchronous eed of the motor. The primary current produces a rotating field, the speed of which, in relation the rotor, is equal to half the synchronous speed. This field induces, in the rotor windings, series of E.M.F.'s, the frequency of which is half the frequency of the primary current. These M.F.'s induce polyphase currents, which circulate through the direct-current armature windings, d produce in turn a rotating field, the speed of which, in relation to the shaft, is equal to half e speed of the primary field. The phases of the armature of the direct-current machine being nnected in such a way that the field tends to revolve in a direction opposite to that of the shaft, is field remains stationary and the machine runs as a synchronous set.

The alternating current side operates partly as a motor and partly as a transformer, while e direct-current side operates partly as a generator and partly as a rotary converter.

Both parts of the machine are smaller than corresponding induction-motors or d.c. generators d the slower speed is beneficial to commutation.

In cases where the alternating and direct current sides have different numbers of poles, e motor converter runs at a speed which is inversely proportional to the sum of the number poles.

With a view to obtaining the highest possible efficiency, in accordance with the theory the rotary converter, the number of phases in the a.c. rotor is increased, twelve phases bei commonly adopted. No difficulty is caused by this arrangement, since the connections betwe the rotor and armature are made direct, and without the use of slip rings. In most cases, on three phases are used for starting, and only three slip rings are therefore required.

The A.C.E.C. Motor Converters.

The A.C.E.C. la Cour motor converters, fig. 32, follow the general design described. Starti and self-synchronising are obtained by a patented device. The A.C.E.C. is the sole licens for Belgium of the la Cour and Arnold patents relating to motor converters, and, now that t British master-patent has expired, is supplying these machines for use in Great Britain and t colonies.

Starting of Motor Converters.

The A.C.E.C. supplies its own patented devices by the use of which the starting a synchronising of a motor converter are effected simply by closing the main switch; the machi runs up to speed and automatically comes into synchronism with the high-tension supp In the operation of the A.C.E.C. patent devices the following general points relating to t starting of motor converters should be taken into consideration.

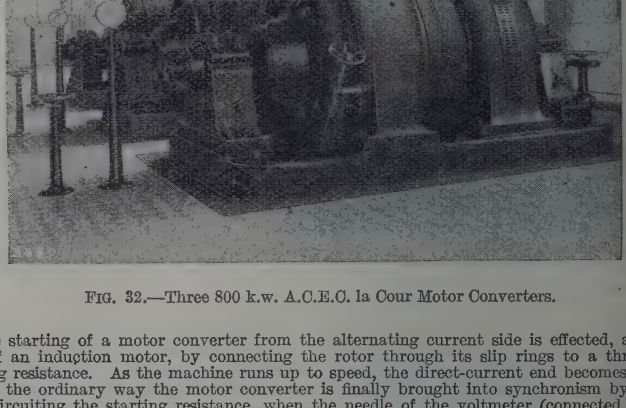

Fig. 32.—Three 800 k.w. A.C.E.C. la Cour Motor Converters.

The starting of a motor converter from the alternating current side is effected, as in t case of an induction motor, by connecting the rotor through its slip rings to a three-pha starting resistance. As the machine runs up to speed, the direct-current end becomes excit and in the ordinary way the motor converter is finally brought into synchronism by quick short-circuiting the starting resistance, when the needle of the voltmeter (connected betwe two of the rotor slip rings) is seen to pass or approach the zero point. It will be readily und stood that the short-circuiting process just described is one of some nicety, requiring the attenti of a skilled and experienced operator, and it is to obviate this difficulty and uncertainty that t A.C.E.C. patented devices have been developed.

These devices are based on the well-known fact that machines of the multiphase stator a single-phase rotor type have a second synchronous speed at half that of the primary field. F starting and synchronising a motor converter in which the alternating and direct-curre ends have the same number of poles, an additional resistance, or, better, a single-phase reactan coil, is connected between two of the slip rings. When the number of poles is different in t two machines, either a single-phase or a three-phase reactance coil is used. The effect of th reactances is to produce a resultant retarding torque when the E.M.F. in the rotor is in advan of the E.M.F. in the armature, and an accelerating torque in the contrary case, so that or the motor converter has attained synchronous speed, it remains in step at that speed.

With the A.C.E.C. patent devices, which embody these principles, the starting and synchron ing operations are as follows:—The rotor circuit being closed on three phases by means of t starting resistance, and on a single phase by a suitable reactance coil, the field rheostat also be

approximately in its normal position, the main switch is closed. The machine at once starts d automatically runs up to synchronous speed, when the needle of the synchronising volt- ter comes back to zero. The rotor slip rings are then short-circuited by means of a three-pole itch, and the short-circuiting device for all the phases of the rotor closed. It will be seen at the whole operation is simplicity itself, and one which can be performed without difficulty risk by an unskilled person.

The fixed starting resistance and the self-synchronising coil, since they are never touched, n be placed in any convenient position, the usual practice being to fix them in the pit below e machine so that no floor space is required for their accommodation. The synchronising ltmeter is generally mounted on the main switchboard.

General Design and Construction.

The practice of building motor converters with three bearings has been abandoned favour of the two-bearing design, except in the case of very large machines. The advantages the two-bearing type are economy in floor space, a simple, strong, and easily accessible arrange- ent of the electrical connections between the rotor and the armature, and the ease with which e set can be erected and dismantled on account of the fact that the rotor and armature are ch mounted on separate shafts provided with massive couplings bolted together at the centre.

The modern design with two bearings entirely avoids the inherent source of weakness and nsequent liability to break down, which is involved by the use of a hollow shaft for the connec- ons between the rotor and armature of three-bearing machines.

Mercury Vapour Rectifiers.

The necessity of converting alternating to direct current in many cases, and the desirability dispensing with running machinery in sub-stations, etc., has led to the development of the ctifying properties of the mercury vapour lamp for this purpose. Essentially the rectifier nsists of an arc *in vacuo* between iron anodes and a mercury cathode, which allows the current pass in one direction only, namely, from the anodes to the cathode, as the names imply. In der to enable the rectifier to deal with large amounts of power, the original glass bulb has en replaced by an iron container, the difficulty of making stanch joints having been overcome. Whereas in rectifying single-phase current the resulting unidirectional current pulsates between ro and a maximum value, in the case of three-phase current the pulsations are reduced in nplitude by using three anodes connected to the three phases; or better still, by connecting the ansformer to give six-phase current and using six anodes, the fluctuation can be still further ppressed. Rectifiers of this type can now be made for outputs of 1,000 amperes per cylinder, id being characterised by small depreciation and maintenance, and high efficiency, besides quiring very little attention, are rapidly coming into use. They work well in parallel with ie another and with a battery; the average overall efficiency is about 90 per cent., the power ctor on full load about 94 per cent. The rectifier is practically independent of frequency and ave-form. As there is a constant drop of 15 to 20 volts through the rectifier, the higher the oltage the higher the efficiency—hence their suitability for high-voltage d.c. traction.

The rectifier consists of an iron cylinder, exhausted to at least 0·1 mm. of mercury, with ie mercury cathode at the bottom and six iron anodes suspended from the cover, suitably sulated. Auxiliary anodes, one for starting the rectifier and two for excitation (to keep the ctifier in operation if the load temporarily falls to zero), are provided. The rectifier chamber water-cooled, as the temperature in the interior must not exceed 70° C., and a cooled chamber n the top of the main cylinder condenses the vaporised mercury, which returns to the cathode y gravitation. A vacuum pump is necessary to maintain the high vacuum, but after the esidual gases are all removed the pump need not be used regularly. Choking coils or induction gulators ensure stability of operation and provide means of regulating the d.c. voltage. The ansformer used in conjunction with the rectifier is specially wound, and is practically equivalent o an ordinary transformer of a k.v.a. rating about 40 or 50 per cent. larger than the d.c. output. . 750-kw. rectifier occupies about the same space as a rotary converter of 100 kw., and weighs ,100 kilograms.

The 'Tungar' rectifier, which is suitable for charging small storage batteries, is more closely llied to the 'valves' used in wireless telegraphy, the cathode being an incandescent filament.

MOTORS.

DIRECT-CURRENT MOTORS.

Shunt-wound Motors.

The shunt is the most common type of field winding, and is generally applied to motors lesigned for operating at constant speed under constant or varying loads. Nearly all com- nercial applications, particularly those of large capacity, require this type of motor. When ecessary, considerable speed variation can usually be secured by means of a rheostat in the ield circuit, increased resistance resulting in an increased speed.

On many shunt-wound commutating-pole motors a stability winding is used on the field fo the purpose of insuring stability under all conditions of operation. This is, in effect, a ligh series winding, which, however, does not change the speed-torque characteristics from those o an ordinary shunt-wound motor.

Series-wound Motors.

These are variable-speed machines particularly adapted to such uses as railway and cran service. The characteristic features of a series-wound motor are its great torque at startin and low running speeds possible.

Compound-wound Motors.

For some special classes of service, in which it is necessary to start under heavy loa and later operate at approximately constant speed, a series winding is added to assist th shunt field at the low-speed points. A compound-wound motor combines the characteristi of both shunt and series-wound motors. In most cases, however, the series winding has com paratively little effect except during the starting period, and may be short-circuited, if desire at higher speeds.

Starting Motors.

Except very small machines, all direct-current shunt and compound-wound motors ar started by first giving the shunt field full excitation and then connecting the armature, with starting resistance in series, to the circuit. The resistance is then cut out in steps as the moto accelerates, the time required to attain full speed varying from about 15 seconds for small, t one minute for large motors. These limits should be used with discretion, since more time required to start with heavy load than with light load.

After all connections are made according to instructions and all mechanical preparation are complete, see that all the field adjusting resistance (if used) is cut out and that the startin resistance is all in circuit. Close the circuit-breaker (if used), then the line switch, and lastl cut out the starting resistance step by step, allowing enough time for smooth speed acceleration Too rapid starting results in excessive starting current and possibly flashing at the brushes. Th motor should generally start when the armature circuit is first closed through the startin resistance, and failure to start when the second or third step of resistance is cut out is a signa to open the line switch or circuit-breaker at once and find the cause of the failure.

Stopping Motors.

Never move a starter or controller handle to the off position under any circumstances by doing so the shunt-field circuit of the motor is opened. The high inductance of th motor field may generate voltage enough to puncture the insulation. If it is necessary to open shunt-field circuit it should be done very slowly, allowing the field current to die out, throug the resistance of the arc across the switch terminals. If a field circuit must be opened in th manner often, a field switch should be installed, so that a local circuit is closed through the fiel before the latter is disconnected from the line. Starting rheostats are usually so arranged tha the field circuit is always closed through the motor armature. If the starter or controller is pro vided with a low-voltage release, the line switch or circuit-breaker should always be opened firs for stopping; the motor speed will then decrease until the starting resistance is automaticall cut into circuit.

Brushholder Adjustments.

The correct position for the brushes in either direction is clearly marked before th machine is shipped, and before starting up the position should be checked. Sparkin at the brushes when the machine is operating with load can frequently be entirely remove by shifting the brushes slowly from or towards the neutral point. In any case the correc distance of the brushes from the neutral point is very slight, and the movement should be mad with great care, for shifting the brushes too much will cause violent sparking.

Care of Commutator and Brushes.

Carbon brushes are used on all direct-current machines nowadays. The chief considera tions in caring for such machines are to keep the commutators clean, the brushes properl adjusted, and the contact surface of the brushes good. The last condition, once fulfille will usually take care of itself until the brushes are worn out, provided the other condition are complied with. At intervals depending on the service and the location, the commutato contact surface and end should be thoroughly wiped with clean cloth that is free from lin

B T-H Motors

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Ball and Roller Bearings

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Aluminium Squirrel-Cage Rotors

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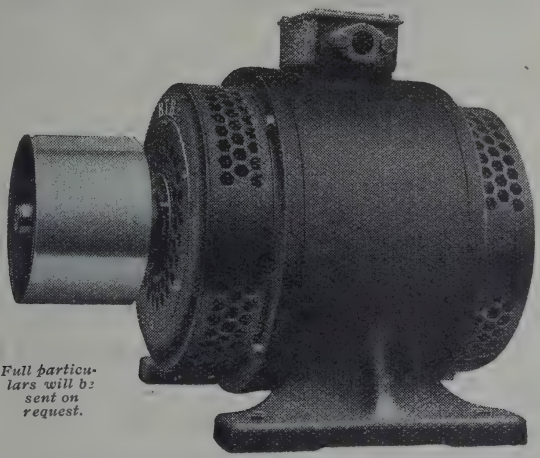

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few drops of oil on the cloth or a piece of paraffin rubbed lightly across the commutator surface will give all the lubrication necessary. Lubricant should be used very sparingly on a commutator, and no grease, oil, or dirt should be allowed to accumulate on the commutator or the brushes.

The ideal appearance of a commutator surface is polished dark brown or chocolate colour. Such a commutator needs no attention other than cleaning when necessary. If the surface has a raw copper colour with gradual roughening, it should be smoothed with sandpaper or, if very rough, with a piece of sandstone; emery paper or cloth should not be used for this purpose. The sandpaper should be held against the commutator by means of a block having the same curvature as the commutator. The sandstone likewise should be curved to fit the commutator. The brushes should be lifted from the commutator surface when using sandpaper or stone, and should not be placed in contact again until the commutator surface is thoroughly cleaned of all gritty particles.

Bedding the Brushes.

When making proper contact with the commutator, the face of the brush is glazed. The glazed portion does not extend over very nearly all the brush face the brushes should be ground in by wrapping a long strip of fine sandpaper closely around the commutator with the rough side toward the brushes and then rotating the commutator and the sandpaper slowly through perhaps one revolution. Shorter pieces of sandpaper held close to the commutator surface and drawn a few times back and forth under each brush or set of brushes will answer the same purpose. The commutator surface should be wiped clean after the brushes have been ground in, and lubricated with a few drops of fresh oil on a clean cloth.

Field Coils.

An open-circuited shunt field coil can be detected by touching the terminals of a voltmeter to the terminals of the individual coils while full voltage is applied to the field circuit. The voltmeter will show no deflection until the defective coil is reached and will then indicate the full voltage.

A short-circuited shunt field can be found by the same test, the voltmeter deflection being least in the defective coil. The short-circuiting of one field coil may result in burning out one or more of the others if full voltage is applied to the circuit.

In replacing a field coil make sure that the polarity of the pole differs from that of either adjacent pole. The polarity can be tested with a small bar magnet or a piece of steel wire suspended from its centre by a string. In holding the magnet near the poles successively it should reverse at each pole, i.e. no two successive poles should attract the same end of the magnet.

Cautions.

Never allow the load to be entirely removed from a series-wound direct-current motor while operating, or to be reduced enough to cause a dangerously high speed. A series motor should not be belted, on account of the possibility of the belt running off, thus permitting the motor to race.

Never open the shunt-field circuit of a motor in operation, otherwise the motor may race and produce serious damage.

When the shunt-field circuit of a motor or a generator is excited, never open it quickly unless a path for the inductive discharge is provided. The circuit can be opened slowly, if desired, the arc at the opening serving to reduce the field current gradually. *Do not permit any part of the body to bridge this opening*, or a serious shock will be received.

Always follow a fixed regular order in closing and opening switches, unless there are special reasons for departing from this order. A routine method will aid in avoiding mistakes. Keep all switches open when the motors are idle. Close switches carefully, keeping firm hold of the handle until completely closed.

A routine method of making inspections, replenishing lubricants, etc., will also prevent oversights and possible damage.

(*Metropolitan-Vickers Instruction Book.*)

AVERAGE EFFICIENCIES OF D.C. MOTORS.

(*Meares.*)

Output, B.H.P.	½	1	2	3	5	10	20	50	100	200
Efficiency, per cent.	73	77	82	85	84	86	87	91	92	93

Specification for Direct-current Motors.

(The English Electric Co. Ltd.)

These machines are of the two end-shield type, and are supplied with standard shaft extensio but without pulley, coupling, sliding base, or foundation bolts, unless otherwise ordered.

Commutation poles are fitted as standard on all sizes from C.B. 7 upwards.

C.B. machines are usually supplied in the Protected or in the Enclosed-ventilated type but they are also made as Pipe-ventilated, Drip-proof, or Totally-enclosed machines.

The *Protected type* motor is so designed that the internal rotating parts and live parts ar protected mechanically from accidental or careless contact, a perforated metal cover bein fitted to the cylindrical opening over the armature fan.

The *Enclosed ventilated* type is similar to the Protected type, but a perforated metal cove is fitted over both cylindrical openings in the frame.

The frame is circular, of cast steel. The four main poles are bolted to the frame and ar laminated except in the smallest sizes, C.B. 5 and C.B. 6, which have solid poles. Commutatio poles, when fitted, are of solid wrought iron.

End shields are in the form of end plates bolted to facings on the magnet frame, and form substantial supports for the bearings.

Ball or roller bearings, or in certain cases a combination of both, are used, and are of ampl proportions. On the larger machines a ball-thrust bearing is fitted.

The bearings are enclosed in dust-proof housings.

This type of bearing has stood the test of lengthy experience in practical use. It requir practically no attention. As the bearings will work equally well in any position, provide the shaft is horizontal, the motor may be fixed to wall or ceiling without altering the position o bearings or end shields, as is necessary with ring-lubricated oil bearings.

The field coils of all sizes are former wound, thoroughly impregnated and taped al over. All coils are heavily insulated from the poles and the frame, to safeguard agains earthing.

The armature is slotted and drum wound, and is specially designed to give thorough ventil tion of the windings, core, and field coils. The core plates are keyed directly to the shaft, an are held in position by two end flanges. The windings are carefully impregnated.

The commutator is built up of segments of hard-drawn copper which are held in positio by end flanges fitting into deep V grooves in the segments.

The brush rocker which carries the brush spindles is mounted on a turned seating on th end-shield. The brush holders are substantial castings, and the brushes are easily replaceabl

A terminal box is arranged on the magnet frame, and is provided with a cast-iron cover. flange is provided on the terminal box to receive screwed conduit.

The standard direction of rotation is counter-clockwise when viewed from the commutato end; if the opposite direction of rotation is required, this must be stated on the order.

The following accessories are supplied as extras, if required :—

Pulley for rope or belt (standard or otherwise) or half-coupling or flexible coupling.

Sliding base with adjusting screws and four bolts for fixing the machine to the base.

Foundation bolts.

Speed Regulation of Direct-current Shunt-wound Motors.

There are three commercial methods of varying the speed of direct-current shunt-woun motors: (1) by altering the terminal voltage; (2) by a resistance in series with the machine (3) by a resistance in series with the shunt circuit. The first method is not employed as a ru with the ordinary industrial motor, but is only used in connection with self-contained plants suc as winding, and certain printing press control equipments. The second method is sometim adopted where a small speed reduction is required. With it, fine regulation is difficult to obtai while the power consumption of the motor remains practically the same throughout the whol range of speed, an amount of the power proportional to the speed reduction being dissipated i the resistance. The method is convenient where it is desired to regulate the speed down t about half for very short periods, such as for crane and haulage work. The third method control is one which has received a good deal of attention during the last few years, and moto have been developed which are capable of speed regulation by field resistance up to 4 : 1, and i certain cases up to 6 : 1, the torque being maintained constant over the whole range.

Such large variations of speed generally require some special device to compensate for t cross magnetisation of the armature due to armature reaction, and for this purpose inte poles or auxiliary poles are employed. The poles are placed mid-way between the main fie poles and carry either the full armature current or a percentage of it. The interpole flux therefo varies directly as the load and as the armature reaction, and as the tendency of the motor spark increases as the load, so the compensating flux increases proportionately.

The size of motors with shunt regulation is determined by the minimum speed and t maximum b.h.p., although it may be necessary for the motor to give a much lower output the minimum speed. This is clear when it is considered that minimum speed requires maximu

and maximum speed requires minimum flux, that the magnetic circuit must be large enough arry the full flux, and that the dimensions of the armature are also determined by the number size of the armature conductors. The only variable, therefore, is the field flux. The efficiency s not largely vary throughout the range of speed at a given load, owing to the fact that at the imum speed the electrical losses are a maximum, whereas the friction and windage losses are

APPROXIMATE COMMERCIAL EFFICIENCY OF DIRECT-CURRENT MOTORS PLOTTED AS A FUNCTION OF THE BRAKE H.P.

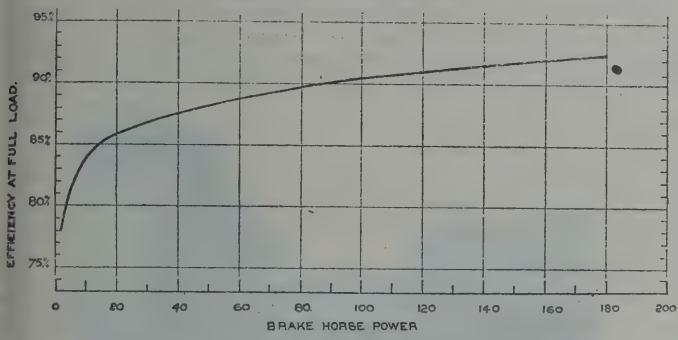

FIG. 33.

nimum ; but at the maximum speed the electrical losses are a minimum and the friction and wage losses a maximum. The curve shown in fig. 33, giving the full-load commercial efficiency as function of the brake horse-power, is typical of constant speed motors running at the normal ds recommended by the British Engineering Standards Association. Motors with series tance regulation have their sizes determined by the maximum speed and maximum out, and although the torque can remain constant throughout yet the output or power will educed in proportion to the speed.

Direct-Current Traction Motors.

DIRECT-CURRENT, SERIES-WOUND TRACTION MOTORS.

*British Standard Specification for Traction Motors (Direct-Current, Series-wound.) No. 173—1923.**

Types of enclosure are : (1) Open traction motor with no unnecessary restriction to ventilation ; protected type in which only rotating and live parts are shielded from accidental contact ; totally enclosed, there being no air circulation between inside and outside of case ; (4) ven- ed, having free circulation between the sides of the case ; (5) grid ventilated, which has orated covers over frame openings and no special provision for air circulation ; (6) self- ilated, having air-fan ; and (7) forced ventilated (draught) type, in which air is forced ugh by external means.

Classes of Rating.—(1) Nominal one-hour rating to be the h.p. output at vehicle axle, at the rated age and constant current, which the motor can produce for one hour, the limit of temperature measured by thermometer being 70° C. on any accessible part of winding and 90° C. on commu- r. (2) Continuous rating is defined as the input in amperes at which motor can be worked at and full rated voltage respectively, the temperature rise measured by thermometer not to ed 85° C. on commutator, and on insulated windings and their imbedding cores 65° C. and . for Class A and Class B insulation respectively. Class A includes enamelled wire and cotton, paper, etc., when impregnated or oil immersed. Class B, asbestos and built-up and cemented insulation.

he motor must run sparklessly in both directions with fixed brush position from no oad to one hour rated load, and without injurious sparking at 30 per cent. excess current input ied for two minutes. The statement of efficiency to be made on result of direct measurement

* By permission of the British Engineering Standards Association.

at 75° C. and not on the basis of addition of losses. The new machine must withstand, at t conclusion of the one-hour test, an alternating voltage, at 25 to 100 frequency, of 1,000 plus tw the line voltage (minimum 2,000 volts R.M.S.), applied for one minute, between the windings a frame. The insulation resistance in megohms, when the high voltage test is applied, to be r less than line volts (1,000 + Rated B.H.P.). The specification lays down methods of carryi out performance and voltage tests, and the information as regards type, voltage, speeds, weig and characteristics, to be supplied by the maker.

The Metropolitan-Vickers Electrical Co. Direct-current Traction Motor.

(The Metropolitan-Vickers Electrical Co., Ltd.)

Fig. 34 is a view of a standard direct-current series-wound motor made by the Metropolit Vickers Electrical Co., Ltd., for tramway service.* This motor is of 45 b.h.p.; the field fram

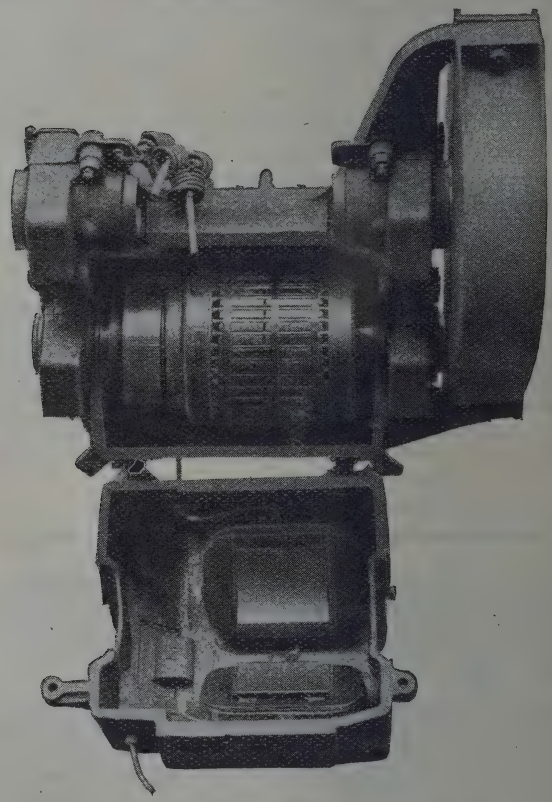

Fig. 34.

of cast-steel divided into an upper and lower half, the two parts being hinged together on the opposite to the axle. The figure shows the lower half hanging open, exposing the arma the bearings of which are bolted to the upper half of the frame. The pole pieces are buil of annealed soft-steel punchings riveted together between wrought-iron end-plates. The

* For 'Electric Traction' see Section XIV., p. 757.

s shown in the figure are held in place by a brass support resting on the projecting pole tip. armature is of the slotted drum type, the core being built up of annealed soft-steel punch- . Ventilation is provided by six axial and one radial air-duct. The armature coils are pletely formed before being put in place and are held by steel wire bands sunk in the ace of the armature, so that in the event of the armature bearings being worn the bands do touch the pole pieces. The winding is of the two-circuit type designed to give a balance rmature circuits should the armature get out of centre owing to wear of bearings. The mutator consists of 117 hard-drawn segments pressed on and keyed to the armature spider. bearings are of cast iron with special Babbitt metal linings; either oil or grease may be

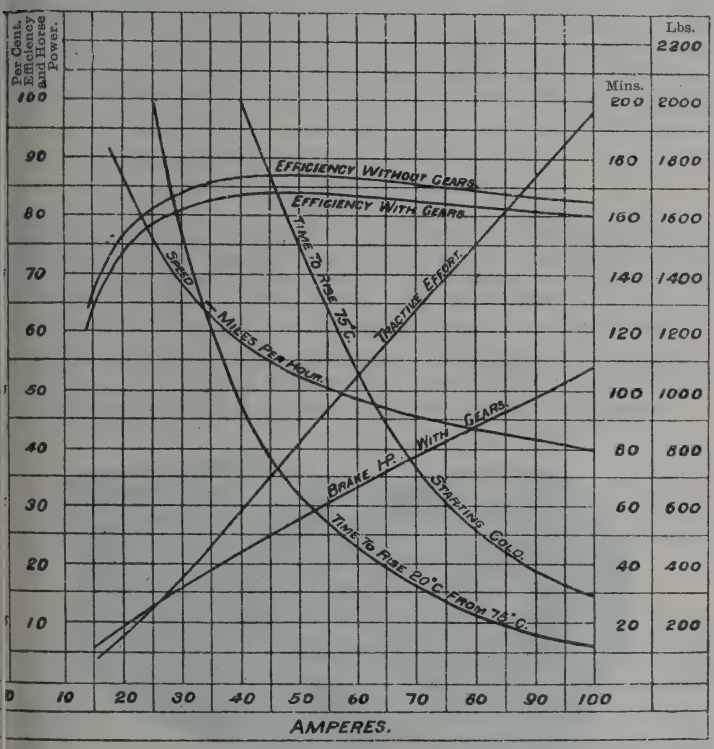

FIG. 35.

l. The pinion is of forged steel and the gear wheel of cast steel made in two parts bolted ther. The gears that may be used vary from a 15-tooth pinion and 70-tooth gear to a 22-tooth on and 63-tooth gear; the standard gear ratio is 16 to 69.

The method of suspension in this case is what is known as the cross-bar type. A rectangular ension-bar is supported on the truck frame, and the motor is bolted to this through machined ngs on the upper field-frame. On the other side the motor is supported on the gear wheel axle he usual way.

The weights of this motor are as follows. Motor complete with gear-wheel and gear-case, 4 lbs. Armature and pinion alone, 540 lbs. Axle gear-wheel and case alone, 340 lbs. The rance between the top of the rail and the lowest part of the motor with 30 in. wheels is $2\frac{3}{8}$ ins.

Fig. 35 gives the characteristic curves for this motor, from which all necessary information

regarding the performance of the motor may be derived. The curves given are those of efficien speed, tractive effort, horse-power, and temperature.

The upper temperature curve shows that under the standard conditions under which tramw motors are generally rated, i.e. 75° C. rise in temperature after one hour's continuous run, t corresponding current for this motor would be 75 amperes, which at 500 volts represents input of 37,500 watts. Following the 75-ampere line to the speed curve, the speed for t current and volts is seen to be 11·1 miles per hour, and continuing the ampere line up to t tractive effort curve the tractive effort is seen to be 1,380 lbs.; this is the useful draw-bar p with gear and driving wheel used in the test. Using the formula watts $= 2 \times S \times T$, t output in watts is found to be 30,600, or 41 horse-power, giving an efficiency of 82 per cent. shown on the efficiency curve for 75 amperes. The corresponding efficiency without gears given as 85 per cent., representing a draw-bar pull of 1,430 lbs., showing a loss of 50 lbs. in t gears. The above rating of 41 horse-power is that for one hour's run; the continuous rat will be considerably less than this, and depends upon the mean terminal voltage. The continuo capacity at 300 volts is given as 38 amperes, and is equivalent to a load of about 550 lbs. at t draw-bar. On the other hand, the motor will stand large momentary overloads without inju or sparking.

G.E.C. 'Witton' D.C. Interpole Tramway Motors.

(The General Electric Co. Ltd.)

These tramway motors are designed for direct voltages 500 to 600 volts, and outputs from 30 90 b.h.p. They can be adapted for operating at 1,200 volts. The weight per b.h.p. has be reduced 28·3 lbs. While the majority of machines in this range are intended for car drivi wheels 33 in. in dia. (new), special motors are available for wheels 24 to 27 ins. in dia. The mot are designed within a minimum track gauge. Among the points of advantage incorporated are

1. Strongly proportioned box frame construction of high permeability cast steel.

2. Positive axial ventilation of the 'parallel flow' type (Oerlikon system), a double fan at pinion end drawing two distinct streams of air through the motor.

3. Hoffman roller armature bearings with lubrication and grease sealing, and reliable locki

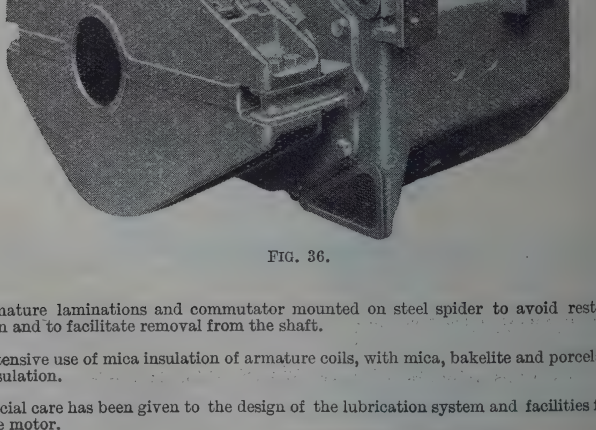

Fig. 36.

4. Armature laminations and commutator mounted on steel spider to avoid restriction ventilation and to facilitate removal from the shaft.

5. Extensive use of mica insulation of armature coils, with mica, bakelite and porcelain bru holder insulation.

6. Special care has been given to the design of the lubrication system and facilities for insp tion of the motor.

7. Large diameter commutator tightened from the front and permitting of renewal of any
nent without removal of commutator.

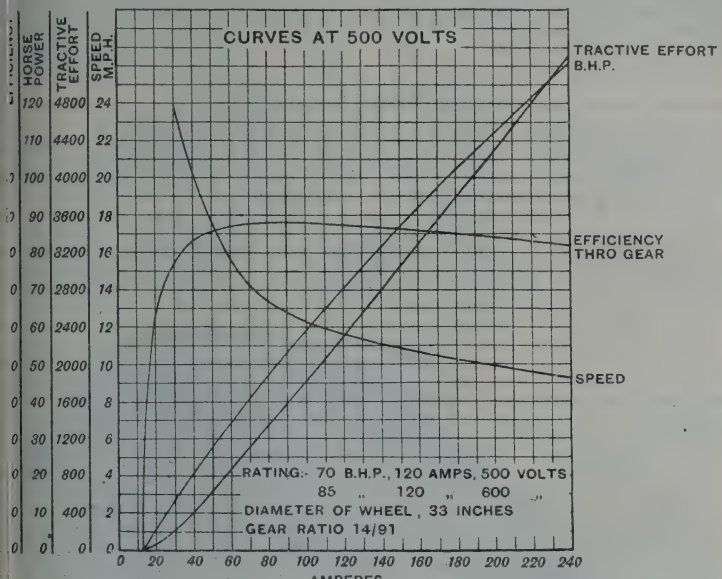

FIG. 37.—Characteristic Curves of G.E.C. 'Witton' D.C. Traction Motor, Type W.T. 32 R.

3. Exceptionally high efficiency.

A general view of the G.E.C. traction motor is shown in fig. 36 and the performance curves in
f 37.

The B.T.H. Co.'s Self-Ventilated, Interpole Traction Motor.

(The British Thomson-Houston Co., Ltd., Rugby.)

As an example of the most modern type of light-weight direct-current series motor made by the
1 .H. Co. may be mentioned the motor rated at 52 h.p., 88 amperes at 525 volts, for a temperature
r by thermometer on the windings not exceeding 25° C. on an hourly rating. The weight of the
n or complete with gearing, gear case and axle linings is 1,865 lbs. for use with wheel diameters of
2 o 27 ins. and 1,990 lbs. for wheel diameters of 30 to 33 ins.

t *Magnet Frame.*—The magnet frame is of cast steel, and is provided with machined seatings for
pole pieces and brush holders.

Armature Bearings.—The armature is carried in roller bearings, designed to take end thrust,
i ddition to the radial load. The bearings are arranged for lubrication with grease; greasers
s fitted with non-return valve, and screw threads for the connection of the grease gun.

Pole Pieces.—The four exciting pole pieces are built up of soft iron laminations, mounted on a
s l key, into which are screwed the bolts for holding the poles to the magnet frame. The
i rpoles are made of drop forged steel.

Armature.—The armature is built up of soft steel laminations, assembled and pressed together
l raulically, and keyed to ensure that no rotational movement takes place with respect to the
s ft. The shaft can readily be removed without disturbing the windings; the commutator can
a be removed independently if necessary.

Ventilation.—The motor is self-ventilated by the parallel method. A double-sided fan is
1 vided at the pinion end of the armature which draws air into the frame at the commutator end,
e elling it at the pinion end. Air flows in two streams, one stream passing over the surface of the
a nature and field coils, while the other passes through the armature, by means of longitudinal
(ts in the commutator shell and core punchings.

Axle Bearings.—The axle caps are of cast steel, tongued and bolted to machined surfaces on

the magnet frame. The caps have liberal-sized oil boxes designed for lubrication by means oily waste. Auxiliary wells are provided for filling and for gauging the supply of oil.

Gear Case.—The gear case is made of malleable cast iron, bolted to the frame at three poir and provided with a door in the upper half, spring closed, for inspection and for lubrication of gearing.

The English Electric Co. Direct-Current Traction Motor.

(*The English Electric Co., Ltd.*)

The direct current series wound traction motor gives in result the effect of the change-sp gear of a motor-car engine, which enables a small-powered motor to exert a big effort when requi for acceleration or for climbing gradients. It is capable of working both large and small ur both for short distances and main line traffic. The three features of design which have contribu to give the d.c. motor its present wide range in traction work are :—

(*a*) commutating poles ; (*b*) ventilation ; (*c*) high-tension design.

(*a*) *Commutating Poles.*—The coils are connected in series with the armature, and their eff is to counterbalance, under the brushes, the field set up by armature reaction, so that commutat under all conditions of loading is practically sparkless, even with the field shunted, thus givin range of economical speed to traction equipments.

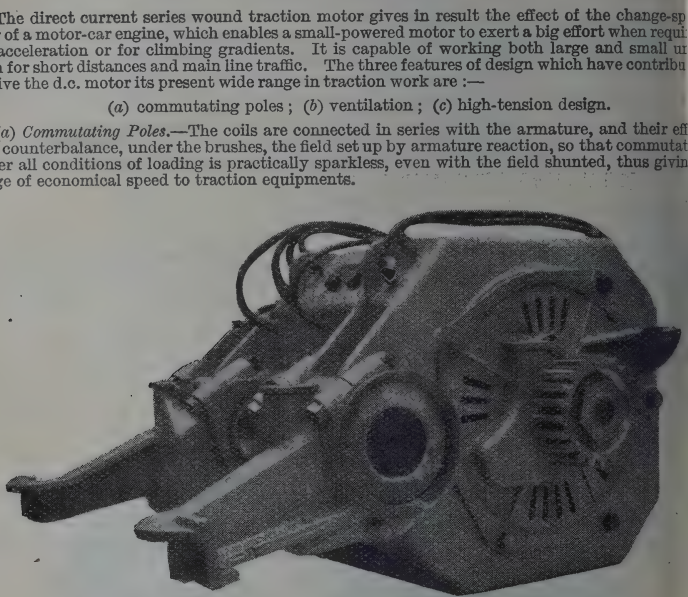

Fig. 38.—English Electric Co.'s Direct Current Traction Motor.

(*b*) *Ventilation.*—Through the introduction of ventilation, it is now possible to transmit u 450 h.p. on a single axle, on standard gauge, with 50-in. wheels, on the one hour rating of the mo

All traction motors manufactured by *The English Electric Company*, ranging from 30 h.p 400 h.p., are fitted with commutating poles and are either self- or forced-ventilated. S ventilated motors range from 30 h.p. to 330 h.p. Ventilation is effected by means of a fan wh forms part of the armature spider at the pinion end. The air is drawn in through apertu at the commutator end of the motor, and expelled at the pinion end. The fan is provided v two sets of blades, one of which draws the air through ventilating ducts in the armature, and other over the surface of the armature and round the fields. Forced-ventilated motors ra from 180 h.p. upwards, the ventilating air being supplied by motor-driven fans.

(*c*) *High-tension d.c. Motors.*—High-tension d.c. motors have been supplied in connec with the following schemes, amongst others :—L.M.S. Railway (England) and Cataluña Rail (Spain), both with a line voltage of 1,200 ; Midi Railway and Paris-Orleans Railway (Fran Midland Railway (New Zealand) ; Imperial Government Railways (Japan) and The Great In Peninsula Railway : the last five having a line voltage of 1,500 ; Montreal Harbour (Canada) voltage 2,400. Motors of similar design are also being supplied for the Morocco Railways f line voltage of 3,000.

An experimental line at 3,500 volts gave entirely successful results.

The high-tension motors are specially insulated, mica and mica compound being u throughout for the insulation of armature, field coils, and brushes, so that the dielectric stren of the machines is not affected at high temperature.

MOTORS "English Electric"

OVER 160 "English Electric" MOTORS

This picture shows a group of motors which is part of an order for over 160 machines built for The Associated Daimler Company's new works at Southall. A large number of these motors are applied to both individual and group driving of various classes of machine tools.

MOTORS ARE STOCKED IN A VARIETY OF TYPES AND SIZES.
The most up to-date designs are available to meet all requirements of efficiency, starting torque and power factor.

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Efficiency

Ransomes' Electric Motors never give trouble. Every machine is thoroughly tested to comply in every respect with B.E.S.A. Specification No. 168/26, thus ensuring a plant with low temperature rise, high overload capacity and efficient insulation.

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RANSOMES' Electric Motors.

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A.C. & D.C. MOTORS.

Protected, enclosed ventilated, totally enclosed and drip-proof machines are supplied, as well as motor-generator sets, steam-driven generating sets, etc.

Write for Catalogues and all information.

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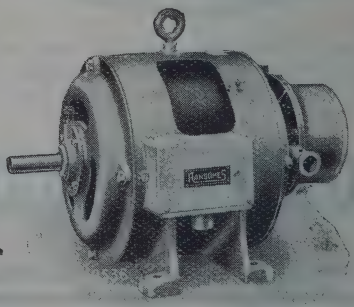

On the larger sizes, such as 350 h.p. motors supplied to Chemin de Fer de Midi, the motors ve on the axles through twin gearing, the teeth of the pinions at each end of the armature ng staggered to assist in giving uniformity of turning moment.

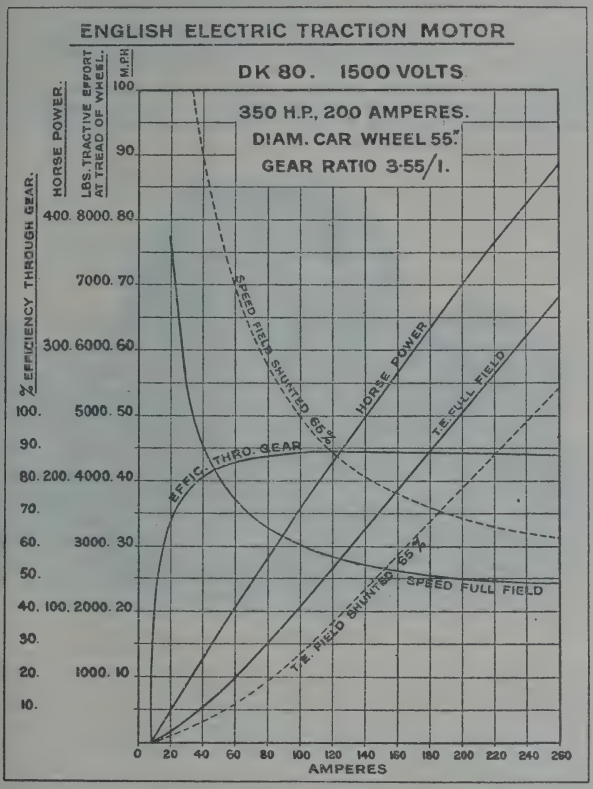

FIG. 39.

Fig. 38 shows a typical English Electric 350 h.p., 1,500 volt, traction motor, of which the cteristic curve is shown in fig. 39.

ALTERNATING-CURRENT MOTORS.

lternating-current Motors may be divided into the following classes:—Synchronous I ction, Induction-type Synchronous, and Commutator Motors.

Synchronous Motors.

n alternating-current generator will, if brought up to speed, excited, and connected to a s able alternating-current supply, run as a motor at a speed in revolutions per second equal t e frequency divided by the number of pairs of poles. Such motors are called synchronous n ors, and they will operate only at synchronous speed. They will not start under l , and have to be started by auxiliary means. If overloaded beyond a certain point t will fall out of step with the supply system and come to a standstill. Their sphere of u ulness is limited, and they are most commonly employed as phase regulators on trans- n ion lines, or for driving direct-current generators.

The English Electric Co. Synchronous Motor.

(The English Electric Co., Ltd.).

The following is a specification of a synchronous motor (Class G.L.), made by the Engli Electric Co.

These machines are made in various standard types as follows: The Engine Base Ty the Sole Plate Type, the Bedplate and Two-Pedestal Bearing Type, the Bedplate and Thr Pedestal Bearing Type, and the Engine Shaft Type.

The *Engine Base Type* consists of a stator frame with feet, core, coils, terminals, and shrou one pedestal bearing, a rotor with poles and field coils, shaft, slip-rings and coupling, compl collector gear, screws for fixing stator frame and pedestal to the engine base, and screws adjusting the height of the frame.

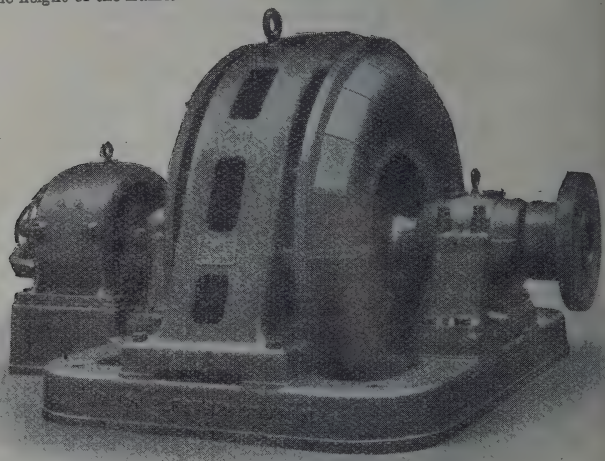

Fig. 40.—English Electric Co.'s Synchronous Motor.

The *Sole Plate Type* is practically the same as the Engine Base Type, with the additio three sole plates suitable for building directly into the foundations.

The *Bedplate and Two-Pedestal Bearing Type* is similar to the Engine Base Type, but a second pedestal bearing and a bedplate on which the stator frame and the two pedestal bear are mounted. The shaft is suitable for drive with solid or flexible coupling or, in special c with a gear wheel, or pulley for belt or rope.

The *Bedplate and Three-Pedestal Bearing Type* is the same as the above, but has a t bearing with a correspondingly extended bedplate. The shaft is suitable for fitting with wheel or pulley for belt or rope.

The *Engine Shaft Type* differs from the Sole Plate Type by the omission of the shaft, coup and the pedestal, together with its sole plate, the rotor being suitably bored for forcing dir on to the engine shaft.

Stator.—The cast iron stator frame is of substantial design and great stiffness, the forming an integral part of the casting.

For the small machines the frame is cast in one piece, but on account of transport limita the larger sizes are cast either in two or four pieces, which are held together by bolts.

Machines of small and medium size can be supplied with either high or low height of cen

The core is built up of best quality core plate stampings of high permeability and low loss, effectively insulated from each other to reduce eddy currents to a minimum. In the sm sizes the stampings are complete rings, in the larger sizes they are in segments.

The outer circumferences of the laminations are located on steel dove-tail keys, and laminations are firmly held in position by means of heavy clamping rings. Ventilating are provided at frequent intervals to allow free circulation of air.

The inner circumference of the core is slotted for the reception of the stator winding.

Semi-closed slots are used whenever possible, as they afford a mechanical support for coils and tend to reduce the excitation loss and the eddy current loss in the pole tips.

The stator winding is usually of the hairpin type held in place in the slots by means of wedges f insulating material. The coils are amply insulated and thoroughly impregnated before being ut into place.

The outhanging portions of the coils are protected from mechanical injury by shrouds secured) the frame. In all cases where the pole pitch is large or the duty gives rise to forces likely to istort the windings, these portions of the winding are supported by special brackets so as to ive as strong a mechanical construction as possible.

Terminals.—Connections from the stator windings are brought out as heavily insulated flexible ads which pass through a cleat board supported on the frame. This arrangement of terminals resents the safest and simplest means of connecting the machine to the external circuit.

Rotor.—The rotor consists of a cast wheel of steel or iron to which the poles are attached.

For the largest sizes the wheel is cast in two or more pieces, the sections being held together y shrink keys and bolts. The hub is held together by shrink rings.

The hub is provided when required with register and bolt circle suitable for bolting direct to ie engine makers' coupling or with a sleeve extension for bolting direct to the engine makers' ywheel. In small and medium-sized rotors, the centre, sleeve and coupling are cast in one piece.

The poles are rectangular in shape, being either steel castings or built up of steel stampings, either case of high permeability material. They are secured to the wheel by means of bolts rovided with lock washers, which pass through the rim from the inside.

For the small sizes when space does not permit of these bolts, the pole laminations are punched ith dove-tails for fixing into the rotor centre. These dove-tails are held in place by two taper edges.

The pole stampings are held together by heavy rivets passing through cast steel flanged end ates, the flanges being formed so as to serve also as supports for the field winding.

All pole pieces are built to permit the use of a damping winding when required, as, for example, connection with synchronous motors, single-phase machines, and generators driven by gas oil engines and generally to facilitate parallel operation with other generators. The bars hich pass through the pole face are efficiently connected by welded joints to the end rings.

Field Coils.—Whenever possible the field coils consist of copper strip wound on edge and refully insulated from the pole limb. This form of winding is specially recommended owing the excellent cooling of the windings and its great mechanical strength. It is advisable, herefore, to select a low voltage for excitation, so that a strip-on-edge winding can be used.

Slip-rings.—These are of gun-metal and are subjected to special heat treatment which makes r good wearing quality of the rings and brushes. The rings are shrunk on to a cast-iron bush sulated by a micanite sleeve. The complete bush with rings is pressed on to the shaft. The ds connecting the rings to the rotor windings are designed so that they can be replaced if ecessary without removing the rings.

Brushes and Brush Gear.—The brush holders and brushes are liberal in size, and there are ually two brushes for each ring mounted in one holder.

The brushes used are of a special composition of copper and carbon, which gives low brush sistance, low contact resistance, and low coefficient of friction.

The bearing at the collector end is provided with a seating for supporting the brush spindles hich carry the brush holders.

Shaft.—The shaft is designed on ample lines. It is of forged steel finished to size by grinding the bearing surfaces. The rotor centre, which is pressed hydraulically on to the shaft, is held place usually by one key sunk in the shaft, but where the drive renders it advisable, tangential ys are used.

Bearings.—The bearings are of the self-aligning sleeve type liberally designed. All bearings e split horizontally to facilitate inspection and removal.

Best quality white metal only is used for the lining. The bearings are of the self-oiling type th adequate oiling rings, the housing being made with a generous reservoir of oil provided th a definite system of oil circulation for the proper lubrication of the bearing and the cooling the oil.

The housing is furnished with overflow, oil gauge, and drain plug.

Means are provided to prevent oil creeping along the shaft outside the bearing and so reaching e windings.

Balance.—Great importance is attached to smooth running, and the rotor is balanced both ring manufacture and at final erection to ensure this feature.

Ventilation.—In these machines special attention has been given to providing a positive stem of ventilation. Air is driven outwards by fan blades on the rotor and is directed on to e windings and core by the special formation of the shrouds protecting the overhanging portions the stator winding.

Exciters.—Whenever conditions permit, direct-coupled exciters are used. In most cases e direct-coupled exciter has its armature overhung on an extension of the main shaft at the llector end, no outboard exciter bearing being used.

The exciter frame is mounted either on a stool fitted to the bedplate or sole-plate, or ernatively on a cast-iron bracket bolted to the bearing housing. In exceptional cases belt iven exciters are used, in which case the exciter has to be supplied with a sliding base, belt d the necessary pulleys both on the exciter and synchronous machine.

Induction Motors.

Induction motors may be classed as polyphase or single-phase induction motors. Th action of a polyphase induction motor may be likened to that of a direct-current moto in which both the fields and the armature are capable of rotation. Supposing the fields of suc a motor to be fully excited and rotate with the armature at rest and short-circuited, a curren of any desired magnitude may be induced in the armature, since the generation of a curren depends simply on the relative motion of the fields and the armature. The torque produce by the action of the fields on the induced current will tend to turn the armature, and if the field be kept rotating at a uniform rate, the armature will speed up until the relative motion of th fields and the armature is sufficient to generate a current that exactly balances the load ; uniform speed has then been reached. The slip, or the difference between the speed of the armatur and the speed of the fields, is generally stated in per cent. of the speed that would be reache if the armature were rotating at the same speed as the fields. This speed is spoken of as th speed of synchronism. In a polyphase induction motor the rotation of the field is produce by magnetising the fixed part, or stator, by two or more alternating currents in such a wa that the resultant magnetic field rotates at a uniform speed. Generally three alternating current are used differing in phase by 120°. One advantage of such a motor over the direct-curren motor is found in the absence of a commutator, for the current in the armature, or, as it is called the rotor, can be induced by short-circuiting its coils, the current from the line being led directl into the stator without any moving contacts.

In the single-phase induction motor there is an inductive action between the field and th armature, similar to that which takes place in a polyphase induction motor : the field, however is not a simple rotating field, but may be regarded as two fields rotating in opposite directions The result of this is that at starting the armature is subject to an equal pull in both directions— in other words, the motor will not start by itself. But when once the armature has been started in either direction, the torque in that direction increases while that in the opposite directio decreases. As a result, the motor works as an induction machine at a speed just belo synchronism similarly to the polyphase motor. This type of induction motor therefore need some special starting device.

In a polyphase system the ratio of the power component of the current to the total current as measured by the power factor, depends mainly upon the width of the air-gap between th fixed and moving parts of the motor. Hence it is of great importance to reduce the clearanc to the smallest limit consistent with safety. This necessitates very careful construction, espe cially for polyphase motors on railways. Experience shows that induction motors can be con structed to run well under all conditions.

Variation of Speed with Load.—In a normal polyphase motor the speed is nearly independen of the load. This is in marked contrast to the d.c. series motor, but shows a strong resemblanc to the torque-speed characteristic of a normal shunt motor.

Maximum Load.—As the load increases the speed slightly decreases, until the maximum loa is reached. If the load be increased beyond this the motor is brought to a standstill. In prac tice the working load should not exceed 50 to 60 per cent. of the maximum load.

Speed Regulation.—If resistance be placed in the circuit of the rotor so as to increase th total resistance, say, to double its value, the slip for equal torque will be double what it wa with the original resistance. Thus with any load not greater than the maximum, any require speed can be obtained by merely altering the rotor resistance. This is a wasteful method o speed regulation, and various methods are in use for obtaining economical speed control. Thes include :—

(1) Changing the number of poles, with or without change in the number of phases.

(2) Cascade connection with one or more motors.

(3) Addition of variable-speed set.

Starting.—There is a certain rotor resistance corresponding to standstill with maximu torque. If the rotor resistance has this value at the moment when the motor is connected t the line, it will start with its maximum torque. If the resistance is suitably taken out of th circuit as the motor speeds up, the torque during starting can be maintained constant at an value not greater than the maximum. In other words, the torque, and therefore the acceleratio can be maintained practically up to full speed.

Windings.—There are two kinds of windings. In the first the rotor winding consists o copper bars, rather longer than the rotor core, which are all connected together at their end In the second the rotor has a winding arranged in such a manner as to allow of an outside resis ance being introduced into the rotor at starting to supplement for the time being the resistanc of the winding. The former is shortly described as a ' short-circuited ' or ' squirrel-cage ' roto the latter as a ' slip-ring ' rotor.

Comparison of Motors.—If the full voltage is applied to the motor at starting with the rotor short-circuited there will be, owing to the low resistance of the bars, a considerable rush of current at starting. In the motor with the slip-ring rotor the current at starting may be kept quite low by means of the supplementary resistance. When giving its full-load effort at starting, such a rotor with resistance in its circuit will take its normal full-load current. A short-circuited rotor will take several times this, but the current can be kept down by using a starting transformer or star-delta switch. These appliances feed the motor at reduced pressure until it begins to get up its speed, but they render motors with short-circuited rotors suitable only for moderate starting torques.

On account of the constructional simplicity of short-circuited rotors it is preferable, whenever possible, to use motors having these. Save as regards starting current, the short-circuited rotor is superior in every respect to the wound rotor. The momentary excess of current it takes at starting does no harm to a small motor, but its effect on the regulation of the supply system may be sometimes objectionable, a point which must be carefully considered.

Effect of Starting Motors.—In choosing motors it is necessary to distinguish between those intended to work on town supply mains where the greater part of the current is used for lighting, and those suitable to a scheme in which the bulk of the current is used for power, the lighting being but incidental. In the former case it is necessary that the working of motors should not interfere with the constancy of pressure on the lighting circuits; in the latter case an occasional jump in the lighting may be of no importance.

The effect of a sudden overdraft of current at a low power factor is disturbance to a greater or less extent of the whole supply system, and fluctuations in pressure such as would cause no inconvenience in the working of a power transmission plant would not be permitted on town lighting circuits. The magnitude of the disturbance depends primarily on the amount of the overdraft relatively to the capacity of the generating plant, and to the margin of current-carrying capacity in the supply network.

Choice of Motors.—It will be evident from the foregoing that the choice of the motor depends upon circumstances, and that neither class can be pronounced the better under all conditions.

Motors with short-circuited rotors take momentarily up to five times their full-load current, if at starting they have to give their full-load effort, or from one to one-and-a-quarter times their full-load current giving 25 to 30 per cent. of their full-load effort, and using a starting device. For connection to town mains it is usual, consequent on the possibility of disturbance to neighbouring lighting circuits which might arise from the starting, to limit this class of motor to 5 h.p. or so, when it has to start at full load effort, or to 10 h.p. when operated with a starting transformer.

In a power transmission scheme where there are no neighbours to consider and the lighting is subsidiary, the short-circuited class of rotor can be employed for large sizes, provided that at starting no individual motor takes a current great enough to prejudicially affect the working of the plant. Thus, in a 500 h.p. transmission, motors of 25 h.p. may be switched right on to the mains without the use of starting transformers, while if the starting effort required is only from 25 to 30 per cent. of the full load effort, motors of 50 h.p. provided with starting transformers are quite permissible.

The conditions under which motors with **slip-ring** rotors should be used are determined by elimination, that is to say, motors of this class are installed in all cases where it is not advisable to use the other. They have their place on town mains for sizes above 5 or 10 h.p., and in power transmission work, when they have to start at full load effort, and their sizes are comparatively large in proportion to the generating plant. Again, in all cases where motors have to start with overload effort, a slip-ring rotor should be used. Not only do motors of this class give at starting their full load effort with only full load current, but 50 or 100 per cent. over the full load effort can be obtained with a current proportionately increased. This control of the current at starting constitutes the advantage of motors with slip-ring rotors.

The curve in fig. 41 shows the power-factor at full-load of polyphase induction motors, as designed by Messrs. Crompton & Co., plotted as a function of the horse-power per revolution. Other things being equal, the maximum power-factor that can be obtained depends upon the number of poles with a given core diameter. For the same size of machine the larger the number of poles the lower will be the power-factor. It will be noticed from the curves that as the size of the machine increases the curves become very flat, and therefore after a certain point a very large increase in size will only increase the power-factor by a very small amount. For the smaller motors, however, the power-factor increases much more rapidly with the size. The horse-power ratings shown are for a normal temperature rise, and show the maximum power factor that can be reached in these conditions.

The standard windings of these motors are arranged to work on voltages of 110, 220, 440, and 500. They can, however, be wound for any other periodicity and for any higher voltage. The machines can be supplied for polyphase or single-phase circuits with either slip-ring or short-circuited rotors. They are manufactured in 19 standard sizes and are supplied in the same types, and are of the same substantial design and construction as the direct-current motors.

The machines are designed to give a high power-factor at all loads, and to withstand heavy overloads before stalling. When required to start against a load, it is advisable to use motors with slip-ring rotors and starting resistances. Motors with short-circuited rotors are capable of exerting their full-load torque when starting, but the sudden rush of current may be as high

CURVE SHOWING THE POWER FACTOR OF POLYPHASE INDUCTION MOTORS PLOTTED AS A FUNCTION OF THE H.P. PER REVOLUTION.

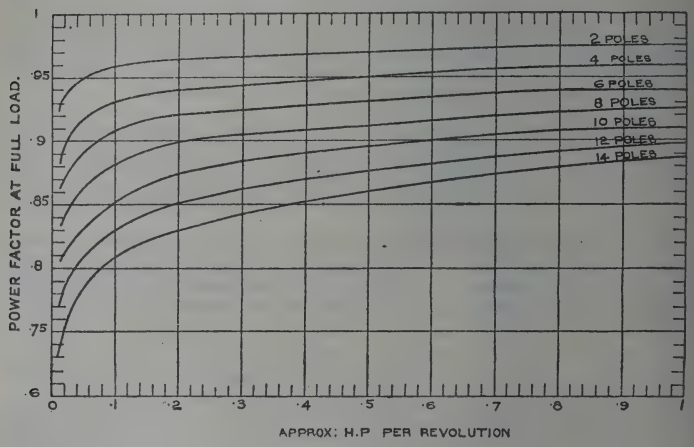

FIG. 41.

as four or five times the normal full-load current. Motors of this type may be either switched direct on the line or a special auto-transformer may be used to reduce the line current at starting. Special motors can be designed with permanently short-circuited rotors, and with high resistance winding, capable of starting up against the full-load or even higher torque, but such motors are usually required for special kinds of intermittent working, such as hydro-extractors.

SPECIFICATION FOR INDUCTION MOTORS.

(*The English Electric Co. Ltd.*)

The standard machine consists of stator frame with end shields, rotor, terminals, and complete internal connections. Unless otherwise stated in the quotation, the machine is supplied without pulley, coupling, sliding base, foundation bolts, or spanners.

These motors are usually supplied in the Protected or in the Enclosed-Ventilated type, but they are also made as Pipe-ventilated or Drip-proof Motors.

The *Protected type* motor is so designed that the internal rotating parts and live parts are protected mechanically from accidental or careless contact, a perforated metal cover being fitted to the cylindrical opening over the rotor fan.

The *Enclosed-ventilated type* is similar to the protected type, but a perforated metal cover is fitted over both cylindrical openings in the frame.

The stator frame is of cast iron. The stator core is built up of insulated stampings bedding directly on the stator frame. The coils are of the 'push-through' type in the larger sizes and of the 'dropped-in' type in the smaller sizes, the slots being nearly closed.

The rotor is built up of stampings with nearly closed slots.

In the case of squirrel-cage rotors the end rings are cast on to the rotor bars. The winding is specially designed to give a good starting torque.

In slip-ring rotors the ends of the windings are separated sufficiently to allow a free circulation of cool air.

A cast-iron terminal box is provided on the stator frame, and is fitted with a flange to take screwed conduit. Up to 650 volts, six terminals are provided, but for certain 210-volt motors the standard terminal box will take three terminals only. For pressures above 650 volts three porcelain-insulated terminals are provided.

A trifurcating box can be supplied to fit the above-mentioned terminal box. A trifurcating box can also be supplied for the rotor leads.

End shields are in the form of end plates bolted to facings on the stator frame, and form substantial supports for the bearings.

Ball or roller bearings, or in certain cases a combination of both, are used, and are of ample proportions. On the larger machines a ball-thrust bearing is fitted.

The bearings are enclosed in dust-proof housings.

This type of bearing has stood the test of lengthy experience in practical use, and is particularly advantageous in the case of induction motors, as there is no appreciable wear of bearings and consequently no change in the length of air gap after extended use. As the bearings will work equally well in any position, provided the shaft is horizontal, the motor may be fixed to wall or ceiling, without altering the position of bearings or end shields, as is necessary with ring-lubricated machines.

The slip rings are of phosphor bronze, and are arranged outside the end shield on an extension of the motor shaft. There is no earth connection to the slip rings.

The standard design permits of the addition of a short-circuiting and brush-lifting device, by which, through the movement of a hand wheel, the slip rings are short circuited and the brushes lifted out of contact with the rings, thus increasing the efficiency of the motor and reducing wear on both slip rings and brushes. With this device, a cover giving total enclosure to the slip rings is always supplied, and the brush holders are of the lever type.

If the short-circuiting and brush-lifting device is not provided, the slip rings are enclosed in a perforated metal cover and box-type brush holders are used.

The following accessories are supplied as extras, if required :—

Pulley, standard or otherwise, or half-coupling or flexible coupling.

Sliding base, with adjusting screws and four bolts for fixing the motor to the base.

Foundation bolts for fixing the sliding base to the foundations.

Spanners and spanner rack.

The Cascade Induction Motor.

The 'cascade' principle was originally applied to two motors mechanically coupled with heir windings electrically connected in such a way as to make it possible to obtain two speeds. n the case of induction motors, the arrangement adopted was to connect the rotor slip-rings of notor No. 1 to the stator windings of motor No. 2, the torque of the combination being conrolled by resistances placed in the circuit of the rotor of No. 2, slip-rings being used. If both nachines had an equal number of poles, the 'cascade' connection gave effects equivalent to loubling the number of poles. Or if, for example, one was an eight-pole and one a four-pole notor, the speed for 'cascade' connection was that for a twelve-pole machine. Considerable ise has been made of this system, notably on railways, the locomotives on the Valtellina line nd for the Simplon tunnel being operated on this principle. The same effect may be secured y connecting the two rotors in series : the starting resistances may then be placed in the stator ircuit and the use of slip-rings can be avoided.

In the Hunt 'Cascade' Induction Motor made by Sandycroft, Ltd., this principle has been deeloped so that the advantages secured hitherto only with two motors can be obtained in a single notor. In an ordinary induction motor, the stator acts on the rotor and there the inductive ction stops. Starting torque and speed regulation can only be obtained by inserting resistances n the rotor winding. In the 'Cascade' motor, the rotor, by means of a supplementary magnetic eld, reacts inductively upon the stator, to which the starting and speed regulating resistances re connected. The rotor in fact reflects back to the stator part of the energy received from t. This is accomplished by winding the rotor in such a way that it can, under the inductive ction of the stator, simultaneously produce two magnetic fields of different numbers of poles ; ne of these reacts on the stator and generates in its winding induced currents. Each branch f the stator winding is divided into two parallel circuits which are tapped at suitable points. n the case of single-speed motors, or two-speed motors requiring starting or regulation with educed rheostatic losses below two-thirds speed, these points are connected to resistances by hich the torque and speed are controlled.

Owing to the presence of two magnetic fields, one of which is at its maximum when the other s at its minimum, a very even turning movement is obtained at slow speeds, and a perfectly even pull with maximum torque can be obtained at as low as two revolutions per minute. This s a feature of importance with all kinds of winding engines. The slip of an induction motor lepends upon the resistance of the windings in which the secondary currents circulate. In the Cascade' motor, these windings are in the stator and are of very low resistance, consequently he slip in these motors is very much less than that of ordinary induction motors, and the speed

variation between full load and no load is only about 1·2 per cent. For constant speed wor the absence of slip-rings is a matter of moment, especially in mining installations. These moto develop full-load starting torque with full-load current, and have a higher power factor tha ordinary motors at low speeds where the tendency is for the power factor to become unfavourabl

The question of economical running at two or more speeds is one of great importance. Th synchronous motor must run in step with its generator, and the induction motor runs at a spee very nearly that of synchronism. The speed of the former cannot be varied, the speed of th latter can only be varied by inserting resistances in the rotor at great loss of efficiency. A simpl modification of the windings of the 'Cascade' motor, described above, enables two speeds to b obtained without rheostatic losses. Slip-rings are connected to a normal rotor winding in sta mesh connection. When these rings are open circuited, the portion of the winding connecte to the slip-rings is idle, the rotor reacts on the stator, as previously described, and the moto runs at 'Cascade' speed. When the slip-ring circuit is closed, the rotor winding becomes sym metrical, and produces only one number of poles; there is no reflex action on the stator and th motor runs as an ordinary induction motor. Thus, for example, in a twelve-pole 'Cascade motor, running at 500 r.p.m., there are two fields, one of eight and one of four poles, the latt being the result of rotor reaction. When this is removed by current through the slip-rings, th effective number of poles is eight, and the motor runs at 750 r.p.m. without any resistance. I intermediate speeds are required, they may be obtained by the use of resistances in the usua manner. Other economical speed changes can be obtained in addition by Creedy's extension o the principle of the cascade motor, or by pole-changing, etc. A special application of the two speed motor, apart from economical running at two speeds, is the avoidance of large startin peaks by two-speed starting in connection with winding and similar work, combined with a reduc tion in starting losses.

A self-synchronising synchronous type of Hunt motor is now on the market and has man unique features. It resembles the Cascade Induction Motor, but has a modified form of stato winding. At synchronous speed the auxiliary field is stationary, and is excited by direct curren supplied to the stator windings. These windings are connected to form two parallel-connecte star windings, and the exciter is coupled to the neutral points. The direct current produce a field having half as many poles as the main field. The machine is started by resistance connected to the slip-rings, and when so connected the speed can be taken up to synchronou (Cascade) speed or even above it, so that all the usual difficulties of pulling-in are obviated The motor will start and synchronise with loads of two to three times normal, and with a high starting-power factor and low current consumption. With motors designed for a leading powe factor of 0·7, the starting current for full-load torque is of the order of 10 per cent. to 15 pe cent. more than normal full-load current, and the starting-power factor is 88 per cent. to 9 per cent., depending upon the speed for which the machine is built. A remarkable featur possessed by this machine is its entire immunity from 'hunting' or 'phase-swinging.' Extensiv tests have been made, but no trace of these troubles has ever been found.

The latest development of the Hunt machine is a self-paralleling generator. This moto closely resembles the synchronous motor, but, as slip-rings are not required, the rotor windin is of the low-voltage short-circuited type as used for the induction motor. These machine possess the same properties as the synchronous motor, and will run in parallel under condition which would be impossible with generators of the usual type.

Induction-type Synchronous Motors.

The induction-type synchronous motor is a polyphase motor with a cylindrical rotor; it i started as an induction motor of the slip-ring type, and synchronises itself when direct curren is switched on the rotor. It combines the good starting characteristics of the induction moto with the property of power-factor correction of the synchronous motor, and for this reason its use is extending. It may with advantage be run at a leading power factor at all loads; th leading current increases somewhat as the load is reduced, and the speed is constant at all loads A small d.c. exciter is mounted on the motor shaft. The stator is identical with that of the ordinary induction motor; the rotor may be wound three-phase or single-phase. Whilst starting, with a resistance in the rotor circuit, the machine exerts a large torque, and can be made to accelerate against more than double full-load torque. The maximum current during starting is about twice the full-load current, and persists for a very short period. The overload above which the motor falls out of step is 100 per cent. or less, depending on the power factor for which the machine is designed; on falling out of synchronism it will usually continue to run as an induction motor until the overload is reduced. In the operation of starting, the main notch is closed, and the rotor starting resistance is gradually cut out and short-circuited. The rotor circuit is then momentarily opened, and closed on the exciter; and the exciting current is adjusted to give the desired leading power-factor.

In some cases the power is supplied to the rotor, and the excitation to the stator.

The efficiency is slightly lower than that of a plain induction motor; the cost is 25 to 40 per cent. higher (including all accessories). The machine is most suitable for a continuous load of 100 h.p. or more.

AVERAGE EFFICIENCIES OF POLYPHASE INDUCTION MOTORS.

(*Meares.*)

)utput, B.H.P.	1	5	10	20	50	100	150	200	300
fficiency per cent.	80	85	86	88	89	90	91	92	93

Alternating-current Commutator Motors.

Alternating-current commutator motors are in most respects similar to ordinary direct-urrent motors, and may have either series or shunt characteristics. They operate under serious lisadvantages, owing to the transformer e.m.f. induced in the coils short-circuited by the brushes, ıecessitating a low commutator voltage; but for certain purposes they are practically indis-ıensable. For single-phase railroad traction the 'neutralised series' motor is used, the speed ıeing controlled by a variable-ratio transformer. For smaller powers the single-phase 'repul-ion' motor is very suitable, the speed being controlled by moving the brushes over a range rom standstill to 30 per cent. above synchronism. Single-phase commutator motors with hunt characteristics are also satisfactory machines. The efficiency of single-phase shunt commu-ator motors is somewhat lower than that of direct-current motors, and the cost somewhat higher, ut the weight is less.

Three-phase commutator motors are also made to work with a series or with a shunt charac-eristic, but have not come into extended use, except for special applications such as steel rolling-ill drives. Where variable speed is necessary, the multi-speed or the cascade induction motor an be considered as alternatives to a.c. commutator motors.

VARIABLE SPEED POLYPHASE COMMUTATOR MOTORS.

(*The British Thomson-Houston Co., Ltd.*)

This motor, known as the Schrage motor, has been developed by The British Thomson-ouston Co. for industrial applications requiring variable speed. While possessing the speed ıaracteristic of a d.c. shunt-wound motor, it is suitable for operation on polyphase alternating ırrent circuits.

The motors are provided with the following windings:—

(1) Primary winding located on the rotor and, by means of slip rings, connected to the supply ads.

(2) Secondary winding located on the stator.

(3) Regulating winding placed in the same slots on the rotor as the primary winding. The gulating winding is connected to a commutator and thence, by means of brushes, in series with ıe secondary winding on the stator.

For normal speed regulation, no external resistance is required in order to effect speed variation, ıd hence the motor operates with high efficiency at all speeds. Normal speed variation obtained simply by turning the handwheel provided, which changes the position of the brushes ı the commutator. The movement of the brushes can also be effected very conveniently from distance either mechanically by means of wire rope and pulleys or by spindle and bevel gear heels, or electrically by means of a small pilot motor coupled to the brush-shifting spindle and ntrolled by push buttons.

The polyphase shunt motor—unlike the d.c. variable-speed shunt-wound motor, where the aximum torque is developed at the lowest speed and decreases as the speed increases—exerts constant torque throughout the whole speed range, i.e. the output is directly proportional to ıe speed.

The normal speed range of the standard motor is 3 : 1.

The motor operates at speeds above or below the synchronous speed and at any speed between ıe maximum and minimum values. When running near synchronous speed the motor operates ctly as an ordinary induction motor, the secondary winding being short-circuited through ıe brushes across one or more commutator segments. According to the amount that the two ts of brushes are displaced in one direction or the other, so the speed will vary either above or elow synchronous speed. It is usual, therefore, to select a synchronous speed about midway etween the maximum and the minimum speeds desired.

The difference between the no-load speed and the full-load speed for any brush setting is pproximately 5 per cent. to 10 per cent. of the maximum speed of the motor, the exact per-ntage depending on the size of the motor. A creeping speed can be obtained by inserting a nall resistance in each phase of the stator winding.

This motor is more stable than the ordinary induction motor when running at creeping speeds ecause it has normal operating speeds much below the synchronous speed.

Reversal of direction of rotation is effected by interchanging two of the line leads connected ı the slip-rings.

Carbon Brushes.

*British Standard Specification for Parallel-sided Carbon Brushes for D.C. Commutator Machines No. 96—1922.**

Definitions are given of centre line, brush dimensions, chamfer, and bevel, and these ar exemplified by figs. 42 and 43, chamfer being the slope produced by removal of the four edges t prevent binding in holder box, and measured by taking one-half of the difference in side dimen sions before and after chamfering (see Table II.). Flexibles to be of twisted copper strand, th diameter of each individual wire not exceeding 0·0048 inch (0·12 mm.). One terminal only c the shoe type pressed on to the flexible shall be provided, the copper terminal shoe for all size

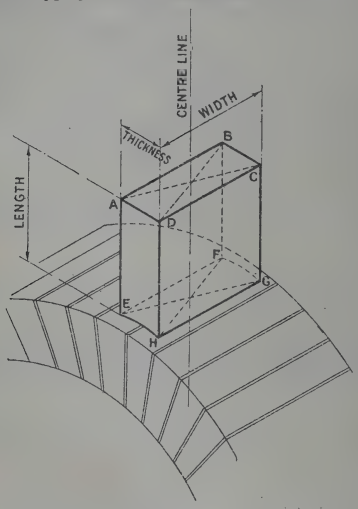

FIG. 42.

ABCD is the top.
EFGH is the contact surface.
AEFB, CGHD } are the sides.
BFGC, DHEA }
AE, BF, CG, DH are the edges.

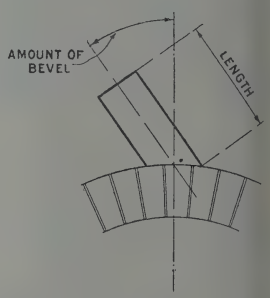

FIG. 43.

being suitable for a No. 1 B.A. fixing screw (Table I.). Table III. refers to all classes of carbo and metal carbon brushes. Dimensions of compressed, unburnt graphite brushes increase wit temperature. Sizes, when cold, must be stated by maker, and shall be less than values in Table I at maker's discretion. When hot, dimensions must not exceed the values in Table III. Toleranc permitted in actual dimensions stated by maker: length +0·060 inch, width +0·008 inch thickness +0·006 inch to −0·000 inch in each case. The brush boxes shall be of the sam nominal size as brushes with tolerances of width +0·008 to +0·001 inch, thickness +0·005 t +0·001 inch.

TABLE I.—FLEXIBLES AND TERMINALS.

Brush No. (See Table III.)	Number of Flexibles.	Length of Flexible.	
		Inches.	Approx. Metric Equivalents. mm.
1 to 3	1	3	76
4 to 8	1	3½	89
9	1	4	102
10 to 15	2		

* By permission of the British Engineering Standards Association.

TABLE II.—AMOUNT OF CHAMFER.

Brush No. (See Table III.)	Chamfer. Inch.	Chamfer. Approx. Metric Equivalents. mm.
1 to 3	0·040	1·02
4 ,, 8	0·060	1·52
9 ,, 15	0·060	1·52

TABLE III.—NOMINAL DIMENSIONS.

Brush No.	Length. Inches.	Length. Approx. Metric Equivalents. mm.	Width. Inches.	Width. Approx. Metric Equivalents. mm.	Thickness. Inches.	Thickness. Approx. Metric Equivalents. mm.
1					¼ 0·250	6·35
2	1½ 1·250	31·75	⅝ 0·625	15·88	5/16 0·3125	7·94
3					⅜ 0·375	9·53
4					5/16 0·3125	7·94
5					⅜ 0·375	9·53
6	1½ 1·500	38·10	⅞ 0·875	22·23	½ 0·500	12·70
7					⅝ 0·625	15·88
8					¾ 0·750	19·05
9					⅜ 0·375	9·53
10					½ 0·500	12·70
11					⅝ 0·625	15·88
12	1¾ 1·750	44·45	1¼ 1·250	31·75	¾ 0·750	19·05
13					⅞ 0·875	22·23
14					1 1·000	25·40
15					1⅛ 1·125	28·58

The dimensions of copper-plated brushes shall be measured over the plating.

British Standard Switchgear.*

Specifications for air-break switches and circuit breakers for pressures up to 660 volts are ven in the *British Engineering Standards Association's Reports* Nos. 109 and 110, 1923. ıe specifications do not apply to switchgear for use in circuits containing high inductance. sts of standard current ratings are given, and it is specified that the temperature rise on con- ıuous full load shall not exceed 20° C. for switchgear rated below 100 amperes, or 30° C. for 0 amperes and upwards.

Distinction is made between: (1) A switch, being a mechanical device for non-automatically eaking a circuit carrying load-current; (2) An isolating switch for disconnecting a circuit only en carrying no load current; and (3) A circuit breaker, a mechanical device for breaking tomatically a circuit under abnormal conditions such as that of short circuit.

Marble or slate slabs must be free from metallic veins, and, if of slate, must be treated all er with a damp-proof medium; the slabs are to be insulated from fixing bolts and the sup- rting framework. The sizes of round copper-back connections and their spacing are tabulated the Reports. The test pressure to be applied to a switch or circuit breaker is 1,000 volts us twice the rated pressure, with a minimum of 2,000 volts alternating.

* By permission of the British Engineering Standards Association.

In the case of circuit breakers, the temperature rise of coils is not to exceed 50° C. when the insulating material is impregnated cotton, silk, or paper, or enamelled wire, and 70° with materials such as asbestos, micanite, and built-up mica, and bare coils. Reverse-current devices must be capable of operating with 15 per cent. or less of the rated current; low-voltage releases must not operate unless the pressure falls to 65 per cent. or less of the rated pressure, but must operate before the pressure falls below 25 per cent. of the normal, at the rated frequency. A reverse-current circuit breaker must not be rendered inoperative if the pressure across the potential coil falls to (Class A) zero, (Class B) 50 per cent. of normal, and a reverse-current device must not operate with a forward current of any magnitude. Magnet-closing circuit breakers must operate between the limits 20 per cent. below and above normal pressure, and pressure-operated tripping coils must operate between the limits 50 per cent. below and 20 per cent. above normal pressure, at 40° C.

When type tests have been made by a recognised authority, a millivolt drop test is to be accepted in lieu of a temperature test.

Specification 116—1923 gives the standard ratings, sizes, and marking, the temperature and voltage tests for oil-immersed switches and breakers for alternating current circuits. The temperature rise above the cooling air at any part must not exceed that measured at the hottest part of the oil, viz. 30° C. for ratings up to and including 2,000 amperes, 40° C. above 2,000 amperes when the temperature of the cooling air exceeds 40°C the temperature rise must be such that the total temperature attained does not exceed 80° C. Temperature limits of coils and test voltages for switches as in Nos. 109 and 110; but, when operated from secondary of transformers the maximum testing voltage for coils to be 2,000, and for switches rated for 1,000 volts and upwards 2,000 volts *plus* 2¼ times the rated voltage. These conditions shall also be fulfilled after erection on site. Type tests specify that the circuit breaker shall interrupt its rated k.v.a. breaking capacity twice at a two-minute interval. A switch shall break twice in succession twice the rated current at rated voltage and after this carry its normal current without exceeding limits of temperature rise and then break twice the rated current a third time. A mechanical endurance test is to be carried out by operating 500 times with the main contacts carrying no current. Method of calculating k.v.a. to be broken and notes on selection of oil circuit-breakers are given in appendices.

Specifications for totally enclosed air-break switches (No. 124—1923) and air-break circuit breakers (No. 130—1923) for circuits not exceeding 660 volts provide, in addition, for efficient earthing of containing case, arc shields and lining, and insulation of the interlocked handle. The insulation resistance must not be less than 10 megohms.

Condition to be fulfilled by flame-proof air-break switches and circuit breakers (Nos. 126 and 127—1923) require a test of flame-proofness by subjecting the apparatus to a single breaking test when filled and surrounded with the maximum explosive mixture of methane and air or the equivalent. Switches must then break a circuit carrying a current 50 per cent. in excess of normal at rated voltage on a non-inductive load; circuit breakers to operate under same conditions of current, voltage, and impedance as in service.

ELECTRO-MECHANICAL BRAKES.

Electro-mechanical brakes are used in connection with a variety of electrically driven machines, such as lifts, cranes, hoists, elevators, conveyors, rolling mills, paper reeling, slip ways, presses, machine tools, etc., where either a quick 'stop' or adjustable gradual 'stop' is desired when the power is cut off either intentionally or unintentionally.

These brakes consist primarily of an electro magnet which operates the brake blocks through a system of levers or other medium. The magnet is so arranged that, when the current is applied, the magnet is energised and lifts the brake blocks from the drum. If for any reason the current is cut off the magnet is de-energised and the brake blocks are pressed against the drum, the requisite pressure being obtained by springs, weights, or a combination of each.

The brakes are quite automatic in action; thus, in the case of an electrically driven crane as soon as the driver applies the current to the motor to raise the load the brake is automatically released, and when he switches off the current to stop the brake is immediately applied. Should for any reason the supply current fail, the brake automatically goes on and takes charge of the load.

It is desirable that an electro-mechanical brake should have the following features: compactness of design, robust construction, few and simple working parts, easy adjustment of brake blocks and pressure exerted by same. Coils should be liberally rated, well insulated, and protected from mechanical injury, and so placed that they are not likely to be damaged by oil exuding from the machine. The brake blocks should be readily renewable. If springs are used they should be of the compression pattern.

(*Elliston, Evans & Jackson, Ltd., London.*)

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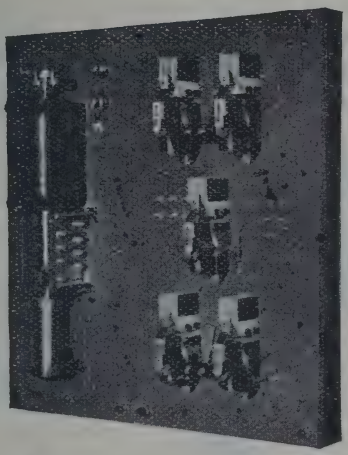

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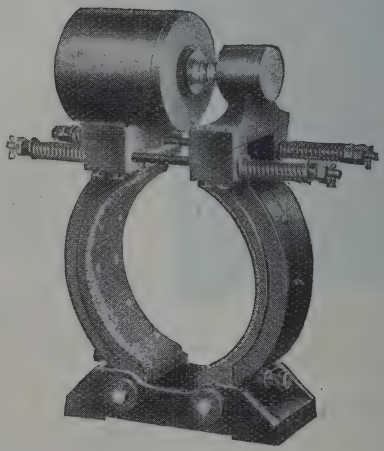

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F. 2293

Motor Starters and Controllers.

'Starters' are devices for starting and accelerating a motor to normal speed, and comprise (*a*) Rheostatic starters (face-plate, drum, multiple switch, contactor, and liquid starters); (*b*) Compensation or auto-transformer starters for 2- or 3-phase motors; (*c*) Switch starters star-delta connections for 3-phase starters, series-parallel connections for 2-phase machines).

'Controllers' (including shunt regulators) are used to regulate the speed of a motor, and may or may not be used for starting.

The following British Engineering Standards Association Specifications deal with starters:—

No. 117—1923. Drum starters for electric motors.

No. 118—1923. Drum controllers and resistances for use therewith, for electric motors (D.C. and A.C. slip-ring).

No. 123—1923. Face-plate controllers and resistances for use therewith, for electric motors D.C. and A.C. slip-ring type).

No. 123—1923. Face-plate controllers and resistances for use therewith, for electric motors (D.C. and A.C. slip-ring type).

No. 129—1923. Contactor controllers and resistances for use therewith, for electric motors (D.C. and A.C. slip-ring type) (excluding controllers for traction purposes).

No. 140—1923. Liquid starters for electric motors (D.C. and A.C. 2- and 3-phase induction with slip-rings).

No. 147—1923. Multiple switch starters for electric motors (D.C.).

No. 155—1923. Contactor starters for electric motors (D.C. and A.C. 2- and 3-phase induction with slip-rings).

No. 167—1923. Auto-transformer starters (hand-operated pattern for electric motors (A.C. 2- and 3-phase induction without slip-rings).

No. 246—1927. Face-plate starters for electric motors (D.C.).

No. 247—1927. Face-plate rotor starters for electric motors (A.C. 2- and 3-phase induction with slip rings).

AUTOMATIC CONTROL GEAR.

An automatic controller entirely eliminates the personal judgment of the operator in many cases, which is a distinct advantage where men accustomed to heavy work such as is met with in shipyards, steel mills and the like, are called upon to start up large machines. The controllers are now made suitable for practically any purpose, any horse-power, any supply, and for any particular design of motor requiring special starting apparatus.

The foolproof nature of automatic gear is not the only or the principal argument in its favour as compared with hand-operated controllers under frequent and heavy service.

An automatic controller is one in which the current supply to the motor is regulated by means of one or more switch units, each unit being operated by an electro-magnet; the operation of the magnet is controlled by an auxiliary switch, which therefore only has to deal with very small magnet-currents. This auxiliary switch can be put at any distance from the motor in the most convenient place, whereas the main automatic controller can be installed beside the motor, thus effecting the greatest economy in cable connections.

The original face-plate type of starter, which is still the standard type for moderate size motors starting up only a few times per day, has had to give place to the drum type controller for frequently operated motors as on cranes. This type of controller has been greatly improved in its mechanical and electrical construction, but its design has such inherent limitations when it has to deal with the large currents now employed that excessive wear of the contacts is produced. This necessitates constant attention to the wearing parts, and high maintenance charges. By inherent limitations is meant the fundamental fact that in order to carry larger currents the contact pressures must be increased, and such increase greatly increases the mechanical wear, so that in some cases the contacts may have to be renewed after a few weeks' operation. With an automatic controller of proper design, the wear is very much less, and does not increase with the size of the controller. Contacts operating under severe conditions will only require renewal about once or twice a year.

D.C. motors are controlled by a number of solenoid-operated switches or 'contactors' fitted with powerful magnetic blow-outs and arc shields; they are electrically interlocked so that they can only close in correct sequence, and so arranged that the motor cannot be started up except with all resistance in the armature circuit.

In some cases the time intervals between the closing of successive contactors depend upon the acceleration of the motor. This is generally determined by means of series relays fitted to each contactor except the last one. These relays are in the main motor circuit, and are adjusted so as to operate when the motor current drops to the value at which further acceleration is impossible. The operation of the relay closes the control circuit of the next contactor, which therefore closes, thereby cutting out a section of the resistance and speeding up the motor. This is repeated each time until the motor reaches full speed. It is thus evident that the motor current is kept within safe limits while the motor is accelerated to full speed in the minimum time, which means the minimum loss of power in the starting resistances.

The automatic control of any a.c. motor is now as reliable as with a d.c. motor for a.c. switches and contactors are manufactured for controlling motors of any horse-power on high or low tension supplies. A standard controller for a slip-ring motor consists of a stator switch or contactor and a number of D.P. rotor contactors complete with relays, the number depending on the h.p.

The stator switch coil is controlled by a small switch, accumulator switch or float switc pressure regulator or other means, and on being energised closes the stator switch automaticall and the motor is connected to the mains with all the rotor resistance in circuit.

A time element controls the closing of the first D.P. rotor switch, which, on closing aut matically, cuts out a section of the resistance in the three phases of the rotor circuit. As wi the d.c. set, this is repeated until the motor is up to full speed with the leads to the rings shor circuited.

Pumps are arranged to stop and start according to the rise or fall of water in a tank by mea of float gear and an automatic controller. The automatic control of air compressors is bei universally adopted on account of the great convenience and economy effected in many case irrespective of the benefit of the elimination of skilled attendance.

Each plant requires individual investigation in order to ascertain the most economical meth of control. On a d.c. or a.c. supply the compressor can be arranged to stop and start at max mum and minimum pressures only, or to stop and start at maximum and minimum pressure the speed being reduced or increased between certain definite pressures, unloading at startin or to run continuously, unloading only at maximum pressure, when the demand for air is grea

For certain duties, such as lifts, plate-edge planers or live rolls, operated by a.c. slip-ri motors, where a large initial starting torque is usual, the ' Eddystat ' controller has many uniq advantages. This controller is called an ' Eddystat ' controller because it utilises the surpl power required when accelerating, to produce eddy current losses, just as the ordinary resistan type of controller uses up the surplus power in creating an ohmic loss in the resistances. Th controller has no moving parts, but requires a contactor for operating in the stator circuit, a when the duty is such that the motor runs continuously for a considerable period of time, it preferable to have a double pole switch to short-circuit the ' Eddystat ' controller.

The arrangement consists of three solid steel cores and insulated copper windings with tapping which are connected across the sliprings, as shown in fig. 44. On starting the motor the rot current is forced through the controller at line frequency, and the highest rotor volts, and pr duces the maximum eddy current loss. As the motor speeds up, the voltage and frequenc decrease in proportion, and consequently the eddy current losses decrease automatically.

DIAGRAM OF CONNECTIONS OF ' EDDYSTAT ' CONTROLLER.

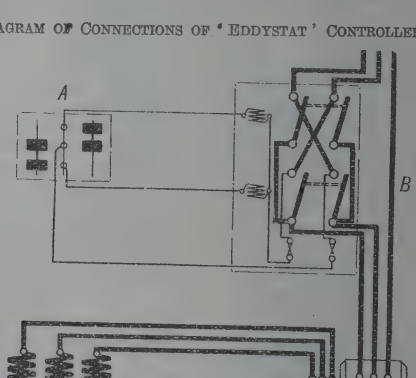


Fig. 44.

A—Master Controller. *B*—Reversing Contactors. *C*—' Eddystat ' Controller.

NOTE.—An increase in the starting torque can be obtained by moving the star connectio *a b c* up to the tappings immediately above.

A further increase is possible by connecting the coils in delta.

Braking and Reversing.—This controller also acts as a very powerful electric brake, becaus if the stator circuit is reversed when the motor is at full speed, twice line frequency and twic standstill rotor voltage will be applied to the controller. For automatic reversing equipments such as plate-edge planers or live rolls, this reduces the time of reversal, and increases the output The maximum current when reversing in this manner is very little in excess of the current take when starting up from standstill. The controller thus acts like a plugging resistance, but with

he additional advantage that a single-speed master controller is sufficient. This eliminates he judgment of the operator, which is necessary when plugging with a three-point master ontroller. As the 'Eddystat' controller is always connected in the rotor circuit the motor s fully protected, a valuable feature absent in other forms of control.

Oil Immersed Type.—The 'Eddystat' controller is specially suitable for installation in iery mines, explosives factories and chemical works, as, in addition to having no moving parts, t can be totally immersed in an oil tank, like a transformer.

For the control of large cranes, whether the supply is direct or alternating current, the standard ractice at the present time is to install contactor controllers on the crane with small master irum controller in the driver's cabin, in preference to the large drum controllers previously ised.

Absolute control is afforded, and the manipulation is more efficient, with the added advantage hat, due to interlocking, no damage can be caused to the gearing through carelessness. When owering, the driver can vary the braking effect according to the load; in fact he has as efficient ontrol as with a drum controller, but the apparatus being foolproof needs less care and attention, nd frequent repairs are eliminated.

Automatic controllers are being installed in all up-to-date steel works and rolling mills, on harges, blast-furnace hoists, screw-down gear, live rolls, lifting tables, skids, and main rolls.

TRANSFORMERS.

Transformers in Parallel.

The simple distributing transformer usually has two high-voltage leads and four low-voltage eads coming out from its windings, as indicated in 1, fig. 45. It will be seen from fig. 2 that he two centre leads of the low-voltage coils are crossed inside the transformer before they are rought out through the case. This does not make any change in connecting the two sections in eries on the outside of the transformer, as this is the same as connecting two batteries in series.

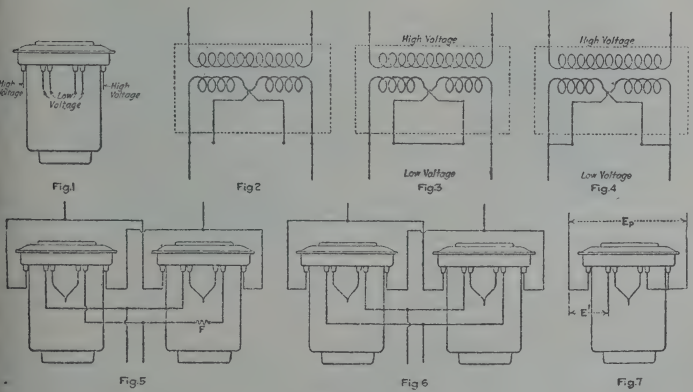


FIG. 45.

When the coils are connected in parallel, care must be exercised and adjacent leads connected ogether, as in fig. 4. Looking at the connections from the outside of the transformer, it would ppear as though the two sections of the winding were short-circuited, but the diagram shows hat the right-hand terminals of each section are connected together, also the left-hand terminals. his is just what is done in connecting batteries or other direct-current elements in parallel—ke poles are connected.

Transformers to operate in parallel should be the same voltage, frequency, size, and possess the same characteristics, which means that they should be of the same make. In connecting transformers in parallel, it is only necessary to observe the same rules as used for connecting two or more pieces of direct-current apparatus in parallel; namely, connect like poles to like poles. The question now arises which are like terminals on two or more transformers. This is easily determined in most cases. After the transformers are arranged symmetrically, as in fig. 5, connect the right-hand terminals together and the left-hand terminals together and bring out a lead from each junction point, as indicated.

There is, however, a chance that one of the transformers may have its leads brought out in such a way as to cause a short-circuit when the transformers are connected as shown in the figure. To guard against this a piece of small fuse wire may be connected, as indicated at F. If the connections are correct, the fuse will not blow when the transformers are made alive without load; otherwise the fuse will blow. In case of a wrong connection it may be remedied by crossing either the high or low-voltage leads on one of the transformers, as indicated in fig. 6. A better way would be to test the transformers and find out which has wrong polarity and correct it.

The polarity may be tested as represented in fig. 7. Connect the high-voltage terminals to the line and with one terminal of the low-voltage coil to the high-voltage winding, as indicated in the figure. Measure the electromotive force at Ep and E'. If it is greater at E' than at Ep the transformer has the correct polarity; if less, the polarity is wrong and either the high or the low-voltage leads must be crossed inside the transformer. The test may be made with 110 or 220-volt current.

THE ENGLISH ELECTRIC CO.'S. TRANSFORMERS.

In these transformers the windings are designed so that there is ample provision for the circulation of oil; this assures a very low temperature gradient between copper and oil, so that any danger of excessive heating is eliminated. Two patterns are manufactured, viz. the 'core' type and the 'shell' type. The principal advantage of the latter type, which is specially suitable for single-phase units and for exceptionally heavy currents, is that the windings are completely boxed in with insulation, which is built round with the core or the clamping gear; this design results in a very robust and solid construction, which is very well able to withstand the forces caused by short circuit. The disposition of the windings is such that the oil ducts are in a vertical plane, which is an ideal condition to produce rapid circulation of oil, and, consequently, improved temperature conditions.

Fig. 46 (p. 2297) shows the general arrangement of these transformers.

All coils are rectangular and are wound in flat single sections with one turn per layer. In general, three types of coil are used, the choice depending on the current and voltage. For 'low voltages' the conductor consists of one or more rectangular double-cotton-covered wires. Insulation between the single-turn layers is provided by strips of hard insulating material. For 'high voltages' the conductor is a flat wire with half-round edges. It is encased in a sleeve of insulation consisting of several layers of highest quality paper. Each layer is applied as a strip wound spirally with the edges butting but not overlapping, and successive layers are staggered so that their edges do not coincide. In addition a strip of hard insulation is inserted between layers.

For 'very heavy currents' the conductor consists of a number of rectangular double-cotton covered wires wound one over the other. Each coil or section has only one turn, and a complete group of adjacent sections is wound as a continuous single layer coil of several turns. This arrangement avoids the necessity of joints between adjacent sections.

In all types of coil, to the inside of the first turn and to the outside of the last turn is taped a strip of insulation which maintains the necessary creepage distance between adjacent coils round the projecting edges of the washer that is placed between them.

As before stated, a very important feature in the design of the windings and insulation is the adequate provision that is made for the circulation of oil, so that a very low temperature gradient between copper and oil is assured, and any danger of excessive local heating eliminated. With this object the H.V. and L.V. windings are arranged in a sandwich manner, the number of groups depending on the output of the transformer and the reactance required. Adjacent coils are separated by a washer and oil duct, the latter being maintained by suitable spacers of insulating material. Along the vertical portions of the coil these spacers are wave-shaped and are so disposed that every wire is supported and is also exposed to oil for the greater part of its length. At the corners of the coil specially formed spacers are used to deflect oil into the horizontal portions which are not in the direct line of oil flow. The complete set of coils in a group is assembled with the various channels, angles, and sheets of insulating material which provide the necessary insulation between H.V. and L.V. windings, and between the windings and the core, and the whole is bound together with strong webbing. Finally, all the groups are banded tightly together so that the

omplete windings and insulation can be handled as a single unit. The insulation used is suitable or forming into the various shapes required, and possesses the property of very readily absorbing il, in which state it has the useful feature that its dielectric constant approximates to that of oil.

The amount of insulation between turns is determined not by the normal volts per turn, but y considerations of line voltage and service conditions. At the ends of the windings adjacent o the line this insulation is considerably reinforced to withstand the effect of surges. The rein- orcement is graded down through approximately 5 per cent. of the total number of turns, to the ıormal insulation used in the body of the winding.

The core is built of thin laminations of very high quality non-ageing silicon steel, and one ide of each lamination is coated with an insulating material that does not deteriorate with heating. The shape of the laminations is rectangular, and for single-phase transformers there are only two lifferent sizes, while for three-phase transformers only four sizes are required. The complete set of windings and insulation is placed in position in a massive structural steel frame on which the ore is built, and the laminations are stacked around the vertical coil sides with the corner joints arefully interleaved. The completely assembled core is clamped very tightly by means of strong ie-bolts that unite the bottom frame with a similar one placed on top of the stack of laminations, vood packing being inserted between the frames and the core. In the largest transformers liagonal cross braces are used between the upper and lower frames to prevent distortion of the ore during transport.

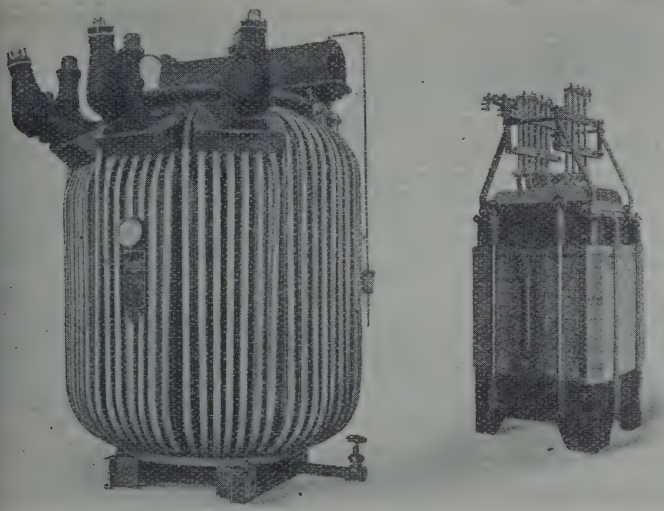


FIG. 46.

For single-phase transformers circular tanks are used : for three-phase transformers the tanks ıave flat sides and half-round ends. These designs result in tanks of great strength and remarkably leasing appearance. All tanks are of boiler plate with welded seams. Round the top of the ank side is welded a strong rim of steel to which the flat boiler plate cover is bolted. Massive ifting lugs are riveted to the tank side, and in order to prevent oil leakage along the rivet holes . thin plate of steel is welded inside the tank so as to enclose all the rivet heads. The design of he tank and lugs is such as to permit the complete transformer filled with oil to be lifted. The ank is supported on a structural steel base in which plain or flanged rollers can be fitted if required. A valve is fitted at the lowest point of the tank, so that it may be completely drained of oil. A auge is supplied so as to indicate at all times the level of the oil. A thermometer pocket suitable or the insertion of an ordinary mercury thermometer is provided on the tank side or cover.

In general, outlet terminals are located in the cover. For low voltages solid porcelain bushings ıre used : for voltages above 40,000 the bushings are of the condenser type. For very heavy urrents the outlet terminals consist of copper bars brought out through the cover.

Metropolitan Vickers Electrical Co.'s Transformers.

Metropolitan Vickers transformers include a wide variety of power and distribution transformers for either indoor or outdoor service; specially designed transformers for use with rotary converters, electric furnaces, high-voltage tests, and for collieries; also voltage and current transformers for use with all forms of electrical instruments and protective relays.

Both 'core' type and 'shell' type constructions are employed, but for normal conditions and capacities, single-phase units are most commonly made of the shell type, and three-phase units of the core type. Shell-type, single-phase transformers have been supplied in units up to 18,13 kva., and three-phase, core-type transformers up to 25,000 kva.

The highest pressure for which 'Metrovick' transformers have so far been built for publi service is 132,000 volts, but all experimental work has been done and designs have been com pleted for transformers for service up to 220,000 volts. Transformers to give 500,000 volts hav been installed in the high-tension research laboratory, and enabled routine tests and research wor to be carried out at pressure up to over one million volts.

Considerations affecting the choice between groups of three single-phase transformers an three-phase transformers are capital cost, spares, floor space, and continuity of supply. A three phase transformer is approximately 10 to 15 per cent. lighter in weight than a bank of thre single-phase transformers, while the latter require approximately 50 to 70 per cent. more floo space than the three-phase unit. On the other hand with groups of single-phase units a singl unit can be carried as a spare for three or four groups; also a breakdown fault would be confine to one unit, whereas in a three-phase transformer a failure on one phase may cause damage t the other two phases.

Self-cooled transformers can be built in sizes up to approximately 20,000 kva. capacity, but i sizes above 4,000 kva. a saving can usually be made by artificial cooling. Methods of artificia cooling of oil-immersed transformers include a water-cooling coil fitted inside the tank at the top an outer sheet metal casing for cooling by air blast from motor driven fans; pumping the o through a cooler of either the water or the air-blast type mounted outside the transformer.

Dry transformers up to about 150 kva. single-phase and 200 kva. three-phase are supplie protected by an expanded metal screen. Above this capacity, dry-type single-phase, air-blas transformers have been supplied to a limited extent for ratings from 300 to 1,500 kva.

The increasing cost of erecting buildings has emphasised the advantages of installing trans formers out of doors. This practice is being favoured for large power transformers in the layou of modern large generating stations and sub-stations, for which Metrovick transformers of th outdoor type have been installed for service up to 132,000 volts, and also is being adopted in creasingly for power and lighting transformers in rural distribution systems.

A development that is finding increasing favour is a tapping switch mounted within th transformer and operated from outside the case. This switch enables voltage changes to be mad quickly and without opening the tank, so that interruption is reduced to a minimum and eve at the highest voltages perfect safety is ensured to the operator. Transformers have been supplie so arranged that tap changing can be effected without any interruption in the continuity of supply Another convenient device for tap changing on distribution transformers is a set of sockets an adjustable plugs. This device enables transformers of a standard voltage to serve the require ments of a whole system, the voltage of individual transformers being adjusted, at the time o installation or subsequently, to compensate for voltage drop in the transmission lines.

Notes on Transformers.

To seal up holes in transformers or oil-switch cases where wires pass through, a mixture o sulphur and plaster of Paris may be used; a mixture containing equal quantities gives a materia which sets very hard, and which is impervious to transformer oil. The sulphur should be melte in a ladle or pot and then an equal quantity of plaster of Paris mixed thoroughly into it. Thi mixture should be poured into place while hot.

Trouble is often experienced from oil being siphoned out of transformer cases on account of th braided insulation on the lead wires. When this takes place it is usually found that the insulatio on the wires dips down into the oil. If the oil level is lowered below the terminal board insid the case and the insulation on the leads scraped off so that where the wire enters the surface o the oil its metallic surface only is exposed to possible contact with the oil, and the leads ar properly sealed, there will be little trouble due to siphon action.

Static Balancers in Three-Phase Circuits.

In three-phase distribution circuits, the voltages commonly used for power purposes are ofte too high for lighting circuits; accordingly, where lighting is desired, it is necessary to introduc some means of obtaining a reduced voltage. A customary method of providing for this is to tak

dvantage of the fact that by using a star connected generator or transformer having its secondary inding connected in star, it is possible to obtain between any one phase and the neutral point f either generator or transformer a reduced voltage. For example, in a circuit with 400 volts etween the phases, it is possible, by taking out a connection from the star point, to obtain a

oltage between this point and any one phase of $\frac{400}{\sqrt{3}} = 230$ volts only. To do this, however, the

enerator or transformer has to be star connected in such a manner that a cable can be brought ut from the star point, and this cable must be led to the point where lighting is required. Apart om the cost of this cable, which for any distance is considerable, any out-of-balance lighting ould cause unbalanced voltages due to the resistance of this cable and thus would affect the

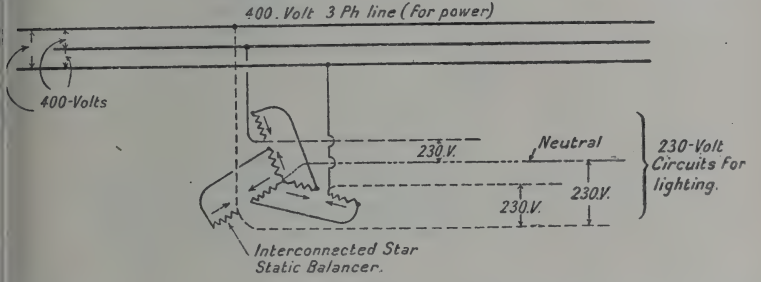


FIG. 47.

ghting detrimentally. Alternatively to the above arrangement, it is possible, by using static alancers, to save the cost of the cable referred to, and also to minimise very largely the out-of-alance effects.

The Metrovick static balancer, which is shown diagrammatically in fig. 47, consists of a hree-phase auto-transformer having a lead brought out from the neutral point of the windings, nd the three phases so inter-connected, that current flowing through the neutral passes equally hrough them.

Static balancers for ordinary industrial conditions are quite small, and of correspondingly ow cost. On a 100-k.v.a. circuit, with a maximum out-of-balance current not exceeding 25 per ent. of the full-load current in the outers, a balancer would be similar in size to a 5-k.v.a. trans-ormer, and under these conditions, the out-of-balance of the phase voltage would correspond o one-third the percentage voltage drop of such a 5-k.v.a. transformer. In cases where the oltage required for lighting is not exactly but only approximately the line voltage divided by $\sqrt{3}$ a combined balance and auto-transformer may be used to advantage.

The advantages gained by using static balancers are: (1) The balancer may be placed at any oint on the system where lighting is required and the length of neutral wire greatly reduced. 2) The drop in the neutral wire is much reduced, so that better voltage balancing is obtained etween the different phases. (3) The current is more equally distributed between the line wires. 4) A standard polyphase wattmeter can be used instead of a special four-wire wattmeter. (5) It s possible to supply a four-wire circuit from a transformer group connected in star-star or star-elta, thereby saving in the cost of the main transformers.

Induction Regulators and Booster Transformers.

(The English Electric Company, Ltd.).

The principal applications of induction regulators and booster transformers are:

1. The regulation of feeder voltage under all conditions of load.

2. The control of the reactive current in ring mains and in interconnector cables linking power areas where it is desirable that the station voltages shall be variable independently of each other.

3. The control of the alternating voltage applied to the slip-rings of synchronous converters in order to obtain voltage control on the direct current side.

Booster Transformers.

The apparatus consists of a potential and a series or current transformer. The primary winding of the potential transformer is connected across the mains and the secondary provided with a number of tappings which are brought out to a regulating switch. The series transformer has its secondary winding in series with the line and its primary excited from the variable secondary of the potential transformer, as shown in Fig. 48. When the reversing arm of the regulating switch

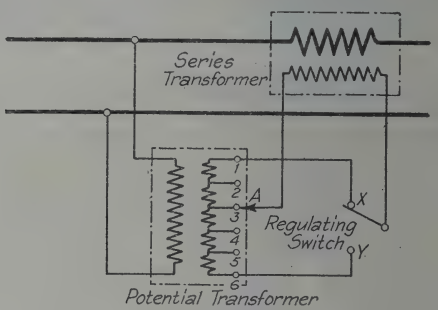


FIG. 48.

is on contact X, and the tapping contact A is on stud No. 1, the primary winding of the series transformer is short-circuited and the secondary of the potential transformer is open-circuited. The voltage of the feeder therefore is unaffected and the potential transformer takes only a magnetising current. As contact A is moved successively to studs 2, 3, etc., a voltage will be induced in the secondary winding of the series transformer and the outgoing line voltage increased. The voltage boost is thus a maximum on stud No. 6. If the operation be commenced with the reversing arm on control Y, then the tapping contact A on stud No. 6 gives normal mean voltage, and movement to successive studs Nos. 5, 4, etc., will induce in the series transformer a voltage opposing the line voltage; while on stud No. 1, the outgoing feeder voltage will be a minimum. To ensure continuity of circuit, the English Electric Co.'s booster transformer has a main circuit breaker and a pilot circuit breaker with renewable contacts which take all the arcing, the pilot breaker completing a circuit through a choke coil or buffer reactance. A 3-phase booster transformer consists of three separate identical units coupled together for simultaneous operation by hand, or motor operated from remote control, or by means of contactors. Where the supply voltage does not exceed 3,000 it is possible to omit the series transformer and to use the tapped secondary winding of the potential transformer directly in series with the line.

Induction Regulators.

Induction regulators provide a means of gradual change in the feeder voltage without the interposition of switches. They consist of two elements, one fixed and the other movable at will through 90 degs. for the 4-pole design and 180 degs. for the 2-pole. In double-range regulators the movements are through 180 and 360 degs. for 4- and 2-pole types respectively. The construction is similar to that of an induction motor, but usually with a vertical shaft. The rotor shaft projects through the tank cover and has keyed to it a worm quadrant which engages through reduction gearing with a handwheel or motor.

With single-phase regulators, the magnetic flux produced by the movable primary winding is pulsating and the voltage induced in the stationary secondary winding, connected in series with the line, is proportional to the amount of this flux linked with it. The movable primary carries a short-circuited compensating winding which is electrically and mechanically at right angles to the primary winding. As the regulator approaches the neutral position the reactance of the series winding is neutralised by this short-circuited coil.

In three-phase induction regulators the magnetic field rotates and the secondary windings are linked by a constant value of flux irrespective of the angular position. The secondary voltage is therefore constant and is added to or subtracted from the feeder voltage by varying its phase angle relatively to the feeder voltage. This is shown in Fig. 48A, in which OA is the line voltage, OB is the secondary voltage per phase, and AB the resultant feeder voltage. The regulated voltage AB and the unregulated voltage OA are only in phase with one another at the maximum and minimum

positions of the regulator. In ring mains or in an interconnector cable linking generating systems, phase displacement would cause circulating currents to flow. To correct this displacement it is necessary to resort to (1) the twin induction regulator, where each unit is half the total kva. rating required, or (2) a bank of single-phase regulators.

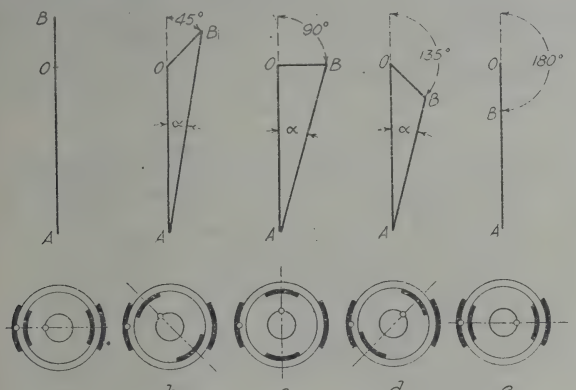


FIG. 48A.

The English Electric Co.'s induction regulators are designed for air cooling and for oil self cooling for upwards of 1,000 kva. in one unit. Very large sizes are designed for forced oil circulation. There is a growing tendency to accommodate induction regulators with the transformers and switchgear of outdoor substations. The operating gear is then enclosed in a weatherproof cover and the control panel, with its sensitive relays, mounted in an air-tight metal cabinet.

Power Factor Improvement.

With the continual growth of alternating current distribution, the necessity of improving the power factor resulting from an industrial load has become more and more apparent, as a low power factor, by reducing the working capacity of the generating plant and mains and lowering the efficiency of the system, adds to both the fixed and the running charges, besides unfavourably influencing the voltage regulation of the network. In fig. 49 curves are given for commercial induction motors at 500 and 1,000 r.p.m., showing the effect of output and speed on the power factor at various loads.

The power factor can be raised by three methods:—(1) Static condensers; (2) Rotary condensers; (3) Phase adjusters.

(1) Static condensers afford one of the simplest and most efficient solutions of the problem, as they require no attendance and involve very little loss of energy. In the *General Electric Review* of August 1918, W. B. Taylor gives a diagram, fig. 50 (page 2303), by means of which the capacity of the static condenser required to neutralise more or less completely the wattless component of the power can be determined. The use of the diagram is best explained by an example. An a.c. feeder carries a current of 500 amperes at 500 volts, and the power factor is 0·6; required the capacity necessary to raise the power factor to 0·9. Taking on the 0·6 p.f. line the point corresponding to 250 k.v.a., it will be found that the wattless k.v.a. (ordinate) is 200 and the energy kw. (abscissa) 150. The 150-kw. ordinate cuts the 0·9 p.f. line at a height corresponding to 73 wattless k.v.a. Subtracting 73 from 200 gives 127 k.v.a. as the required condenser capacity. Similarly 88 k.v.a. would raise the power factor to 0·8 and 47 k.v.a. would raise it to 0·7.

The effect of added capacity is greatest when the power factor is lowest; owing to the relatively large capacity required to bring the power factor up to unity, it is not commercially advisable to attempt to raise it much above 0·9. The condensers should be fixed near the load, in order to improve the power factor in the mains as well as at the generator. The condensers should

be disconnected at times of light load, if the leading current they can then take be no required in other parts of the system. High voltage and high frequency are favourabl to the use of static condensers; they are made for pressures up to 750 volts by the *British Insulate and Helsby Cables, Ltd.*, and for higher pressures they are connected in series. In the case c low pressures such as 400 volts, it may be found economical to install transformers to raise th voltage at the terminals of the condensers, thus reducing the capacity required. Another metho is to insert a suitable amount of inductance in series with the condensers, whereby the pressur across the latter is increased. To protect the condensers, the control switches should be fitte

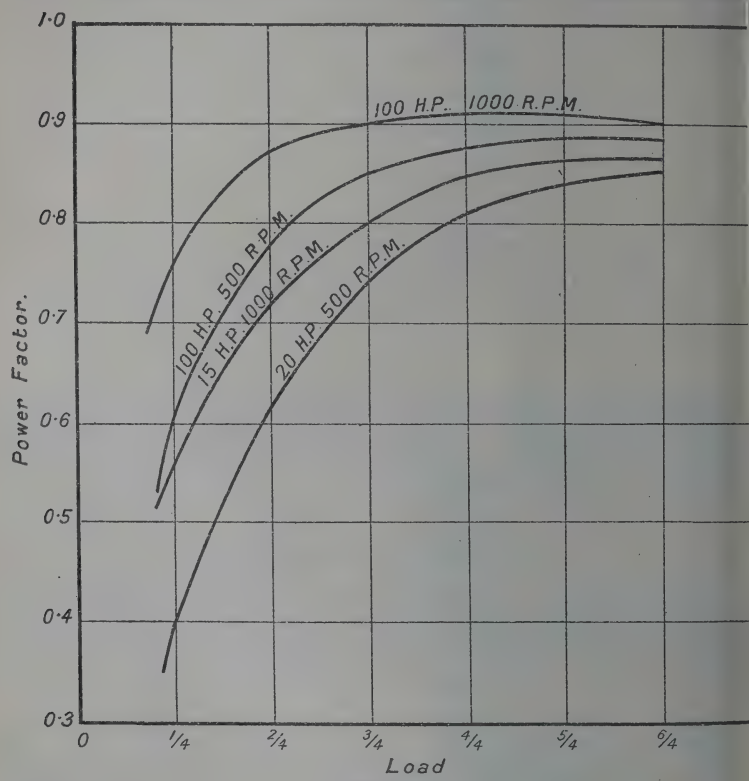


FIG. 49.

with overload trips, and to prevent accidents due to the stored-up charge, provision should be made for discharging the condensers through resistances when they are switched off. The efficiency of condensers exceeds 99·5 per cent.

(2) Rotary condensers are simply synchronous a.c. motors, over-excited so as to take a leading current, in which condition they act like static condensers. The motor may be run without load, but in this case the method is costly, and it is preferable to use a loaded motor. A rotary converter can be employed for the same purpose. The necessary capacity to produce a given improvement in the power factor of the system is determined in the same way as that of static condensers, using fig. 50; the greater the mechanical load on the motor, the less will be its condenser effect, the rule being that the square of the k.v.a. capacity of the machine is equal to the sum of the squares of the kw. load and of the wattless k.v.a., so that the motor is used to the best advantage when the wattless output = the power output × 0·71 of the k.v.a. rating of the motor. The synchronous motor is usually started up as an induction motor with the aid

f an auxiliary squirrel-cage winding embedded in the poles of the field system, or by means of n induction motor coupled to the same shaft, the field being unexcited until full speed is attained; irect-current excitation must be provided, either by a direct-coupled exciter or by an external ource.

(3) The phase adjuster is a special machine, resembling a commutator induction motor, hich is coupled to the slip-rings of an induction motor whose power factor needs correction, and mechanically driven, either from the shaft of the main motor or by a small separate motor, the ower taken being only that required to overcome friction and windage, and being fully compen- ated by reduced losses in the main motor. The function of the phase adjuster is to supply the agnetising current for the motor, thus raising the power factor to unity, or even passing that

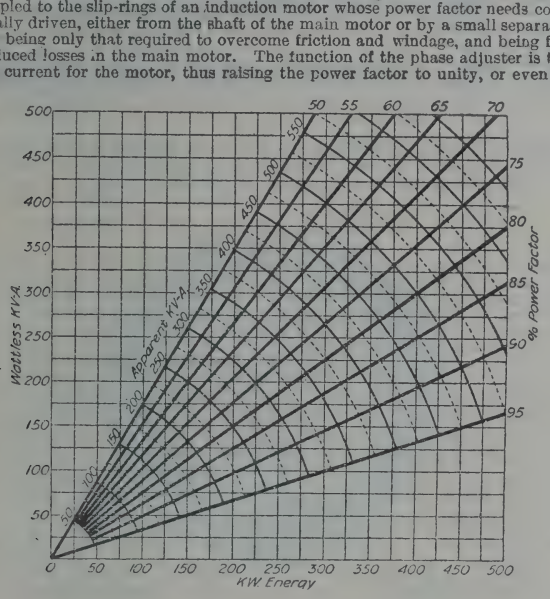


FIG. 50.

int and supplying current to the system to compensate for low power factor in other machines. 1 oscillatory type of phase adjuster is also made. A great advantage of this method is that e power factor of the individual motor is improved, so that a smaller motor can be used, with luced losses. Advantages common to all methods are that the losses in the generators and oles are reduced, and the load factor of the plant is raised so that fewer generators need be), and considerable economy of fuel as well as of capital outlay can be effected.

Electric Measuring Instruments.

Ammeters and Voltmeters.—The types available are (1) Moving-coil, permanent-magnet; Moving-iron; (3) Hot-wire; (4) Dynamometer; (5) Induction type; (6) Electrostatic volt- ters.

The following British Engineering Standards Association Specifications deal with electric asuring instruments:—

No. 81—1927. Instrument transformers.

No. 89—1926. Indicating ammeters, voltmeters, watt-meters, frequency and power tor meters.

No. 90—1927. Graphic (Recording or Chart-Recording) ammeters, voltmeters, and watt- ters.

Sizes of Enamelled Copper Wire for Electrical Instruments.

A 'tentative' British Standard Specification No. 156 (1922), has been issued, giving the ensions and resistances of enamelled copper wire for instruments and apparatus. The sizes

of the bare wires correspond with those given in Specification No. 128 above. Tests are pr scribed as follows:—

Mechanical.—The enamel must not be easily removed from the wire with the thumbna Below 0·0084 in. diameter, a 10-in. sample shall be extensible to 11 ins. without cracking t enamel; above that diameter, a sample shall be wound round a mandril not more than fo times the diameter of the bare wire without cracking the enamel.

Chemical.—The enamel shall not be dissolved when immersed for one hour in absolu alcohol or dilute sulphuric acid (sp. gr. 1·25); and the samples shall pass the mechanical tes after immersion as above.

Baking.—After baking at 266° F. for one hour the samples shall pass the mechanical tests.

Electrical.—Test samples twisted together shall withstand an arc test at a pressure varyi from 150 volts (R.M.S.) up to 0·0032 in. to 1200 volts above 0·029 in. diameter. A samp passed through a mercury bath at a p.d. of 6 volts d.c. shall not make more than forty contac in 50 yards.

The thickness of the coating prescribed ranges from ¼ mil on the smallest wires to ½ mil 6 mils diameter, 1 mil at 28 mils diameter, and 1·1 at 48 mils, but wide limits of variati are permitted. Tables of minimum and maximum dimensions are given.

Weston Standard Ammeters and Voltmeters.

Direct Current.

In these instruments, although the scales are remarkably uniform, no particular 'law' deflections is assumed, as must be done when printed or engraved scales are used. A skeleton each scale is laid out by actual comparison with an accurate standard, and the lines afterwards a inked in. Finally, the work is checked by comparison with the same standard. No multiplyi constant is necessary (except with high-range voltmeters), as simple inspection of the position the pointer on the scale gives the value in amperes or volts. Time in making readings is therefo saved, and errors of calculation are avoided. The scales of all direct-current instruments ha practically uniform divisions from zero to the top mark. The range is thus greater than is commo while the uniform size of the scale divisions permits of their visual subdivision with unifor accuracy. The pointer comes to rest at once, although absolutely no friction can be detecte thus reducing the time required for readings, and preventing unnecessary wear of the moving part

There is no 'magnetic lag,' giving rise to different deflections with the same current or pote tial, as in instruments having iron in the moving parts. The 'temperature correction' is negligib being for all voltmeters having a range above 15 volts, not greater than ¼ per cent. for a range 35° F. above, or 35° below, 70°, and for the ammeter, less than 1 per cent. for the same range temperature. The instruments of the 'Direct Current' type may be kept in circuit any leng of time, as the heating effect, except in the higher ranges, is so small as to be inappreciable. the voltmeters provided with a 'calibrating' coil, changes in scale-value resulting from accident injury are easily checked; this is a very valuable feature, as all instruments are subject to occ sional accidents and to rough usage, which may prove injurious. The user of these instrumen can at any time roughly check their scale-values by applying a single cell of some constant for to the terminals of the calibrating coil.

Alternating and Direct Current.

These instruments can be used in measuring the current or voltage of both alternating a direct-current circuits with equal accuracy, being of the electrodynamometer type. Owing the principle of operation, they cannot be made with a uniform scale throughout, but the upp two-thirds of the scale is practically uniform. To prevent errors from parallax, mirror scal plates and knife-edge pointers are provided. The entire movable and field coil system is mount in a double closed iron shield, which effectually protects it from external magnetic fields a electrostatic influences. Damping is accomplished by means of an air damper, which is ve effective.

In voltmeters it is necessary for great accuracy to have the current taken by the instrume as small as practicable; the Weston Model 341 voltmeter is designed with this object in vie and the current required is much less than is usual in this type of instrument. For ordina measurements no corrections are necessary for temperature or for frequencies up to 133 cycl per second, nor is it necessary to take reverse readings on direct-current circuits. When gre accuracy is required, however, such corrections can be made. The instruments may be l in circuit continuously. In general, they are guaranteed to have an accuracy of ¼ of one per cen of full-scale value on the working portion of the scale.

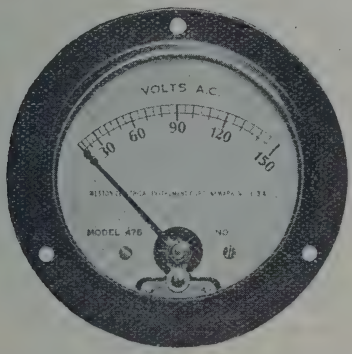
Similar characteristics are found in the portable wattmeters made by the company.

All ammeters are really milli-voltmeters, as they merely measure the drop of potential acr a constant resistance. This constant resistance is termed a shunt. The potential drop is direct proportional to the current passing through the shunt, and if the shunt is correctly designe the instrument can therefore be graduated in amperes. The resistance of these shunts is ve low: for a Weston switchboard ammeter of 100 amperes the resistance of the shunt is approx mately 0·0005 ohm. The shunt must not be strained when fixing to the bus bars, for strain might affect the resistance and so alter the reading of the instrument. For this reason shunts a usually securely fastened to a base of hard wood. Low-range ammeters up to about 200 amper can have the shunt contained within the instrument case. The resistance of the instrumen

WESTON

ELECTRICAL INSTRUMENT CO. LTD.

SMALL PANEL INSTRUMENTS FOR ALTERNATING CURRENT



MODEL 476.		MODEL 517.	
Case Diam.:	2·56″	Case Diam.:	2·06″
Flange Diam.:	3·25″	Flange Diam.:	2·56″
Depth:	1·63″	Depth:	1·72″
Scale length:	2″	Scale length:	1·5″

List Price from 40s.

THE SPECIAL FEATURES OF THESE TWO NEW MODELS ARE :

Low Power consumption. Excellent Damping.
High Sensitivity, *i.e.*, 6 mA for 300 volt range and approximately 9 mA for 150 volt range.
Accuracy 2 per cent. for A.C. (commercial frequencies), and also suitable for D.C. circuits.
High Self-contained Range, *i.e.*, up to 300 volts.
Legible Scale. Weston Manufacture.

15 GREAT SAFFRON HILL, LONDON, E.C. 1.

Telephone No.: 2029 Holborn. Telegrams: 'Pivoted, Smith, London.'

WESTON

Instruments for Research.

For Research Work the following Portable Instruments are recommended:

	Accuracy.	Scale Length.
Model 1, Standard Portable D.C. Ammeters, Mil-ammeters, Voltmeters and Milli-voltmeters	$\frac{1}{4}\%$	$5\frac{1}{4}''$
Model 5, Laboratory Standard D.C. Ammeters, Mil-ammeters, Voltmeters and Milli-voltmeters	$\frac{1}{10}\%$	$11\frac{7}{8}''$
Model 310, Standard Portable Single-phase A.C. and D.C. Wattmeters, including Special Low-power Factor Instruments	$\frac{1}{4}\%$	$5\frac{1}{4}''$
Model 329, Standard Portable Polyphase Wattmeters	$\frac{1}{2}\%$	$5\frac{1}{4}''$
Model 322, Standard Portable Micro-ammeters	$\frac{1}{4}\%$	$5\frac{1}{4}''$
Model 341, Standard Portable A.C. and D.C. Voltmeters	$\frac{1}{4}\%$	$5\frac{1}{4}''$
Model 370, Standard Portable A.C. and D.C. Ammeters and Mil-ammeters	$\frac{1}{4}\%$	$5\frac{1}{4}''$
Model 326, Electrodynamometer Laboratory Standard A.C. and D.C. Ammeters Voltmeters and Wattmeters	$\frac{1}{10}\%$	$12''$
Model 412, Portable Thermo Voltmeters, Mil-ammeters and Ammeters	$\frac{1}{2}\%$	$5\frac{1}{4}''$
Ranges from 2 M.A. Res. 750 ohms for D.C. and A.C., including radio frequencies. Voltmeters from 0—3 volts, sensitivity 27 ohms per volt to 125 or 500 ohms per volts.		
Model 492, Portable Thermo Voltmeter for frequencies up to approximately 2,000,000 cycles.		
Ranges 1 volt (140 ohms per volt) to 20 volts (500 ohms per volt). Accuracy at 600,000 cycles.	$\frac{1}{4}\%$	$5\frac{1}{4}''$

WESTON Transformers of high accuracy are supplied to operate in conjunction with our A.C. Instruments.

Full particulars will be sent upon application.

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NEW ADDRESS,

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(See also previous page.)

oes not exceed about 2 ohms, and about 25 to 30 milli-amperes is required for full-scale eflection.

Voltmeters which are placed directly across the circuit must be high-resistance instruments. hese only require about 10 or 15 milli-amperes for full-scale deflection. For special testing work 'eston voltmeters can be obtained which have a resistance of 2,500 ohms per volt, and only quire 0·0004 ampere for full-scale deflection. It is important to have a high-resistance volt- eter for testing the E.M.F. of dry batteries, etc.

Owing to the temperature coefficient of copper being high, all copper in the instrument ould be reduced as much as possible to eliminate temperature errors. The moving system ould be as light as possible to reduce the wear upon the pivots, which should work in good wels. The air gap must be small to ensure the permanence of the magnet, which must be ecially aged and carefully made. In Weston instruments the air gap is approximately 0·04 in. ny number of different range shunts may be used with moving coil ammeters, so that accurate adings may be taken over a wide range.

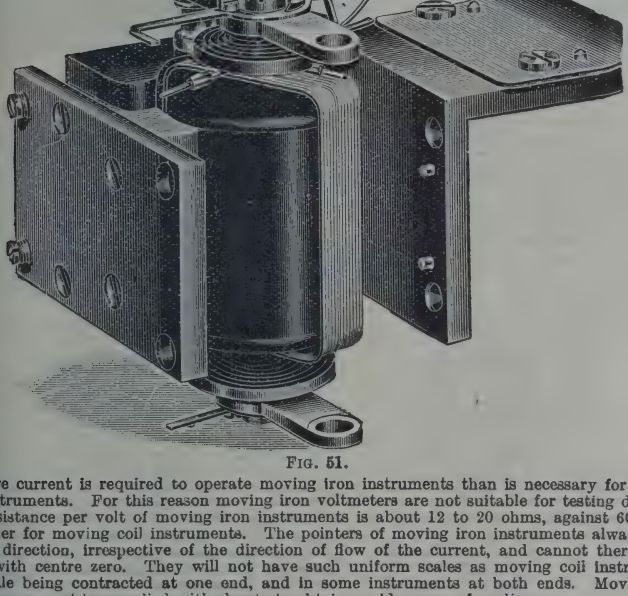

FIG. 51.

More current is required to operate moving iron instruments than is necessary for moving il instruments. For this reason moving iron voltmeters are not suitable for testing dry cells. e resistance per volt of moving iron instruments is about 12 to 20 ohms, against 60 to 100 higher for moving coil instruments. The pointers of moving iron instruments always move one direction, irrespective of the direction of flow of the current, and cannot therefore be ade with centre zero. They will not have such uniform scales as moving coil instruments, e scale being contracted at one end, and in some instruments at both ends. Moving iron ameters cannot be supplied with shunts to obtain a wide range of readings.

In reading instruments, the eye, the pointer, and the mark on the scale should be in a line at ht angles to the plane in which the pointer moves, in order to avoid errors due to parallax. edgewise instruments this line of vision must pass through the centre of the arc swept out by e pointer; one eye must be closed. In multi-range instruments each range should be a simple ultiple of the other ranges; and the figures upon the scale of the instrument should preferably dicate the number of scale divisions. An instrument having a range of 150 or multiples thereof ould be calibrated to have 150 divisions, figured 0–150. There is less liability of error in ading direct in scale divisions, and afterwards multiplying by a correct constant, than in entally calculating the value of a fraction of a scale division, especially if there is a rapidly ctuating load.

The accuracy of an instrument is best expressed as a percentage of the maximum load the strument is intended to measure. For instance, an instrument having a range of 500 volts th an accuracy of $\frac{1}{10}$ per cent. should be correct at every point upon the scale to within half a lt. If the instrument has 100 scale divisions, this corresponds to $\frac{1}{10}$ of a scale division, hich could be accurately read upon a portable instrument with a knife-edge pointer working er a mirror to eliminate errors due to parallax. If, however, the accuracy is taken as a per- ntage of the actual reading, when reading this instrument at 100 volts the error would not

have to exceed 0·1 volt, which would correspond to $\frac{1}{10}$ of a scale division, and would not readable by the naked eye. If the instrument is supplied with an additional range to re 0–100, an accuracy of $\frac{1}{10}$ per cent. upon this range would represent 0·1 volt, and would cor spond to $\frac{1}{10}$ of a scale division.

Fig. 51 shows the moving coil of a Weston d.c. milli-voltmeter in position, for which purpose t magnet and one pole piece have been removed. The moving coil is a light rectangular aluminiu frame, upon which are wound a few turns of silk-insulated copper wire: this frame is pivoted work in hard and highly-polished sapphire jewels. The pivots are small, specially harden and very finely ground and polished, so that no friction can be detected when they work in t jewel centres. The moving coil rotates in the narrow air gap formed between the pole piec only one of which is shown, and a soft iron core. As this air gap is only 0·04 in. it is essent for the moving coil to be very accurately pivoted, so as to move freely in this narrow angu space. With such a narrow air gap it is also necessary for the sides of the rectangular fra to be formed to a radius slightly greater than the radius of the core. The motion of this c is controlled by two flat spiral springs, which are made from a special Weston alloy; they arranged to work in opposition to each other, so that one uncoils and the other coils up when t moving coil rotates. The inside end of each spring is fastened to one end of the winding up the coil, and the outside end fastened to an adjustable arm. One of the binding posts is connect directly to one of the arms, and the other binding post is connected to the other arm through suitable resistance. The magnet, which is very carefully aged, is accurately ground to fit o the pole pieces, to which it is securely fastened.

The Synchroscope.

Apart from special methods only applicable to polyphase machines, two devices are in gene use for synchronising alternators, (*a*) the synchronising lamp or voltmeter, and (*b*) the rotat field synchroscope. The former is more simple, but suffers from the defect of being insensit as regards the exact moment of switching in, which should be when the machines are in ex coincidence of phase. Machines may be as much as 16° out of phase before the s hronising voltmeter shows 1 per cent. of variation from its maximum reading, so that a li rror of judgment may result in a considerable shock on switching in. A further objection is t lthough the rapidity of fluctuation of the lamp or voltmeter reading indicates the differe between the frequencies of the machines, there nothing to show which of the two machines is faster, and considerable time may thus be wast In order to make the lamp method of real servi therefore, it is necessary to combine it with so device for indicating exact coincidence of ph and also whether the incoming machine is fast slow; and this is what has been done in the West Synchroscope.

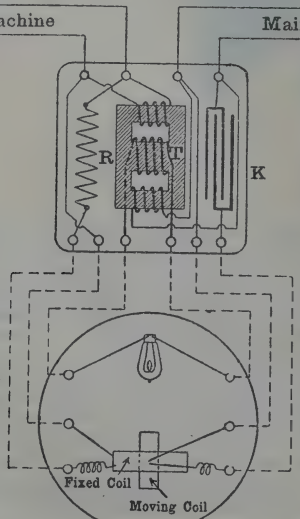

FIG. 52.

If an ordinary dynamometer wattmeter both its fixed and moving coils wound with f wire, and two alternating voltages are applied the terminals of these coils, it will show v accurately when these two voltages are in ex *quadrature*, as the wattmeter will indicate zero this case, and deflect to right or left if the ph difference is greater or less than 90. By conne ing a condenser in series with one of the coils, a introducing a small amount of inductance into t other, it is easy to arrange that the wattme indicates zero when the two voltages are in ph instead of in quadrature, and this can be check by connecting the two circuits to the same supp Under these circumstances, if one circuit is co nected to the bus bars and the other to t incoming machine it is only necessary to see th the synchronising lamp is bright and the wa meter pointer at zero to be able to throw in witho any shock.

But this only indicates when the machin are in exact synchronism, and not whether t incoming machine is too slow or too fast. If t speed of the incoming machine is low or hig the lamp will flicker in the ordinary manner a the wattmeter will also deflect to right and l alternately as the voltage of the machine alternately lags and leads with respect to that of t bus bars. The rate of oscillation of the pointer, like the rate of fluctuation of the light, sho the amount by which the speed of the machine is high or low, although neither of them by its indicates which. But if the lamp and wattmeter are combined, so that the dial of the latter

uminated by the former, the difficulty is at once solved. For if the machine is fast the watt-eter pointer swings over from left to right while the lamp is bright, while when it swings back ie lamp is dark. In consequence the backswing is not seen, and instead of the pointer appearing oscillate it appears to rise with the dawn of light at the left-hand side of the scale, to swing ross in full light and to disappear on the right of the dial with the extinction of the light, almost actly like the rising and setting of the sun, and as if it were steadily revolving in one direction. hen the machine is slow, the lamp is bright as the pointer swings from right to left, and the rection of rotation is therefore apparently reversed. As far as its practical application is ncerned, the instrument resembles in every way the rotating field synchroscopes (except that ie fluctuation of the light is visible), and the arrangement is extremely simple, and free from ıy loose contacts.

The actual indicating instrument is almost identical in construction with the switch-board attmeter, the only differences being that the dial carries a bold central mark with two arrows ıdicating 'Fast' and 'Slow,' and that the synchronising lamp is inserted behind it. This lamp ın be easily withdrawn and replaced. An auxiliary box contains an ordinary synchronising ansformer, T, for the lamp, and a non-inductive resistance, R, and a condenser, K, for connect-ıg in series with the two wattmeter coils respectively. A small inductive coil for adjusting ie exact quadrature is included in the instrument case. Fig. 52 is a diagram of the connections the instrument and box, which will be readily understood from the principle of the instrument.

METERS

In all commercial motor meters there is necessarily a certain amount of friction, which as me goes on tends to increase more or less according to the design, and to cause the meter to ow down.

This defect manifests itself particularly at low loads, and is the more serious as the majority meters are worked at points very low down on their load curves. For long periods the working oint is frequently at or below one-tenth full load capacity, and in many instances, particularly here metal filament lamps are used, the working load is liable to be between one-twentieth and ne-fiftieth the full load capacity of the meter for many consecutive hours daily.

Pointer type clocks should have light machine cut gears, and should run with an exceedingly nall amount of friction, which, being constant, is easily compensated for. This fact constitutes n important advantage in favour of clocks of this type.

Roller cyclometer clocks have more friction than the pointer type, and moreover possess the efect that as the friction is a varying quantity it cannot be compensated for. A meter may have move round one counter only, or again it may have to move up to five counters at one time.

Jumping figure cyclometer clocks are a modification of the roller type, having the friction ad more evenly distributed through the use of a falling weight device. This weight is wound up owly by the meter. It is released at the proper time, and in falling carries round the additional ounters which it is necessary to move.

This partial equalisation of friction makes cyclometer clocks which have springing figures etter than the roller type, although not so good as the pointer type clocks, where the friction is a onstant quantity. An important feature of springing figures in comparison with roller type ounters is that with the former no halving of figures takes place.

In all meters, the friction tends to increase more or less according to the design, etc., of the ieter, and to cause the speed to slow down correspondingly, and it is essential to obtain the ighest possible accuracy initially.

Manufacturers are generally willing to guarantee the accuracy of their meters, so that .c. meters can be obtained which are capable of easy adjustment within plus or minus 2 per ent. from 50 per cent. overload down to one-fiftieth of full load.

The voltage drop in the main coils should be as low as possible. The drop varies with the ze of the meter, being greatest in the smaller sizes and diminishing as the ampere capacity ncreases, due to the fact that in meters of large capacity fewer turns are required to create a milar torque. The loss in the shunt circuit should also be small, but should not be reduced t the expense of the torque, as in meters where the torque is reduced in consequence of the urrent in the shunt circuit being very low, the retarding effect of friction becomes great, affecting ie accuracy of the meter under low load conditions. Moreover, with low torque more com-ensation will be required to balance the friction, and under such conditions trouble from 'creep-ıg' through vibration, due to street traffic or other external causes, will be much more liable o occur.

A record should be kept of the life of every meter on the system of any supply undertaking. s meters are received from the makers they should be checked against a standard which should e certified from time to time by some recognised authority such as the National Physical Labora-ory. This check should be made at various loads, say 125 per cent., $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{10}$, $\frac{1}{20}$ and $\frac{1}{50}$ ull load, at unity power factor, and at half load 50 per cent. power factor, and the results ob-ained should be plotted on a card; a note of any subsequent attention required by the meter hould be added to its record, and at the end of recognised intervals—say every two or three ears—each meter should be brought in for overhaul and tested carefully before breaking any eals. The result obtained should be added to the record, thus affording a means of continuously tudying the behaviour of every meter.

The following tests, arranged in order of their relative importance, are easily made :—

(1) Accuracy at varying currents, from 2 per cent. to 150 per cent. load with volta frequency and power factor constant.

(2) Accuracy at varying voltage with constant current and frequency.

(3) Accuracy at varying power factor with voltage, frequency and current constant.

(4) Accuracy at varying frequency with constant load and voltage.

British Standard Specification for Electricity Meters.*

(*No.* 37—1919.) (*Abstract.*)

— 16. The construction of the meter shall be mechanically sound and suitable for its purp and shall be such as to give reasonable assurance of permanence in all mechanical electrical a magnetic adjustments and shall not be seriously affected by external magnetic fields.

17. The parts of the meter within the case shall be carried on a substantial stiff framew forming, if desired, part of the case. The framework shall not be liable to distortion by chan of temperature, presence of moisture, or other cause. They shall be completely enclosed in substantial dust-tight metal case, the front and sides of which may be glazed. The case sh be of sufficient strength to afford adequate protection to the working parts against mechani injury with reasonable usage, and capable of being sealed in such a manner that access to t working parts and the electric or magnetic adjustments of the meter can only be obtained breaking the seals. Care shall be taken to ensure that the mechanism as well as the inter of the case is free from dust or other extraneous matter immediately prior to sealing.

18. One or more substantially glazed dust-tight windows shall be provided in the front the case in such a manner as to give a clear view of the register, and also of those working pa the observation of which is necessary for rapid testing of the meter. It shall be impossible remove the glass without breaking the seals of the case or breaking the glass itself.

20. The terminals of the meter itself, unless of the switchboard type, shall be enclosed by separate cover suitable for sealing, or contained in an external compartment of the case.

21. All meters of sizes above 100 amperes shall be provided with soldering sockets, exc where provision is made for coupling with strip or bar connections.

22. The pressure circuit shall be connected to the supply side of the main circuit, and disconnecting device shall be provided in the terminal compartment, to enable the pressu circuit to be entirely disconnected from the main circuit, in order that it may be supplied w current from a separate source for purposes of testing. The disconnecting device is not necessa where separate terminals are provided for the pressure circuit.

23. The meter, unless of the switchboard type having external connections, shall be p vided with separate facilities enabling the purchaser to seal independently the terminal co partment and the meter case. Facilities may also be provided for independent sealing by t manufacturer.

24. Every meter, the accuracy of which is affected by small changes in level, shall be provid with means of ascertaining, without breaking the seals, that it is correctly levelled.

25. A diagram of connections to be attached to the meter.

26. The circuits of the meter shall be capable of carrying full load continuously witho injury to any part of the meter, without any permanent change in its accuracy, and witho the temperature of any accessible part of the case exceeding 10° C. above the temperature the surrounding air, except when a shunt is employed in a separate compartment forming integral part of the meter, when the temperature of any accessible part of the case of su compartment shall not exceed 30° C. above the temperature of the surrounding air.

27. Every external resistance shall be completely enclosed in a strong metal case.

Every external resistance shall be so constructed that when the marked pressure is appli to the meter and resistance combined and is maintained continuously, no injury shall be do to any part of the resistance, and the temperature of any accessible part of the case shall n exceed that of the surrounding atmosphere by more than 30° C.

28. The insulation resistance between all the electric circuits of the meter coupled togeth and the containing case, or other metal not intended to be insulated when the meter is in u shall be not less than 5 megohms.

* By permission of the British Engineering Standards Association.

The insulation resistance between the main circuit and the pressure circuit (if any) shall not less than 2 megohms.

The insulating material between all the electric circuits and the containing case, or other tal not intended to be insulated when the meter is in use, shall withstand, for one minute, alternating pressure equal to twice the pressure of the circuit for which the meter is intended, th a minimum of 1,000 volts. All the electric circuits shall be coupled together before plying the high pressure.

The insulation resistance shall be measured with a pressure of not less than 200 volts nor re than 500 volts (direct), applied for a sufficient time for the reading of the insulation indicator become practically steady.

29. The rate of loss of energy in the pressure circuit at marked pressure shall not exceed values given in the following table:—

Meter.	Marked Pressures up to 250 volts.	Marked Pressures above 250 volts.
Direct current	5 watts	2 watts per 100 volts
Alternating current	2 watts	1 watt per 100 volts

The rate of loss of energy in the meter current circuit for all meters having a marked rent not exceeding 50 amperes shall not exceed 10 watts; with the further restriction that pressure drop shall not exceed 2 volts.

When the meter has more than one element the above requirements shall apply to each ment independently.

30. The forward direction of rotation of the rotor, if any, shall be clearly indicated.

32. The following shall be the standard sizes of meters:—2·5, 5, 10, 20, 40, 50, 100, 150,), 300, 400, 500, 600, 800, 1,000, 1,500, 2,000, 3,000, 4,000, and 5,000 amperes.

34. When a current equal to one-hundredth of the marked current of the meter (or when s is less than one-twentieth of an ampere, then one-twentieth of an ampere) traverses its main cuit, the rotor shall start and continue running steadily, the pressure circuit, if any, being ergised at the marked pressure in phase with the current in the main circuit.

35. The error of the meter at the standard or marked temperature, pressure, frequency d at unity power factor shall not exceed the following values:—

PERMISSIBLE LIMIT OF ERROR.

Load.	Meters without external shunts or transformers.	Meters with external shunts or transformers.
	Per cent. from true reading. + or −	Per cent. from true reading. + or −
Full load to one-fifth full load (inclusive)	2	2·5
From one-fifth to one-tenth full load	2·5	2·5
At one-twentieth full load	4·5	5·0

36. If the meter has a pressure circuit, a variation of 5 per cent. above or below the marked ssure at any load from full to one-tenth shall not cause a change in the rate of registration respect of such variation of more than one per cent.

39. The meter shall not be injured, and its accuracy shall not be permanently impaired, by a rrent 25 per cent. in excess of its marked current maintained for a period of one hour, or by e passage of a current in the main circuit not exceeding 30 times the marked current of the

meter for a period not exceeding half a second, the rotor, if any, being free to rotate, and pressure circuit being energised at marked pressure.

40. The meter shall not be injured, and its accuracy shall not be permanently impaired the application of a pressure 15 per cent. above the marked pressure for a period of one hour.

41. Every meter having a pressure circuit shall not register with its main circuit open v the pressure circuit alone is acting, either when marked pressure is applied or when this pres is increased to 10 per cent. above the marked pressure.

INSULATION MEASURING INSTRUMENTS.

(Evershed & Vignoles.)

These instruments are very largely used for the measurement of the resistance of insul and conductors; they embrace ranges from 1 microhm up to 10,000 megohms. All are d reading in the strictest sense, and the ruling feature of each is to provide a means of mea ment which shall be so simple that it can be used by any unskilled person, so rapid to use a test shall occupy but a few seconds, and so portable that the instrument can be taken anyw to do the work required.

THE 'MEGGER' TESTING SET consists of a moving-coil type ohmmeter combined in one with a high-pressure generator driven by a folding crank handle. The general principles o construction and the electrical connections of the set are shown in the following diagram.

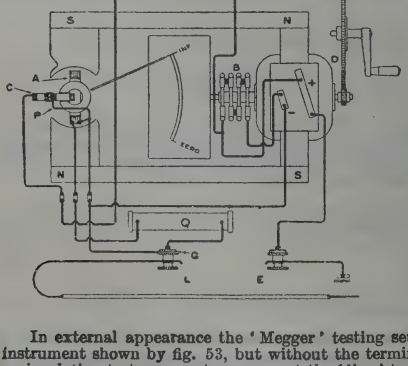

FIG. 53.—Megger Testing Set. Diagram of Connections.

A = current coil; P = pressure C = compensating coil; N, S = magn Q, R = resistances; B = brush g D = driving gear; + − = generator minals; G = guard plate; L = ext 'line' terminal; E = external 'ea terminal.

In external appearance the 'Megger' testing set is similar to the 'Bridge Megger' te instrument shown by fig. 53, but without the terminals at the end of the case. To carry an insulation test on a system, connect the 'line' terminal to the circuit and the 'earth' term to a good earth. If testing between two wires, connect one wire to each terminal.

When the handle of the generator is turned at about 100 r.p.m. the rated voltage wi developed, and the value of the insulation resistance under test will be indicated directly by pointer over the scale. The instruments are fitted with either variable or constant-pres generators; the constant-pressure type should always be used when testing the insulatio circuits having considerable electrostatic capacity, such as large house-wiring installat supply and feeder cables, etc. The constant-pressure device consists of a centrifugal fric clutch, which secures that when the handle is turned above the slipping speed, the speed o generator, and consequently the terminal E.M.F., remains constant. All 'Megger' and 'Br Megger' testing sets are provided with a system of guarded insulation to ensure that no inte or surface leakage can affect the readings. Any error in tests of high insulation due to lea across the surface of the material under test can be eliminated by the use of a guard wire nected to the 'guard' terminal, which is provided on all high-range instruments.

THE BRIDGE-MEGGER TESTING SET, fig. 54, is a combined ohmmeter and generator of usual 'Megger' type for insulation testing, but also arranged so that the ohmmeter can be verted into a Bridge Galvanometer by means of the change-over switch fitted. The cur for the Bridge tests is provided by the generator (constant-pressure type), and a direct-rea

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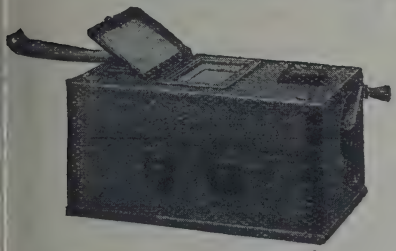

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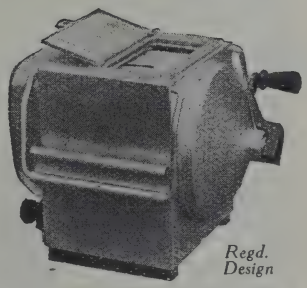

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esistance box of special and convenient design is supplied as a standard of comparison. The hole combination forms the most rapid known means of measuring that range of resistances for hich the Bridge method is adapted, and the value of the resistance is given plainly in a row of gures, which prevents errors. The series of ranges covers Bridge measurements from 0·01 ohm

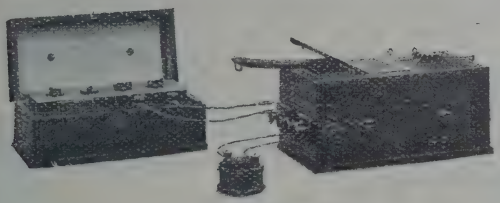

FIG. 54.—Bridge-Megger Testing Set in Use.

pwards, and insulation measurements up to 2,000 megohms. In addition to the measurement f insulation and conductor resistances, the set may be used for the localisation of faults on elephone and telegraph cables, or on electric light cables if their resistance falls within the imits of Bridge methods.

THE 'DUCTER' POTENTIAL OHMMETER TESTING SET provides for the measurement of resistances from 1 microhm up to 100 ohms by the direct deflection method. The current for his set is supplied by a separate battery, and a pair of duplex handspikes are used for making ontact on the resistance under test. With these instruments the resistances of switch and fuse ontacts, armature windings, rheostat coils, rail-bonds, sheathing and earth circuits in collieries, oints and the like, are easily and rapidly determined.

MEG INSULATION TESTER.

The most recent development in Evershed & Vignoles' resistance-measuring instruments, the 'Meg' Insulation Tester (fig. 55), which was introduced in 1922. While the Megger and ridge Megger continue to be the standard instruments where the measuring instrument must e capable of dealing with a very long range of resistance values, it was felt that there was room

FIG. 55.

or a smaller, lighter, and less costly instrument of the Megger type. The 'Meg,' with its ranges p to 20, 50 or 100 megohms, is quite suitable for most classes of insulation testing, and is sed very extensively for switchboard wiring, testing generator and motor coils, etc. Two odels of the 'Meg' insulation tester are made for variable pressure and constant pressure, the tter having a speed-control device which ensures constant voltage, an important feature where he capacity of the insulation to be tested exceeds 0·5 microfarad, as, for instance, house wiring, nsulation, etc.

ELECTRIC LAMPS.*

Metal Filament Lamps.

The gas-filled lamp, like the vacuum lamp, which it is rapidly replacing, has a filament o tungsten, the melting point of which is over 3,000° C.; this fact enables the filament to be ope ated at a higher temperature than any other metal, with the result that a high proportion of i total radiation is in the visible spectrum. While the melting point of tungsten is very high oxidises readily at quite a low temperature (about 300° C.). When new it can be readily ben into any desired shape. It is this property which facilitates the manufacture of the filamen both in the ordinary up and down winding and also in the spiralised form.

In a tungsten lamp an increase in voltage produces an increase in resistance (in a carbo filament the resistance under such variation remains practically constant). Fig. 56 shows th relationship between watts and voltage of a modern Tungsten electric lamp, while the lume characteristic is shown in fig. 57.

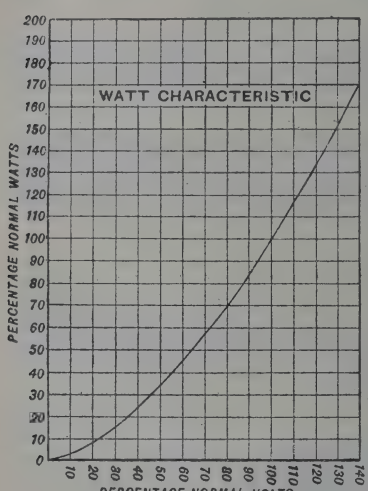

FIG. 56.

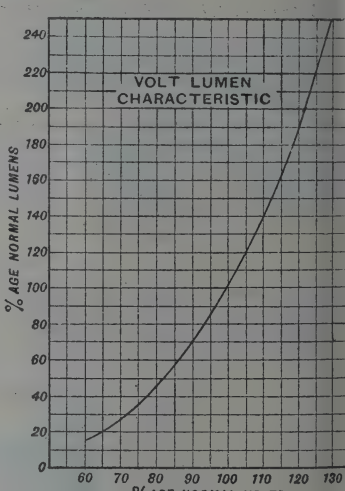

FIG. 57.

An increase in voltage produces an increase in temperature of the filament, so that a ver great volume of light is obtained. An increase of 10 per cent. volts brings about an increa of 41 per cent. in light output, while a reduction of 10 per cent. reduces the light output by 32 p cent. For this reason under-running is to be greatly deprecated in view of the great loss luminous energy. On alternating current of low frequency a flickering is obtained dependen upon the heat capacity of the filament itself, but the remedy in such cases is to eliminate th use of small lamps by installing a smaller number of larger units. This effect of flickering is le conspicuous in the tungsten lamp than in the carbon lamp because of the temperature coefficien As far as possible it is recommended that where difficulties are experienced in this direction th lamps of not less than 100 watts be employed.

In the case of the gas-filled lamp the bulb temperature is considerable, while the lamp whi is not gas-filled remains comparatively cool.

All lamps manufactured in this country by the members of the Electric Lamp Manufacture Association are made in accordance with specifications which ensure that a uniform produ is obtained of a standard quality.

* See also Sect. XXXVIII., Part III, Lighting, p. 2521.

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Standard Tungsten Vacuum Electric Lamps.*

The following table (from the B.E.S.A. Specification No. 161—1925) gives figures relating to standard tungsten vacuum lamps :—

Rating.		Standard Caps.	Maximum Overall Dimensions.				Torsion Test for Bayonet Cap.
			Length.		Bulb Diameter.		
Volts.	Watts.						
1	2	3	4		5		6
			mm.	Ins. (approx.)	mm.	Ins. (approx.)	
100 to 130	10	B.C.	122	4·8	61	2·4	25 pound-inches.
100 to 130 and 200 to 260	20	B.C.	140	5·5	63	2·5	
	30	,,	140	5·5	63	2·5	
	40	,,	140	5·5	63	2·5	
	60	,,	150	5·9	70	2·75	

Standard Tungsten Gas-Filled Electric Lamps.*

The following table (B.E.S.A. Specification No. 161—1925) gives figures relating to standard tungsten gas-filled lamps :—

Rating.		Standard Caps.	Maximum Overall Dimensions.						Light-Centre length with Standard Cap. Tolerance ± 10 per cent. with max. of 10 mm.†		Torsion Test for Bayonet, and Edison and Goliath Edison Screw Cap.	
			Length.		Diam. of Bulb.		Diam. of Neck.				Bayonet and Edison	Goliath.
olts.	Watts.											
1	2	3	4		5		6		7		9	9
			mm.	Ins. approx.	mm.	Ins. approx.	mm.	Ins. approx.	mm.	Ins. approx.		
100 to 130	30	B.C.	120	4·7	62	2·4	35	1·4	80	3·2		
	40	,,	125	4·9	62	2·4	35	1·4	85	3·4		
	60	,,	125	4·9	72	2·8	40‡	1·6	85	3·4		
100 to 130 and 200 to 260	75	,,	150	6·0	72	2·8	40‡	1·6	100	4·0	25 pound-inches.	45 pound-inches.
	100	,,	170	6·7	82	3·2	42‡	1·7	120	4·8		
	150	,,	170	6·7	92	3·6	45	1·8	120	4·8		
	150	E.S.	180	7·1	92	3·6	45	1·8	130	5·2		
	200	,,	215	8·5	103	4·1	48	1·9	150	5·9		
	300	G.E.S.	250	9·9	113	4·5	55	2·2	180	7·1		
	500	,,	280	11·1	133	5·3	60§	2·4	205	8·1		
	1000	,,	340	13·4	173	6·8	70	2·8	250	9·9		
	1500	,,	340	13·4	173	6·8	70	2·8	250	9·9		

* By permission of the British Engineering Standards Association.
† It is hoped to reduce these tolerances at a later date.
‡ It is intended to reduce this dimension to 38 mm. as soon as possible.
§ It is intended to reduce this dimension to 57 mm. as soon as possible.

The following tables (B.E.S.A. Specification No. 161—1925†) give figures relating to Tractio Train, and Bus Lamps:—

STANDARD VACUUM TRACTION LAMPS (SERIES). STANDARD VACUUM TRAIN LIGHTING LAM

Rating.		Standard Caps.	Maximum Overall Dimensions.				Rating.		Standard Caps.	Maximum Overall Dimensions.			
Volts.	Watts.		Length.		Diameter of Bulb.		Volts.	Watts.		Length.		Diamet of Bulb	
1	2	3	4		5		1	2	3	4		5	
			mm.	in.*	mm.	in.*				mm.	in.*	mm.	in
100								15	B.C.	76	3	52	
110	30	B.C. or E.S.	110	4·3	61	2·4	16	20	B.C.	76	3	52	
120								15	B.C.	76	3	52	
130	40	B.C. or E.S.	110	4·3	61	2·4		20	B.C.	76	3	52	

STANDARD GAS-FILLED BUS LAMPS.

Rating.					Overall Dimensions.							
Volts.	Watts.	Filament Shape.	Standard Cap.	Type of Bulb.	Length.				Diameter of Bulb.			
					Max.		Min.		Max.		Min.	
1	2	3	4	5	6	7	8	9	10	11	12	13
					mm.	in.*	mm.	in.*	mm.	in.*	mm.	in.
14	14	V	B.C.	Clear Pipless.	72	2·8	63	2·5	52	2·0	48	1·

* Approximate.

Note.—The 'Torsion Test' for Bayonet or Edison Caps for all three tables is 25 pound-inch

Efficiency of Electric Lamps.

Type of Lamp.	Average Efficiency in Lumens per Watt.	Average Efficiency in Spherical Candles per Watt.
Carbon	3·3	4·1
Tantalum	6·0	2·1
Tungsten (Vacuum)	8·0	1·5
Tungsten (Gas-filled)	12·5	1·0

Intrinsic Brilliancy of Lamp Filaments.—The candle power per square inch of the filame of carbon 3·1 w.p.c., tantalum 2 w.p.c., and tungsten 1·25 w.p.c. lamps is 480, 625, 750, and 1,0 respectively, while the gas-filled lamp is 5,000.

Quality of Light.—The light of tungsten lamps more closely approaches daylight than that other illuminants. It naturally follows that tungsten lamps cause colours to retain more nea their true values than any other artificial light source.

† By permission of the British Engineering Standards Association.

Mazda Lamps.

(The British Thomson-Houston Co., Ltd.)

Mazda lamps, the filaments of which are made from pure-drawn tungsten wire, give a brilliant white light. They can be operated satisfactorily in any position, but in the larger sizes it is better to use the lamps set vertically. The lamps operate equally well on either continuous or alternating current circuits

Mazda lamps, including both the vacuum and gasfilled types, have made it possible to design lighting units of suitable sizes for all lighting conditions, and of such high efficiency as to compete effectually with all other types of artificial illuminants. Users of electric light have a choice of sizes ranging from 5 watts to 1500 watts. Every size is adapted, as regards filament position and shape of bulb, for use in conjunction with specially designed glass or metal reflectors.

The gasfilled lamp is claimed to give, for the same current consumption, considerably more light than the previous best incandescent lamp. The recent development of 30 and 40 watt gasfilled lamps in standard supply voltages has brought the advantages of the gasfilled principle within reach of the ordinary householder.

The strength and durability of the drawn wire filament ensure satisfactory results from Mazda lamps under all conditions of service. They have successfully withstood the severe conditions of use aboard battleships during target practice.

The flexibility of the Mazda drawn tungsten wire has made possible the production of special forms of filaments which could not be produced with a brittle squirted tungsten wire used in previous lamp bulbs. Helical coil filaments, as used in Mazda headlight bulbs, are better in regard to focus than the types of filaments hitherto employed.

The intrinsic brilliancy of the lamp is stated to be eight times that of ordinary metal filament lamps.

The gasfilled lamp is now made in small sizes for headlight use. The master patents governing the manufacture of Mazda vacuum and gasfilled lamps are the property of the makers of Mazda lamps.

Siemens Lamps.

(Siemens & English Electric Lamp Co., Ltd.)

These lamps have drawn tungsten wire filaments, and the Standard Vacuum type operate at an efficiency of, approximately, 1·2 watts per c.p. The 'gasfilled' lamp represents the latest development in metal filament lamp manufacture, and the larger sizes attain an efficiency of, approximately, 0·5 watts per c.p. Both types of lamps are made in an extensive range of voltages and candle-powers.

Siemens Standard Type Lamps.—These are made in voltages from 20 to 260, and in wattages from 5 to 60, and cover the lamps in general demand for ordinary electric lighting schemes of average intensity.

Siemens Traction Type Lamps.—This type of lamp has been introduced to meet the requirements experienced in situations where lamps are subjected to severe shock and vibration, and is now largely used on the leading tramway systems and tube railways. A totally new arrangement of the filament is employed, which ensures maximum strength and adequate support. The complete length of filament is spiralised and carried in a series of loops on a special spider in the usual Siemens manner. The distance between the top and bottom supports is considerably reduced, which ensures maximum strength, while neighbouring lengths of filament are more widely separated, thus obviating short-circuiting of adjacent lengths of filament, which sometimes occurs in the ordinary type of lamp subjected to severe vibration. The filament has no sharp bends, and will not 'sag,' so that the lamp may be used in any position. The vertical candle-power of the lamp is increased, and the light emitted is uniform in all directions other than towards the cap end. It is claimed for this design that these additional advantages have been obtained without loss of efficiency in operation.

Siemens Gasfilled Lamps.—The gasfilled lamp was originally introduced in high candle-power types only, but the range has been increased, with the result that these lamps are now obtainable for standard lighting voltages from, approximately, 30 to 1,500 watts. Owing to their high efficiency, these lamps became known to the public as 'Half Watt' type lamps. It is, however, an essential condition to their production that they should be gasfilled in order to obtain a satisfactory life at the efficiency mentioned. The leading manufacturers are therefore stamping the word 'gasfilled' on the bulbs of these lamps, so that the consumer may be protected should he be offered lamps which, though resembling genuine high-efficiency lamps, are not gasfilled.

The range of Siemens gasfilled lamps now includes automobile head-light lamps, from 4 to 14 volts, from 8 to 48 watts; Siemens gasfilled lamps for railway lighting, 25 volts, can be obtained from 15 to 100 watts. The 50- to 60-volt gasfilled lamps are supplied from 15 to 500 watts; 100- to 130-volt from 30 to 1,500 watts; and the high voltage gasfilled lamps, 200- to

260-volts, from 40 to 1,500 watts. These high candle-power lamps are being employed in large numbers for general lighting in stores, workshops, factories, offices, shops, etc., and for street lighting; they produce illumination without flicker, and require no attention after installation, save occasional cleaning.

Siemens Automobile and Battery Type Lamps.—In addition to the range of gas-filled automobile head-light lamps mentioned above, Siemens Battery Lamps are made for automobile lighting, sign lighting, omnibus and yacht lighting; while there is also a variety of types suitable for use in miners' hand and rescue lamps. The voltages of these vary from 2 to 14, and the wattages from, approximately, 1 to 36 watts.

Osram (G.E.C.) Lamps.

(The General Electric Co., Ltd.)

The Osram (G.E.C.) lamps have filaments drawn from tungsten; they have also pipless bulbs, which greatly improves their appearance and renders them less liable to be broken, both in transit and in use.

The efficiency of these lamps approximates to ½ watt per candle, as compared with vacuum lamps which consume about 1 watt per candle. The Osram gas-filled lamp is known as the 'Gasfilled' type lamp, and is made from 15 to 1,500 watts. The high candle-power lamps are largely used in the place of arc lamps.

The Osram vacuum type lamp is made in sizes from 10 to 600 c.p., and, in addition, standard types have been supplemented by special types for different purposes, such as with concentrated filaments for projection and focusing work; and for use from low voltage batteries, such as miners' and general portable hand-lamps and automobiles (including motor-buses). The Osram (G.E.C.) lamp 'Gasfilled' type is also made for automobile headlights.

A modification of the gas-filled lamp is the 'White Osram,' which is a standard clear Osram lamp, the bulb of which is coated with a film of unglazed porcelain. This coating has the effect of efficiently diffusing the light, and eliminating all glare from the intensely bright filament. White Osram lamps should be used in all positions where the lamp itself is visible.

For industrial lighting, bowl sprayed White Osrams—that is, lamps having only the lower part of the bulb coated—when used with top reflectors, such as G.E.C. enamelled steel reflectors, are specially recommended.

A further development of the White Osram is the 'Colour Sprayed Osram' lamp, which is produced in six standard colours—red, orange, yellow, green, blue, and flame tint. Colour sprayed lamps are the most convenient means of obtaining colour light for both indoor and outdoor decorations, such as dances, concerts, restaurants, seaside promenades, etc.

In addition to the Osram lamps for ordinary lighting, they are made for a wide variety of special purposes, such as the 'Daylight' lamp for colour matching, projection lamps, ship type lamps, candle type lamps, striplite lamps, automobile type lamps, miners' lamps, etc.

The lamps are an entirely British product, every component part, including the brass caps, being produced within the G.E.C. organisation.

The Osglim Discharge Lamp.

(Osram G.E.C. Lamp Works.)

Whereas discharge lamps usually require at least 2,000 volts, by filling the lamp with neon gas the discharge will start on about 200 volts. The current flows through the neon from one electrode to the other, the gas glowing round the cathode with a soft rosy light. By using a resistance inside the cap, the consumption of the lamp is reduced to 5 watts. The faint light from this lamp (known as the 'Osglim') makes it ideal as a night light, or wherever subdued illumination and low consumption are important. By making the cathode in the form of letters or figures, effective indicators or advertising signs are obtained. The lamp can also be made suitable for use in the photographic dark room.

Attachment of Flexible Cords to Sockets

The majority of short circuits occurring in pendant sockets and the attachment-plug caps of portable electrical appliances, according to the Underwriters' Laboratories (America), are due to loose strands of the flexible cord, which become separated from the terminals when the binding screws or terminals are loosened. This loosening is frequently the result of the omission of a knot or its equivalent in the cord inside the cap of the socket or attachment plug, the strain due to pulling separable connections apart or dragging portables around by their cords being transmitted directly to the small binding-screw connections.

The so-called 'Underwriters' knot,' fig. 58, provides an easily-tied strained relief forming a rather flat knot, which will fit snugly in the recess provided for the purpose inside the cap of pendant sockets and attachment plugs.

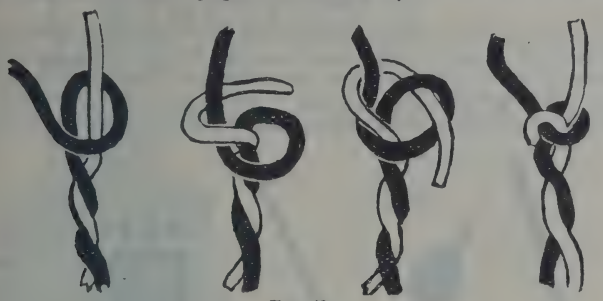

FIG. 58.

ARC LAMPS.

In a D.C. arc lamp the top or positive carbon burns about 1½ inches per hour, and twice as fast as the bottom or negative carbon of the same diameter. A 1,000-candle-power lamp requires carbons about $\frac{9}{16}$ inch in diameter and consumes about 1,000 watts.

SIZES OF CARBONS.

Current of Lamp, in amperes .	4	5	6	7	8	9	10	12	14	15	20
Diam of Plain Carbons, in mm. .	7	7	8	8	9	9	10	11	12	12	13
Diam. of Cored Carbons, in mm. .	10	12	14	14	16	16	17	19	21	21	23

THE ANGOLD MAGAZINE FLAME ARC LAMP.

(The General Electric Co. Ltd.)

The Angold Magazine Flame Arc Lamp is arranged to burn carbons of comparatively short length (maximum 15 ins.) without copper coating or metal core; twelve pairs of these carbons can be filled in the magazine at one time, and thereby, according to the type of lamp, 120 to 150 hours be obtained.

The carbons are so arranged that as soon as one pair is consumed the next pair comes into operation. The magazines can be filled up if only part of the trim has been consumed, so that at any time the full burning hours obtainable with a full magazine can be assured. The positive carbons cannot be put into the negative magazine, and when the last carbons are consumed, the feeding gear is automatically put out of action. Partly burnt carbons need not be removed. The interval of time during which the light is extinguished does not exceed two seconds.

The direct current lamp is manufactured for 8 or 10 amperes and can be supplied with self-contained equivalent resistance and automatic cut-out, or it can be supplied without these accessories. In the latter case, however, the lamps can only be used singly, on suitable voltage, or two in series on 100-120 volts. For longer series (or even for two lamps on higher voltage) equivalent resistances and automatic cut-outs have to be provided. If it is inconvenient to have these accessories self-contained they can be supplied in the suspension type, or if it is necessary to lower the lamp from contact gear a box type is recommended.

Both 8-ampere and 10-ampere lamps are designed for 9 mm. positive and 8 mm. negative carbons, 15 ins. long. Each trim of carbons consists of 12 pairs.

An alternating-current lamp of this make will burn in parallel singly on any voltage between 100 and 250 volts—25 cycles to 100 cycles. Each lamp is fitted with a self-contained transformer choker so that it can be connected directly to the mains.

THE STUDIO ARC LAMP.

(The General Electric Co., Ltd.)

The G.E.C. Studio Arc Lamp is of the semi-enclosed type, and the high voltage long arc produced yields the highest possible actinic values.

It is equally suitable for portraiture and blue printing, as, owing to the purity of the light and to the absence of shadows, exceptionally good results are obtained.

It is supplied for use on A.C. or D.C. circuits.

To obtain the high voltage necessary the lamp is run singly on 220-250 volts. For average work a 16-ampere with these voltages is generally used.

ELECTRIC CLOCKS AND TIME SERVICE.

THE PUL-SYN-ETIC SYSTEM.

The 'Pul-syn-etic' system, designed by *Messrs. Gent & Co., Ltd., Leicester*, is arranged to operat any number of impulse clocks, workmen's time recorders, turret clocks, etc., installed i any large building or institution and connected electrically in series. The hands of such dial are all caused to advance simultaneously at half-minute intervals by means of step-by-ste impulse propulsion movements (fig. 59) (or where inaudible working is required, the Silen Triangle Movement Fig. 59A) which, taking the place of the ordinary spring, or weight, an train of wheels, are operated by electric currents sent out periodically by a MASTER PENDULU

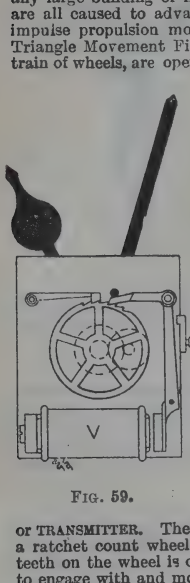

FIG. 59.

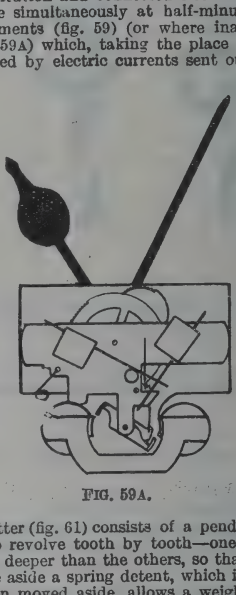

FIG. 59A.

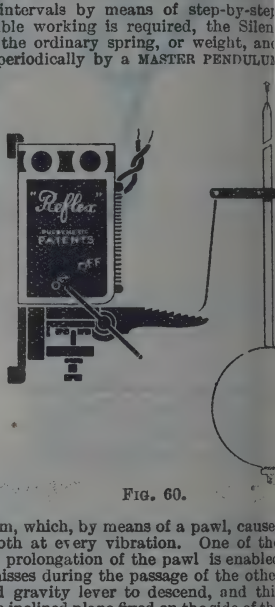

FIG. 60.

or TRANSMITTER. The latter (fig. 61) consists of a pendulum, which, by means of a pawl, cause a ratchet count wheel to revolve tooth by tooth—one tooth at every vibration. One of th teeth on the wheel is cut deeper than the others, so that a prolongation of the pawl is enable to engage with and move aside a spring detent, which it misses during the passage of the othe teeth. The detent, when moved aside, allows a weighted gravity lever to descend, and thi through the medium of a friction roller carried thereon and an inclined plane fixed on the side of th pendulum, gives an impulse to the latter, imparting energy sufficient to enable the pendulum t swing during another revolution of the wheel—that is, for period of half a minute. This gravity impulse is, of course constant and invariable, so that other factors, such a temperature variation, etc., being suitably provided for, th time-keeping qualities of the pendulum are exceptionall good. The descent of the gravity lever is caused to clos an electrical circuit, which fulfils a dual function: (a energising an electro-magnet, which causes the restoration o the gravity lever to its potential position, and (b) sending a electrical impulse through the external circuit to operat the impulse movements. The duration of this contact i about 0·05 second; but, depending upon the total self-in duction of the circuit, its duration is self-regulating, in tha the contact is not broken until the self-induction has bee overcome and all the dials operated.

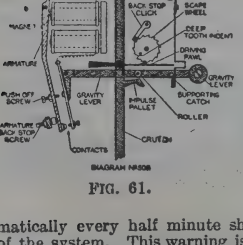

FIG. 61.

The system includes in series with the transmitter an the clocks a weak battery warning-bell which rings auto matically every half minute should the battery run down and so endanger the safe workin of the system. This warning is given before the actual breakdown point is reached, affordin a safe margin of time in which to recharge or renew the battery. The 'Pul-syn-etic' syste is noted for its low current consumption, and it is claimed that it takes the least current of an known Impulse system.

The system lends itself conveniently to the automatic operation of sound signals for th starting and ceasing of work, and also to the convenient operation of output and idle machin recorders. This class of recorder has proved itself useful in connection with textile machine and machines which should not be idle during working hours.

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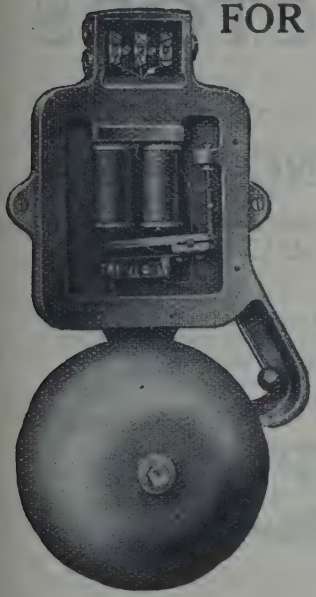
FOR ALL INDUSTRIES



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for connecting to A.C. or D.C. Service Mains

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LIGHTNING CONDUCTORS

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Workmen's Time Recorders are now controlled from the half-minute impulses of the system by means of the 'Pul-syn-etic Reflex' Pendulum Control (fig. 60). With this control the recorders remain independent units, and no mechanical alterations are made, but with the 'Reflex' fitting, as shown in fig. 60, attached to their pendulums, all recorders are compelled to keep in step with the transmitter.

Even if the electrical connections be removed the recorders continue to work under their own power as before, but uncontrolled. This 'Reflex' control is also applicable to the pendulums of large public clocks, and its introduction is a marked advance in the science of the Unification of Time.

For large turret clocks, the accuracy of whose performance is subject to interference from variation in wind pressure or from accumulations of snow and ice on the hands, a special WAITING TRAIN movement is used, in which the hands are driven continuously by a special type of electric movement sufficiently powerful to overcome any such resistance ordinarily to be expected. The hands are caused to travel at a slightly faster rate than usual, to gain in fact about two seconds per half minute. Every half minute, however, the driving train disconnects itself from the hands, which then wait until the driving power is reconnected by means of the usual half-minute electric impulse current sent out by the transmitter driving the other impulse clocks in the building. The waiting period is practically unnoticeable—so that in very large turret clocks immunity from the usual weather interruptions is achieved, together with a greater degree of accuracy in timekeeping than in clocks operated in the usual manner. Efficient electric striking, or striking and chiming apparatus, can be supplied for bells of any size.

This WAITING TRAIN movement has been chosen for driving the hands of the large electric clock, in the towers of the offices of the Royal Liver Friendly Society at Liverpool. This has four 25-ft. dials, and the weight of a pair of hands is 5 cwt. The minute hands are 14 ft. long, 2 ft. 6 ins. wide at the greatest width, and 9 ins. thick where attached to the spindle. The combined weight of each pair of hands, spindles, and internal counter-weights, is a trifle over half a ton. The area of the hands exposed to snow and wind is very great, nevertheless the type of mechanism employed has shown itself able to withstand the disturbing effect of several severe storms since its erection in 1911. The size of the Liver Clock has now been exceeded by the new 'Singer Clock' in the tower of the works of the Singer Mfg. Co., Ltd., Clydebank, which clock has four 26-ft. dials, all driven by a single 'Waiting-Train' movement.

For ship use special clocks are provided, the Impulse Transmitter being fitted with an automatic arrangement, which enables the whole of the ship's clocks to be automatically advanced or automatically retarded, while sailing east or west. These 'Pul-syn-etic' marine clocks are installed in a large number of liners and ocean-going steamers.

LIGHTNING CONDUCTORS.

CODE OF RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS.

(Lightning Rod Conference, 1882, *and Lightning Research Committee, Royal Institute of British Architects*, 1905.)

Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth. Horizontal conductors should connect all the vertical rods (*a*) along the ridge, or any other suitable position on the roof; (*b*) at or near the ground line. The uppermost conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet. Short vertical rods should be erected along minor pinnacles and connected with the uppermost horizontal conductor. All roof metals, such as finials, ridging rain-water and ventilating pipes, metal cowls, lead flashing, gutters, etc., should be connected to the horizontal conductors. All large masses of metal in the building should be connected to earth, either directly or by means of the lower horizontal conductor. Where roofs are partially or wholly metal lined they should be connected to earth by means of vertical rods at several points. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas meter should be metallically connected with house services leading from the meter.

Material for Rod.—Copper, weighing not less than 6 oz. per foot run, either in the form of tape or rope of stout wires, no individual wire being less than No. 12 S.W.G. Iron may be used but should not weigh less than 36 oz. per foot run. Subsidiary conductors for connecting metal ridging, etc., to earth may with advantage be of iron and of a smaller gauge, such as No. 4 S.W.G. galvanised iron.

Points.—The point of the terminal should not be sharper than a cone of which the height is equal to the radius of its base; but a foot lower down a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fixed three or four sharp copper points, each about 6 ins. long. The number of conductors or points to be specified depends upon the size of the building, the material of which it is constructed, and the comparative heights of the several parts; no general rules can be given, but even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, as accidents often occur owing to the good conducting power of the heated air and soot in a chimney.

Fixing.—Rods should preferably be taken down the side of the building which is most exposed to rain. They should be held firmly by holdfasts of the same metal as the conductors (not by insulators), but not so tightly as to prevent free expansion and contraction due to changes

of temperature. They should not be bent abruptly round sharp corners; the vertical rods shoul be carried at a certain distance from the wall to prevent dirt accumulating, and to avoid th necessity of running them round projecting masonry or brickwork. In some cases it may b necessary to carry a rod through a string-course or other projecting stonework to avoid curvature in which case the hole should be large enough to give ample clearance to the conductor, but i is better to run outside, keeping the rod away from the structure by means of holdfasts a mentioned above.

Joints.—Joints in series of conductors should be as few as possible. As a rule they shoul only be necessary where the vertical and horizontal conductors are connected, and the mai conductors themselves should always be continuous, without artificial joints. Connection between vertical and horizontal conductors should always be in places readily accessible fo inspection. Every joint, besides being well cleaned, screwed, scarfed, or riveted, should b thoroughly soldered, and should be protected from the action of the air, especially in cities.

Painting.—Iron rods, whether galvanised or not, should be painted; copper rods may b painted or not, according to architectural requirements.

Protection.—Copper rods to the height of 10 ft. above the ground should be protected fron injury and theft by being enclosed in an iron pipe reaching some distance into the ground.

Earth Connections.—It is essential that the lower extremity of the conductor be buried i permanently damp soil; hence proximity to rain-water pipes and to drains is desirable. It i a very good plan to make the conductor bifurcate close below the surface of the ground, an adopt two of the following methods for securing the escape of the lightning to earth: a strip of copper tape may be led from the bottom of the rod to the nearest gas or water *main*—no merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of coppe 3 ft. sq. and $\frac{1}{16}$ in. thick, buried in permanently wet earth, and surrounded by coke, charcoal or pulverised arc-lamp carbons (coke, however, is likely to set up corrosive action on the earth plate), or many yards of the tape may be laid in a trench filled with coke, well rammed. Wher iron is used for the rod, a galvanised iron earth-plate should be employed. A tubular earth connection driven into moist ground makes an effective earth, especially if it is connected t a rain-water pipe. (See also 'Earth Connections,' *below*.)

Masses of Metal.—As far as practicable the conductor should be connected to all extensiv masses of metal, such as ornamental ironwork, hot-water pipes, etc., both external and internal but it should be kept away from all soft metal pipes, and from internal gas-pipes of every kind Church bells and turret clocks should be connected with the conductor. In the case of a lon line of metal ridging, each end of the ridging should be directly connected to earth by a rod Where the ridge is non-metallic, a horizontal conductor should be run at a short distance abov the ridge and be connected to earth.

Factory Chimneys.—These should have a copper band round the top, and stout sharp coppe points, each about 1 ft. long, at intervals of one or two feet all round the circumference. Th rods should be connected with all bands and metallic masses in or near the chimney. As a alternative, the rods above the band may be curved into an arch provided with three or fou points. Two lightning rods should be carried down from the band to earth.

Collieries.—Undoubted evidence exists of the explosion of firedamp in coal mines through sparks from atmospheric electricity being led in to the mine by the wire ropes of the shaft an the iron rails in the galleries; hence the head-gear of all shafts should be protected by prope lightning conductors.

Inspection.—Before giving his final certificate the architect should have the conductor care fully examined and tested by a qualified person, as injury to it often occurs up to the latest perio of the works from accidental causes, and often from the carelessness of the workmen.

Earth Connections.

In making earth connections for electrical circuits, lightning rods, etc., it is desirable to provid several paths to earth, as far apart as possible. Connection should be made with the stratum of permanently moist earth nearest the surface of the ground, rather than to deeper layers o even to the water in a deep well. The best earth connection is a water pipe. For most purpose galvanised iron pipes, about 1 in. in diameter, give satisfactory results; in a series of experiment such pipes, driven into stony clay soil, gave the following average results per pipe.—

1 ft. deep	149 ohms	4 ft. deep	50 ohms.
2 ft. „	88 „	6 ft. „	56 „
3 ft. „	64 „	8 ft. „	29 „

Generally, if moist earth is reached, pipes need not be driven deeper than 10 ft. The resist ance of two earth-pipes in series, driven 10 ft. deep, becomes practically constant at any distanc apart from 10 ft. upwards. Earth-pipes connected in parallel should be at least one foot apar They need not be larger than 2 ins. in diameter.

If earth-plates are used it is better to bury two small plates 20 ft. apart, connected by a stou wire, than one large plate. They should be on edge, with the soil well rammed on both sides In shallow soil over rock, long narrow strips of metal buried in trenches should be used. Patente devices offer no special advantages. Two plates in parallel, each 2 ft. by 4 ft., 6 ft. deep, 5 f apart in stony clay soil had a joint resistance of 16 ohms. A strip of galvanised iron 1·5 ins. wid and 20 ft. long, in a trench 12 ins. deep, had a resistance of 17·7 ohms. The resistance of a wate

ipe is usually less than 1 ohm, averaging ½ ohm. The addition of salt to the soil round the arth connection greatly reduces the resistance; so does the packing of coke or charcoal round he plate, but both these devices hasten the corrosion of the plate. As a high potential gradient nay exist on the surface near the earth connection, unless it is of the buried type, the earth-pipe nd connecting lead should be guarded to prevent accidental contact with them. The joint etween the lead and the earth-pipe or plate should be embedded in concrete for protection, nd the earth-wire should be covered throughout its length. All earth connections should be nspected and tested at least once a year.

Phœnix Office Rules for Lightning Conductors.

The Phœnix Fire Office, in their rules for lightning conductors, point out that the only way o obtain absolute security against lightning is to enclose the building in a metal framework onstituting the 'bird-cage' system of conductors. This can be accomplished generally by tilising the rain-water pipes and gutters as part of the system. The ordinary conductors must be ixed in addition, and the whole system effectively earthed. The material of the conductor should e of copper tape, measuring at least 1 inch by ¼ inch, or, if copper cable be adopted, it should ot consist of less than seven strands, each ¼ inch diameter. Soft iron may be used in place of opper, and, except for chemical reasons and for permanence, the sectional area need not be reater than in the case of copper. Conductors should be kept a certain distance away from alls so as to prevent the accumulation of dirt, but they must not be insulated. If a copper late is used for the earth connection it should not be less than 3 square feet in area and ¼ inch n thickness, and should be adopted only where it will always be in water or moist earth; otherise connection should be made to the water mains, or the 'tubular' system should be employed. he number of connections depends on the ground area of the building, but there are few structures where less than two are necessary. The elevation rod of factory chimneys should be a ircular band placed round the top of the shaft, with points fixed at an angle of 45°, and exending outwards, or an arch of metal, provided with points, may be fixed across the mouth f the chimney.

Domestic Uses of Electricity.

It is seldom that lighting is the only domestic service obtained when an electricity supply is vailable. Provided the cost of electricity is not exorbitant, certain valuable appliances are to e met with in most households, *e.g.* flat iron, vacuum cleaner, desk fan, toaster, coffee percolator, ilk boiler, kettle, warming pan, hair dryer, bowl fire, etc., etc. Such services can be had at a ery small running cost, since the amount of energy consumed is generally small. Where electric nergy can be obtained at a low rate, *e.g.* at an overall charge of ¾*d.* to 1½*d.* per unit, main domestic ervices such as heating, cooking, and hot-water supply are available at costs comparable with ther methods, such as coal or gas. Even where the cost of electricity may be prohibitive for eneral use, it may be low enough for occasional use. In addition the advantages of cleanliness, onvenience, comfort, labour-saving, etc., are valuable assets. Reliable appliances for all the bove-mentioned services are now available, and when the capital costs of wiring and of apparatus re suitably reduced or embraced in hire-purchase systems, etc., a great expansion of domestic lectrification can be looked for. Already electricity at an overall cost of about ¾*d.* per unit to ccupants of all-electric houses is available to about four million people in Great Britain, and upply authorities are becoming widely interested in schemes for assisting consumers.

Data concerning heating, cooking, and hot-water supply in private households will now be iven. In Table I figures are reproduced from p. 305, vol. 64, of the *Journal I.E.E.* These igures were given by Prof. A. H. Barker in the discussion of a paper on 'An All-Electric House,' y Prof. S. Parker-Smith, and are intended to show how many heat units are needed per person er annum for the stated services:

Table I.—Net B.Th.U. used per Person per Annum.

Description.	Estimate for well-to-do Person.	Estimate for Artisan.	From Barker's Experiments for One Person Living Alone.	From Parker-Smith's All-Electric House.
Heating . . .	3,000,000	1,000,000	4,500,000	3,400,000
Hot-water supply and laundry . .	8,000,000	2,000,000	2,100,000	4,150,000
Cooking . . .	400,000	180,000	800,000	474,000
Total .	11,400,000	3,180,000	7,400,000	8,024,000

In table II. the consumption and costs in the ' All-Electric House ' just referred to are given.

TABLE II.—ALL-ELECTRIC HOUSE (10 ROOMS). SIX PERSONS IN HOUSE, EXCLUDING GUEST TOTAL CONSUMPTIONS AND COSTS IN TWO SUCCESSIVE YEARS.

Details.	First Year.		Second Year.	
	Units.	Cost.	Units.	Cost.
	kw. hours.	£ s. d.	kw. hours.	£ s. d.
Fixed charge per annum .	—	12 10 0	—	12 10 0
Day load at ½d. per unit .	10,299	21 9 2	9,713	20 4 8
Night load at ¼d. per unit *	6,043	9 8 10	5,827	9 2 1
Total for year . .	16,342	43 8 0	15,540	41 16 9

In Table III. the consumptions for the several services are analysed (see *Jour. I.E.E.*, vol. 6 p. 888).

TABLE III.—ANALYSIS OF CONSUMPTIONS IN TABLE II. (DIFFERENCES IN TOTALS DUE T METER INACCURACIES.

Description.	First Year.	Second Year.	Remarks.
	kw. hours.	kw. hours.	
Heating . .	5,954	6,636	Obtained by electric fires.
Hot water { day .	1,242	1,245	Hot water stored in 87-gallon tank.
Hot water { night .	6,043	5,827	
Cooking † . .	2,777	1,858	Improvement due to self-contained utensils.
Lighting . .	568	687	Ample lighting at low cost.
Total . . .	16,584	16,253	
House closed . .	19 days.	10 days.	

THE ARTISAN'S ALL-ELECTRIC HOME.

Figures were published by Dr. S. Parker-Smith in *The Electrician* (vol. 96, p. 346). Allowin for losses in the hot water and cooking appliances, the estimate for an artisan given in Table I. i increased to 3,750,000 B.Th.U. or 1100 kw. hours per person per annum, making 5,500 kw hours per annum for a household of 5 persons. At an overall cost of 1*d.* per unit, this works ou at slightly under £23 per annum—a rather high figure for some families. In many areas, however the cost per unit averages ½*d.* to ¾*d.*, bringing the annual outlay down to a figure between £12 an £17, which is well within the reach of many artisans' families, and compares favourably wit alternative methods.

* Used for heating water in well-lagged storage tank during night hours (11 P.M. to 7 A.M.).

† At first boiling plates were used. The open-type proved unreliable when fatty liquid (*e.g.* milk) boiled over. The closed-type proved too slow for ordinary domestic cooking operations Much greater reliability, speed, and economy resulted when utensils with self-contained element (similar to the electric kettle) were used. In the first year the consumption for cooking per perso per day averaged 1·27 units. This was reduced by about one-half with the self-contained utensils

For large kitchens in restaurants, works canteens, etc., various sizes and combinations of ıparatus are made. The following data are taken from actual installations.

Class of Kitchen.	Total kilowatts.	Annual Consumption units.	No. of Meals per week.
Restaurant	247·6	146,500	9,518
Staff feeding	120·6	97·140	2,944
,, ,, ...	40·5	21·141	991
,, ,, ...	32·8	20,690	640

British Standard Specification No. 106 (1920) gives particulars of electric cooking ranges ır 5 and 10 persons respectively.

ELECTRICAL PRECIPITATION OF SMOKE AND DUST.

In recent years the Lodge system of precipitating dust particles or fumes in gases, such as the ıe gases from metallurgical works, cement mills or boiler furnaces, has been greatly developed r the Research Corporation, U.S.A., under Cottrell's patents. The apparatus consists of iron ıpes through which the gases are led, preferably downwards, with a steel or nichrome wire ıspended in the axis of each tube; the wires are charged to a pressure of 30,000 to 100,000 ılts and the pipes are earthed. The electric charge is derived from a.c. transformers with echanical rectifiers driven in synchronism with the alternating pressure so that the polarity ! the wires is always negative. The process can be carried on without cooling the gases and quires little power, from 5 to 50 kilowatts being usually sufficient. Resistance should be serted in the low-pressure circuit to limit the short-circuit current and to provide means of gulation, and reactance in the high-pressure circuit to prevent surging of the electric charge. rom 80 to 98 per cent. of the dust can be deposited; in some cases the introduction of steam is ecessary. In the case of blast furnace and cement mill gases, large quantities of potash can e recovered, particularly if salt is added to the charges of the blast furnace. Particulars of me successful installations are given below:—

Nature of Process.	Number of Pipes.	Length and Diameter of Pipes.	Pressure volts.	Rate of Flow of Gases.	Remarks.
Copper converter	608	10 ft. × 5 in.	30,000	10 ft. per sec.	97·25 per cent. recovered.
Silver furnace .	Chamber 8 ft. × 6 ft. × 16 ft.		50,000	—	Electrodes 6 in. lead strip.
Cement mills .	800	15·5 ft. × 12 in.	70,000	3·5 ft. per sec.	Temp. 900° F. 20 tons per day.
Copper and lead smelting works	384	15 ft. × 12½ in.	60,000	10,000 cub. ft. per day	Plant increased to 1,312 pipes.
Detarring coal gas	—	—	40,000 to 80,000	30,000 cub. ft. per hour	Unrectified alternating current.

Careful tests should be made before deciding on the dimensions, etc., of the apparatus to be stalled. Corrosive substances can be dealt with satisfactorily. At a certain cement factory the otash recovered is worth more than the cement. The kenotron is an efficient rectifier up to 50,000 volts. A similar process is used for separating oil from water.

ELECTRICITY IN AGRICULTURE.

The principal use of electricity in agriculture is to drive machines, in addition to lighting the rm buildings; it is also experimentally used for stimulating the growth of plants. Motors are ed either to drive stationary machines indoors from counter-shafting, or, being mounted on heeled trucks or stretchers, to drive portable machines out of doors, through belting. A farm ad has an excellent diversity factor, and as it does not come on during the evening peak load is very acceptable to a public supply system. Experience shows that for remunerative supply, t least 25 per cent. should be arable or dairy land. At Hereford the average revenue from farms about 20*l.* each per annum. With an electric milker one person can milk six cows

at once, using 20 watt-hours per cow. To churn 165 lb. of butter requires 1 kw.-hour. Cuttu 1 ton of ensilage consumes 1·38 kw.-hours. Threshing corn requires 70 watt-hours per bush of oats, 100 watt-hours per bushel of barley, 160 watt-hours per bushel of wheat. Grinding bushel of oats takes 420 watt-hours. Elevating 1 ton of hay, 200 watt-hours. The most suitab type of machine is the three-phase induction motor, on account of its simplicity and safe from fire; fire risk is a most important consideration in connection with farm work.

Electric ploughing is a special application of electricity under exceptional conditions; is usually effected with hauling gear mounted on trucks, which travel along the sides of the fiel hauling the plough (with three to five shares) to and fro across the land. The tractive effo required for ploughing in light soil is 740–820 lb. per sq. ft. of section ploughed; in heavy so 1,100–1,250 lb. For ploughing a furrow or furrows w ft. wide and d ft. deep, at v ft. per secon rhe horse-power required = $kwdv/550$, k being a constant as above, depending upon the so The speed v should not exceed 5 or 6 ft. per second. The motor should be capable of haulir double the normal load at times. Furrows up to 650 yds. long can be ploughed in this wa On a large farm the capital charges amount to 12*s.* per acre, wages to 2*s.*, energy at 1*d.* per ur to 2*s.* 6*d.* per acre for deep ploughing (12–14 ins. deep), total 16*s.* 6*d.* per acre. For ordina ploughing the cost is 11*s.* 4*d.* per acre. The hauling gear can be used also for harrowing and rollir the land, and for driving other machinery. The motor for ploughing should be of 25–30 h.p. (*Delamarre.*)

A large-sized plough can work 27 acres per day against one acre with horses.

For stimulating plant growth, the silent discharge from fine bare wires suspended abo the crops at a pressure of 50,000 volts or more, d.c., has been much used for experimental pu poses. The Agricultural Discharge Co. suspends the wires 10/12 yds. apart, at a height 16/18 ft., using one pole to 3 or 4 acres.

The Board of Agriculture reported in 1918 that experiments extending over six years show an average increase of 22 per cent. in the yield of spring cereals; some tests gave over 30 p cent. increase. The cost of a 100-acre equipment is estimated at 4*l.* per acre.

In a paper by R. Borlase-Matthews (*Journal I.E.E.*, 1926, vol. 64, p. 801) recent advanc are described and the results of much experimental work given. Details of the results obtain with electric ploughing, rotary tillers, and the reduction of plough friction by passing a curre between the coulter and ploughshare are recorded. Crop treatment has resulted in the productic of a better milling wheat and superior malting barley. The electrical method of preserving gre fodder (silage) has been improved by the addition of tubular heaters. In this case, the load kept constant during the whole time of treatment, energy consumption averaging 1½ kw. hou per cwt. of material. Central manuring plants are in use in which the contents of the manu tank are agitated by electrically-driven revolving arms or by circulation through centrifug pumps. The liquid is pumped out to stands in the fields and distributed by a hose pipe. T mains used for manuring can be employed for irrigating. The consumption for combined wateru and manuring is stated to be 90 units per acre. By illumination of live-stock sheds and poult houses, half an hour per day per man is saved in the feeding of stock, and an increase of 15 43 per cent in egg production during winter months is obtained. Lighting and heating in co nexion with beehives has resulted in an additional 17 lb. of honey per hive per annum.

Agricultural type motors have been developed on the Continent and machines suitable f the very severe conditions which obtain are available. Such a machine is totally enclosed a embodies moisture-proof vacuum impregnated windings and internal ventilation. Ball bearin should be used, simple over-load circuit breaker provided, while the starter should be enclosed the motor frame. Since the motor should be capable of working in any position the cable co nection should be made through a plug and socket. A 5-h.p. motor is the largest size require on most farms except for ploughing, 2 h.p. being a generally useful size. This entails the use suitable farm machinery. Recent practice tends towards the use of permanently installed moto on individual lines. Belt drives should be avoided by the use of self-contained compound r duction gearing, a friction drive replacing gear-wheels for motors of less than 5 h.p. Conducto are generally run outside the buildings under roof-eaves of farm buildings. For interior wirin the use of tough rubber-protected cable is advisable.

TELEPHONY.

Telephonic Transmissions.

The actual frequencies in normal speech range from about 200 to 2,500 periods per secon the mean frequency is assumed to be 800 for all transmisson calculations. Electromaget waves travel along telephone cables with a velocity depending on the electrical characteristi of the cable—i.e. resistance, inductance, capacity, and leakance; hence there is a time-la between the application of an e.m.f. at the end of a cable and the time when it affects a poi some way along the cable. At a certain distance a complete period will have been lost; th length to this point is called the 'wave-length' of the cable (α).

The magnitude of the e.m.f. also suffers attenuation, owing to the loss of energy due to esistance and leakage, according to a logarithmic law, involving the ' attenuation constant ' of he cable (β). These constants are found by the following formulæ :—

$$\alpha = \sqrt{\tfrac{1}{2}\left\{\sqrt{(R^2 + \omega^2L^2)(G^2 + \omega^2C^2)} - (RG - \omega^2LC)\right\}}$$

$$\beta = \sqrt{\tfrac{1}{2}\left\{\sqrt{(R^2 + \omega^2L^2)(G^2 + \omega^2C^2)} + (RG - \omega^2LC)\right\}}$$

er mile in each case, where,

R = resistance in ohms per mile;
L = inductance in henries per mile:
G = leakance in mhos per mile;
C = capacity in farads per mile;
ω = angular velocity in radians per second = $2\pi f$, where f is the frequency in periods per second.

These constants are of the greatest importance, as they measure the speaking qualities of the able.

The relative attenuation of the different frequencies present in the voice—i.e. the ' distortion '—is measured by the rate of change of the attenuation constant β with frequency, and is esignated by δ. Measurements are made at frequencies giving ω values of 3,000, 5,000, and ,000 radians per second, and the distortion is given by the formula :

$$\delta = 25\,(\beta_{7000} - \beta_{3000})/\beta_{5000} \text{ per cent.}$$

Transmission can be improved by decreasing R and C and by increasing L; the two former nethods are limited by the resulting increase in the weight and size of the cable. β would be ndependent of frequency, and the cable therefore distortionless, if R/L were equal to G/C; for n ordinary cable R/L is of the order of 5,000, and for gutta-percha G/C is about 120, so that nductance has to be added, to diminish both attenuation and distortion. This is done either y winding iron wire uniformly in a close helix along the length of the conductor, or by inserting nductance coils at intervals; in the latter case there should be at least nine coils per wave-length t 800 periods per second.

Loading has been extensively adopted for land-lines, but is more necessary for cables, underround or submarine; for the former, coils are used, but for the latter, both methods are employed.

To provide a standard of comparison for different types of cable, the Post Office has adopted ' standard cable ' having the following characteristics (unloaded) per mile: Total resistance, . 88 ohms; inductance, L, 1 millihenry; capacity, C, 0·054 microfarad; leakance, G, 1 microho; G/C, 18·5; wave-length constant, α, 0·1119; wave-length, 56 miles; attenuation constant, β, 0·1062; distortion, 9·5 per cent.

The British Post Office standard for long-distance communication is that the audibility should ot be worse than over 35 miles of standard cable. Allowing 10 miles for the local lines, the alance for the transmission line proper is 25 miles. Examples of the lengths of certain types f line giving this equivalent are given in the table, all being 150 lb. per mile.

Loading.	R ohms	L μH	C μF	G, μ mhos	G/C	α	Wave-length, miles.	β	Standard Cable Equiv't.	Length = 25 m.s.c.	Distortion.
nil	11·73	1·0	0·065	1	15·4	0·537	117	0·0356	0·335	74·5	5·5
nil	11·73	3·76	0·0084	1	120	0·0292	215	0·0087	0·082	304	2·6
nil	11·73	1·25	0·15	18	120	0·0851	74	0·0525	0·494	50·5	6·0
coils, 80 m.H. per naut.	16·08	70	0·15	18	120	0·513	12·2	0·0179	0·169	148	11·6
coils, 80 m.H. per naut.	16·08	70	0·15	3	20	0·513	12·2	0·0127	0·120	208	5·0
Continuous, 3 layers 0·008 inch iron	13·21	21	0·18	3·6	20	0·308	20·4	0·0199	0·188	133	5·0

The thermionic valve (p. 2332) is an almost ideal relay for telephonic transmission. For perfe action the impedance of the line must be the same in both directions and for all frequencie for this purpose each side is balanced by an artificial line, enabling even cables to be relay on to aerial lines, but in this connection continuously loaded cables are much more suitat than coil-loaded cables. A double-relay repeater gives an improvement equal to 15–25 mil of standard cable; with the aid of successive repeater stations, good speech is now possit between New York and San Francisco, a distance of about 3,000 miles.

(*A. Rosen, Journal I.E.E.*)

Loaded and Repeated Telephone Cable Circuits.

(*Standard Telephones & Cables, Ltd.*)

The introduction of the telephone repeater to the sphere of practical telephony has made possible to give high-grade telephone transmission over very long distances, and also to redu

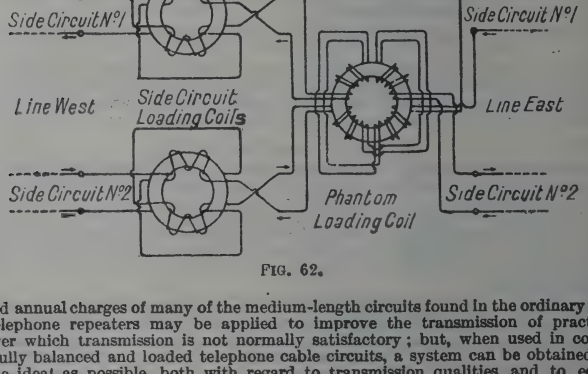

FIG. 62.

the cost and annual charges of many of the medium-length circuits found in the ordinary telephor plant. Telephone repeaters may be applied to improve the transmission of practically a circuits over which transmission is not normally satisfactory; but, when used in conjunctic with carefully balanced and loaded telephone cable circuits, a system can be obtained which as near the ideal as possible, both with regard to transmission qualities and to economic considerations.

Details of modern loading equipment and modern repeaters are briefly described under th following sub-headings.

LOADING.

The loading coils manufactured by *Standard Telephones & Cables, Ltd.* (formerly Western Electric Co., Ltd.), are designed to give the highest efficiency under all conditions of service. They have toroidal cores, which are constructed of a special magnetic material, rendering them immune from magnetisation troubles. The arrangement of the two side circuit coils and the phantom circuit coil, comprising a 'unit of loading,' is shown in fig. 62.

Loading coils can be designed to meet almost any inductance requirement. It has, however, been found convenient to establish certain standard types of coils, which cover the range of inductance required in most cases. These are, broadly speaking, classified (according to the amount of inductance) as 'extra light,' 'light,' 'medium,' and 'heavy' loading coils. The inductance of these coils covers a total range of from 25 to 250 millihenrys. When repeaters are used upon loaded lines it is necessary that the inductance of the coils be maintained within fine limits.

The coils, in suitable numbers, are contained in cast-iron cases, fig. 63, which are approximately cylindrical in form, and which contain vertical spindles on which the loading coils are mounted and completely surrounded by insulating compound.

FIG. 63.

Telephone Repeaters.

The three-electrode vacuum tube is the special feature of the modern telephone repeater as it is the special feature of modern radio-telephony and telegraphy. This vacuum tube is the most successful device for amplifying telephone currents that has yet been produced.

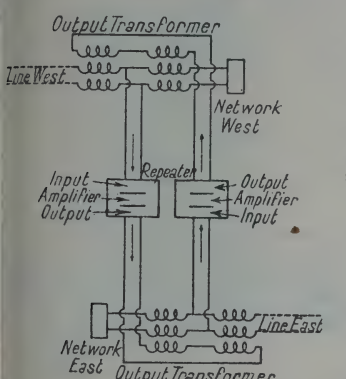

FIG. 64.

With the conducting and magnetic materials available to-day, the transmitted current on the best loaded line ultimately becomes attenuated beyond the value needed for commercial operation of the best telephone receiver. When this condition is reached the limit of improvement by loading alone has been obtained. This limit of distance is reached far short of the distances over which commercial telephony is desired, and other means for extending the range must be sought.

These are found in the telephone repeater, which is an amplifier or a device placed in the line at appropriate intervals for the purpose of adding new electrical energy to the circuit. In general, the current after passing the repeater is not better in wave form than the attenuated current which comes to it, and to this extent the repeater cannot serve one function of loading, which is to reduce the distortion. The modern telephone repeater functions so well, however, that the amplified current is to all intents and purposes an exact magnified image of the control current which it receives. In other words, it does not itself impair the quality of transmitted speech, so that if the line distortion is not too great a number of repeaters may be introduced in tandem between the transmitting and receiving stations for the purpose of extending the ranges.

The one-way repeater is the simplest form of repeater circuit. It is a device which can be connected between two telephone lines. Voice waves enter the input terminals from the transmitting ends of the circuit, and act upon the internal mechanism of the repeater in such a way as to set up an electromotive force in the output circuit which causes an output current to flow through the output impedance of the repeater to the receiving end.

Since it is essential that telephone lines should transmit equally well in both directions, it was found necessary to combine two of these one-way repeaters by special circuit arrangements, and the resulting apparatus is known as the two-way repeater (fig. 64). It will be seen that in addition to the two one-way repeaters there is additional apparatus supplied to prevent the flow of currents from the output circuit of each amplifier into the input circuit of the other. This consists of a three-winding transformer and a network, which are placed at each point where the circuits branch. Each network is made to balance its respective line, and consequently the output circuit of one amplifier and the input of the other have been effectively separated, while at the same time the inputs and outputs of the amplifiers have been left connected to the telephone circuits.

The two-way or 22-type repeater is usually used on circuits up to a length of 350 miles. Over this length the four-wire repeater is used in conjunction with a 4-wire circuit, which consists of two one-way transmission paths connected together at the ends by suitable transformers. The one-way paths may be either physical or phantom circuits. If these are physical circuits, the four-wire circuit really uses four conductors; while if the one-way paths are phantom circuits, the four-wire circuit has eight conductors. In principle the four-wire repeater consists of two one-way repeaters, each of which contains two vacuum tubes connected in tandem.

Poles for Telegraph and Telephone Lines.

Report No. 139, 1921, of the British Engineering Standards Association, provides a specification for red fir poles. They should be felled when the sap is down, and contain the natural untrimmed butt of the tree. After seasoning, the poles should be impregnated with a minimum of 12 lbs. of creosote oil per cu. ft., the specific gravity of the oil being between 1·015 and 1·07 at 38° C. The properties of the oil are detailed in the Report, together with the methods of determining them, and the limiting dimensions of light, medium, and heavy poles, from 16 to 35 ft. long, are tabulated.

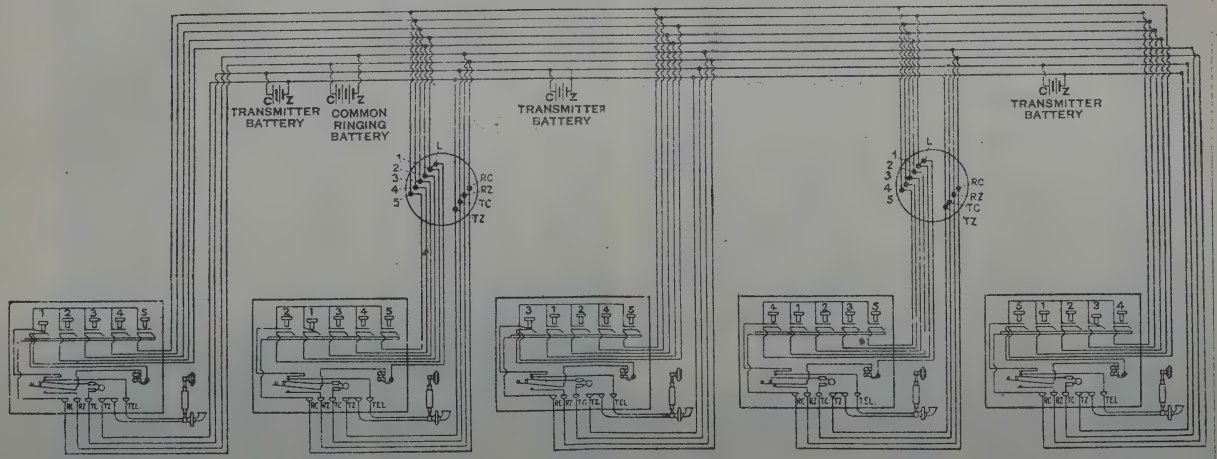

FIG. 65.—Wiring Diagram for G.E.C. Intercommunication Telephone System.

(SPEAKING AND RINGING BATTERIES SHOULD NOT BE LESS THAN THREE CELLS EACH.)

Intercommunication Telephones.

(General Electric Co., Ltd.)

The circuit diagram of the G.E.C. Intercommunication Telephones is given in fig. 65, and a all instrument (metal-cased, electro-magnetic type without induction coils) in fig. 66.

FIG. 66.—G.E.C. Wall Pattern Instrument.

This type of instrument has been specially designed by the G.E.C. with a view to strength and smooth and reliable working.

All working parts are easily removed should it be necessary at any time to make adjustments without disconnecting any of the internal wiring.

The push button line selector, line and instrument bar springs, together with the spring operated by the cradle switch, are all mounted on a steel frame by machine-cut screws, the frame being securely fixed on a stout hard wood base by means of metal bridge pieces at each end. Faults caused by warping woodwork or loose wood screws are thus obviated. The instrument possesses several unique points. It can be used either for a table or wall instrument, the cradle being of a design allowing the instrument to be fixed in either a horizontal or vertical position. This facilitates the keeping of stocks and ordering for export.

The instrument is made from one standard pattern, and can be readily extended from the minimum number of five lines to a maximum of twenty lines, by simply adding extra push buttons and springs, which are supplied at a reasonable price and in banks of five per set. These extra lines can be added without removing the instrument from its fixed position.

It is equipped with a hand combination, buzzer wound to 25 ohms, impedance coil and cradle vitch, the cover being of black enamelled pressed steel.

To reduce inductive cross-talk, which is so noticeable with some types of intercommunication lephones, the G.E.C. have introduced the 'electro-magnetic' circuit in which no induction coil used. Diagram fig. 69 shows a complete system with internal and external wiring. It will noticed that more than one speaking battery of two cells is used, in order to keep the voltage nstant on the common speaking battery leads. One battery only will suffice, providing all the struments are within 50 or 60 feet of the battery. One ringing battery of three cells is usually fficient to operate the calling signal. All lines are fitted with a black button with the exception the home line, which is usually fitted with a red button.

With the electro-magnetic circuit the receiver, transmitter, and impedance coil are in series id connected across the speaking battery terminals marked T. C. and T. Z.

The receiver is constructed with a soft iron core for one pole, and the case as the other, and is ily magnetised when the current is allowed to flow through the coil winding. The usual practice, course, is to have permanent magnets, but if this type of receiver were used with the electro-agnetic circuit the permanent magnets would in time become depolarised unless care were ken to ensure the receiver and battery being so connected as to allow the current to flow in the ght direction. To answer an incoming call the hand-combination must be removed from the adle rest and the red button pressed down; it is automatically held in this position by a sliding ir which is drilled with the necessary number of holes to allow each of the plungers attached the buttons to pass through, the bar being kept under tension by a spiral spring which forces e bar back and automatically holds the button down and at the same time brings the instrument ring in contact with the line spring and completes the line circuit. The bank of springs which e operated when the hand-combination is removed from the cradle rest automatically complete ie speaking circuit.

To call out, the button corresponding to the tablet on which the name of the person required written should be depressed; this movement temporarily connects the line spring on to the mmon ringing battery bar, allowing the current to pass along the line and operate the buzzer the called instrument.

When the pressure is removed from the button the ringing circuit is disconnected and the line id instrument springs are brought into contact, this circuit being completed in the same manner an incoming call. The button last pressed remains down, but is automatically replaced when nother is depressed.

RADIO-TELEGRAPHY.

In a radio-telegraphic system electric impulses from a transformer cause sparks acro a spark gap, which charges, discharges, and recharges the aerial. If the inductance an capacity of the aerial have values of, say, 0·56 microhenry (L) and 0·00004 microfarad (C then there will be oscillatory waves in the aerial whose time interval between the crests successive waves is given by the formula $2\pi\sqrt{LC}$, which with the foregoing values of L and gives the time interval as ·03 millionth of a second. The wave length, that is, the distanc between the crests of successive waves, or more strictly, between points of equal intensity electric stress, is equal to the velocity of propagation, multiplied by the time interval. Henc in the case of the oscillator just considered, the wave length is $300 \times 10^6 \times \frac{0{\cdot}03}{10^6} = 9$ metre

In practical wireless telegraphy the oscillating circuits employed have much larger values L and C, and the wave length is from 300 to 6,000 metres.

A plain aerial radiates energy rapidly, that is to say, it is a good radiator. After eac discharge there are only three or four rapidly damped oscillations, whereas a much greate number is necessary for long-distance work. If the voltage of the charge is too great, the ai breaks down at the top end of the aerial, by what is known as a brush discharge, and thus limit is fixed to the energy which can be imparted to the short train of electro-magnetic wave The practical result is that the maximum range obtainable is about seventy miles.

For long-distance working it is necessary to impress a large amount of energy on the aeria without requiring too great a voltage, and at the same time to produce a long series, or train waves, with very little damping. An arrangement of this kind is adopted in the Marcon system, as shown by fig. 67, and is the foundation of all the practical wireless telegraphy o to-day: it has enabled commercial working to be carried out at a range of 2,400 miles, betwee Clifden, Galway, and Glace Bay, Nova Scotia.

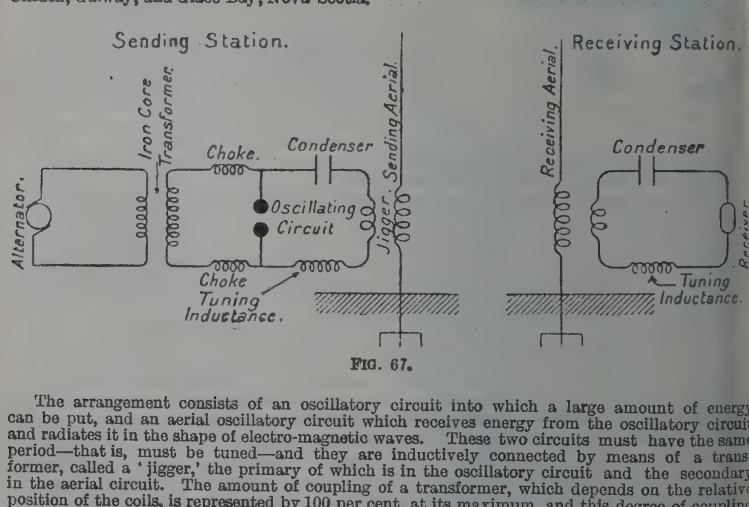

FIG. 67.

The arrangement consists of an oscillatory circuit into which a large amount of energy can be put, and an aerial oscillatory circuit which receives energy from the oscillatory circui and radiates it in the shape of electro-magnetic waves. These two circuits must have the same period—that is, must be tuned—and they are inductively connected by means of a trans former, called a 'jigger,' the primary of which is in the oscillatory circuit and the secondary in the aerial circuit. The amount of coupling of a transformer, which depends on the relativ position of the coils, is represented by 100 per cent. at its maximum, and this degree of couplin occurs when the coils are absolutely concentric; when they are at right angles to each other th coupling is zero. When the degree of coupling is 100 per cent., all the energy (apart from losses is transferred from the primary to the secondary in half a cycle, but if it is desired to transfe only a small portion of the energy at each oscillation from the primary to the secondary, th degree of coupling must be small. In wireless telegraphy the coupling is about 6 per cent. o even less.

Fig. 67 shows both the sending and the receiving arrangement, the signals being received on a telephone receiver. The receiving apparatus can be so arranged that it will not respond to signals sent out with wave lengths other than those to which it is tuned. In this way, a receiving statio can isolate itself from other wireless stations, and thus not be interfered with when receiving message from its own station. The train of electro-magnetic waves maintains oscillations in th

eceiving aerial, which are inductively transmitted to the oscillating circuit, and being properly imed, the energy is accumulated therein, and becomes sufficient in amount to actuate the receiver, nd give signals in the telephone. Unless the time period of both the small and large systems is the ame as that of the waves, there will be no accumulation of energy in the large system at the eceiving station, and the energy transmitted to the oscillating circuit will be insufficient to ctuate the receiver. The oscillating circuits and the aerials at the sending and at the receiving tations must therefore be tuned to the same period, which must be the period adopted for the lectro-magnetic waves.

For small stations, the condenser takes the form of an ordinary Leyden jar with inner and uter coatings of tinfoil. In some cases, for portable wireless stations, the test-tube form is dopted, and the tinfoil at the bottom is strengthened by a copper cap. Recently, however, est-tube condensers have been used, coated inside and out with electrolytically-deposited copper. t is important that the capacity of each jar or tube of a set should have the same capacity. For ship stations, thin zinc sheets are placed either in wooden boxes lined with zinc, or else in alvanised iron boxes which are filled with special oil of high flash point and high dielectric trength. The capacity of these condensers is 0·065 microfarad, and they are arranged in groups o that they can be connected either in series or parallel. For this purpose a commutator—nown as a Swiss commutator—is used, and the connections are made by long plugs split in two irections. For land stations, a satisfactory type of condenser consists of glass plates coated n both sides with tinfoil, a large number of such plates being immersed in oil contained in glazed arthenware vessels. At some high-power stations air-condensers are used; in the latest, they onsist of thin zinc sheets suspended from the roof and placed about 6 ins. apart. The cubic pace occupied by such a condenser is necessarily large. Thus for a capacity of 1·8 microfarad he space required is 200,000 cubic feet. The primary of the high-frequency air core transformer r 'jigger' consists of a few turns of conductor and is placed in the oscillating circuit; the econdary has more turns than the primary and is placed in the aerial circuit.

The secondary of the jigger, which is included in the aerial circuit, consists of a few turns f conductor, and it is connected to an inductance fitted with a suitable arrangement for utting more or less turns in circuit for tuning purposes. The size and nature of the con-uctor used, and the number of turns both in the primary and in the secondary, depend on the ze of the station. Excepting for very large stations, the same aerial is used, both for sending nd receiving. Three principal types are in use, namely, 'T,' 'L' and 'Umbrella.' With the mbrella type the electro-magnetic waves are radiated equally in all directions; with the T type, hich is that generally adopted for ship work, the radiation is almost uniform in all directions, ut with the L type there is a very distinct directional effect, and in this case, the aerials are rranged with a comparatively short vertical height and a long horizontal length pointing away om the station to which it is desired to send messages.

For ship work the masts of the ship are utilised; for land work frequently wooden masts, milar to those on ships, are employed, but recently tubular steel masts have been adopted uilt in sections consisting of half-cylinders bolted together by means of flanges. The longi-udinal flanges are placed alternately at right angles to each other, and by an ingenious arrange-ent the mast forms its own scaffolding for erection. Steel masts of lattice form are also mployed. The earth connection consists of wires led to ground plates, and great care is needed o obtain a good earth. This is a matter which requires expert knowledge. Sometimes, nstead of the actual earth, a wire-gauze net is spread on the ground, and in this case the earth onnection is obtained partially by a condenser effect.

The following table gives the results of observations as to the range, the power absorbed, and he wave length :—

Power Required.	Range in Nautical Miles.				Wave Length (Metres).
	Oversea.	Over Land.			
		Flat.	Hilly.	Mountainous.	
300 watts . .	100	77	30	13	300
	100	95	73	52	1200
1½ kw. . .	220	170	67	28	300
	220	210	160	115	1200
3 kw. . .	280	220	84	36	300
	280	270	200	145	1200
5 kw. . .	340	260	100	43	300
	340	325	240	175	1200
10 kw. . .	470	360	138	59	300
	470	450	330	240	1200

(*Sankey.*)

Thermionic Valves.

During the war the 'thermionic valve,' based upon an invention of Dr. J. A. Fleming, w developed to such a degree as to revolutionise practice in wireless telegraphy, and to rend wireless telephony commercially practicable; it has also been usefully applied in connecti with long-distance wire telephony, and in other directions. Its action depends upon the emissi of electrons from a heated filament in an evacuated bulb, and their reception upon a cold pla in the same enclosure, together with a controlling 'grid' to which an electromotive force is applie In wireless telegraphy the grid is energised through a transformer, by the infinitesimal currer received on the antenna, with the result that variations are produced in the current flowi between the plate and filament, which are far greater than the original waves; these effects c similarly be magnified, almost without limit, and thus the reception of wireless signals sent ha way round the world has become possible. The magnified signals, within limits, are practica free from distortion, a fact which enables the device to be used for telephony, speech beii reproduced with great clearness and fidelity. Besides acting as a detector of minute elect oscillations, the valve can also be used to rectify currents which oscillate in direction, and l making the valve react upon itself it can be used as a generator of high-frequency oscillatio In conjunction with the microphone, the valve is used to vary the amplitude of the waves emitte thus solving the problem of wireless telephony. The valves are extremely economical of energ it is stated that wireless telephonic communication can be maintained over a distance of sixte miles with an expenditure of only ten watts. In ordinary telephony the valve is used as a rel on long lines, in which capacity it is far superior to any type of mechanical relay.

Thanks largely to the three-electrode valve, for long-distance transmission much small antennæ now serve, and the continuous-wave system is generally adopted; for receiving signal so great is the magnifying power of the valve that a fixed antenna is almost superfluou a coil of wire wound on a frame a few feet square sufficing for the purpose. The ratio of magni cation of the signals may be several hundred thousand times. Wireless telephony has bee accomplished over distances of several thousand miles between land stations, and is perfect feasible between vessels at sea, and between aircraft, over considerable distances.

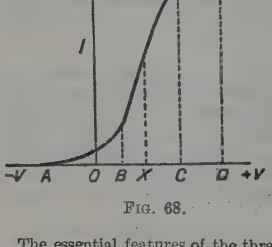

FIG. 68.

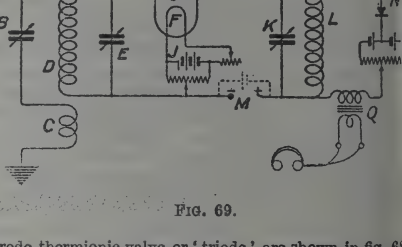

FIG. 69.

The essential features of the three-electrode thermionic valve or 'triode' are shown in fig. 6 which is a curve plotted between the plate current I (a few milliamperes) and the grid voltag or P.D. between the grid and the filament, V, the pressure applied between the plate or anode an the filament being constant. It will be seen that when the grid is slightly negative to the filamen at A, the plate current is completely stopped; when the grid voltage is zero, the plate curren has a low value, but as the grid becomes more positive to the filament the plate current increase very rapidly (between B and C), until a maximum or 'saturation' value is reached at I Assuming the grid voltage to be at the value corresponding to point X on the curve, obviousl an alternating voltage applied to the grid will cause an alternating current to flow in the plat circuit, with greatly increased amplitude, but of similar wave-form. Under these condition the valve acts as an amplifier. When the grid voltage is that corresponding to point B on th curve, a slight increase in the positive voltage of the grid will produce a current wave in th plate circuit as before, but a slight decrease in the voltage of the grid will have little effect on th plate current, the result being that, when an alternating voltage is applied to the grid, a serie of practically unidirectional currents will flow in the plate circuit. The valve under these condi tions acts as a combined rectifier and amplifier. Similar rectifying effects are produced at th point C, but in the reverse direction. The shape of the curve and its position vary with th temperature of the filament and the pressure applied to the plate, but the curve is always of th same nature.

The variations in the connections and combinations of apparatus used in conjunction wit valves are limitless; precise knowledge as to the phenomena which take place within the valv

is not yet available, but its practical operation is well understood; below are given some examples of its principal uses in the simpler forms. Fig. 69 shows the connections of a single valve used as a high-frequency amplifier in wireless telegraphy; the aerial antenna A is connected to earth through a variable condenser B and coil C, and is tuned by means of the condenser, with added inductance if necessary, to the wave-length to be received. The coil C with coil D forms an air-core transformer or 'jigger,' by which the electrical oscillations received on the antenna are transferred to the grid circuit, consisting of coil D and a variable condenser E, tuned to the same wave-length as the antenna. One terminal of the condenser E is connected to the filament F by way of a regulating potentiometer, and the other terminal to the grid G in the valve. The filament is kept incandescent by the small battery J, with a regulating resistance. The plate circuit of the valve consists of the anode or plate P, inductance coil L and variable condenser K, and a high-voltage battery M, of which the negative terminal is connected to the filament. Shunted across the plate circuit inductance is a rectifying crystal N, and the primary of an iron-cored transformer Q, the secondary of which is connected to a pair of telephone receivers. The plate circuit is tuned to the wave-length of the incoming signals, and a current flows round this circuit through the valve.

The incoming oscillations, transferred from the antenna to the grid circuit by the 'jigger,' set up a magnified alternating electromotive force between the grid and the filament, superposed upon the potential difference due to the battery J. Owing to the characteristic properties of the valve, an oscillatory current of much greater amplitude is set up in the plate circuit, which is rectified by the crystal and affects the telephone receiver. A number of valves may be connected together in cascade to produce successive amplifications, the final ratio being of the order of 20,000 or more; with suitable arrangements it is possible to detect with certainty an alternating current in the input circuit corresponding to one-ten-thousand-millionth part of one volt.

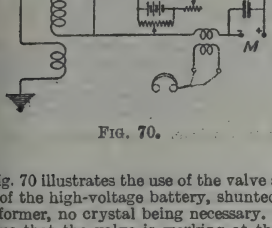

FIG. 70.

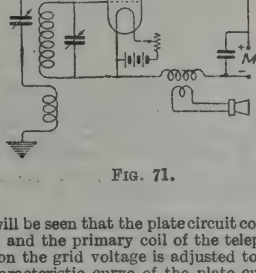

FIG. 71.

Fig. 70 illustrates the use of the valve as a rectifier. It will be seen that the plate circuit consists only of the high-voltage battery, shunted by a condenser, and the primary coil of the telephone transformer, no crystal being necessary. In this application the grid voltage is adjusted to such a value that the valve is working at the bend of the characteristic curve of the plate current (point B in fig. 68). Besides rectifying the current, the device affords a large measure of amplification, and by using a rectifying valve at the end of a series of amplifying valves a highly sensitive and efficient receiving apparatus is obtained.

Fig. 71 shows the connections of a valve used as a generator of continuous oscillations, for the reception of signals on the 'continuous-wave' system, by 'beats.' The frequency of vibration of the incoming signals being far above the limits of audition, a very efficient method of rendering the signals audible is by combining them with locally generated oscillations at a slightly different frequency, producing 'beats' as in music, the frequency of the beats being equal to the difference between the frequencies of the two sets of waves. It will be seen that the circuits are almost the same as those of fig. 70, the only change being the addition of a reaction coil R magnetically coupled with the inductance in the grid circuit. The arrangement is known as a 'self-heterodyne,' the valve performing the three functions of rectifying, magnifying, and heterodyning by the production of local oscillations. These oscillations are produced by the reaction of the current in the plate circuit on the grid circuit, and the necessary adjustment is made by varying the position of the reaction coil with regard to the inductance. The grid potentiometer, which is omitted from fig. 69, can be dispensed with in the other diagrams also, the valve being adjusted by the plate potential. When it is desired to use the valve as a transmitter, impressing continuous waves on the antenna, the plate and high-voltage battery are connected to the tuning circuit, and the grid to the reaction coil, the telephone being omitted. For wireless telephony a microphone is added, so arranged as to vary the amplitude of the oscillations in accordance with the speed vibrations. The foregoing illustrations are taken from the *Wireless World*.

The evolution of the valve has made possible wireless telephony over a distance of 1,800 miles with only 2·5 kw.; communication with aeroplanes at a distance of 200 miles with 75

watts; the recording of time signals with an accuracy of 0·02 second; and the determinatic of the direction of a source of wireless signals, with portable apparatus. Other uses to whic the valve has been put are to actuate a calling-up device on board ship, to maintain a tunin fork in vibration, to produce the rotation of a toothed disc by a direct current, and to measu infinitesimal currents and pressures.

INSULATING MATERIALS.

British Engineering Standards Specifications No. 231—1925, for Pressboard, and No. 216—192 for Vulcanised Fibre for Electrical Purposes, refer to the composition, dimensions, tensile, shearin tearing, and electrical strengths, freedom from conducting particles, and other physical pr perties. The methods of determination are specified. Specification No. 234—1925, for Eboni for Panels for Radio Reception Purposes, in addition to the above information, gives standa values and tests relating to sulphur, acetone, and ash contents, the breaking strength, surfa leakage dielectric loss, and electric strength.

DEXONITE.

This material (*Derine Ltd., Stratford, London, E.*) possesses the properties of vulcanite a ebonite, but unlike the two latter it retains its normal degree of hardness under high temperatu It is easy to tool, screw, and tap, is not brittle, and is capable of being moulded into any sha or size. It has a high electrical resistance, and is non-corrosive and acid resisting. *Speci Gravity* at 60° F., 1·2765. *Tensile Strength:* Stress per sq. in. at maximum load, 6,765 lb equivalent to 3·02 tons.

Articles made from Dexonite include insulating parts for electrical apparatus, medical i quisites, binocular parts, etc. It is also supplied in sheet, rod, or tube form to any convenie sizes.

MACONITE.

See p. 2245.

PAPER AND OTHER MATERIALS.

'Willesden' Paper (*The Willesden Paper and Canvas Works, Ltd.*) is a material largely used f electrical insulation, chiefly on the field magnets and armatures of continuous current dynam and is found by manufacturers to be of great value, as it is less hygroscopic than other materi formerly employed. It can also be used with advantage instead of vulcanised fibre in many plac such as small switches, washers on fuse and switch boards, and for telephone work, etc.

'Press Paper,' and mica in thin lamina or built up into thicker plates and rings, are mu used as insulating materials.

Asbestos Millboard Tubes, for the construction of electrical resistances and other electric appliances, are made in all lengths and diameters with walls of any thickness.

Insulating Oils for Electrical Purposes.

BRITISH STANDARD SPECIFICATION FOR INSULATING OILS FOR ELECTRICAL PURPOSES.*

(No. 148. 1927.) (*Abstract.*)

Classification and Temperature Limits.

Two classes of oil, Class A and Class B, are referred to in this Specification.

2. Class A oils, sometimes referred to as non-sludging oils, are suitable for use in transformers which the working temperature of the oil, measured by a thermometer, exceeds 80° C. (176° F

They are also suitable for use in oil switches in which the temperature exceeds 70° C. (158° F

They may be used with advantage in all oil switches of above 500-amperes capacity having th main contacts under oil and operated for long periods near their rated current or in hot situation

Class B oils are suitable for use in transformers in which the working temperature of the oil do not usually exceed 75° C. 67° F.).

They are also suitable for general use in oil switches not subjected to conditions requiring t use of Class A oils.

3. The oil of each class shall be a pure hydrocarbon (mineral) oil, clean and sufficiently fr

* By permission of the British Engineering Standards Association.

MICA

CANADIAN and INDIAN MICA—CUT SLAB and SPLITTINGS.
Minimum Stock, 200,000 lbs.

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EBONITE, SHEET, TUBE and ROD.

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M.Inst.C.E., M.I.Mech.E. M.I.E.E.

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JOINT RESISTANCES.
ELEMENTARY COMBINATIONS OF RESISTANCE, INDUCTANCE, AND CAPACITY.
TELEPHONIC TRANSMISSION—ATTENUATION EQUATION.
PRACTICAL FORMULÆ (TELEPHONIC TRANSMISSION).
REFLECTION.
INSTRUMENTAL MEASUREMENT OF AN ALTERNATING CURRENT.

LONDON: CROSBY LOCKWOOD & SON

7 Stationers' Hall Court, Ludgate Hill, E.C. 4

from moisture or other matter likely to injure its insulating properties, and shall satisfy the requirements of the specification.

4. The characteristics shall be within the limits shown in the following Schedule :—

Class of Oil.	Sludge (maximum).	Viscosity at 15·5° C. (60° F.) (maximum).	Electric Strength (minimum).	Flash Point (minimum).	Evaporation (maximum).	Cold Test (maximum).
	Per cent.	Redwood Secs.	Volts.		Per cent.	
A.0	0·1	200	30,000	145° C. (293° F.)	1·6	0° C. (32° F.)
A.10						— 10° C. (14° F.)
A.30						— 30° C. (— 22° F.)
B.0	0·8	200	30,000	145° C. (293° F.)	1·6	0° C. (32° F.)
B.10						— 10° C. (14°F.)
B.30						— 30° C. (— 22°F.)

6. The oil shall not contain any inorganic acid. The acid value per gramme of oil due to organic acids shall not exceed 0·2 mg. KOH.

7. The saponification value per gramme of oil shall not exceed 4 mg. KOH.

8. The oil shall not cause discoloration of copper.

Test for Moisture in Transformer Oil.

While a thorough test for the suitability of oil for transformers and oil switches can be made only with high-tension testing apparatus, very good indications of the presence of moisture have been obtained by Mr. J. K. Mackie, superintendent of the Connecticut Power Co., as follows:—A sample of the oil to be tested is drawn from the bottom of the transformer, oil switch, or storage tank. (Samples from the upper parts of the tank are not considered suitable for the test, as water is heavier than oil and usually collects at the bottom.) In the sample thus taken is placed powdered anhydrous copper sulphate. If moisture is present the copper sulphate will be dissolved, producing a blue colour that will diffuse through the oil if moisture is in suspension. Since enough copper sulphate is added to ensure a saturated solution, the intensity of the blue tint will be a measure of the amount of moisture present. As small percentages of moisture have a very deleterious effect on the dielectric strength of oil, however, the lightest shade of blue is sufficient indication that the oil should be dried by filtering. It may be pointed out that other substances giving a deeper tint than copper sulphate may be used, the only requirement being that they dissolve quickly in water but not in oil.

'No-Mag' Non-Magnetic Cast Iron.

This is a patented non-magnetic cast iron, which combines the non-magnetic property with a high electric resistance, thereby giving great freedom from hysteresis and eddy currents.

The efficiency of 'No-Mag' non-magnetic cast iron is shown as follows:—

Metal.	Magnetic Permeability.	Specific Resistance.
	Maximum.	Micro-ohms per cm. cube.
Ordinary cast iron	330·00	95·0
'No-Mag'	1·03	140·0
Brass	1·00	7·5

The 'No-Mag' can be applied for the purposes of oil switch covers, bus bar clamps, brackets, cable boxes, transformer covers, separating pieces, sealing bells, etc.; by using 'No-Mag' for end plates and shields for generators and motors the losses due to stray flux are reduced to a minimum, thus allowing economies in design.

Anchorage for Overhead Line Structures.

In the *Electrical World* Mr. A. W. Malone describes a cheap and effective method making anchorages for overhead telegraphic or electric light line structures. A small hole bored or drilled into the ground at a suitable angle, and an explosive is ignited at the botto of it; a specially designed steel tension rod is inserted into the hole, which is then filled up wi

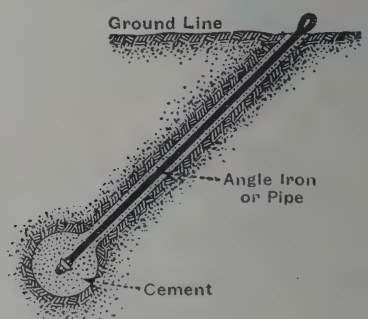

FIG. 72.

concrete. The explosion makes a cavity, which eventually contains a ball of concrete, as shov in fig. 72. Exhaustive tests show that this type of anchorage is many times as resistant uprooting as the ordinary type, whilst it is far cheaper in labour, time, and material. A Malo anchor having a concrete 'bulb' 26 ins. in diameter, 9 ft. below the ground surface, offered resistance of 56,000 lbs. after yielding 2 ins., whereas a grillage type of footing had a resistan of only 15,000 lbs.

X-Rays in Industry.

(C. Norman Kemp, B.Sc., F.R.S. (Edin.), A.I.C.)

The term 'opacity' has reference to a characteristic of certain substances in their reaction ordinary light (λ about 8,000-3,900 Ångström units).

No substance known is totally opaque to X-rays, owing to their extremely small wave-lengt although, of course, a sufficient thickness of a dense material may, in a given case, effect comple absorption, this being proportional to atomic weight and thickness.

From Planck's equation there may be derived the simple and useful relation that the produ of the *maximum* tube voltage and the *minimum* resulting X-ray wave-length is a constant, t wave-lengths being expressed in Ångström units (Å.U.),

i.e.

$$\lambda_{min.} \; V_{max.} = 12{,}400,$$

whence

$$\lambda_{min.} \text{ at } 12{,}400 \text{ volts} = 1.0 \text{ Å.U.}; \quad \lambda_{min} \text{ at } 124{,}000 \text{ volts} = 0{\cdot}1 \text{ Å.U.}$$

Within the range of wave-lengths from 1 to 0·1 Å.U. a vast amount of modern radiologi work is done, commonly employed tube voltages being 45, 60, and 100 kv.

For work on metals, however, the last figure is often largely exceeded, values up to 500 k being used, and 1000 kv. having been proposed, if not actually attempted, with the object reducing exposure times, and increasing the thicknesses which may be examined.

Industrial applications are based on the employment of X-radiations having a penetrati power (a function of λ) and an intensity related to the atomic weights (or numbers) of the co stituent elements of the material under examination, so that, as indicated, very high tube voltag are necessary for the radiography of iron and steel products.

At present, definite information as to the homogeneity of such materials may readily secured with commercially available equipment with an exposure of 30 minutes, this permitti of the detection of flaws in steel down to a sixteenth of an inch in size and up to three inches thickness. Some of the practical uses of X-rays may be conveniently grouped as follows:—

1. Examination of natural objects or substances for information as to internal structure.

2. Examination of substances or objects from stage to stage in manufacturing processes with a view to more effective control, tending towards the elimination of waste, with consequent cheapening of production.

3. Examination of manufactured products or assembled articles for homogeneity or freedom from foreign matter in the one case, and correctness of assembly in the other.

4. General research in the foregoing and other directions whereby new applications and new methods of attacking existing problems are sought.

One of the most recent applications of radiological technique is the study of the internal structure, or, as it has been called, the ' mineral skeleton ' of coals, anthracites, cokes, etc., which may be visually studied, and also photographically recorded if required.

Particularly valuable in this connection is the use of stereoscopic radiography, whereby the interior of the specimens may be viewed in natural relief, and the ash-forming constituents examined as regards nature, quantity, and distribution.

The outstanding feature of X-ray methods lies in the provision of an easy, rapid, and non-destructive test of opaque materials, a field capable of almost unlimited extension as a result of continued research.

SECTION XXXVI

NAVAL ARCHITECTURE AND MARINE ENGINEERING

(Contributed and Revised by Professor Percy A. Hillhouse, D.Sc., M.I.N.A., and James Thomson, M.I.N.A.)

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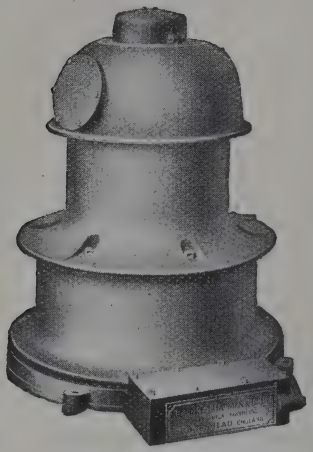

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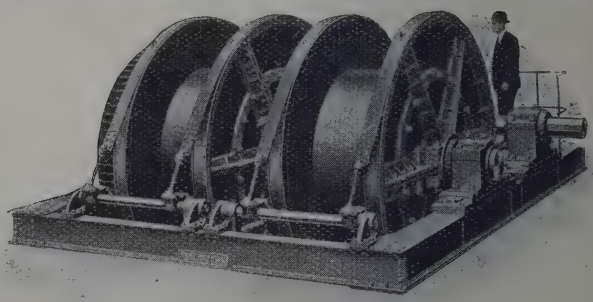

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[See also announcement facing page 1593.]

F. 2341

SECTION XXXVI

NAVAL ARCHITECTURE AND MARINE ENGINEERING. DIMENSIONS AND GEOMETRY OF SHIPS—DISPLACEMENT, STABILITY, AND TRIM—WEIGHTS OF HULL AND MACHINERY—DEADWEIGHT—RESISTANCE OF SHIPS—ADMIRALTY COEFFICIENTS—ECONOMICAL SPEEDS—COAL CONSUMPTION—RUDDERS—ESTIMATING HORSE-POWER—DESIGNING MARINE ENGINES AND BOILERS—TURBINES—REDUCTION GEAR—TURBINE MACHINERY—CONDENSING PLANTS—DIESEL ENGINES—PROPELLERS.

(Contributed and Revised by Professor Percy A. Hillhouse, D.Sc., M.I.N.A., and James Thomson, M.I.N.A.)

DIMENSIONS OF SHIPS.

Moulded Dimensions.

LENGTH L = 'Length between Perpendiculars' = Length on load water-line measured from the fore side of the stem ('F.P.,' or 'Fore Perpendicular') to the aft side of the stern post ('A.P.,' or 'After Perpendicular'), or fore side of rudder stock if there is no stern post.

BREADTH B = 'Moulded Breadth' = Breadth measured over the widest part of the frame at the middle of the length L.

DEPTH D = 'Moulded Depth' = Depth measured from top of keel to top of deck beam at side at the middle of the length L. To avoid error the name of the deck to which the depth is measured should be stated.

Registered Dimensions.

LENGTH = Length from fore part of stem head to aft side of stern post, or fore side of rudder stock if there is no stern post.

BREADTH = Breadth measured over the outside of the shell plating at the widest part.

DEPTH = 'Depth of Hold' = Depth measured from top of ceiling to top of deck beam at the centre line of the vessel at the middle of the length. This depth is measured to the 'tonnage deck,' which is the 'second deck from below.'

Overall Dimensions.

LENGTH = 'Length Overall' = Length measured from the foremost point of the stem or figure-head (but excluding bowsprit if any) to the aft side of the taffrail, or cruiser stern.

BREADTH = 'Breadth Extreme' measured over the outside of the shell plating or belting or paddle sponsons, if any.

DEPTH = Depth from top of keel to top of deck amidships.

Drafts of a Ship.

The DRAFT d of a ship is the distance of the lowest point of the keel (or of the line of the keel produced) below the water line.

The MEAN DRAFT is half the sum of the drafts at the forward and after perpendiculars or at the stem and the stern post.

The MOULDED DRAFT δ is the distance of the top of the keel (or of the line of the top of ke produced) below the water line.

The LIGHT DRAFTS of a vessel are the drafts forward and aft when the vessel is floatin complete, with water in boilers, but without crew, fuel, cargo, stores, water or other loads.

The LOAD DRAFT of a vessel is the mean draft of the vessel when floating complete and rea for sea and with all fuel, cargo, passengers, crew, baggage, stores, spares, water, and other load The maximum load draft is determined by the freeboard tables of the Board of Trade; f passenger vessels the actual draft is limited to that determined by the spacing of the wate tight bulkheads, in accordance with the recommendations of the Convention for the Safety Life at Sea. This draft is called 'The Bulkhead Draft.'

The FREEBOARD of a vessel is the height of the top of the wood deck at side at the middle of t length above the water line. The minimum freeboard allowable for any vessel entering or leavir a British port is fixed by law. It is assigned for each vessel by the Board of Trade or Classificatic Society, and must be marked upon each side of the vessel amidships by the 'Freeboard Disc' 'Plimsoll Mark.'

The 'TRIM' or 'LEAD' of a vessel is the difference between the drafts forward and aft. It said to be 'by the head' or 'by the stern' according as the draft forward or the draft aft is t greater. When the drafts forward and aft are equal, the vessel is said to be 'on even kee 'Change of Trim' is the arithmetical sum of the changes of draft forward and aft produced b the shifting of any weight.

Displacement.

The DISPLACEMENT of a vessel is the amount of water displaced by the underwater portions her hull. It may be stated either by volume or by weight. The weight of the water displaced b a floating vessel is equal to the total weight of the vessel and her contents. If the vessel b floating in salt water, her displacement in tons, Δ, is equal to $\frac{1}{35}$ of her volume of displacement, V in cubic feet. If in fresh water, $\Delta = \frac{V}{35{\cdot}8}$.

The TONS PER INCH of a vessel at any draft is the number of tons weight which must be place on board in order to increase the mean draft one inch.

$$\text{Tons per inch, in salt water} = \frac{\text{area of water plane}}{420} = \frac{A}{420},$$

$$\text{Tons per inch, in fresh water} = \frac{A}{430},$$

where A is the area of the water plane in square feet.

Coefficients of Displacement.

The BLOCK COEFFICIENT, or *Coefficient of Fineness*, C_b, is the ratio of the immersed volum of displacement to the volume of the circumscribing parallelepipedon.

$$\text{Block coefficient} = C_b = \frac{V}{L\,B\,\delta} = \frac{35\,\Delta}{L\,B\,\delta} \text{ in salt water} = \frac{35{\cdot}8\,\Delta}{L\,B\,\delta} \text{ in fresh water,}$$

where V = Immersed volume of displacement in cubic feet,
Δ = Displacement in tons,
L = Length on load water-line, in feet,
B = Moulded breadth in feet,
δ = Moulded draft in feet.

Builders of cargo vessels usually estimate block coefficient with reference to length B.P breadth over shell plating, and draft including keel.

The PRISMATIC COEFFICIENT, C_p, is the ratio of the immersed volume of displacement to t volume of the circumscribing cylinder having the same form of cross-section as the vess below the water-line amidships.

$$\text{Prismatic coefficient} = C_p = \frac{V}{La} = \frac{35\,\Delta \text{ or } 35{\cdot}8\,\Delta}{La},$$

where a is the immersed area of the midship section to outside of frame in square feet.

The MIDSHIP SECTION COEFFICIENT, C_m, is the ratio of the area of the midship section up t the water-line to the area of the circumscribing rectangle.

$$\left.\begin{matrix}\text{Midship section coefficient} \\ \text{or midship area coefficient}\end{matrix}\right\} = C_m = \frac{a}{B\,\delta}.$$

From the above values for the three coefficients it is easily seen that

$$C_p \times C_m = C_b.$$

Mr. W. H. Riddlesworth, M.Sc., gives the following approximate formulas connecting draft, displacement, and block coefficient:—

Let α = water plane area coefficient $= \frac{A}{LB}$.

β = block coefficient.
δ = moulded draft.
Δ = displacement in tons.

Then, approximately,

(1) The waterplane area coefficient is equal to one-third plus two-thirds of the block coefficient, *i.e.*

$$\alpha = \tfrac{1}{3} + \tfrac{2}{3}\beta$$

(2) The change (c) in block coefficient per foot change in draft is equal to the complement of the block coefficient divided by three times the draft,

i.e.

$$c = \frac{1-\beta}{3\delta}.$$

(3) The complement of the block coefficient varies inversely as the cube root of the draft,

i.e.

$$1-\beta = \text{constant} \div \sqrt[3]{\delta},$$

the constant being determined for each ship from any one known draft δ_0 and the corresponding block coefficient β_0; constant $1-\beta_0 \div \sqrt[3]{\delta_0}$.

The above three relations have been found to be both useful and reliable in practical work.

Wetted Surface.

The WETTED SURFACE or IMMERSED SURFACE of a vessel is the total area of the surface of the shell plating, keel, bilge keels and rudder in contact with the water in which the vessel is afloat.

Approximately,

$$\left.\begin{aligned} S &= L(1{\cdot}7\,\delta + C_b B) \quad \text{(Mumford)} \\ S &= 3{\cdot}4\,V^{\frac{2}{3}} + 0{\cdot}5\,LV^{\frac{1}{3}} \quad \text{(Froude)} \\ S &= 15{\cdot}4\sqrt{L\,\Delta} \quad \text{(Taylor)} \end{aligned}\right\} + \text{surfaces of keel, bilge keels, and rudder.}$$

where L = length between perpendiculars, in feet,
δ = moulded draft, in feet,
C_b = block coefficient,
B = moulded breadth, in feet,
Δ = displacement, in tons; V = displacement in cubic feet.
S = wetted surface, in square feet.

Curves of Displacement, etc.

As the draft of a vessel changes, the displacement, area of water plane, coefficients, etc., also vary, and it is customary to record these changes by means of curves whose vertical abscissæ represent draft, while the horizontal ordinates represent areas, displacements, coefficients, etc.

The ordinate of the curve of displacement at any draft is proportional to the area of the curve of water plane areas up to that draft.

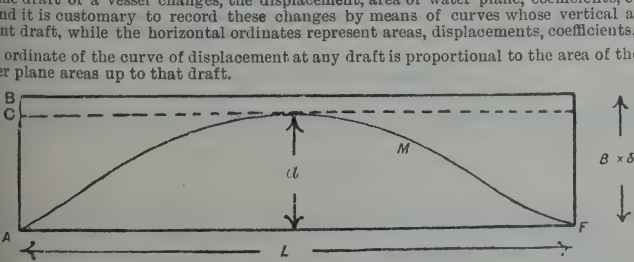


FIG. 1.

The PRISMATIC CURVE or CURVE OF AREAS for any draft is a curve whose horizontal base represents to scale the length of the vessel on load water-line, and whose ordinate at any point is proportional to the immersed area of the corresponding transverse section of the vessel. This curve shows the longitudinal distribution of the displacement, which has an important bearing upon the resistance.

Let A M F (fig. 1) be a prismatic curve, inscribed within a rectangle C F of height repr
senting the area of the midship section, and surrounded by another rectangle B F of heig
representing the area of the rectangle circumscribing the midship section. Then

Area of prismatic curve is proportional to displacement.

$$\frac{\text{Area of prismatic curve}}{\text{Area of rectangle C F}} = \frac{V}{L \times a} = \text{Prismatic coefficient.}$$

$$\frac{\text{Area of prismatic curve}}{\text{Area of rectangle B F}} = \frac{V}{L \times B \times \delta} = \text{Block coefficient.}$$

$$\frac{\text{Height of rectangle C F}}{\text{Height of rectangle B F}} = \frac{a}{B \times \delta} = \text{Midship section coefficient.}$$

Centre of Buoyancy.

The CENTRE OF BUOYANCY, B, at any draft, is the centre of gravity of the volume of displac
ment at that draft. The vertical position of the centre of buoyancy is the same as that of t
centre of gravity of the curve of water plane areas, and its longitudinal position is the same
that of the centre of gravity of the prismatic curve.

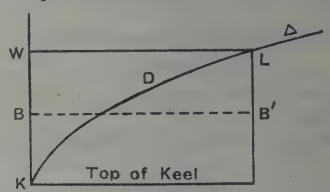


FIG. 2.

To find the height, K B, of the centre of buoyancy above the top of keel, draw the line BI
across the displacement curve so that the area of the rectangle WB′ is equal to the area W L D
above the displacement curve.

MORRISH'S RULE.

$$\text{Very approximately } K B = \frac{5}{6}\delta - \frac{V}{3A};$$

where K B is the height of the centre of buoyancy above top of keel, in feet;

δ is the moulded draft, in feet;
V is the displacement, in cubic feet;
A is the area of the water plane, in square feet;
$\frac{V}{A}$ is called 'Rankine's Mean Draft.'

KB is approximately 0·55 of the draft.

Centre of Flotation.

The CENTRE OF FLOTATION is the centre of gravity of the water plane. The two waterlin
defining any small change of trim or heel intersect at the centre of flotation.

Transverse Metacentre.

If a vessel be slightly inclined to one side the centre of buoyancy, B, will move slightly fr
the middle line towards that side, say to B′, and the vertical line through B′ representing t
upward pressure of the water will cut the inclined middle line at the point M called the 'Tra
verse metacentre.'

$$B M = \frac{I}{V}.$$

where,

BM is the height of the transverse metacentre above the centre of buoyancy,
I is the transverse moment of inertia of the water-plane about its middle line,
and V is the volume of displacement.

MB is approximately equal to 0·77 breadth^2 ÷ draft, at load draft.

The METACENTRIC HEIGHT, G M or m, in any condition of loading is the vertical distan
between the transverse metacentre, M, and the centre of gravity, G, of the whole vessel and i
contents. If, in the upright condition, G lies above M the vessel is unstable and will not rema
upright; if G lies below M, the vessel is stable and will return to the upright position if slight
inclined and set free. G M is a measure of the vessel's 'Initial Stability.'

The value of G M can be obtained either by separate calculation of the heights of G and M
by an inclining experiment.

Inclining Experiment.

In carrying out an 'Inclining Experiment' on a vessel, to determine the height, KG, of the centre of gravity, the following procedure should be observed :—

Have the vessel free from wind, tide, current, transverse mooring ropes, gangways, and particularly from loose water or other weights liable to move when the vessel is inclined. Have no men on board except those engaged on the experiment. Read the drafts carefully at each end from a small boat. Move any known weight w (enough to produce an inclination of about 2°) transversely across the deck through a total distance, a, and observe the corresponding deflection d, of a simple pendulum of length l, suspended anywhere on board. Several shifts of the weights are usually made to each side of the ship and the mean value of d taken. From the draft readings and the curves of displacement and transverse metacentres we can obtain the value of Δ, and of KM.

Then GM as inclined $= \frac{w\,a\,l}{\Delta\,d}$, w and Δ being in tons, GM and a in feet, and l and d in inches,

and KG as inclined = KM − GM.

These results apply only to the vessel in the inclining condition. To obtain the metacentric height for any other condition it is necessary to make suitable corrections for the different amounts and positions of the various items of loading and for the new values of Δ and KM.

It is usual to estimate the value of GM for the following conditions :—

Light Condition.—Ship and machinery complete, boilers and condensers full, but no fuel, cargo, passengers, crew, baggage, stores, spares, fresh or salt water, or reserve feed-water on board.

Docking Condition.

Load Condition.—Fully loaded condition; ship and machinery complete, boilers and condensers full, and with all fuel, passengers, crew, baggage, stores, spares, fresh and salt water, reserve feed-water, and holds filled with homogeneous cargo of such density as to bring the vessel to her load draft.

Spent Condition.—Same as full load condition, but with all fuel, water, and stores consumed.

Ballasted Condition.—Same as spent condition, but with water-ballast tanks filled.

Any other special conditions likely to arise in practice.

Rolling Period of a Vessel.

In Smooth Water.

K=Radius of gyration of the vessel and all weights on board, about a longitudinal axis passing through her centre of gravity.

m = Metacentric height;

2 T = Time of double roll, say from port to starboard and back again, in seconds;

g = Force of gravity = 32·2.

Then

$$T = \pi \sqrt{\frac{K^2}{g\,m}} = \cdot 554 \frac{K}{\sqrt{m}},$$ neglecting water and air resistances.

The period 2T of a double roll varies from about 3 to 30 seconds; in large Atlantic liners it is about 20 seconds.

Stability.

The INITIAL STABILITY of a vessel is the measure of the tendency of the vessel to return to the upright if she is forcibly inclined to a small angle, θ, of not more than about 10°.

Initial Stability or Righting Moment at the inclination θ = $RM_\theta = \Delta\,m\,\theta$ foot-tons.

where,

Δ = displacement in tons;

m = metacentric height in feet;

θ = angle of heel in circular measure

= inclination in degrees ÷ 57·3.

Curve of Stability.—When a vessel is inclined to any angle θ (fig. 3), the centre of buoyancy moves to one side (B to B′). The upward force of buoyancy, Δ, now acts through B′, while the weight acts downwards through G, the centre of gravity. These two forces form the righting couple, whose arm is GZ (the righting arm) and whose moment is W.GZ

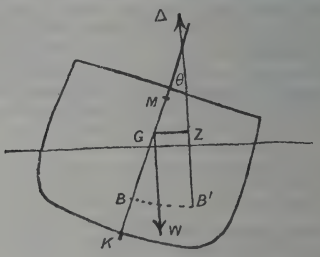


Fig. 3.

(the righting moment). When θ is small, B′Z passes through M, as already stated, and $GZ = m\theta$; at larger angles GZ must be separately calculated, and it is customary to obtain its value at each 10° of inclination and to connect the series of righting arms by a curve which is called the curve of stability (fig. 4).

OR is called the 'Range of Stability,' H the 'Maximum Righting Arm,' occurring at some

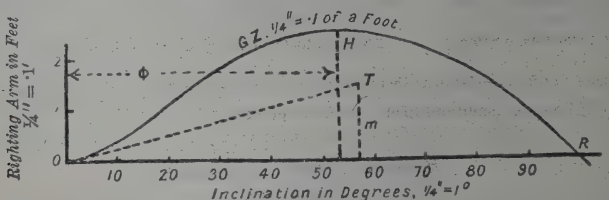


Fig. 4.

angle ϕ, while the initial slope of the curve is measured by the metacentric height, m, set up at 57·3° ($\theta = 1$), as shown in the figure, where OT is tangent to the curve at the origin O. (The scales marked are those to which the curves are usually drawn, but of course do not apply to the reduced figure.) The area of the curve of stability up to any angle is proportional to the work which must be done (by wind or other external forces) in order to incline the vessel to that angle. The work so done is called 'Dynamical Stability.'

Longitudinal Metacentre.

If a vessel be slightly inclined about a transverse horizontal axis, the centre of buoyancy will move longitudinally, and the point in which the vertical line through the new centre of buoyancy cuts that through the centre of buoyancy corresponding to even keel is called the 'longitudinal metacentre.'

The height of the longitudinal metacentre above the centre of buoyancy $= LBM = \frac{I}{V}$, where I is the moment of inertia of the waterplane about a transverse axis through its centre of gravity, and V is the volume of displacement.

The Longitudinal Metacentric Height, LGM, is the height of the longitudinal metacentre above the centre of gravity $= LBM - BG = M$.

The longitudinal GM is used in calculating changes of trim. If any weight, w, be moved longitudinally through a distance, a, the 'moment to change trim' is wa.

The 'moment to change trim one inch' or 'inch trim moment' $= {}''M = \frac{\Delta M}{12L} \overset{*}{=} \frac{I}{420L}$

Approximately, $''M = \frac{30\,t^2}{B}$

where, $''M$ = inch trim moment, in foot tons.
Δ = displacement, in tons.
L = length between draft marks, in feet.
t = tons per inch.
B = moulded breadth, in feet.
I = longitudinal moment of inertia of water plane.

The *change of trim* in inches due to any moment $w\,a$ is $\frac{w\,a}{''M}$. Of this total change of trim half is usually added to the draft at the end towards which the weight w was moved, and half deducted from the draft at the other end.

If instead of merely moving a weight already on board, we desire to find the alteration of drafts due to placing a new weight on board, first imagine the weight to be placed at the centre of flotation F. This will increase the drafts both forward and aft equally by an amount $\frac{w}{t}$. Then imagine the weight moved longitudinally to its assigned position and calculate the change of trim. Then combine these changes of drafts with the additional immersions $\frac{w}{t}$ and so find the total changes of draft forward and aft.

Curves connecting the mean draft with the position of the centre of flotation, the tons per inch, and the inch trim moment should be prepared to facilitate such calculations.

For large additions of weight the above method is not accurate, and it is necessary to prepare a complete list of all the items making up the displacement, together with their moments forward or aft of midships. Then

$\frac{\text{Total moment}}{\text{Total weight}} = \text{G}\,\boxtimes$ or $\boxtimes\,\text{G} =$ distance of centre of gravity aft or forward of midships.

From a curve connecting draft with the distance of the centre of buoyancy for even keel from midships, we can find the value of B $\boxtimes$ or $\boxtimes$ B, and hence the value of GB or BG, that is the longitudinal distance of the centre of gravity aft of or forward of the centre of buoyancy. The moment to change trim is then $\Delta \times$GB, and the change of trim $\frac{\Delta\,\text{GB}}{''M}$.

RALSTON'S STABILITY AND TRIM INDICATOR.

This useful piece of apparatus determines the metacentric height and trim of a vessel by mechanical means instead of by calculation. It consists of a capacity profile of the vessel

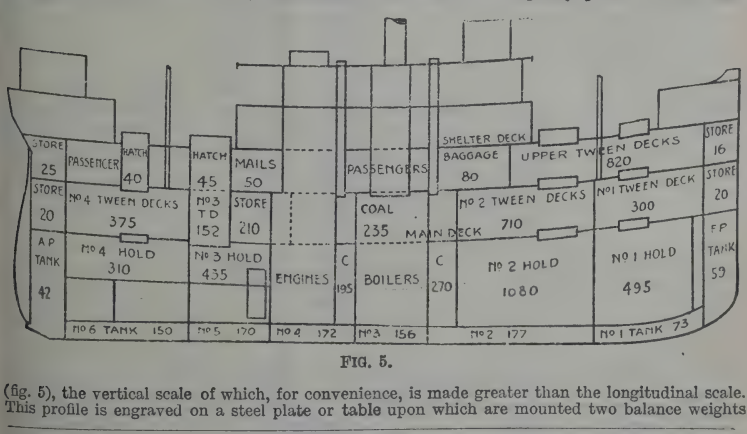


FIG. 5.

(fig. 5), the vertical scale of which, for convenience, is made greater than the longitudinal scale. This profile is engraved on a steel plate or table upon which are mounted two balance weights

* $\overset{*}{=}$ is the symbol for 'approximately equal.'

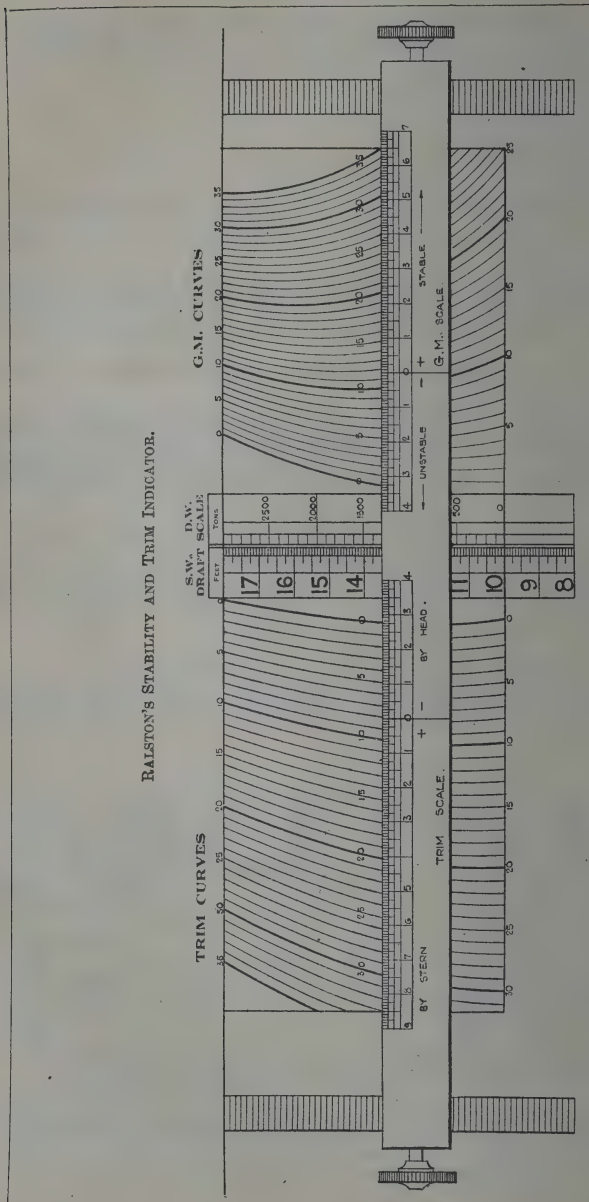

RALSTON'S STABILITY AND TRIM INDICATOR.
TRIM CURVES
G.M. CURVES
S.W. D.W. DRAFT SCALE
FEET
TONS
2500
2000
1900
17
16
15
14
11
10
9
8
BY STERN
TRIM SCALE
BY HEAD.
UNSTABLE
STABLE
G.M. SCALE
200
0

FIG. 6.

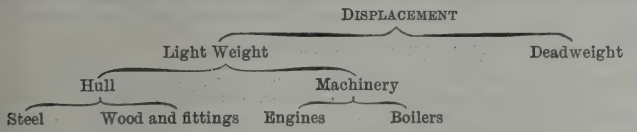
or sliders, one for stability and the other for trim. These are moved by rack and pinion over vertical and horizontal scales of 'index numbers,' engraved on the edges of the plate. The combined weight of table and sliders is made proportional to the light weight of the ship and in the zero position of the sliders the common centre of gravity corresponds in position to that of the ship in the light condition. The weights of cargo, fuel, stores, water, etc., are represented by a series of small brass weights which are placed in position on the capacity profile so as to represent any condition of loading for which it is desired to know the metacentric height and trim.

A separate diagram (fig. 6) gives mean draft and deadweight together with a series of G.M. and trim curves distinguished by index numbers corresponding to those over which the sliders move. The G.M. and trim scale movable over this diagram can be set to any draft and deadweight by means of racks and pinions. In use the table is supported firstly upon a longitudinal axis passing through the light C.G., and the vertical slider moved until balance is obtained and the 'index number' noted. The G.M. scale is then set to the correct deadweight and draft and the metacentric height read at the curve having the same index number. The table is then transferred to a vertical axis passing through the light C.G. and a similar process repeated to obtain the trim.

The instrument is simple, ingenious, and accurate; it takes into account all the features of the vessel's form and weight-distribution, obviates a considerable amount of calculation, and is being extensively adopted in the mercantile marine.

Weights.

The total weight or displacement of a merchant vessel may be subdivided as follows :—



The *Weight of Steel* includes :—

Steel and iron plates and bars of all kinds.
Structural forgings and castings, whether of steel or of bronze.
Pillars.
Steel masts.

The *Weight of Wood and Fittings* includes :—

Carpenter work.	Deck machinery and piping.	Cement.
Joiner work.	Electric lighting installation.	Insulation.
Plumber work.	Refrigerating machinery.	Rigging and sails.
Wood masts and spars.	Heating installation.	Canvas covers and awnings.
Upholstery.	Ventilation.	Sheet iron work.
Boats.	Galley outfit.	Fixed ballast.
Smithwork.	Paint.	Deck Coverings. Etc.

The *Weight of Engines* includes :—

Main propelling engines.	Sanitary and fresh-water pumps.	Piping in engine-room and tunnel.
Shafting and propellers.	Floors, ladders, and gratings in engine spaces.	Water in condensers and piping.
Condensers and circulating pumps.	Feed water.	Tools, etc.
Air-pumps and bilge-pumps.	Oil in forced lubrication system and drain tank.	
Electric generators.		

The *Weight of Boilers* includes :—

Main boilers and donkey boiler.	Piping in boiler rooms.	Floor-plates, ladders, and gratings in boiler-rooms.
Uptakes and funnels.	Feed-pumps.	Tools.
Fans and fan engines.	Feed water.	Etc.
	Hot water in boilers.	

Deadweight includes :—

Spare gear.	Reserve feed water.	Stores and provisions.
Crew and effects.	Water ballast.	Bedding and napery.
Passengers and baggage.	Bilge water.	Cutlery and crockery.
Coal in bunkers and on fire bars.	Cooling water.	Glass and silverware.
Fresh water for ship's use.	Mails and cargo.	Weights added by the owner.
Salt water for ship's use.	Oil fuel in tanks and pipes.	Etc.

Hull weight may be estimated either in detail or as a whole. Detail calculation requires that complete plans of the vessel are available, together with reference lists giving weight-rates or actual weights of all varieties of fittings. An accurate record of the finished total weights of the various items of the outfit of previous completed vessels is of great value in this connection.

For preliminary work, where a rapid estimate of the weights is required, the method of coefficients is largely relied on. In this method the whole weight of the hull, or of certain sectional portions thereof, is compared with some arbitrary parameter or parameters of simple form depending upon the principal dimensions of the vessel or of her sectional parts. For each vessel completed an accurate record of these weights is filed, and the values of the 'Coefficients of Weight' $\left(= \frac{\text{weight}}{\text{parameter}} \right)$ worked out. Then for any proposed new vessel the weight of the hull or of any of its parts, is found approximately by multiplying the proper parameter by a suitable coefficient chosen from among those of similar finished vessels.

The most commonly used parameter is the *Cubic Number*, which is the product of the Length, Breadth, and Depth, divided by 100.

$$\text{Cubic number} = N = L \, B \, D \div 100.$$

where L = Length between perpendiculars, in feet,

B = Breadth moulded, in feet,

D = Depth moulded, in feet, taken to the highest deck to which the shell plating extends continuously or almost continuously throughout the whole length of the vessel;

then,

$$\text{Weight of Hull, } H = N \times \text{Coefficient of Weight of Hull} = N \times C_h$$

Similarly,

$$\text{Weight of Steel, } S = N \times C_s.$$

$$\text{Weight of Wood and Fittings, } W = N \times C_w.$$

The weights of deck machinery, refrigerating machinery, insulation, etc., may either be included in the wood and fittings coefficient or separately estimated.

The following table gives average values of these coefficients :—

Type of Vessel.	C_s	C_w.	C_h.
Torpedo Boat Destroyer	·27	·10	·37
Cruiser	·34	·12	·46
Battleship	·33	·12	·45
River Paddle Steamer.	·20	·10	·30
Channel Steamer	·25	·13	·38
Coasting Steamer	·32	·20	·52
Cargo Tramp	·35	·12	·47
Intermediate Liner	·42	·17	·59
Fast Mail Liner	·40	·16	·56
Oil Tanker	·38	·06	·44

Other parameters sometimes used for estimating the weight of wood and fittings are

$$(L \times B) \text{ and } L \, (B + D)$$

Weight of Machinery.

In making preliminary estimates, the weight of machinery can be taken as proportional to the horse-power, the number of horse-power per ton of total machinery weight being recorded for all vessels completed and tried. A more accurate method is to record separately the weight of engines and the weight of boilers per horse-power, and to employ these rates when estimating the weight of proposed machinery of similar type. The weight of reciprocating engines may be taken as proportional to the product of the square of the diameter and the square root of the stroke of the high-pressure cylinder. For cylindrical boilers a suitable weight parameter is the product of boiler volume and square root of working pressure. For the greatest accuracy the weights of both engines and boilers must be made up in detail from the drawings and the detailed weight records of previous jobs.

Deadweight.

The total deadweight may either be specified by the owner or must be made up in detail from the particulars of the service to be performed.

Spare Gear.—Make up the weight in detail from the specified list of spares or allow a total approximate amount by reference to the actual weights carried by similar steamers. The amount may vary from about two tons in river paddle steamers and fast Channel steamers to about 40 tons in an Atlantic liner.

Crew and Effects.—Allow about one ton per ten men.

Passengers.—Allow one ton for every fifteen persons in ordinary cases and for every twenty persons in excursion crowds including women and children.

Baggage.—For the hand baggage of excursion passengers allow about one ton for every 250 persons. For long voyages allow about three tons for every ten persons.

Fuel in Bunkers = horse-power at sea, including that of auxiliaries × pounds of fuel consumed per horse-power per hour ÷ 2240 × distance between fuelling stations farthest apart ÷ service speed, + coal for galleys etc. + allowance for use in port + a margin of 10 to 20 per cent. for emergencies.

For rates of coal consumption see tables on pages 2363, 2383.

Coal on Bars.—Allow about 35 lbs. per square foot of grate area.

Fresh Water.—Allow about one ton per day for every 25 first or second-class passengers and about one ton per day for every 75 third-class or steerage passengers and crew.

Salt Water.—For sanitary purposes from ½ ton to 5 tons according to the extent of the sanitary accommodation.

Reserve Feed Water.—Allow about 4 tons per 1,000 H.P. per 24 hours for short voyages and about half as much in vessels where distilling apparatus is carried.

Provisions.—Allow about one ton per day for every 75 first and second-class passengers and about one ton per day for every 250 third-class or steerage passengers and crew.

Water Ballast.—As may be required for purposes of immersion, stability or trim during the voyage. Say one-half of weight of consumables.

Bilge Water.—Is more or less inevitable, but should not amount to much if proper care in pumping is continually taken. Allow about one-fifth of the vessel's 'tons per inch.'

Mails, cargo and stores.—As required by owners.

Bedding and napery
Cutlery and crockery } Together about one ton for every 15 persons on board.
Glass and silverware

Resistance of Ships.

The total resistance to the ahead motion of a ship is made up of three parts :—

1. 'Skin-friction resistance,' or 'skin resistance.'
2. 'Wave-making resistance,' or 'wave resistance.'
3. 'Eddy-making resistance,' or 'eddy resistance.'

The two latter are usually considered together under the name 'residuary resistance,' or 'wave resistance' merely, since eddy resistance should be very small in comparison with the other two.

HORSE-POWER.

The horse-power required to overcome any of these resistances is proportional to the resistance multiplied by the speed, and is called the 'effective horse-power.' It is from about ·45 to ·57 of the corresponding indicated or shaft horse-power developed within the vessel, the remainder of the power developed being absorbed by engine and shaft friction and losses in the propeller.

The ratio of effective horse-power to indicated or shaft horse-power is called the 'propulsive efficiency,' or 'propulsive coefficient.'

$$e = \frac{\text{E.H.P.}}{\text{I.H.P.}} \text{ or } \frac{\text{E.H.P.}}{\text{S.H.P.}}$$
$$= \text{from } \cdot 45 \text{ to } \cdot 57.$$

Skin Effective Horse-Power.

Skin E.H.P. is directly calculable :—

$$\text{Skin E.H.P.} = E_s = \frac{S}{100} \times F_{10} \times \left(\frac{K}{10}\right)^{2 \cdot 83}.$$

where,

S = wetted surface in square feet.
F_{10} = Skin E.H.P. per 100 square feet at 10 knots.
K = speed in knots.

The following table gives the values of F_{10} and of $\left(\frac{K}{10}\right)^{2 \cdot 83}$ for various lengths and speeds :—

L.	F_{10}.	L.	F_{10}.	K.	$\left(\frac{K}{10}\right)^{2 \cdot 83}$	K.	$\left(\frac{K}{10}\right)^{2 \cdot 83}$
50	1·999	450	1·832	10	1·00	18	5·28
100	1·918	500	1·826	11	1·31	19	6·15
150	1·888	600	1·816	12	1·68	20	7·11
200	1·873	700	1·807	13	2·10	25	13·37
250	1·863	800	1·798	14	2·59	30	22·40
300	1·854	900	1·790	15	3·15	35	34·65
350	1·846	1000	1·782	16	3·78	40	50·56
400	1·839			17	4·49		

From these figures curves may be drawn upon squared paper from which intermediate readings can be obtained.

Wave Effective Horse-Power.

The wave effective horse-power is not directly calculable, although several empirical formulæ and curves of coefficients have been published.

Taylor gives :—

$$\text{Wave E.H.P.} = E_w = B_e \frac{\Delta^{\frac{2}{3}}}{L} \times \cdot 0030707 \ K^6.$$

Where B_e = from ·35 to ·55, according to the degree of fullness of the vessel and her ratio of length to breadth.

The most accurate method of estimating E_w is by using the results of model experiments of actually tried vessels, and Froude's 'Law of Comparison.' The Law of Comparison may be stated thus :—If two vessels of exactly similar form, but of different size, are run at speeds proportional to the square roots of their lengths, then their wave effective horse-powers will be proportional to the products of their displacements by their speeds. If, then, we are designing a vessel n times as long as a model or similar smaller ship whose speeds and corresponding wave E.H.Ps. we know, the following ratios which various elements of the design bear to corresponding elements of the prototype may be used :—

Linear dimensions	n	Speeds	$\sqrt{n}$
Surfaces	n^2	Wave resistances	n^3
Displacements	n^3	Wave E.H.Ps.	$n^3 \sqrt{n} = n^{3 \cdot 5}$

Speeds related as above are called 'Corresponding Speeds,' and the ratio $\frac{K}{\sqrt{L}}$ of speed to square-root of length is called the 'Speed-Length Ratio.'

Model experiments give us the total E.H.P. at any speed. From this the wave E.H.P. can be obtained by separately calculating the skin E.H.P., as above described, and deducting it from the total. The wave E.H.P. for the full-size ship will be $n^{3 \cdot 5}$ times that of the model, and the skin E.H.P. for the full-size ship can be separately calculated. The sum of these two results gives the

total E.H.P. for the full-size ship. It is then finally necessary to assume a suitable value for e, the propulsive coefficient, and calculate the I.H.P. or S.H.P. by dividing the total E.H.P. by e. If we are designing from the trial results of a similar completed vessel, the procedure is slightly different :—

I.H.P. or S.H.P. of Type Ship $\times e$ = E.H.P. of Type Ship

$\frac{S}{100} \times F_{10} \times \left(\frac{K}{10}\right)^{2\cdot83}$ = Skin E.H.P. of Type Ship } at K knots.

Difference = Wave E.H.P. of Type Ship

Multiply by $n^{3\frac{1}{2}}$

and so obtain Wave E.H.P. for Design

$\frac{S'}{100} \times F'_{10} \times \left(\frac{K'}{10}\right)^{2\cdot83}$ = Skin E.H.P. for Design } at $\sqrt{n}$ K knots.

Sum = Total E.H.P. for Design

Divide by e

To obtain I.H.P. or S.H.P. for Design

where,

S = wetted surface of type ship, in square feet,
S' = $n^2 S$ = " design "
K = speed of type ship, in knots,
K' = $\sqrt{n}\,K$ = corresponding speed of design, in knots,
F_{10} = skin E.H.P. per 100 square feet at 10 knots for type ship,
F'_{10} = " " " for design.

D. W. Taylor's book, 'The Speed and Power of Ships,' which contains a series of curves based on model experiments and covering a large range of proportions of dimensions and speeds, will be found to give very accurate estimates of effective horse-power.

For fast, fine vessels, the paper 'On some Results of Model Experiments,' by R. E. Froude, published in the 'Transactions of the Institution of Naval Architects for 1904,' may be advantageously consulted. Many other experimental results have now been published both in Great Britain and America.

Admiralty Coefficients.

The 'Admiralty Coefficient of Performance' = $\frac{\Delta^{\frac{2}{3}} K^3}{P} = C$

where,

Δ = displacement, in tons,
K = speed, in knots,
P = I.H.P. or S.H.P.

Conversely $P = \frac{\Delta^{\frac{2}{3}} K^3}{C}$, so that if C is known or can be correctly assumed, P can readily be calculated. In similar ships at 'corresponding speeds' $\Delta^{\frac{2}{3}} K^3$ varies as $(n^3)^{\frac{2}{3}} (\sqrt{n})^3$, that is, as $n^{3\frac{1}{2}}$. Hence, if P were also to vary as $n^{3\frac{1}{2}}$, the values of C would remain the same. And also, if for any given vessel P varied as K^3, C would be the same for all speeds. For these reasons C is sometimes called the 'Admiralty Constant,' but as the above relations are theoretical assumptions only, and C is found to vary from speed to speed and from ship to ship, it is better to use the term 'Admiralty Coefficient.'

Although wave-making power follows the law of comparison, and therefore varies as $n^{3\frac{1}{2}}$, skin-friction power does not obey the same law and only increases at the lesser rate

$$n^2 \frac{F'}{F} (\sqrt{n})^{2\cdot83} = \frac{F'}{F} n^{3\cdot415}$$

And hence larger ships have relatively less power and larger values of C than smaller vessels. In the case of large vessels, also, a lesser proportion of power is lost in overcoming internal friction and eddy-making, and a further increase of C is the result.

In spite of its known defects, the 'Admiralty Coefficient' is largely used for estimating horse-power, the assumed value being based upon that for a similar, or nearly similar, completed vessel at 'corresponding' speed, and suitable allowances made for variations in size and proportions.

If the prismatic coefficient of the type ship differs from that of the proposed vessel, we may still find suitable values for C by modifying the 'corresponding speed' of the type ship, thus :—

$$K = K' \sqrt{\frac{L}{L'} \cdot \frac{1 - C_p}{1 - C'_p}}$$

where K, L, and C_p are the corresponding speed, length between perpendiculars, and prismatic coefficient respectively for the type ship, and K', L', and C'_p the desired speed, length, and prismatic coefficient for the proposed vessel.

Economical Speeds.

For each vessel there is a certain 'suitable' or 'economical' speed, determinable in relation to her length and fineness, above which she would be wasteful of power or 'overdriven' and below which she would be unnecessarily fine.

The following table (A) expresses these relations, and Table B gives possible values of the Admiralty coefficient on trial for vessels agreeing with Table A :—

TABLE A.

C_p. Prismatic Co-efficient.	$\frac{V}{\sqrt{L}}$ Speed Length Ratio.	C_p. Prismatic Co-efficient.	$\frac{V}{\sqrt{L}}$ Speed Length Ratio.
·61	·925	·73	·758
·63	·897	·75	·730
·65	·869	·77	·703
·67	·842	·79	·675
·69	·814	·81	·647
·71	·786		

TABLE B.

L. Length on Waterline.	C. Admiralty Coeffi-cient.	L. Length on Waterline.	C. Admiralty Coeffi-cient.
100	137	500	307
150	188	550	310
200	227	600	312
250	255	650	315
300	275	700	317
350	289	750	319
400	297	800	321
450	303	850	323

Table B assumes an efficiency, e, of about 55 per cent.; for large turbine work e appears to be about 50 per cent., so that in estimating shaft horse-power in such cases C should be taken at about 10 per cent. less than is given by the above table. For single-reduction geared turbines e = about 53 per cent.; for double-reduction geared turbines e = about 55 per cent.

The formula $Cb = 1{\cdot}06 - \frac{K}{2\sqrt{L}}$ has also been proposed as expressing a suitable connection between block coefficient and speed-length ratio.

Admiralty Coefficient applied to Fuel Consumption.

A variation of the Admiralty Coefficient much used by superintendent engineers, when comparing performances at sea, consists in substituting the daily fuel consumption in tons for horse-power in the formula $C = \frac{\Delta^{\frac{2}{3}} K^3}{P}$. We thus get:—

$$\text{Fuel Coefficient of Performance} = \frac{\Delta^{\frac{2}{3}} K^3}{T}$$

where Δ = mean service displacement in tons,
K = mean service speed in knots,
T = daily fuel consumption in tons.

Rudders.

The area of a vessel's rudder is determined by dividing the product of her length and load draft by about 30 to 40 in the case of warships, 60 to 70 for fast liners, 90 to 100 for slow cargo

tramps. The most efficient angle is about 35° from the middle line, at which angle the total pressure upon the rudder in tons is about $\frac{AK^2}{700}$ for single screw ships, $\frac{AK^2}{1000}$ for twin screws, where A is the rudder area in square feet and K the ship's speed in knots. The centre of pressure at 35° is found by assuming that the pressure on each elementary horizontal strip is applied at a point four-tenths of the breadth of the strip from its leading edge, summing the moments for each strip, and dividing by the total area.

Let h be the distance of the centre of pressure from the axis in inches, and P the total pressure upon the rudder in tons. Then T, the twisting moment in inch-tons, $= Ph$, and

$$D = \text{diameter of stock, in inches} = \sqrt[3]{\left(\frac{16\,T}{\pi F}\right)}$$

where F = maximum allowable shearing stress in material in tons per square inch.

$$\text{If } F = 5{\cdot}1,\ D = \sqrt[3]{T}$$

In practice the diameters of the rudder stocks of all classified vessels are determined by the rules of the Classification Societies.

Estimate Sheet.

When making preliminary estimates of dimensions, weights, power, etc., the following form will be found convenient:—

Number of Inquiry. Type of Vessel. Owners. Date.

Conditions.

Length × Breadth.

Type. Length × Breadth × Depth. Cubic Number.

S Steel Weight. Steel Coefficient.

W Wood and Outfit Weight. W. & O. Coefficient.

M Machinery Weight. H.P. per Ton.

D Deadweight.

$$\frac{\text{Displacement}^{\frac{2}{3}} \cdot \text{Speed}^3}{\text{Admiralty Coefficient}} = \text{Horse Power.} \qquad \frac{\text{Length} \times \text{Breadth} \times \text{Draft full}}{35} = \text{Block Number}$$

$$\frac{\text{Block Number}}{\text{Block Coefficient}} = \frac{\text{Displacement}}{\text{Keel}}$$

For example, in figures:—

Inquiry No. 42. Cargo and Passenger Steamer. Messrs. Brown and Black. 3.3.28.

To carry 6000 tons and steam 13½ knots on 24 ft. draft. Class, 100 A1 at Lloyd's. Sixty first-class. 100 second-class.

		19200	
T.S.S.	400 × 48 × 30		5760
S.	2200	·382	
W.	850	·147	
M.	750	4·54	
D.	6000		

$$\frac{9800^{\frac{2}{3}} \cdot 13\tfrac{1}{2}^3}{313} = 3400 \text{ I.H.P.} \qquad \frac{400 \times 48 \times 23'\ 10''}{35} \quad \begin{matrix} 24'\ 0'' \\ 2'' \text{ keel} \end{matrix} = 13080$$

$$\cdot 75$$

$$9800$$

These figures are arrived at by a process of trial and error-correction until a satisfactory balance is reached between weights and displacement, block coefficient and speed length ratio, horse-power and weight of machinery.

PARTICULARS OF 13-KNOT ATLANTIC CARGO STEAMERS TO ILLUSTRATE THE RELATIVE FUEL ECONOMY OBTAINED BY INCREASE OF DIMENSION

Dimensions.			Draft.	Block Coefficient.	Load Displacement.	Horse-power on Service.	Light Displacement.	Dead-weight.	Coal used on Voyage.	Coal in Bunkers.	Stores and Water.	Cargo.	Tons of Cargo per ton of Coal used.
Length.	Breadth.	Depth to Shelter Deck.											
ft.	ft.	ft. ins.	ft. ins.		tons.		tons.	tons.	tons.	tons.	tons.	tons.	
300	40	31 0	22 0	·742	5,600	3,250	2,335	3,265	500	550	300	2,415	4·8
350	45	34 6	24 2	·762	8,250	3,950	3,260	4,990	610	675	350	3,965	6·5
400	50	38 0	26 4	·780	11,750	4,800	4,440	7,310	740	825	400	6,085	8·1
450	55	41 6	28 6	·796	16,000	5,750	5,900	10,100	890	975	450	8,675	9·8
500	60	45 0	30 8	·810	21,300	6,750	7,670	13,630	1,040	1,150	500	11,980	11·4
550	65	48 6	32 10	·822	27,500	7,850	9,820	17,680	1,210	1,350	550	15,780	13·1
600	70	52 0	35 0	·832	35,000	9,000	12,370	22,630	1,390	1,550	600	20,480	14·7

Type.	Moulded Dimensions. L.	B.	D.	Gross Tonnage.	Steel Wght. — Coefft.	Wood and Outfit Wght. — Coefft.	Wght. of Engines.	Light Wght.	Dead Wght.	Load Dispt. — Block Coefficient.	Load Draft.	H.P. Sea at Sea. — Admiralty Coefficient.	Speed.	Engine.				Boilers. No.	Diam.	Lgth.	Parent Builders.
A	400	52	31	5,030	2,225 0·346	405 0·063	570	3,200	8,175	11,375 0·762	25–1	2,500 268	11	27	44	73	48	3	15–6	11–6	Henderson, Glasgow.
B	400	52	31	5,030	2,325 0·361	405 0·063	570	3,300	8,075	11,375 0·762	25–1	2,500 268	11	27	44	73	48	3	15–6	11–6	Henderson, Glasgow.
C	331	46–6	25–6	3,000	1,390 0·354	300 0·077	460	2,150	5,050	7,200 0·760	21–8	2,200 258	11·5	25	41	68	45	3	14–0	11–6	Tyne I. S. Co., Willington Quay.
D	285	41–9	21–3	2,300	1,110 0·440	240 0·095	420	1,770	2,980	4,750 0·732	19–0	1,900 226	11·5	25	41	68	46	2	16–6	11–9	Austin, Sunderland.
E	376	51–6	29	4,400	1,920 0·342	400 0·071	570	2,890	7,020	9,910 0·749	23–9	2,500 280	11·5	27	44	73	48	3	15–6	11–6	Duncan, Port Glasgow
F	411–6	55–6	29	6,440	2,565 0·388	520 0·079	620	3,705	10,795	14,495 0·775	28–8	3,650 281	12	27	45	75	54	3	16–0	12–3	Thompson, Sunderland.
*	400	53	35–5	5,680	1,920 0·256	430 0·057	620	2,935	9,000	11,935 0·745	26–4	3,650 246	12	27	45	75	54	3	16–3	12–6	Northumberland Co., Howdon.
G	450	58	40	8,000	3,200 0·306	650 0·062	1,350	5,200	10,800	16,000 0·740	29–0	5,500 253	13	26½	44	73	48	3	16–3	20–6	Workman, Clark & Co. Belfast.
H	303	43	23	2,800	1,150 0·384	300 0·100	360	1,810	3,960	5,670 0·780	19–6	1,400 261	10·5	22	36	59	39	2	15–6	10–6	Austin, Sunderland.
†	385	52	29	4,600	2,070 0·357	200 0·035	550	2,820	7,520	10,340 0·750	24–0	2,500 287	11·5	27	44	73	48	3	15–6	11–6	Russell, Port Glasgow.
N	411–6	55–6	38–2	6,500	2,600 0·299	520 0·060	570	3,690	10,500	14,190 0·770	28–0	2,300 294	10·5	Geared Turbine				3	Babcock		Swan, Hunter, Wallsend.
A′	400	52	31	5,250	2,600 0·404	350 0·054	570	3,520	7,885	11,405 0·760	25–1	2,500 269	11	27	44	73	48	3	15–6	11–6	Laing, Sunderland.
Z	400	52	31	5,800	2,360 0·367	317 0·049	570	3,400	8,000	11,400 0·762	25–1	2,500 269	11	27	44	73	48	3	15–6	11–6	Swan, Hunter, Wallsend.

* Shelter deck. † 'Tween deck. A′ Converted oil carrier. Z Oil carrier. All single-screw vessels.

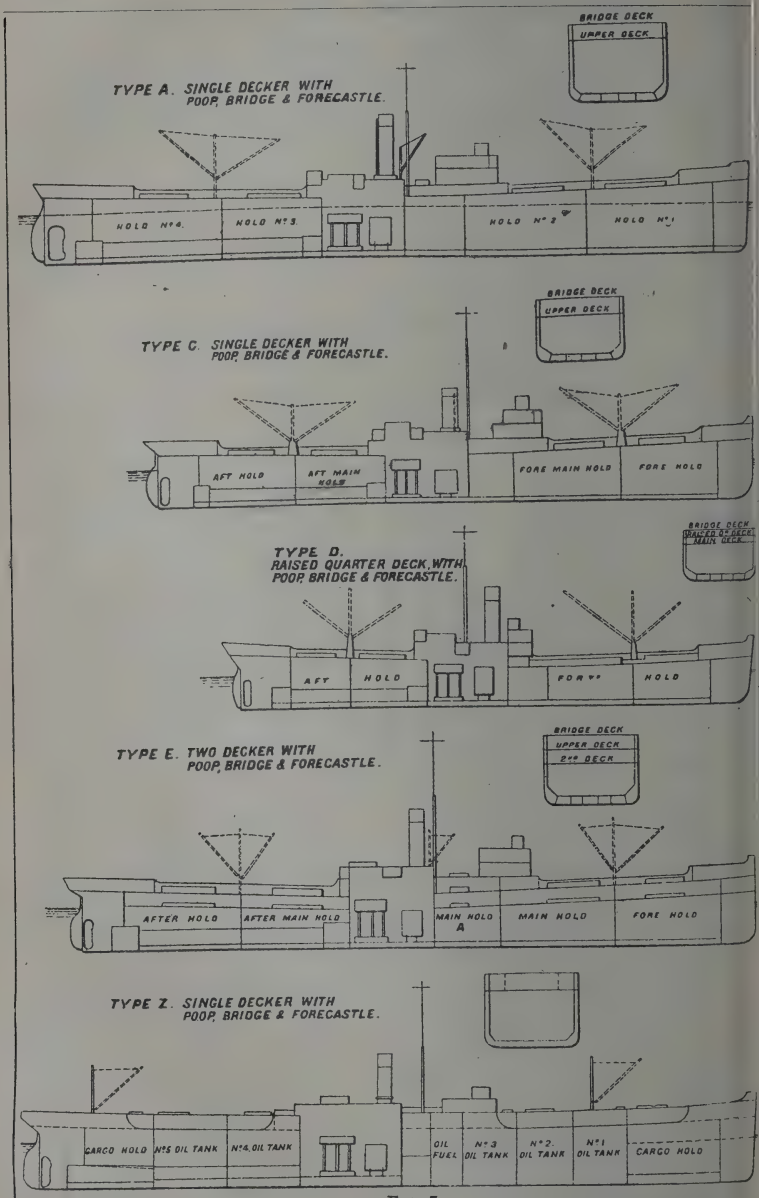


FIG. 7.

(Engineering.)

Nationality.	British.				Ex-German.		German.	French.	Italian.	
Owners.	Cunard Steamship Company.		White Star Line.	Union S.S. Co. of New Zealand.	Cunard S.S. Co.	White Star Line.	Hamburg South American S.S. Co.	Cie. Générale Transatlantique.	Cosulich.	Navigazione Generale Italiana.
Names.	Aquitania.	Mauretania.	Olympic.	Aorangi.	Berengaria.*	Majestic.†	Cap Arcona.	Ile de France.	Saturnia.	Augustus.
Built at	Clydebank	Wallsend	Belfast	Fairfield	Hamburg	Hamburg	Hamburg	St. Nazaire	Trieste	Sestri Ponenti
Date	1914	1907	1911	1924	1912	1922	1927	1927	1927	1927
Length	865′	760′	850′	580′	880′	912′	660′	758′	599′	664′ 6″
Breadth	97′	88′	92′ 6″	72′	98′ 6″	100′ 6″	84′ 3″	92′	79′ 6″	82′ 6″
Depth	64′ 6″	60′ 6″	64′ 9″	46′ 6″	68′	64′ 2″	55′ 5″	61′	46′ 6″	51′ 6″
Gross tonnage	45,647	30,696	46,459	17,500	52,226	56,551	27,560	43,548	23,990	32,500
Draft	36′ 2″	36′ 1·5″	34′ 7″	27′ 9″	39′	38′ 10″	28′ 5″	32′	29′	30′
Displacement	53,130	41,590	52,310	22,000	63,100	64,509	—	41,000	—	32,000
Passengers I.	757	589	947	433	686	875	636	677	279	300
„ II.	635	399	498	284	714	725	274	617	566	578
„ III.	1,998	1,150	1,100	217	2,890	2,216	402	346	1,352	1,300
Engines	Turbine	Turbine	Combination	Diesel	Turbine	Turbine	Turbine	Turbine	Diesel	Diesel
Cranks	—	—	2 × 4	4 × 6	—	—	—	—	2 × 8	4 × 6
Cylinders No.	—	—	2 2 2 2	24	—	—	—	—	16	24
Cylinders Dia.	—	—	54 84 97 97	27·5	—	—	—	—	33	30·2
Stroke	—	—	75	39	—	—	—	—	59	47·2
Revolutions	180	180	78, 160	125	185	180	125	220	125	120
Boilers	21 D	23 D : 2 S	24 D : 5 S	2 S	46 Yarrow	48 Yarrow	8 D. W.T.	24 W.T.	—	—
Pressure	195	195	215	120	285	240	300	228	—	—
Furnaces	168	192	159	6	—	—	—	144	—	—
Heating surface	138,596	157,520	144,142	3,183	203,000	219,504	52,500	125,591	—	—
Grate area	3,542	4,048	3,466	—	3,767	4,013	—	—	—	—
Draught	Howden	Howden	Natural	Natural	Howden	Forced	—	Howden	—	—
Fuel	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil	Oil
Horse-power	60,000	70,000	46,000	13,000	76,250	66,000	24,000	52,000	23,000	28,000
Speed	23	26·06	21 ‡	18·2	22·5	25 ‡	20	23·5	20	20·75

* Ex-Imperator. † Ex-Bismarck. ‡ Estimated.

BASES OF ENGINE AND BOILER DESIGN.

Cylinder Ratios.

Considerations of weight and space usually limit the dimensions of cylinders for the machinery of high speed cross-channel vessels. For ordinary merchant and mail steamers these considerations are of minor importance; coal consumption however is of the utmost importance, and consequently a higher ratio of expansion of steam is utilised, involving larger cylinder dimensions in order to obtain maximum economy of coal consumption. In fast passenger vessels with high revolutions per minute, four-crank triple-expansion engines are invariably adopted, there being one H.P., one M.P., and two L.P. cylinders. This arrangement admits of a satisfactorily balanced engine being obtained, reducing vibration to a minimum, and the weight of the moving parts of the L.P. cylinders is considerably reduced compared with the ordinary three-crank triple engine or four-crank quadruple. The following table of cylinder area ratios is in accordance with modern practice for various types of marine engines:—

TABLE SHOWING CYLINDER AREA RATIOS.

Type of Engine.	Boiler Pressure. Lbs. per Sq. In.	Ratio of Cylinder Areas.			
		L.P. / H.P.	2nd M.P. / H.P.	1st M.P. / H.P.	H.P.
Quadruple expansion	200 to 220	8	4·0	2·0	1
		9	4·3	2·08	1
			M.P. / H.P.		
Triple expansion, ordinary merchant practice	160 to 180	6·5 to 7·5	2·5 to 2·7		1
Cross-channel steamers	180 to 200	6·25	2·4		1
Compound engines, screw	100 to 140	4 to 5	—		1
" " paddle	90 to 130	3·5	—		1

The reciprocating engine is now, however, being displaced by direct or geared turbines in all classes of vessels, from fast passenger and mail steamers and cross-channel boats to cargo vessels, even of the tramp class, owing to the reduction obtainable thereby in fuel consumption.

Mean Pressures and Expansion of Steam.

The total power developed in an engine may be varied by altering the point at which steam is cut off in the H.P. cylinder, and generally provision is made to enable the cut-off in each cylinder to be independently adjusted if necessary to equalise the powers developed in each cylinder. For the maximum designed power the cut-off in the H.P. cylinder takes place at from ·6 to ·75 of the stroke, and the total number of expansions of the steam is

$$= \frac{\text{Volume of L.P. cylinder}}{\text{Volume of H.P. cylinder at point of cut-off}};$$

or

$$\frac{\text{Ratio of } \dfrac{\text{L.P. cylinder area}}{\text{H.P. cylinder area}}}{\text{Cut-off in H.P. cylinder (expressed in fraction of stroke)}}.$$

The total expansion of the steam is usually considered with clearance neglected and neglecting also the fact that release takes place before the end of the stroke. In estimating the mean pressure obtainable in any multiple-stage expansion engine it is referred to the L.P. cylinder, the mean pressure thus obtained being that necessary if the whole of the power were developed in the L.P. cylinder. The actual referred mean pressure is, therefore, in the case of a triple expansion engine equal to

$$\text{Mean pressure in L.P. cylinder} + \frac{\text{Mean pressure in M.P. cylinder}}{\text{Ratio of L.P. to M.P. cylinder area}} + \frac{\text{Mean pressure in H.P. cylinder}}{\text{Ratio of L.P. to H.P. cylinder area}}.$$

The theoretical referred mean pressure may be calculated, assuming that the steam is moderately moist, the curve of expansion being a hyperbola. It depends upon the designed number of expansions and the absolute admission pressure of the steam.

Let Pa = absolute initial pressure,

Pm = absolute theoretical referred mean pressure,

r = total number of expansions,

$\frac{1}{r}$ = cut-off, or reciprocal of r,

then

$$Pm = Pa \frac{1 + \text{hyp. log. } r}{r}.$$

Pressure of Steam in Cylinders of Compound and Triple-expansion Engines.

The values of $\frac{1 + \text{Hyp. Log. } r}{r}$ for Various Expansions are given on page 1759.

The initial pressure, Pa, should be taken 5 to 10 lbs. below the absolute boiler pressure to allow for the drop between boilers and engines, and the back pressure, which must be deducted from Pm as found above, should be taken at not less than 4 lbs. per square inch absolute.

Diagram Factor.

Owing to the losses which occur while the steam is expanding in the various cylinders the actual referred mean pressure obtained from indicator diagrams is less than the theoretical referred mean pressure, and consequently the latter must be multiplied by a diagram factor which takes into account the losses due to clearance, condensation, radiation, friction of ports, compression, drop in pressure between the cylinders, and other losses. The value of this factor is obtained by experience, and, when possible, should be derived from engines similar to the one projected, and working under similar conditions. The values for various types of engines are approximately :—

Quadruple-expansion engines	·63 to ·68
Triple-expansion engines, merchant service	·6 to ·65
„ high-speed cross-channel engines	·56 to ·63
Compound engines	·63 to ·70

When cylinders are jacketed the diagram factors may be increased by about 5 per cent.

The power is usually divided equally among the cylinders of an ordinary compound, triple, or quadruple-expansion engine, and if N is the number of cylinders and P the referred mean pressure (i.e. theoretical mean pressure × diagram factor) the mean pressure in the various cylinders of a triple-expansion engine, for example, will be :

$$\text{L.P. cylinder mean pressure} = \frac{P}{N}$$

$$\text{M.P. „ „ „} = \frac{P}{N} \times \frac{\text{L.P. cylinder area}}{\text{M.P. cylinder area}}$$

$$\text{H.P. „ „ „} = \frac{P}{N} \times \frac{\text{L.P. cylinder area}}{\text{H.P. cylinder area}}$$

In the case of four-crank triple-expansion engines the power developed in each L.P. cylinder is usually five-eighths that of the H.P. or M.P. cylinder.

Piston Speed.

The mean piston speed is usually reckoned in feet per minute and is equal to stroke in feet × 2 × revolutions per minute.

The power which may be obtained from a given weight of engine varies almost directly with the piston speed ; the wear and tear of the engine, however, is increased with the higher speeds on account of the increased inertia stresses involved.

Piston speed may be increased either by increasing the stroke and keeping the revolutions constant or by increasing the revolutions, keeping the stroke constant.

By adopting the former method the cost, dimensions, and weight of the engines are increas whilst by adopting the latter method there is practically no increase in any of the items m tioned. It is evident, therefore, that in cases where weight and space are limited high pist speed must be obtained by high revolutions; these have a limit, however, on account of t stresses due to the inertia of the reciprocating parts.

The piston speed and revolutions of engines fitted in various types of vessels are as shown the following table :—

TABLE SHOWING PISTON SPEED AND REVOLUTIONS OF RECIPROCATING MACHINERY FOR VARIOUS TYPES OF STEAMSHIPS.

Description.	Number of Cranks.	Piston Speed in Feet per Minute.	Revolutions per Minute.
Large mail steamers	4	800 to 900	75 to 90
	3	600 ,, 750	70 ,, 80
Cargo vessels	4	650 ,, 800	70 ,, 100
	3	550 ,, 650	60 ,, 100
Channel steamers	4	800 ,,1000	170 ,, 200
	3	750 ,, 900	130 ,, 180
Paddle steamers	—	550 ,, 650	45 ,, 55

(Also see remarks about propeller revolutions for geared turbines.)

Calculation of Cylinder Diameters.

In determining the diameter of cylinders required for an engine of a given I.H.P., the typ vessel for which the engine has to be designed to a certain extent determines the piston sp and cylinder ratios, due consideration being given to the boiler pressure, the number of expansi being increased as higher boiler pressures are adopted.

Having decided the piston speed and the mean pressure referred to L.P. cylinder as alre described, the area of the L.P. cylinder may be calculated, and from the cylinder ratios deci upon the areas of the remaining cylinders are determined.

Let piston speed = S feet per minute;

referred mean pressure = P lbs. per square inch,

then,

$$\text{Indicated H.P.} = \frac{\text{Area of L.P. cylinder} \times P \times S}{33{,}000}$$

or

$$\text{Area of L.P. cylinder} = \frac{\text{I.H.P.} \times 33{,}000}{P \times S};$$

$$\text{Area of M.P. cylinder} = \text{Area of L.P. cylinder} \times \text{Ratio of } \frac{\text{M.P. cylinder area}}{\text{L.P. cylinder area}};$$

$$\text{Area of H.P. cylinder} = \text{Area of M.P. cylinder} \times \text{Ratio of } \frac{\text{H.P. cylinder area}}{\text{M.P. cylinder area}}.$$

Combined Recipro-Turbine Machinery.

In vessels of say under 18 knots the direct coupled turbine installations are not suita since the comparatively low rotational speed necessary for an efficient propeller necessit for an efficient turbine a considerable increase in dimensions and hence increase in weight cost. In such cases a combination of reciprocating engines and turbines was employed, t being two reciprocating engines to deal with the high-pressure steam and one or two turb to expand the exhaust steam down to the lowest possible pressure. In the steamer 'Otaki' system is credited with a saving of about 17 per cent. in the coal consumption; it has also b fitted to the White Star Liners 'Laurentic' and 'Olympic,' the Orient Liner 'Orama,' other vessels.

In the 'Reina Victoria Eugenia' a four-shaft 'combination' arrangement was adop the two inner shafts being driven by reciprocating engines and the two outer shafts by low-pres turbines. At low powers the reciprocating engines produced about three-quarters of the t power and the turbines one-quarter; at full output the proportions were about two-thirds one-third respectively. The steam consumption was only about 11 lbs. per h.p. per hou about 20 per cent. less than that required for quadruple expansion reciprocating machin

The revolutions of the reciprocating engines were about 113 per min., those of the turbines about 480. The sister vessel 'Infanta Isabel de Borbon' had the usual three-shaft combination, the revolutions of the turbines at full power being 276 per min. and of the reciprocating engines 116 per min.

In a three-shaft combination installation with 92 revolutions per min. for the reciprocating engines and 250 for the turbines, the reciprocating portion of the machinery produced 56 per cent. and the turbine portion 44 per cent. of the total full power, but the propulsive effect of the turbine propeller is rather disappointing. This machinery has been displaced by the geared turbine.

TURBINES.*

The development of the steam turbine as a motor for ship propulsion has progressed rapidly in the last decade. In the earlier stages of its adoption, when the turbine was directly coupled to the propeller shafting, the high revolutions necessary to obtain suitable blade speeds for low steam consumption without abnormally increasing the size and weight of the turbines entailed small propellers which were inefficient except for fast vessels, and even in these the turbines were run at an uneconomically low speed in order to improve the propellers.

The introduction of single-reduction gearing between the turbines and propellers enabled advantage to be taken of high blade speeds and fairly efficient propellers for vessels of over about 16 knots speed, and for all speeds of vessels double-reduction gearing permits the turbine and propeller designers to select the revolutions most suitable for their individual purposes so as to obtain the maximum efficiency of turbine and propeller respectively. The revolutions of the most efficient propeller for a vessel depend on horse-power, speed and form of vessel, and should be worked out in conjunction with experimental results such as those published by Taylor and Froude, but the following method gives very satisfactory results for turbines, gearing and propellers :—

If

R = revolutions of propeller per minute;
SHP = shaft horse-power of each shaft;
V = speed of vessel in knots on trial;

then,

$$R = C\sqrt{\frac{V^5}{SHP}}.$$

VALUES OF C.

—	Direct Coupled.	Single Reduction Gearing.	Double Reduction Gearing.
Merchant vessels—ocean	12 to 13	7 to 8	5 to 6
,, ,, channel	13 ,, 14	9 ,, 10	5 ,, 6
Battleships	10 ,, 12	7 ,, 8	—
Light cruisers	11 ,, 13	9 ,, 10	—
Destroyers	13 ,, 15	7 ,, 8	—

RELATIVE I.H.P., S.H.P. AND COAL CONSUMPTION FOR ALL PURPOSES ON AN OCEAN LINER.

—	Reciprocating		Turbine		
	Triple.	Quadruple.	Direct.	Single Gear.	Double Gear.
Effective horse-power	5,000	5,000	5,000	5,000	5,000
Propulsive coefficient $\frac{EHP}{SHP}$	·6	·6	·50	·54	·6
S.H.P.	8,333	8,333	10,000	9,260	8,333
I.H.P.	8,950	8,950	—	—	—
Lbs. steam per S.H.P.	—	—	14·25	13·75	13·5
,, ,, ,, I.H.P.	17·1	16·2	—	—	—
Lbs. coal per S.H.P.	—	—	1·425	1·375	1·35
,, ,, ,, I.H.P.	1·71	1·62	—	—	—
Tons coal per hour	6·8	6·5	6·4	5·7	5·0

* See also 'Steam Turbines,' p. 1819.

PARTICULARS OF THE 36 HOURS COMPARATIVE TRIAL OF THE 'CAIRNROSS' & 'CAIRNGOWAN

	'Cairnross' Geared Turbines.	'Cairngowan' Triple-expansion Engines.
Draught on trial, mean	23 ft. 8½ ins.	23 ft. 4½ ins.
Displacement on trial . . . . . tons	9,950	9,891
Revolutions per min. (mean for 36 hours)	61·76	61·68
Coal per day . . . . . tons	27·8	32·7
I.H.P.	—	1,790
S.H.P.	1,570	—
Ratio of S.H.P. 'Cairnross' to I.H.P of 'Cairngowan'	·877	—
Lbs. of coal per I.H.P. per hour, all purposes	(equiv.) 1·45	1·704
" " S.H.P. " "	1·65	(equiv.) 1·94
Estimated water consumption per hour, all purposes	22,000 lbs.	27,200 lbs.
" " " per I.H.P. hour	(equiv.) 12·3 lbs.	15·18 lbs.
" " " per S.H.P. hour	14 lbs.	(equiv.) 17·3 lbs.
Hot-well temperature	79° Fah.	104° Fah.
Feed temperature	203° Fah.	221° Fah.
Estimated lbs. of water per lb. of coal from feed temp.	8·5	8·97
Percentage of ash	12·5	9·36
Pressure, steam pipe in engine room	158 lbs.	175 lbs.
Initial pressure h.p. turbine	138 lbs.	—
Vacuum	28·75 ins.	26·8 ins.
Circulating water temperature, inlet	50° Fah.	50° Fah.
" " " outlet	70° Fah.	95° Fah.

COMPARATIVE RESULTS OF PARSONS SINGLE REDUCTION GEARED TURBINES AND RECIPROCATING ENGINES IN SIMILAR SHIPS.

Name of Vessel.	Type of Machinery.	Dimensions and Tonnage (Approx.).			Speed (Knots).	Coal per Day.	Savin in Co for Tur bine
			Gross.	Dis-placement.			
						Tons	
(1) Vespasian .	(A) Turbine single screw .	275×38·75	2,150	4,350	9½	14·17	17%
	(B) Recipro. " " .	"	"	"	9½	17·07	
(2) Cairnross .	(C) Turbine single screw .	370×50¼	4,000	10,000	10·15	27·8	15%
Cairngowan	(D) Recipro. " " .	"	"	"	10·15	32·7	
(3) Mahanada .	(E) Turbine single screw .	470×58	7,200	13,500	12·138	54·8	19%
Malakuta .	(F) Recipro. " " .	"	"	"	11·533	67·4	
(4) Cumberland	(G) Turbine twin screw .	474×60	9,470	15,600	13·11	77·5	15%
Devon. .	(H) Recipro. " " .	473×60	9,661	"	12·8	91·5	

Note.—In 3 and 4 the speeds of the turbine vessels are higher than the corresponding vess with reciprocating machinery. If the speeds had been equal the saving would have been grea than as recorded.

Arrangement of Turbines.

Turbine machinery may be arranged to drive one, two, three, or four lines of shafting.

In mercantile vessels with direct-coupled turbines three lines were adopted, the centre sh being driven by a high-pressure turbine, the steam from which was exhausted into two lo pressure turbines driving the two wing shafts. Astern turbines were incorporated in the end of the l.p. ahead turbine casings, and during normal ahead running revolved idly in vacuu A separate high-pressure steam connection was fitted to each astern turbine, and also to ea low-pressure ahead turbine. When manœuvring in and out of harbour the wing turbines o were employed, each turbine being controlled independently of the other.

In some installations of turbine machinery in large mail steamers four shafts were employ and the steam expanded in series through an h.p. and i.p., and two l.p. turbines. This arran ment, while introducing more complication in the intermediate receiver connections, enabl a higher efficiency to be secured than in the usual three- or four-shaft arrangement.

In torpedo boats and torpedo destroyers the practice was to adopt a three-shaft arrangeme similar to that described above. Most of the vessels fitted in this manner were provided wi h.p. and i.p. cruising turbines in order to maintain economy at low speeds, and these turbin were cut out of action as the power increased.

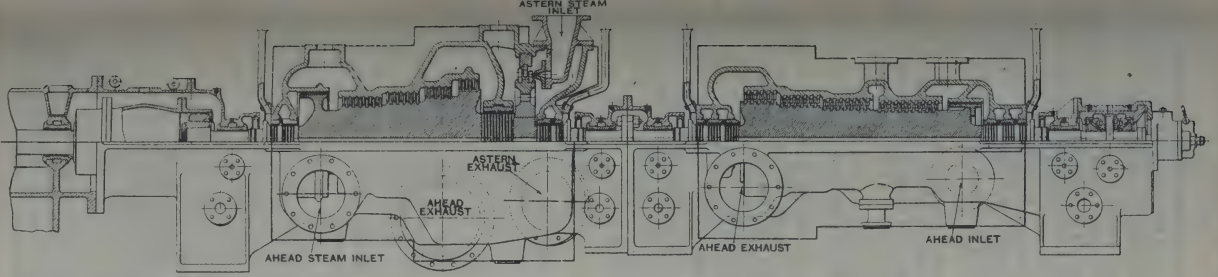


FIG. 8.—Parsons' Turbines, Section through H.P. and M.P. Turbines with H.P. astern incorporated.

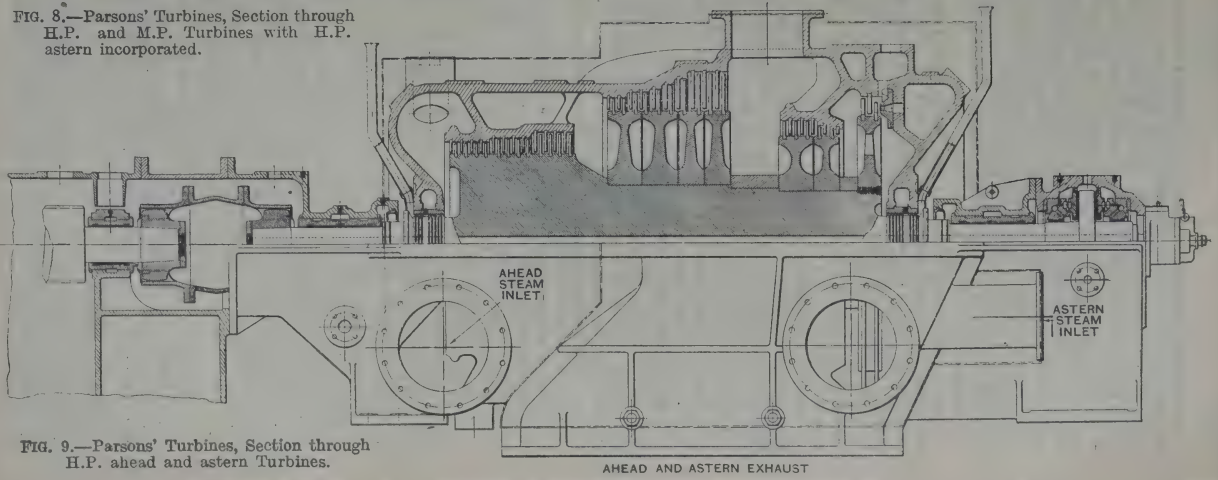


FIG. 9.—Parsons' Turbines, Section through H.P. ahead and astern Turbines.

More recent experience has shown that there are several objections to this arrangement, and in particular to the weight of these cruising turbines, and as a consequence the 'independent' type of turbine has been adopted. Where direct turbines are still fitted the installation usually consists of twin screws driven by turbines of the Parsons' or Brown-Curtis types, having the astern turbine incorporated in the same casing as the ahead turbine.

In light cruisers the machinery usually consists of two independent sets of single-geared turbines fitted in compartments separated by longitudinal or transverse bulkheads, and so arranged that in the event of damage to the one set the other will be available for use. Geared cruising turbines have also been fitted for low power.

In battle cruisers and battleships the turbine installation usually consists of two complete sets arranged in two or three compartments divided by longitudinal bulkheads. In the latter arrangement the h.p. turbines are placed in the wing compartments and the two l.p. turbines in a common central compartment, while in the former the bulkhead is placed between the l.p. turbines.

On each outer shaft there is a h.p. ahead turbine forward and an independent h.p. astern turbine aft. On each inner shaft there is a l.p. ahead turbine, having incorporated with it in the same casing a l.p. astern turbine. All four shafts are thus in use for manœuvring either ahead or astern, the steam exhausting from the h.p. ahead or astern to the l.p. ahead or astern turbine, as the case may be and from thence to the condenser.

With geared turbines each shaft is driven by an independent unit consisting of one h.p. ahead turbine and one l.p. ahead turbine with an astern turbine incorporated in the same casing with the latter.

With double-reduction gearing the high pressure unit is sometimes divided into an h.p. and i.p. in separate casings so as to reduce the length of rotor between bearings and enable higher revolutions to be run without 'whipping.' Where manœuvring requires greater astern power than can be transmitted by one pinion an h.p. astern turbine is fitted at the end of the h.p. or i.p. ahead turbine separately or in the same casing with a diaphragm to prevent astern steam entering the ahead turbine and vice versa. This arrangement is also preferred with superheated steam to minimise the change of temperature in the astern turbine when reversing.

For marine propulsion the two principal types which have been adopted are the Parsons and the Brown-Curtis. In the merchant service turbines of both types with single-reduction gear have been extensively fitted in high-speed steamers for cross-channel mail and passenger service, and the more recent development of double-reduction geared turbines is now being extensively adopted in vessels where the speed is lower, and on that account the propeller revolutions of single-reduction gear are not suitable.

The direct-coupled turbine is rarely fitted now owing to the many advantages and greater economy of the geared installations.

For naval service, so far as this country is concerned, either Parsons' turbines or Brown-Curtis turbines with single-reduction gearing are now being fitted in all battleships, cruisers, or torpedo boat destroyers. With superheated steam it is found that an economy of about 1 per cent. in steam consumption is obtained for each 10° Fahr. of superheat.

With superheated steam and the latest aids to economy, turbine machinery is a successful rival to Diesel engines at large powers. The liner *Empress of Australia*, ex *Tirpitz*, originally fitted with turbo-hydraulic propelling machinery and water-tube boilers, was recently re-engined by the Fairfield S. & E. Co., Ltd., with single reduction geared turbines of the Parsons' type and cylindrical boilers with superheaters. The speed of the vessel was increased from 16½ to 19 knots and at the same time the fuel consumption decreased from 205 to 150 tons per day. The consumption of oil fuel for propelling purposes is less than 0·7 lbs. per s.h.p. per hour. As boiler fuel oil is usually much cheaper per ton than Diesel fuel oil, and the weight, first cost, and maintenance of a turbine installation less than Diesel's, turbine machinery is more economical and suitable for installations of this class for powers above 15,000 s.h.p.

The present tendency is to increase boiler pressures and superheat as in land installations, and the success of this development was demonstrated on a river steamer for the Clyde service, the *King George V.*, which is driven by Parsons' geared turbines of 3,500 s.h.p. The boilers are of the water-tube type generating steam at 520 lbs. pressure and 815° F. temperature. The fuel consumption on the official trials was 1·085 lbs. of coal per s.h.p. per hour for all purposes.

Parsons' Marine Turbines.

Longitudinal sections through typical Parsons' reaction turbines are shown in figs. 8 and 9 and these turbines would be used in the arrangement shown on fig. 13, page 2368, the H.P. and M.P. tandem turbine taking the place of the H.P. turbine shown in the figure.

A set of Parsons' turbines of 3,000 s.h.p. with double-reduction gearing is shown in figs. 10, 11, and 12, p. 2367.

There is one h.p. and one i.p. ahead turbine each developing approximately one quarter of the total power and driving separate pinions geared to one first reduction gear-wheel. The l.p. turbine develops one half power and is geared to the first reduction gear-wheel on the opposite side of the main wheel. An h.p. astern turbine is incorporated in the same casing as the i.p.

PARSONS TURBINES.

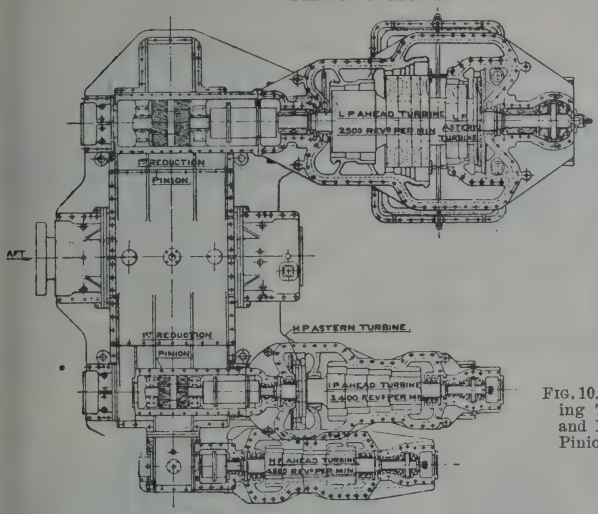


FIG. 10.—Plan View showing Turbine and I.P. and L.P. 1st Reduction Pinion Covers removed.

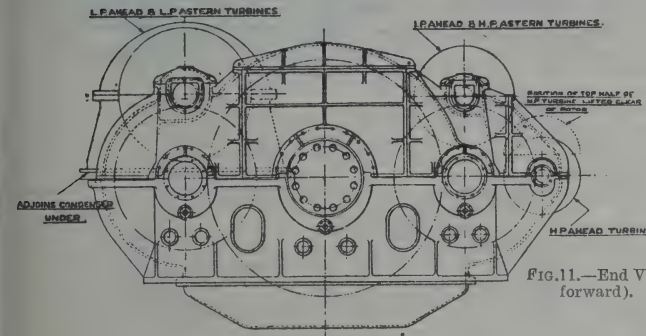


FIG. 11.—End View (looking forward).

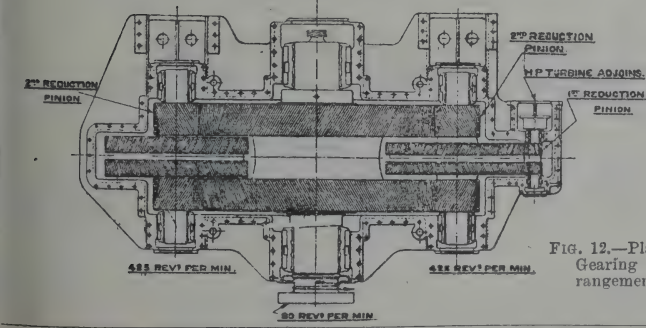


FIG. 12.—Plan View of Gearing showing arrangement of Wheels.

PARSONS TURBINES.

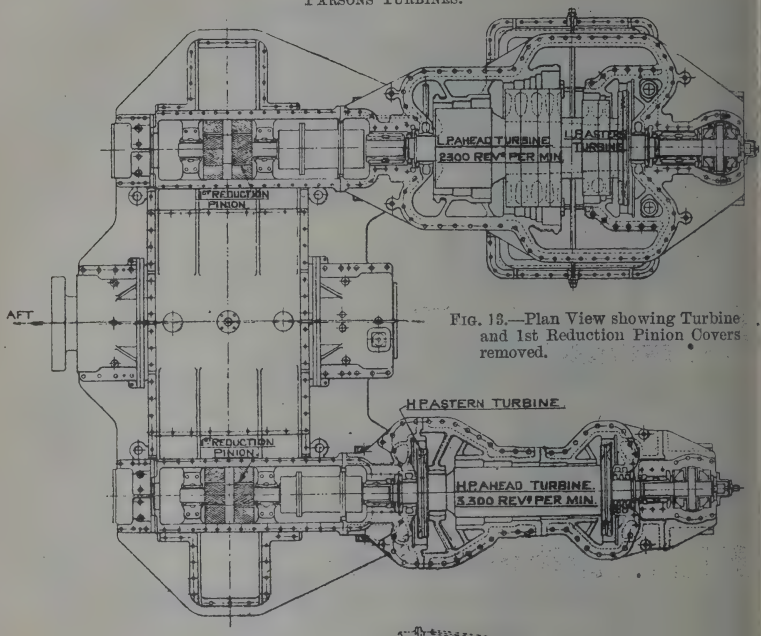


FIG. 13.—Plan View showing Turbine and 1st Reduction Pinion Covers removed.

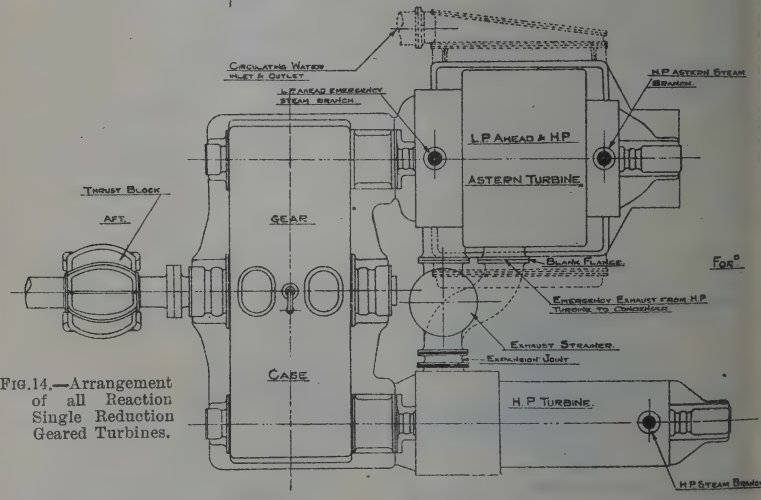


FIG. 14.—Arrangement of all Reaction Single Reduction Geared Turbines.

ıhead turbine but separated from it by a diaphragm and the l.p. astern turbine is also incorporated with the l.p. ahead.

Owing to the high revolutions at which turbines can run with double-reduction gearing, the lesired blade speed can be obtained with a small diameter of rotor and consequently the end thrust due to steam pressure is low enough to be taken entirely on a thrust block of the pivoted ype, thus dispensing with dummies and the leakage caused by them. In addition, the blade ieights to pass the steam are greater than in large rotors of equal power, but as the clearance s not increased the percentage loss due to leakage past the tips is much less in the geared turbine. As a result of these and other advantages the steam consumption is much reduced from that equired for direct-coupled turbines, and if superheat is used, say 200° F., the consumption for urbines only, exhausting to 28 inches vacuum, will be from 8 to 8½ lbs. per hour.

Figs. 11 and 12 show the arrangement of the double-reduction gearing for this set of turbines.

Fig. 13 shows an alternative arrangement with two turbines instead of three. There is one l.p. and one l.p. ahead turbine with a corresponding astern turbine in each casing.

This arrangement is simpler, but the consumption is slightly higher than in the three-turbine ırrangement.

Fig. 14 shows a set of single-reduction geared turbines with one h.p. and one l.p. ahead turbine ınd an h.p. astern turbine incorporated with the latter.

This arrangement is suitable for low powers or where the propellers can be run at higher evolutions as in channel or shallow-draught steamers.

Brown-Curtis Turbines.

Figs. 15, 16, and 17 show a set of Brown-Curtis turbines for a double-reduction geared instalation for one shaft of a liner.

The h.p. turbine is sometimes designed with three wheels each with two rows of buckets r moving blades, and at others with one two-bucket wheel and several single-bucket wheels. The m.p. and l.p. ahead turbines have single bucket wheels, and in the astern turbines there re usually two three-bucket wheels, or if a greater proportion of astern power is required, one hree-bucket and two two-bucket wheels.

The turbines are arranged with the h.p. and m.p. in line and coupled together, driving one inion of the gearing and the l.p. turbine driving a separate pinion. This arrangement enables he designer to choose the revolutions most suitable for each turbine.

The astern turbines are arranged with the first or h.p. stage in the low pressure end of the l.p. ahead turbine casing, but separated from it by a diaphragm, and the l.p. astern in the orresponding l.p. ahead casing exhausting through the common pipe to the condenser. The stern drive is thus distributed over both pinions, and especially with superheated steam the hange in the casing temperature of the first stage when astern steam is turned on is not so great.

The casings and diaphragms are of cast iron, except where superheated steam is used, when ne casing of the h.p. is of cast steel and the diaphragms of special bronze.

The rotors and wheels are of mild steel and specially designed to avoid 'whipping' and to ithstand the stresses caused by the high speed of rotation. The blades or buckets are of special ronze capable of maintaining its strength at high temperatures, and the nozzles are formed of teel plates embedded in the diaphragms during casting. The rotors pass through glands at ach end of the casing, which are packed with carbon rings to prevent the egress of steam at the igh pressure or inlet of air at the low pressure stages.

The end thrust of the rotor is small and is taken up by a thrust block, usually of the Michell ype.

Reduction Gear for Propulsion.*

The development of the turbine has led the way to the adoption of indirect transmission etween the turbine and propeller, in order to utilise to the fullest extent the economy to be erived from running the turbines at high relative speeds and the propellers at reduced speed, s compared with direct-driven turbines. The importance of saving a few ounces of coal per .p. per hour, and five per cent. or more in propeller efficiency in modern large power ships, either aval or mercantile, is obvious. In the former the radius of action with available fuel supply increased, and in the latter a substantial reduction is made in the annual fuel bill.

The following systems have proved successful, and may be now considered beyond the experiıental stage :—

(*a*) Parsons' mechanical gearing.
(*b*) Fottinger's hydraulic transformers.
(*c*) Electric transmission.

(*Continued on p.* 2374.)

* See also pp. 1022, 1869.

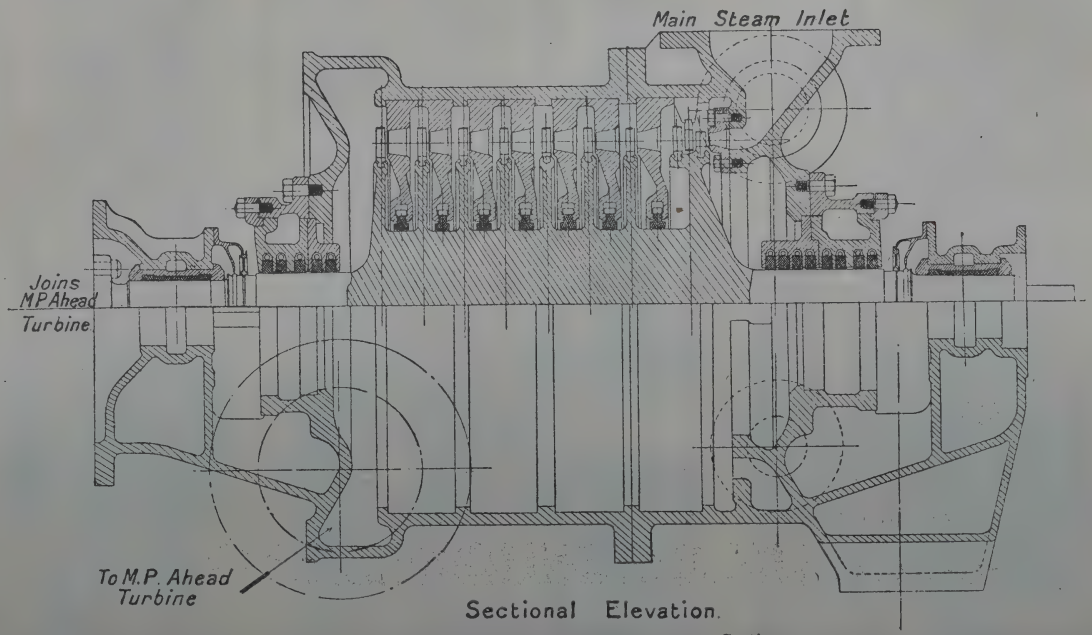


FIG. 15.—H.P. Ahead Turbine (Brown-Curtis).

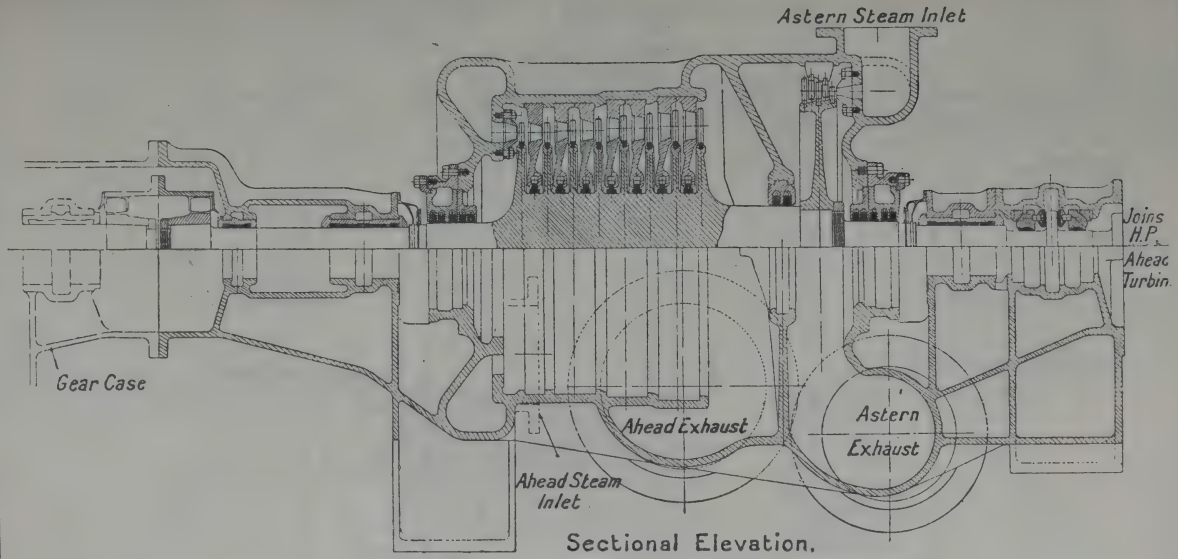


FIG. 16.—M.P. Ahead and H.P. Astern Turbine (Brown-Curtis).

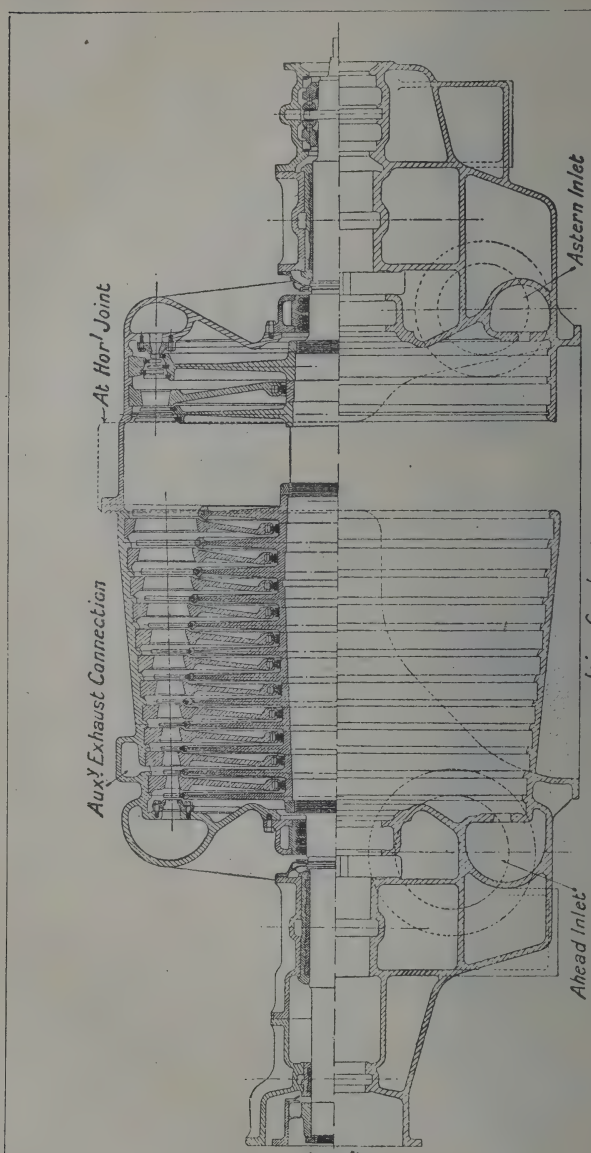


FIG. 17.—L.P. Ahead and Astern Turbine (Brown-Curtis).

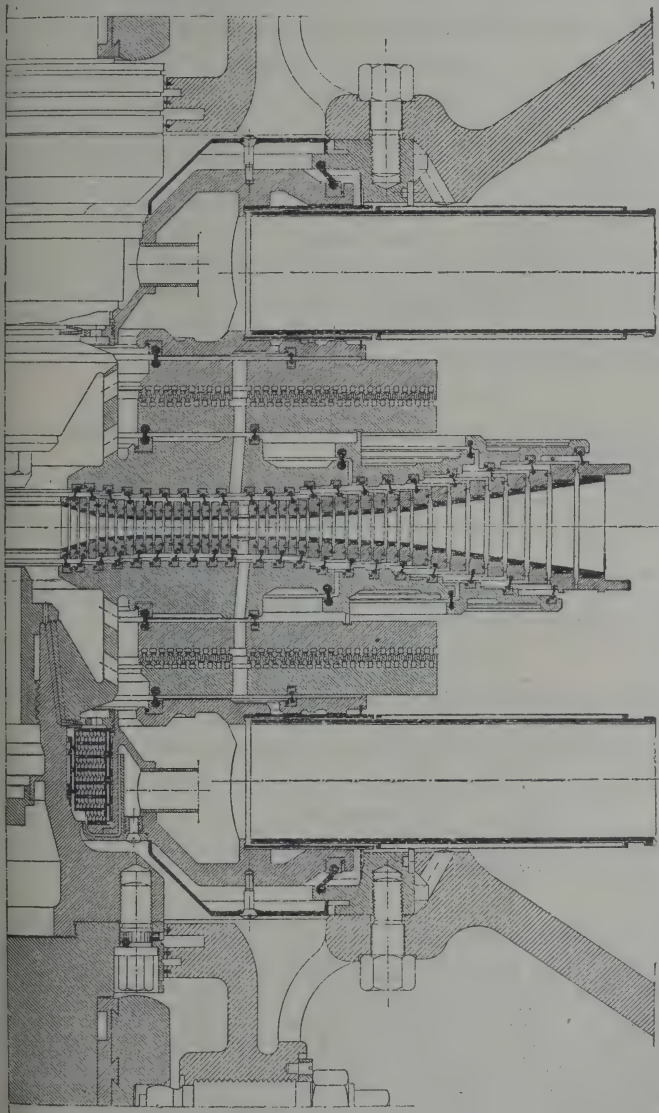


FIG. 18.—Longitudinal Section of a 1,000 K.W. Ljungström Turbine (Lower part).

The details of these systems are described in the following pages.

Each system will have certain fields of application where its particular advantages render its use desirable.

Some of the relative advantages and disadvantages of the systems are as follows:—

(*a*) MECHANICAL GEARING.

Advantages.

(1) Reduction in weight of installation from 10 to 15 per cent. as compared with direct coupled turbines.

(2) Reduction in fuel consumption of 10 per cent. on same basis.

(3) High mechanical efficiency of gearing, 97 to 98 per cent. for double and single reduction gears respectively.

(4) Large speed reduction ratio permissible, so that greatest propeller efficiency can be obtained without impairing turbine efficiency.

(5) Simplicity of mechanism.

Disadvantages.

(1) Separate turbines for astern running are necessary which are only capable of developing about two-thirds of ahead power.

(2) Noise in engine room. This is very slight with the recent improvements in tooth cutting, and is not noticed outside of machinery space.

(3) Wear in teeth. With properly designed gears and properly cut teeth this is very slight. The introduction of the 'Nodal Drive' by removing torsional vibrations from the working range of revolutions has reduced wear and tear considerably.

(*b*) HYDRAULIC TRANSFORMERS.

Advantages.

(1) Astern turbines dispensed with and about 85 per cent. of ahead power available for astern running with reversible transformer.

(2) Absence of noise.

(3) Relatively no wear.

(4) Practically no limitation in power to be transmitted.

(5) Increased manœuvring power due to greater astern power and practically instantaneous reversal.

Disadvantages.

(1) Lower efficiency as compared with mechanical gearing, about 89 per cent.

(2) Limitation in speed reduction ratio, the maximum being about 6 : 1, and in consequence a reduction of efficiency of both turbines and propellers as compared with geared turbines, but not to the same extent as with direct-coupled turbines.

(*c*) ELECTRIC TRANSMISSION.

Advantages.

(1) Astern turbines dispensed with and full power available for astern working.

(2) Absence of noise.

(3) No wear and minimum cost of upkeep.

(4) No restriction in revolutions, so that highest efficiency of turbines and propellers can be realised.

(5) Great economy in multiple screw ships at low power, as one generator can be cut out entirely.

Disadvantages.

(1) Greater first cost than geared turbines.

(2) Higher consumption at full power than geared turbines—say 6 per cent.—due to transmission losses in generator and motor being greater than in gearing.

PARSONS' GEARING.*

This gearing consists of a large gear wheel with double helical teeth about $\frac{7}{8}$ in. pitch, coupled to the propeller shaft, and driven by either one or two pinions, coupled to the turbines. The connection between the pinion spindle and turbine spindle is by means of a claw coupling, which under running conditions permits of any slight lateral movement due to the expansion of the turbine rotor under steam being taken up. The gearing is completely enclosed in a cast-iron casing, which also forms the support for the bearings of the gear wheel shaft and pinion spindles. Jets of lubricating oil from the forced lubrication system impinge on the teeth at the point of contact of the pinion and wheel, and the spindles and shaft bearings are also connected to the forced lubrication system. The double helical gear ensures the transmission of pressure from one tooth to another without shock or vibration, and as the teeth are of true involute form complete line contact exists during the time they are in mesh. The pinions are made of nickel steel, having a tensile strength of about 40 tons per sq. in. with 25 per cent. elongation, and the gear wheels of carbon steel having a tensile strength of about 32 tons per sq. in. with

* See also pp. 1022, 1869.

PARSONS' GEARING.

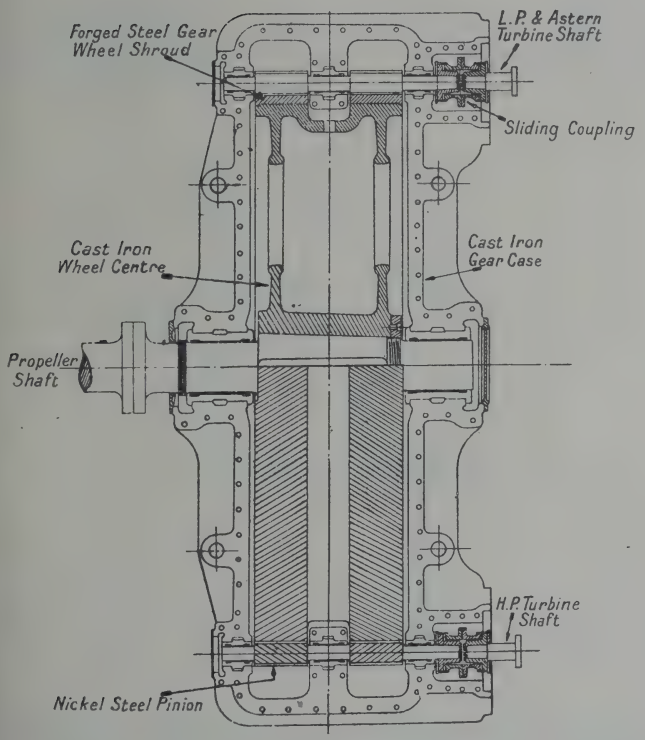


FIG. 19.—Plan with top casing removed.

26 per cent. elongation. Absolute accuracy in cutting the gearing is essential, and any corrective process or hand work after the gear is cut is inadmissible. The machines employed are the result of extensive and costly experiments, both in design and construction. In the double reduction gears the pitch of the teeth in the intermediate pinion and large wheel varies from $\frac{7}{16}$ to 1 inch.

Marine Reduction Gears.

(The Power Plant Co. Ltd., West Drayton.)

According to the ratio of reduction of the turbine speed to the propeller speed, single or double reduction gears are employed; for instance, single reduction gears are quite practicable, and a large number of vessels are running with a reduction up to 20 to 1.

This last reduction has recently been effected for two Dutch Royal Mail steamers by the above company.

Where, however, a power exists about 4,000 h.p., and for any reduction from 20 to 1, the low speed wheel becomes too large for practical purposes; recourse must then be made to double reduction gears.

Up to the present time double reduction gears have been supplied for a total reduction ratio of 70 to 1, but there is no reason why 100 to 1 could not be effected just as easily. The general arrangement of a typical double reduction set is shown in figs. 12 (p. 2367), 19, and 20.

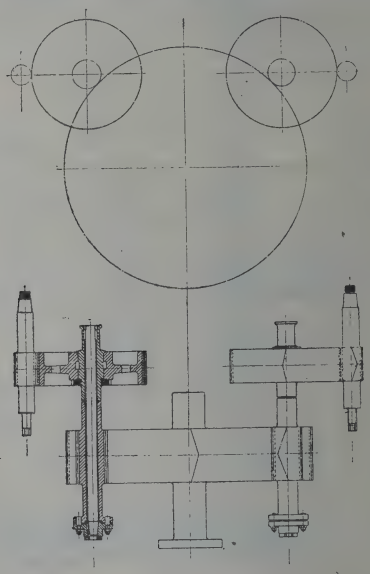


Fig. 20.

The essential feature of these gears is the use of two independent high-speed gear trains, each driven from one turbine, and a second reduction with a common wheel for the drive from both turbines, the low-speed train being arranged symmetrically relative to the high-speed trains. The advantages of the arrangement are that the power from each turbine is transmitted to the final wheel independently, whereby an even distribution of pressure on the teeth of same can be relied upon. The housing of all the gear trains in one casing effects a considerable saving in space fore and aft, where space is of most value, and reduces the gear weight without sacrifice of strength and rigidity. The gear wheels and bearings forming an arrangement symmetrical at right angles to the shafts, the deflections caused by the load are reduced to a minimum. The use of a single gear case simplifies the oiling arrangements and greatly simplifies the construction of the gear seatings in the vessel. The reduction of the number of bearings required to a minimum improves the overall efficiency and simplifies supervision.

With regard to efficiency, single reductions will go up to 98½ per cent., and double reductions up to 97 per cent.

The first steamer to be equipped with reduction gearing (made by *The Power Plant Co., Ltd.*) was the 'Vespasian,' a single-screw steamer of 2,150 tons. This gearing, as tested by Sir Charles Parsons, gave 98½ per cent. efficiency, and a fuel economy of about 13 per cent. was obtained. The cross-channel steamers, 'Normannia' and 'Hantonia' (with gearing made by The Parsons Marine Turbine Co., Ltd.), with a gear ratio of about 7 : 1, consumed only 43 tons of coal per trip, as compared with 70 tons per trip required by direct-driven turbine vessels of similar dimensions and speed, engaged in the same service.

Mechanical gearing for turbines has developed enormously in recent years, and is now being used extensively for ships of all powers and classes. Double reduction gearing makes it possible to run the turbines twenty or thirty times as fast as the propellers, with a consequent gain in overall efficiency.

Fottinger's Hydraulic Transformer.

The hydraulic transformer (fig. 21) consists of two centrifugal pump wheels, A, keyed to the primary shaft, which is driven by the turbine. On the secondary, or propeller, shaft three impulse reaction water turbine wheels are mounted, the after two, B and C, for ahead driving,

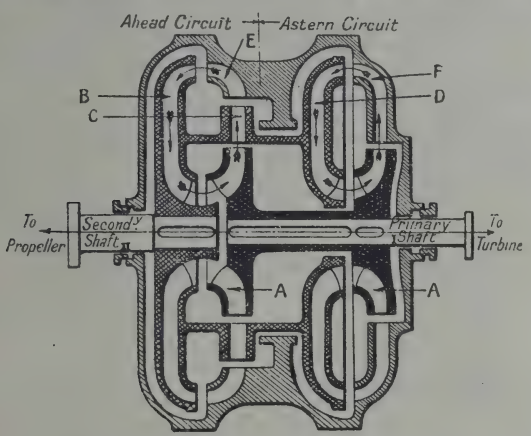


Fig. 21.—Fottinger's Hydraulic Transformer.

and the forward one, D, for astern driving. The wheels for ahead driving absorb the energy delivered to them from the water discharged by the pump wheel in two stages, the primary stage, C, being connected to the astern water turbine wheel, D. Having given up part of its energy in the primary ahead stage, the water moves in continuous compact flow through guide vanes, E, in the casing to the second stage ahead wheel, B, which absorbs the remaining energy in the water. The discharge from the second stage wheel flows back to the beginning of the circuit in the pump wheel, giving up to it the remaining energy of discharge. In the same way the astern driving wheel, D, receives its energy from the water discharged by the forward pump wheel guided into it by the stationary vanes, F, in the casing.

The vanes in the ahead and astern turbine wheels are spaced in opposite directions to each other, thereby giving the reversed motion.

A change valve, controlled by a lever, admits the water from either pump wheel to the corresponding turbine wheel to give the desired direction of rotation.

The wheels and vanes of the transformer are made of bronze, and the casings of cast iron.

The efficiency of the transformer decreases with an increase of speed reduction ratio on account of the higher velocities causing increased fluid friction.

Fresh water is used in the system, and on account of the work done upon it by friction during its passage through the vanes heat is generated. Part of this heat, which would otherwise be lost, is saved by using the water for feeding the boilers, the quantity of water in the transformer system being maintained by filling up with colder water from the air-pump discharge.

The Vulcan Diesel Hydraulic Drive.

The Vulcan gearing, fig. 22, which transmits the power of two Diesel engines to a common propeller shaft, consists of a large helical gear wheel mounted on the propeller shaft, and in which two pinions engage with gear ratio of about 3 : 1. These pinions are connected through liquid clutches to the crank shafts of two Diesel engines. The clutches, built under the Vulcan-Föttinger patents of the Vulcan Werke, each consist of a compartment for running ahead and a compartment for running astern.

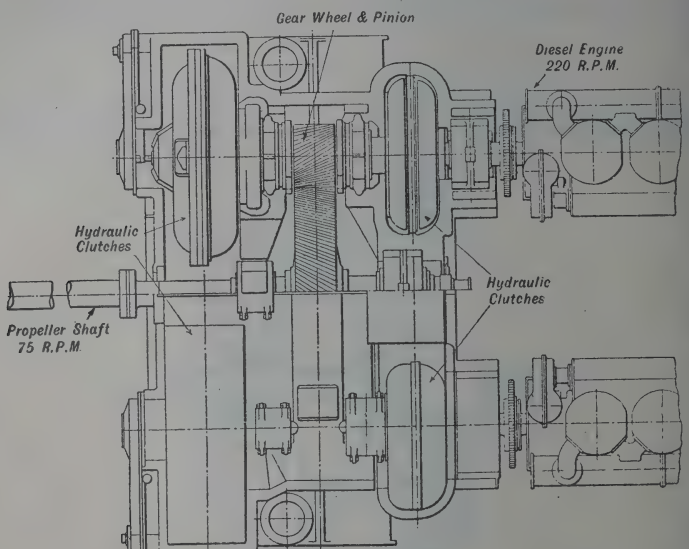


FIG. 22.

The engines are reversed by alternately filling and emptying the ahead and astern compartments by means of a reversing gear operated from the engineer's platform controlling the centrifugal pumps driven from the primary shafts. The driven pinions, and consequently the propeller shaft, run in the same or in the opposite direction to that in which the engine shafts rotate, according to whether the clutches for forward or for astern running are filled with liquid. When the propeller is reversing the Diesel engines require no attention as they run permanently in one direction.

The controlling mechanism is so arranged that the liquid or hydraulic clutches of both the Diesel engines are operated simultaneously. In the event of one of the engines requiring to be stopped during working, an arrangement is provided whereby the two compartments of its respective clutch are emptied and the engine cut out.

The efficiency of the Vulcan gearing is in normal ahead running 97 per cent. The power available for astern running is 65 per cent. of the ahead.

The gearing and the clutches are built together, forming one complete unit in a common cast-iron casing. The hydraulic clutches are of cast iron. The pinions and the wheel rim, which is shrunk on to the cast-iron body of the large gear wheel, are of special steel. The teeth are cut on a precision milling machine by the involute process. The shafts are of Siemens-Martin steel; all bearings are lined with white metal. The front bearing of the large gear wheel is constructed as a thrust bearing and takes up the thrust of the propeller shaft so that no additional propeller thrust block is required.

The liquid used for operating the clutches is lubricating oil. The bearings and teeth of the gear wheels are lubricated with the same oil by which the liquid clutches are operated. The lubricating oil and the oil which drips from the bearings of the gearing and from the clutches is

caught in a collecting reservoir placed underneath the gearing. It is drawn from this collecting reservoir by a lubricating oil pump which pumps the oil through a filter and a collector back to the bearings of the gearing and to the teeth of the gear wheels. Oil-circulating pumps attached to the Diesel engines also draw the oil from this reservoir and deliver the oil to the compartments of the clutches as required.

Driving by high-speed Diesel engines and Vulcan gearing possesses *inter alia* the following advantages over direct drive:—

(1) Less weight, lower first cost and less space, particularly in height, with consequently better utilisation of the available space in the ship.
(2) As two Diesel engines drive on to each propeller shaft, the reliability at sea is increased in consequence of this engine standby, and it is therefore a practical proposition to build ships of 5,000 s.h.p. with a single propeller shaft.
(3) Each of the engines can be disconnected from the helical gear wheel by emptying its corresponding liquid clutch. The engine is started working again by simply refilling the liquid clutch so that it is picked up and carried on by the engine, which remains running.
(4) The engines are of the single-acting, non-reversible, four-cycle type. The thermal strains due to admission of cold air to the hot cylinders are obviated, as the engines run continuously in one direction when manœuvring.
(5) The liquid clutches have the property of completely eliminating all irregularities in the turning moment of the Diesel engines not only during normal working, but also at the critical torsional speeds, as the clutches transmit a uniform turning moment, otherwise only attained by turbine drive.
(6) The vessel may be run with as low a number of revolutions of the propeller as may be desired (five to twenty revolutions per minute), which is of importance when manœuvring.

Installations are being constructed by the Vulcan Company for two 10,000-ton d.w. single-screw vessels of 4,000 b.h.p. for the Hansa and the Hamburg Australian Lines. In these instances the propelling units will be of the four-stroke cycle, single-acting type, conforming to marine practice in having crossheads, but utilising steel castings for the main structural parts of the engines, such as bedplates, columns, and cylinders. Four engines can be applied very conveniently to a single shaft.

Electric Transmission of Power for Propelling Machinery.

The application of electricity for transmitting power between the prime mover and the propeller may be divided into two classes, viz.: Turbo-electric and Diesel-electric.

TURBO-ELECTRIC.

The electrical equipment required is an alternating current generator suitable for direct coupling to a high-speed turbine, a motor of suitable speed for direct coupling to the propeller shaft, a direct current exciter or an auxiliary generator, from which direct current can be obtained, and suitable control gear. The whole can be regarded as a reduction gear having a ratio of reduction determined by the relative number of poles on the motor and generator. Thus with a two-pole generator and a sixty-pole motor the ratio of reduction would be 30 to 1, and, as with mechanical gearing, any variation in speed is obtained by varying the speed of the prime mover.

Two types of alternating current motors have been used for driving propellers:—

(*a*) Induction machines, both slip-ring and squirrel-cage types.
(*b*) Self-starting synchronous motors.

All things considered, the self-starting synchronous motor is the most suitable for this class of work on account of the large air gap, simplicity of construction, accessibility of windings, high power factor, and efficiency. When starting from rest the synchronous motor functions as a squirrel-cage motor with its field unexcited.

On account of its greater flexibility direct current is preferable for vessels up to about 3,000 S.H.P. on one shaft; beyond this power, owing to the limitations of voltage, the cables become excessively large.

Electrically driven ships in service have demonstrated their unquestionable reliability; the main driving power is transmitted magnetically across large air gaps, giving an elastic medium for absorbing shocks, and thus making it the simplest and most reliable form of speed reduction.

The turbine is of simple construction, being built in one casing and directly connected to the generator, thereby reducing the size of the seatings and eliminating distortion and mis-alignment troubles due to local straining of the ship. Bearings, shafts, shaft packings, valves and piping are reduced to a minimum, thus decreasing the friction and leakage losses. The astern turbine is eliminated entirely in an electrically driven vessel, full power astern being available without reversing the direction of rotation of the turbine.

There is an absence of vibration and noise, as the machinery is perfectly balanced, with no rubbing contacts, and the quietness of the running is a feature of great importance in a passenger vessel. Manœuvring is very efficient with this type of power transmission, so that perfect speed control in heavy seas is maintained without danger of racing.

The cost of upkeep, as has been proved by ten years' experience with electrically driven vessels, is much less than with any other type of reduction gear.

The propeller efficiency may be kept very high as the electric drive lends itself practically to any desired speed reduction between the turbine and propeller, and each may therefore be designed to operate at a speed corresponding to its highest efficiency.

DIESEL-ELECTRIC.

The Diesel electric drive will be most suitable for double purpose vessels such as fruit and meat carriers, where a large amount of power is required for operating refrigerating plant, etc., and for dredgers, cable-laying ships, self-propelled floating cranes, and vessels of similar types.

In such vessels it is possible, by the application of electricity, to use the same prime mover for both propelling and auxiliary purposes, also to have a number of comparatively small engines each driving a generator, and a single motor direct coupled to the propeller shaft, which can thus be run at the most suitable and efficient speed irrespective of the speed of the prime mover, the electrical losses being largely offset by the more efficient propeller.

The Diesel engines for electric transmission are simpler in design than those which are coupled directly to the propeller shaft, as the engine speed has no relation to the propeller speed, and as the engines run in one direction only. The large air storage tanks, also, can be eliminated.

With the electric drive accurate and constant knowledge of the power output is always obtainable from meters on the control board; and in this manner the power required at any draft or trim under all weather conditions, the effect of dirty hull on the ship's resistance, etc., can be ascertained and studied.

THE NODAL DRIVE.

The introduction of double reduction gear with high-speed turbines has produced some difficulties peculiar to this class of work.

In some cases there has been excessive noise in the engine-room, and hammering of the gears in the gear-box, followed by flaking of the gear teeth and grooving and deformation of the tooth faces, while occasional fractures of the teeth, which clearly suggest fatigue of the material, are not unknown.

Attempts to neutralise these troubles by using higher grades of steel, the broadening of the tooth faces and reduction of the transmitted loads, have not overcome the difficulty.

Accuracy of cutting of the gears and their alignment in the ship is one of the first essentials to be attained with a geared drive; nevertheless, noise, hammering, and wear have occurred with the best designs and workmanship.

The 'Nodal Drive' has been evolved after an extensive series of experiments and a complete mathematical investigation of the whole problem, the experimental work being carried out on a single-screw steamer of 2,500 S.H.P., driven by three turbines.

The investigations have shown that the troubles experienced with this gear arose from torsional oscillations of the shafts set up by the action of the propeller working in a variable wake, or from other disturbances in the system. These torsional oscillations cannot be eliminated, but they can be controlled.

The torsional oscillations of a shaft to which masses are attached has been studied very fully by various investigators, but the oscillations of a system consisting of several shafts with attached masses, connected by a train of gear wheels, is a more complicated problem.

Investigations have proved conclusively that, in the ordinary arrangement of geared drives, there is no clearly defined oscillating system. The periodicities of free vibration of the system are numerous, and synchronism, or approximate synchronism, between these critical speeds and the running speeds of any element of the system causes hammering of the gear teeth.

In the 'Nodal Drive,' as a result of accurate calculations, a suitable adjustment of the elasticities of all the shafts and the moments of inertia of the attached masses is secured, thus giving a completely defined oscillating system which has the minimum possible number of free vibration periods. These periods can be accurately determined and arranged well clear of the running speeds of the various elements of the system.

Fig. 23 illustrates the 'Nodal Drive' as installed in the experimental ship.

The original arrangement of solid primary pinion shafts, with torsionally stiff connections to the turbines, has been replaced by hollow pinion shafts with internal flexible driving shafts connecting the ends of the pinion shafts with the turbines.

The lengths and diameters of these shafts are so adjusted that the periodicities of the free torsional oscillations about the gear-box of all the shafts and their attached masses are equal.

Fig. 23A is an enlarged view of one of the hollow pinion shafts with the flexible driving shaft in position, and shows the method of supporting the driving shaft inside the hollow shaft, so as to prevent whipping action taking place. Suitable lubricating arrangements are applied to prevent wear of the supporting collars.

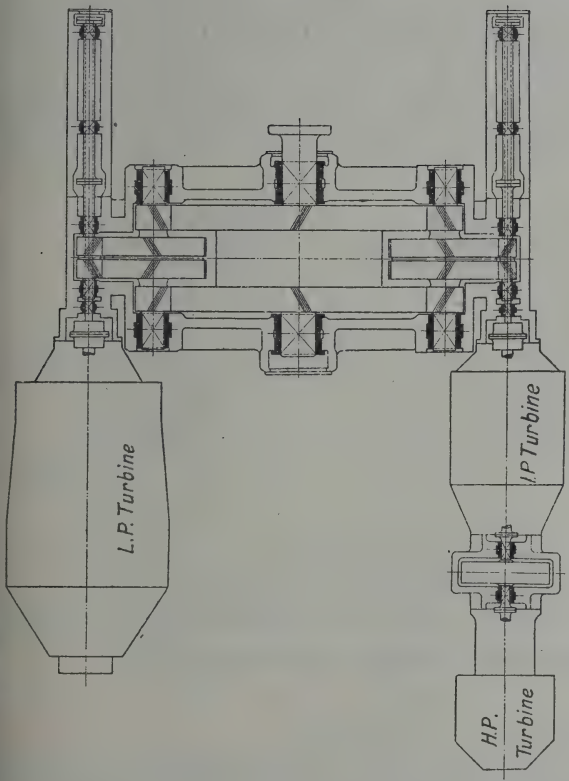


FIG. 23.

THE NODAL DRIVE.

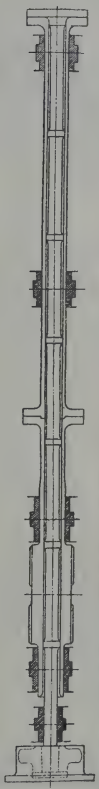


FIG. 23A.

In this experimental installation it was necessary to introduce a flywheel on the H.P. side of the drive in order approximately to equalise the moments of inertia of the two sets of turbines, and thus keep the length of the H.P. flexible driving shaft within reasonable limits. This flywheel is placed between the H.P. and M.P. turbines, and, in effect, binds all the masses in such a way as to form approximately one rigid mass.

In an entirely new design, where the 'Nodal Drive' is embodied from the start, the flywheel may not be an essential feature, since the balancing of the moments of inertia can be accomplished in the turbine design.

The 'Nodal Drive' has already been fitted to eleven steamers, and is giving complete satisfaction.

Cockburns' Geared Turbine Emergency Shut-off and Positive Control Manœuvring Gear for Saturated and Superheated Steam.

In this arrangement, fig. 24, the manœuvring valves are of the single handwheel type. Rotation in one direction from mid position opens the ahead valve, and by the opposite direction the astern valve is opened. With the arrangement shown it is impossible to have the two valves open at the same time.

The emergency valves are incorporated in the bulkhead valves and are steam operated by an automatic governor on the turbine rotors. They shut off steam completely, which, in the case of a broken shaft, prevents the turbine from being spun, as would occur with the ordinary butterfly throttle, through the quantity of steam that passes the latter valve when it is closed.

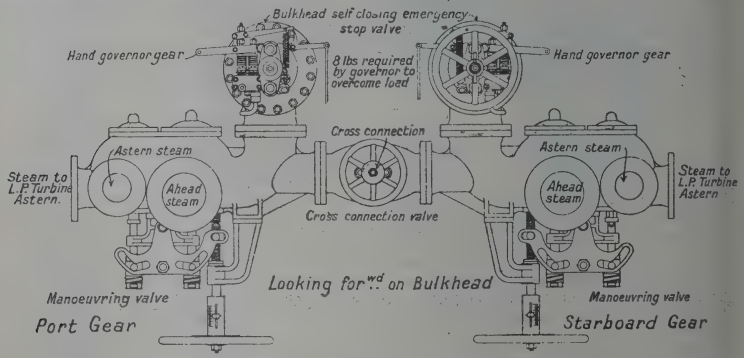


Fig. 24.

The governor gear is connected direct to the operating gear on the valves, as the governor has only to act against a resistance of 4 lbs. on each valve.

The hand emergency gear acts independently of the governor gear.

The bulkhead valves are also arranged to be controlled by the pressure in the lubricating oil system so that the steam is shut off from the main turbines in the event of failure of the oil supply.

Rules for the Dimensions of Steamship Shafts.

See p. 1079.

BOILERS.

In determining the principal dimensions of a boiler, or boiler installation, consideration must in the first instance be given to the system of draught employed, whether it is to be forced or natural draught, and since the quantity of steam which a boiler is capable of generating depends on the weight of coal consumed, it follows that the dimension which must first be decided is that of the grate area, the heating surface being proportioned from the grate area depending upon the type of boiler employed. The efficiency of the boiler largely depends on the rate of evaporation per square foot of heating surface, which should be kept as low as possible.

Coal Combustion.

The weight of coal which can be burnt per square foot of grate area per hour under varying conditions of draught is approximately :—

Natural draught . . .	. 16 to 20 lbs.	Forced draught 2 ins. air pressure	45 to 50 lbs
Forced draught ½ in. air pressure	. 20 to 25 lbs.	,, 3 ins. ,,	. 55 to 60 lbs
,, 1 ,,	. 30 to 35 lbs.	,, 4 ins. ,,	. 60 to 70 lbs

With cylindrical boilers and water-tube boilers for cruisers and battleships the maximum combustion per square foot of grate rarely exceeds 40 lbs. when working with closed stokeholds and 30 lbs. under Howden's system of forced draught; with the express type of water-tube boiler as fitted in torpedo boats and torpedo boat destroyers the combustion varies from 60 to 80 lbs. of coal per square foot of grate.

Boiler Surfaces.

The heating surface and grate area for a required boiler is determined by the method of draught employed, whether natural or forced, the kind of coal used on account of the difference in caloritic values of different varieties of coal, and the type of engine to which steam is being supplied, quadruple expansion engines, for instance, requiring less boiler surface than compound engines on account of the greater economy in steam consumption per I.H.P. of the former.

Economy in coal consumption is obtained by working the boilers easily at low rates of evaporation. Where considerations of weight and space are of importance, as in naval and fast merchant vessels, the boilers are reduced in size, and forced draught is used to increase the rate of evaporation, with corresponding reduction in efficiency. In Howden forced draught the economiser effect of the air tubes in the uptakes increases the efficiency so that this system compares favourably with natural draught and is much superior to the closed stokehold system.

The following table gives the average H.P. developed per square foot of grate, and the ratio of heating surface to grate area of different types of boilers and average consumptions of coal for various types of engines.

TABLE SHOWING PARTICULARS OF BOILERS OF VARIOUS TYPES OF STEAMSHIPS.

Type of Ship.	Type of Engine.	Type of Boiler.	Draught.	Coal per H.P. per Hour in Lbs.	H.P. per sq. foot of Grate.	Ratio Heating Surf. Grate Area.
Merchant	Compound	Cylindrical	Natural	2·0 to 2·3	8 to 7	30 to 25
"	Triple	"	"	1·6 " 1·8	10 " 9	35 " 30
"	"	"	Howden	1·5 " 1·7	15 " 13·5	40
"	Quadruple	"	Natural	1·5 " 1·6	11 " 10	35 to 32
"	"	"	Howden	1·45 " 1·55	16·5 " 15	40
"	Combination	"	Natural	1·3 " 1·4	12·5 " 11·5	35 to 32
"	"	"	Howden	1·25 " 1·35	17·5 " 16·5	40
Fast Passenger and Mail Steamers	4 Crank Triple	"	Closed Stokeholds	1·7 " 1·9	20 " 15	35 to 30
"	"	"	Howden	1·6 " 1·8	18 " 15	40 " 36
"	Quadruple	"	Closed Stokeholds	1·55 " 1·7	17 " 15·5	35 " 30
"	"	"	Howden	1·45 " 1·6	17 " 15·5	40 " 36
"	Turbine, Direct	"	Closed Stokeholds	1·4 " 1·6	19 " 16·5	35 " 30
"	"	"	Howden	1·3 " 1·5	19 " 16·5	40 " 36
"	Turbine Single Gear	"	Natural	1·35 " 1·45	12·5 " 11·5	35 " 32
"	"	"	Howden	1·3 " 1·4	17 " 15·5	40
"	Turbine Double Gear	"	Natural	1·3 " 1·4	13 " 12	35 to 32
"	"	"	Howden	1·25 " 1·35	17·5 " 16	40
Paddle	Compound	"	Natural	2·0 " 2·3	8 " 7	32 to 28
"	"	"	Howden	2·0 " 2·3	17 " 15	40 " 36
"	"	"	Closed Stokeholds	2·2 " 2·5	14·0 " 11	32 " 27
Battleships and Cruisers	Turbine	Water Tube (Babcock-Wilcox)	Closed Stokeholds Moderate forced	1·3 " 1·45	16 " 14·5	35 " 33
"	"	Water Tube (Yarrow)	Closed Stokeholds	1·35 " 1·5	25 " 22·5	60 " 55
Torpedo Boat Destroyers	"	Water Tube (Express)	Closed Stokeholds	1·9 " 2·1	35 " 32	60 " 55
"	"	"	"	Oil fuel 1·0 " 1·1	H.P. per cub. foot of combust'n chamber 9 to 7·5	Heating Surf. cub. ft. of combust'n chamber 9 to 8

Draught.

The two systems of forced draught most commonly adopted are closed stokeholds and Howden's system (page 2111) with closed ashpits. In the former an air pressure is maintained in the boiler rooms by forcing in air with fans, all openings in the boiler room are closed down with doors, and air locks fitted for access purposes. With Howden's system the boiler room is open, no air locks being required, and the air is forced by fans over the surface of a nest of tubes situated in the uptakes, through which the products of combustion pass on the way to the funnel. The air is raised to a temperature of about 250°F. by contact with the hot tubes, and passes through passages on either side of the uptake into a reservoir surrounding the furnace fronts, from which reservoir the air is admitted to the furnaces by valves in the furnace fronts, at the sides and the top, to the ashpit and above the fire respectively. Valves are fitted to control the admission of air above and below the fires: these must be shut before opening the furnace door to fire the boiler, otherwise the flame would be blown out into the stokehold. The proper use of the top valve prevents excessive smoke without reducing the boiler efficiency or the amount of evaporation per lb. of coal. Special strips of twisted steel ribbon called 'retarders' are placed in each boiler tube, causing the hot gases traversing the tubes to take a spiral course and be retained longer in contact with the tubes than they otherwise would.

The latest type of furnace fronts has the side valves controlled by one handle, and is also fitted with a safety guard, so that the furnace doors can only be opened when the air valves are shut, thereby preventing the possibility of any flame coming back through furnace door when it is opened.

On account of the abstraction by the air of what would otherwise be waste heat passing up the funnel a considerable measure of increased boiler efficiency is attained compared with the closed stokehold system, and the uniform condition of furnace temperatures which Howden's system ensures tends to reduce the wear and tear of the boiler.

A more uniform efficiency of furnace can be maintained with forced draught and it may be readily controlled to suit any desired rate of combustion, being quite independent in this respect of prevailing atmospheric conditions.

The Howden-Ljungström Air Preheater.

One of the most important inventions for the reduction of fuel consumption is the air preheater, which may be considered as a development of the Howden air-tube box. By this means 70 per cent. of the heat in the waste gases from the boiler can be recovered, so that a very considerable increase in efficiency is obtained without the disadvantages of excessive weight or corrosion as in the case of feed-water heaters.

The principle involved is exceedingly simple and effective. Briefly described, a large transmission surface is assembled in a rotating part in such a way that the elements are alternately traversed by the waste gases from the boiler and by the cold air to be used for combustion. The gases give up their heat to the elements, and, as these move round into the current of cold air, the heat previously absorbed from the gases is given up to the air. The process is continuous.

In actual construction, the elements consist of thin plates of metal placed close together and corrugated in order to obtain a very large surface. They are fixed in a rotor in such a way that the passages for the gas and the air between the places are parallel with the axis of rotation. The rotor is supported upon disc rollers fixed in a stationary envelope or casing, so that the power required to drive it is very small.

The casing is provided with inlets and outlets for the gases and for the air, which are separated from each other by diametral partitions above and below the rotor. In the upper section of the casing two fans are provided, one to force the cold air through the elements which are at the moment travelling through the air side of the heater, and the other fan to suck the gases through the elements on the gas side. The two fans are mounted on one shaft which passes through the upper partition and which can be driven by an electric motor or in any convenient way, the motor drive being taken by suitable gearing.

A most important feature of the heater is the ease with which the surfaces of the elements can be kept clean. A radial pipe with steam jets is fitted below the rotor, on the gas side, and steam is discharged while the rotor is revolving, so that every portion of the elements must pass through the jets, and no part of the surface can escape the scouring action of the steam. Every particle of soot is blown away, and the efficiency of heat transmission is thus maintained constant. It is necessary to operate the jets for fifteen seconds only every few hours, so that the consumption of steam for this purpose is negligible.

Fig. 25 shows the arrangement of the air pre-heater with two cylindrical boilers, but it is also suitable for using with water tube boilers and furnaces of various types.

An arrangement in which the axis of the preheater rotor is horizontal and separate centrifugal fans are fitted has now been introduced as an alternative. In this case the fans may be situated remote from the preheater, possibly in the engine room or in a separate fan room as circumstances may decide.

The Howden Cellular Air Heater.

(Patent.)

The cellular air heater embodies all the features of the tubular air heater with the following additional advantages:—

1. The heating surface for similar space occupied is approximately double that of a tubular heater.

THE HOWDEN-LJUNGSTRÖM PATENT AIR PREHEATER.

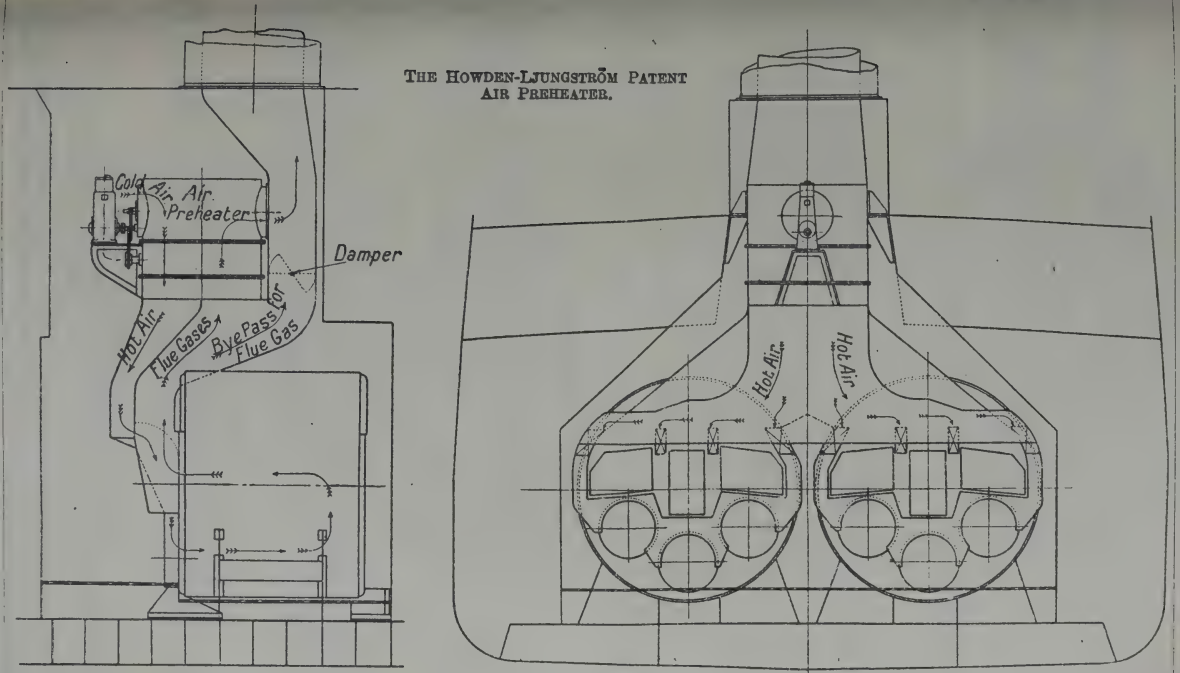


FIG. 25.

2. The gases and air travel substantially in a contra-flow direction.

3. Due to 1 and 2, a higher transfer of heat from the flue gases is obtained.

The heating elements or cells are made of mild steel plate. Each element is carefully manufactured and gauged before assembling. Special precaution is taken to prevent warping of plates and each cell is made truly parallel.

The guide vanes in the air passages are so arranged to divide the incoming air into an equal number of streams which flow directly opposite to the path of the gases on the opposite sides of the elements. These guide vanes are made of steel strips hung on to ferrules secured to the heating elements. The vanes are designed to give the air a turbulent flow. By distributing the air equally over the surface of the plates in the manner mentioned, it ensures that there can be no short circuit of air and thus avoids any part of the plate becoming overheated.

The complete heater when assembled consists of a number of portable sections securely bolted together and which can at any time be removed for repair if necessary.

Furnaces and Firebars.

If forced draught is employed it is not desirable to have firebars longer than 6 ft. on account of the tendency for large quantities of air to pass through the firebars if the fire should burn into holes. With Howden's system 5 ft. 6 ins. is the maximum length of firebar generally adopted. In naval practice with modern water-tube boilers working at full power under a moderate forced draught of 0·5 in. to 0·75 in. of air pressure, grate bars having a maximum length of 7 ft. are frequently employed; this, however, requires skilful firing, and extreme care to ensure the boiler efficiency being maintained at a maximum. For natural draught the length of grate bar should not exceed 6 ft. 6 ins., but increased boiler efficiency will be attained by using shorter bars, on account of the greater control over the fires. The diameter of furnaces for cylindrical boilers (figs. 26 and 27) should not be less than 32 ins., nor greater than 48 ins., and the number of furnaces which can be fitted in boilers of the following dimensions is :—

Boilers up to 9 ft. 0 ins. diameter	1 furnace	Boilers up to 15 ft. 6 ins. diameter	3 furnaces
„ „ „ 13 ft. 0 ins.	„ 2 furnaces	exceeding 15 ft. 6 ins.	„ 4 furnaces

The grate area of a cylindrical boiler is equal to :—Length of firebars × mean diameter of furnace × number of furnaces.

Length of Cylindrical Boilers.

The length of a cylindrical boiler is determined by the length of combustion chamber tubes or the furnace which is practically the same length as the tubes, the length of the combustion chamber and the water spaces at their backs. The combustion chamber measured horizontally should be as long as possible and usually is about 30 ins. in single-ended boilers and from 50 to 57 ins. in double-ended boilers. The water space between the back of the combustion chamber and the back end-plate of the boiler should be from 5 to 7 ins. at the bottom and wider at the top, the taper being about ½ in. per foot on the combustion chamber back.

Heating Surface.

The heating surface of cylindrical boilers consists of the external surface of the tubes, the length being measured between the tube plates, the surface of the furnaces above the firebar level, and the surface of the combustion chambers. The surface of the front tube plate on the boiler end, although in contact with the hot gases, is not usually reckoned as effective heating surface, and should not be included in the total heating surface of the boiler. The heating surface of a water-tube boiler is the total external surface of the tubes in contact with the fire and hot gases.

Diameter of Tubes for Cylindrical Boilers.

In forced-draught boilers the combustion chamber tubes are generally 2½ or 2¾ ins. diameter, and in natural-draught boilers the diameter is 3 ins. to 3½ ins., the increased sectional area being necessary to reduce the resistance to flow of the products of combustion.

Thickness of Cylindrical Boiler Shells.

The shell plates of cylindrical boilers must be of the following thickness to satisfy the requirements of the revised rules of the Board of Trade, Lloyd's, British Corporation, and Bureau Veritas.

The thicknesses shown assume the steel to have a minimum ultimate tensile strength of 28 tons per sq. in., and the longitudinal joint to have double butt straps with an efficiency of riveting equal to 84 per cent.

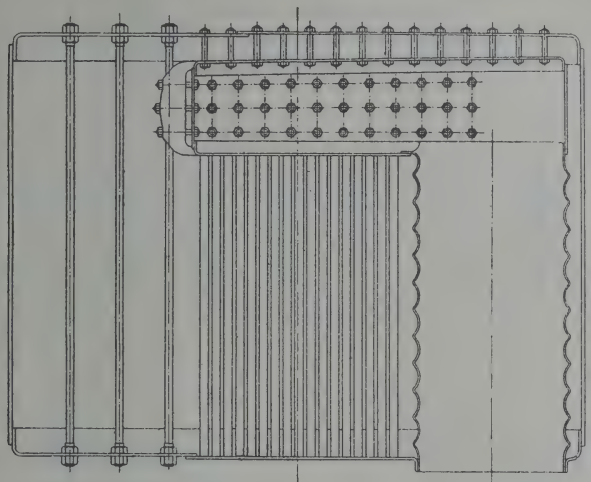


Fig. 27.

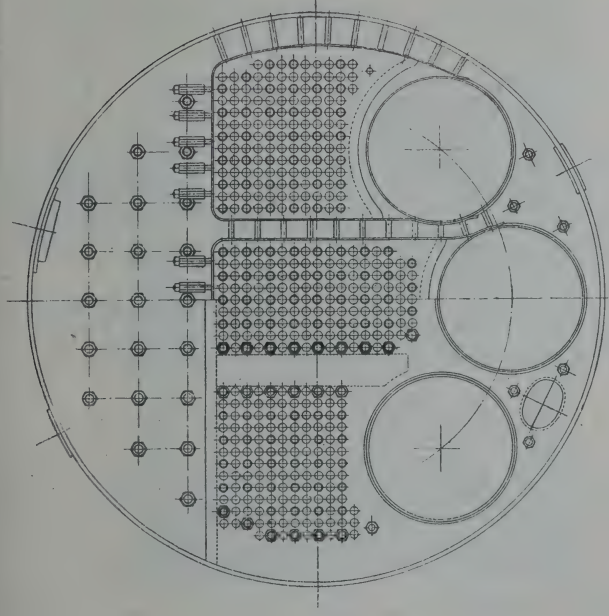


Fig. 26.

THICKNESS OF SHELL PLATES IN INCHES.

Internal Diameter.	Working Pressure, lbs. per Sq. In.							
	220	210	200	190	180	170	160	150
10 feet	1·027	0·983	0·940	0·896	0·852	0·808	0·765	0·721
11 „	1·124	1·076	1·028	0·980	0·931	0·883	0·835	0·787
12 „	1·220	1·168	1·115	1·063	1·010	0·958	0·905	0·853
13 „	1·316	1·260	1·203	1·146	1·089	1·023	0·975	0·918
14 „	1·413	1·352	1·291	1·229	1·167	1·106	1·045	0·984
15 „	1·509	1·444	1·378	1·312	1·246	1·181	1·116	1·050
16 „	1·606	1·536	1·466	1·396	1·326	1·255	1·186	1·116
17 „	1·703	1·629	1·554	1·479	1·404	1·330	1·256	1·182

WATER-TUBE BOILERS.

Water-tube boilers are divided into two distinct classes, viz. :—Large-tube boilers as fitted in merchant vessels, and small-tube boilers as fitted in cruisers, battleships, torpedo boat destroyers, and launches.

The principal advantages of water-tube boilers as compared with cylindrical boilers are :—

(1) Ability to use higher steam pressures (above 250 lbs.).

(2) Rapidity with which steam can be raised.

(3) Capability to endure forcing to a great extent.

(4) Reduced weight.

(5) Reduced space occupied.

The large-tube boilers are of the Babcock & Wilcox type (fig. 28) and the Yarrow type, both of which have straight tubes, the former varying from 4 in. to $1\frac{1}{16}$ in. outside diameter, according to requirements, and the latter $1\frac{3}{4}$ in. diameter. The tubes in the Babcock & Wilcox boiler are expanded into front and rear headers, which are sinuous in form and constructed of forged steel. Opposite each tube in the headers handholes are fitted, giving access for expanding, cleaning and renewal when necessary. The front headers are connected at the top by short tube nipples to the steam drum, and by similar nipples at the bottom to the mud drum. Return tubes about 4 ins. diameter connect the rear headers to the steam space in the steam drum.

The Yarrow large-tube boiler is a development of the Yarrow express type, and is very similar in design and construction. It consists essentially of a central upper steam drum, and two smaller water drums, the latter being situated about the level of the firebars. The generating tubes are expanded into the steam drum and each of the water drums, a manhole being fitted in the front end of each drum for access when expanding or cleaning of the tubes is necessary.

WATER-TUBE BOILERS—EXPRESS TYPE.

The small tube or express type of water-tube boilers principally adopted in British naval practice are the Yarrow, the White Foster, and the Thornycroft type (fig. 29). The tubes of all these boilers are from 1 in. to $1\frac{1}{2}$ in. external diameter, and generally the two rows next the fire are at least $\frac{1}{8}$ in. larger in diameter and one wire gauge thicker.

The White Foster boiler has a similar arrangement of drums, casings, and furnace to that of the Yarrow type. The tubes, however, are bent in such a way that any one can be withdrawn and received through the manholes in the upper steam drum when required.

The modern Thornycroft boilers have one upper steam drum and two lower water drums, and are suitable for burning oil and coal, separately or combined.

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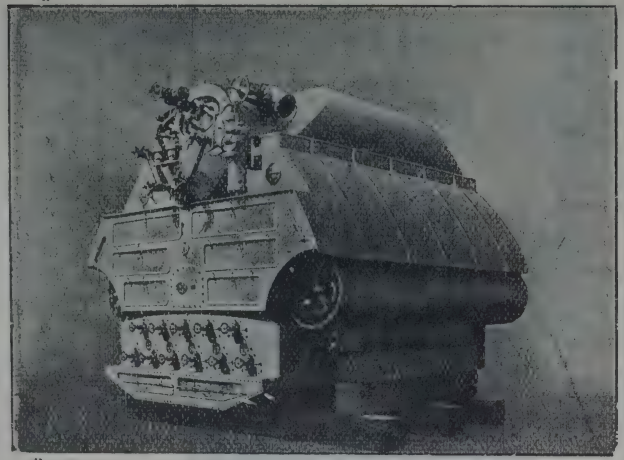

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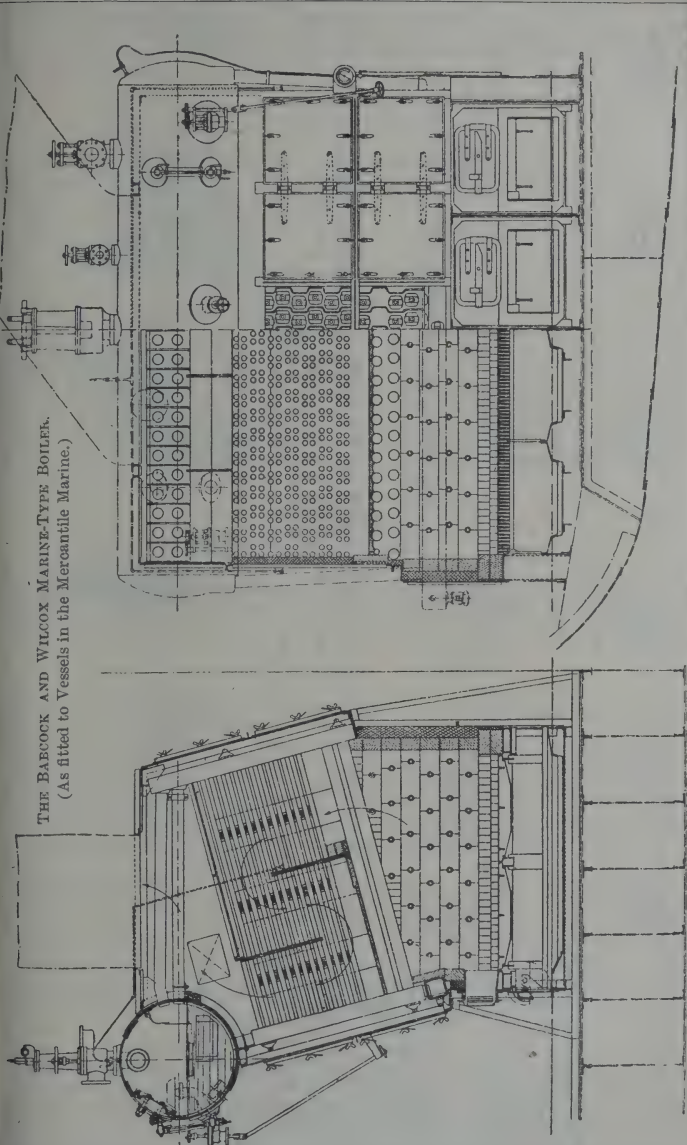


THE BABCOCK AND WILCOX MARINE-TYPE BOILER.
(As fitted to Vessels in the Mercantile Marine.)

FIG. 28.

COMPARATIVE SIZES, WEIGHTS, AND SPACES OF CYLINDRICAL AND BABCOCK AND WILCOX BOILERS.

Type of Ship.	Intermediate Passenger Steamer.		Large Cargo Liner.		Large Combined Passenger and Cargo Liner.		Large Intermediate Atlantic Liner.			Large Fast Atlantic Liner.			Large Fast Atlantic Liner.	
Estimated steam production per hour from feed at 150°F. 200 lb.	75,000		112,500		140,000		240,000			750,000			1,000,000	
Estimated steam per i.h.p. per hour for all purposes	15		15		14		15			15			14·3	
Equivalent horse-power	5,000		7,500		10,000		16,000			50,000			70,000	
Type of boiler	Cylindrical	Babcock	Cylindrical	Babcock	Cylindrical	Babcock	Cylindrical	Babcock		Cylindrical	Babcock	Babcock alternative	Cylindrical	Babcock
Heating surface, sq. ft.	13,300	16,370	21,750	25,850	26,500	32,515	52,150	57,810	66,200	146,000	188,510	164,650	158,350	221,544
Grate area, sq. ft.	335	450	530	650	700	900	1,400	1,600	1,800	4,000	5,170	4,480	4,050	5,474
Approximate weight of boilers and water, and all mountings and fittings, but no funnels or uptakes, or stoke-hold accessories, tons	420	195	585	282	780	380	1,320	672	825	4,200	2,360	2,085	4,750	2,615
Draught	Howden	Assisted	Assisted	Assisted	Howden	Assisted	Natural	Natural	Natural	Assisted	Assisted	Assisted	Howden	Assisted
Floor space occupied by boiler-rooms, sq. ft.	1,850	1,585	3,420	2,280	3,835	3,068	7,275	5,700	5,920	20,268	20,268	13,460	18,235	16,115
Fore and aft length of boiler-rooms and transverse bunkers	56 ft.	44 ft.	72 ft.	51 ft.	77 ft.	71 ft.	7 ft.	106 ft.	117 ft.	321 ft.	321 ft.	252 ft.	—	—
Increase of H.S., per cent.	—	23·0	—	19·0	—	22·5	—	10·81	26·9	—	29·0	12·8	—	39·9
Increase of G.A., per cent.	—	34·3	—	22·5	—	28·5	—	14·3	28·6	—	29·15	12·0	—	35·3
Saving in weight, tons	—	225	—	303	—	400	—	648	495	—	1,840	2,165	—	2,135
Saving in floor space, per cent.	—	41·33	—	Entire forward stoke-hold	—	20 per cent. and longitudinal bulkheads now fitted 6 ft. 6 in. from sides	—	Entire forward stoke-hold	10 ft. saving in length and longitudinal bulkheads 7 ft. in from side adopted	—	Existing spaces used to instal much larger boilers	Longitudinal bulkheads installed	—	11·63
Saving in fore and aft length	—	12 ft.	—	About 27 ft.	—	6 ft.	—	21 ft.	—	—	—	69 ft.	—	53 ft.

The tubes are straight except for a slight curve at the lower end where they enter the water rums. The tubes can be inspected throughout the whole of their length by holding a light in the)wer barrel. The lower water pockets being cylindrical can be made of solid drawn steel,

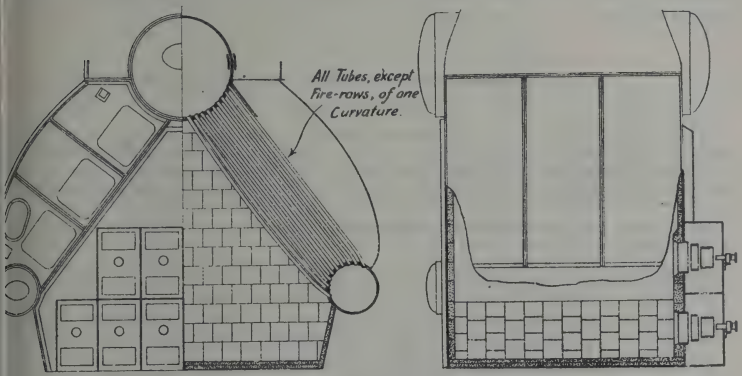


FIG. 29.

The Thornycroft Boiler.
(*Oil fuel Burning.*)

us eliminating possibilities of leakage and also making a lighter and stronger construction. The bes of any one diameter are all curved to the same radius, so that any tube will do for either w, which greatly simplifies the spares. This also allows of the lower drums being made smaller, us saving weight.

THE YARROW WATER-TUBE BOILER WITH SUPERHEATER.

Figs. 30, 31 (page 2393) show this boiler, which consists of a top steam collector, as usual, and o lower water pockets. On the left-hand side is the superheater, and on this side of the boiler ere are fewer rows of generator tubes than on the other side, where there is no superheater, it being ought desirable that the total heating surface and the resistance to the gases on both sides the boiler should be approximately the same. In one of these boilers with a total heating rface of 6,700 sq. ft., 1,265 sq. ft. consisted of superheating surface; the total heating surface the superheater side of the boiler being 3,453 sq. ft., and on the other side 3,247 sq. ft.

The superheater consists of a number of U tubes expanded into two longitudinal collectors, ıall doors being fitted so that access can be obtained to the tubes when required. The leading ature of the arrangement is that the superheater is placed on one side of the boiler only, and a mper is fitted in the up-take on the same side. If this damper is closed the whole of the gases e deflected towards the opposite side of the boiler, and no heated gases pass the superheater, e object being that if the main engines should be suddenly eased or stopped, or when raising eam, the superheater may be shut off, so as to prevent the tubes being damaged, or the steam ing superheated to an excessive extent, owing to there not being sufficient circulation of steam. this way one objection to the introduction of superheating for marine installations is overcome.

A further advantage of the arrangement is that, when the consumption of steam is suddenly duced or stopped, not only does the damper prevent the superheater tubes from being burnt, t it also greatly diminishes the output of the boiler at the time when a reduced supply of steam wanted, because only about one-half of the heating surface comes into contact with the hot gases.) avoid the possibility of the damper getting distorted through over-heating, it is provided with hollow spindle, to whch air is admitted and which passes from thence between the two plates the damper, escaping at the edge, and thus keeping the damper cool. This arrangement of mper has proved thoroughly successful under the most trying conditions.

At the maximum rate of evaporation with the damper open, namely, when burning 1·237 lb. of oil per square foot of heating surface per hour, the degree of superheat was 93·5° F.; 14·6 lbs. of water were evaporated per lb. of oil per hour, with a steam pressure of 242 lbs.

The results of other experiments indicate that in a properly designed boiler of the type described, it is possible to burn, without injury to the boiler, 2 lbs. of oil per square foot of heating surface per hour.

The Clarke-Chapman Marine Water-Tube Boiler.

(Woodeson's Patent.)

The 'Woodeson' patent marine water-tube boiler, as shown by fig. 32 (page 2394), is manufactured by Messrs. Clarke, Chapman & Co. Ltd., Gateshead-on-Tyne, and consists of two sections, each comprising steam drum, water drum, and a number of groups of tubes expanded into same; these tubes are nearly vertical and perfectly straight, and manholes are arranged on steam drums immediately over each group through which any tube can be withdrawn.

The bottom drums are absolutely hanging so that expansion and contraction can take place without causing any damage to the boiler.

In the design of the 'Woodeson' boiler, a special feature is the ease of access for purposes of examination or repairs, the time which has to be expended on the same being practically reduced to a minimum; thus in a boiler of say 6,100 square feet of heating surface, containing 456 tubes, the only work to be done to thoroughly examine the insides of this large number of tubes for their total length is the removal of the manhole doors on one end of each bottom drum, and one manhole door off each of the three steam drums: thus access can be gained to every tube, and these being perfectly straight they can be thoroughly examined for the whole of their length. The removing and replacing of the manhole doors can be done by an ordinary fireman, no skilled mechanic or complicated tools being required. There is an entire absence of screwed joints in the boiler.

Each tube being nearly vertical and perfectly straight and entering the steam drum direct without intervention of any headers, ensures a perfect steam release, and so adds to the efficiency of the boiler, as there are no sharp turns to retard the flow of the steam globules to the steam space. Also, deposits are not retained in the tubes, but are collected in the large mud-drums thus over-heating and destruction of tubes are reduced to a minimum.

The superheater consists of a number of mild-steel tube boxes, into which are expanded the tubes, which are bent to L shape and belled out.

The superheaters are provided with the necessary fittings, including specially designed by-pass valve for regulating the degree of superheat, also a large drain valve in the lowest part of the superheater for draining.

The Niclausse Boiler.

This boiler is principally adopted by the French Navy, though it is used by 15 other navies there being now upwards of 2,000,000 h.p. afloat in the Naval and the Mercantile Marine Services.

Fig. 33 (page 2395) shows the most modern design of this type of boiler, as applied to a large French cruiser of 35,000 h.p. It is the high duty type referred to in the 'Engineer' of March 13 1914, and the Institution of Mechanical Engineers' Journal of July 1914.

The tubes are either 84 or 60 mm. diameter and the boiler is therefore of the large tube type but the characteristic feature of the Niclausse inner tube gives it all the advantages of the small tube type. Its special features comprise a considerable saving of space and deadweight, and in respect of the former it will be noticed that the boilers can be located back to back and adjacent to each other, all access being entirely from the front.

Marine boilers of this type are fired by either oil or coal, or both, and excellent results are claimed by the makers, who lay more stress on average than on test efficiencies. Other features are great flexibility and overload, the cleaning facilities provided, and the ability to quickly effect the withdrawal and replacement of defective tubes, which can be done within an hour from time of stop to restart under full steaming power.

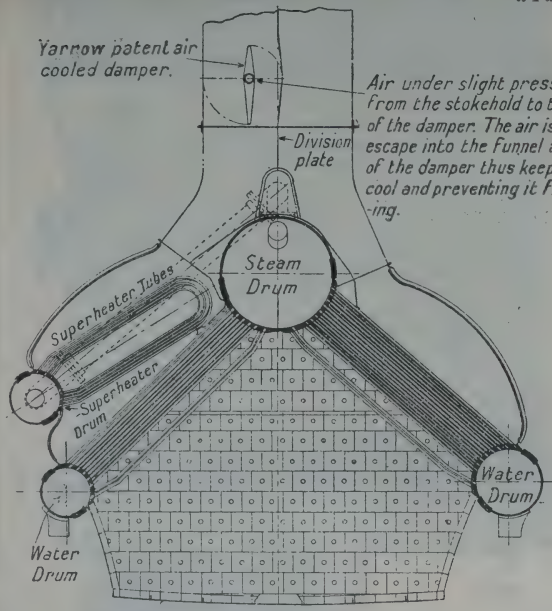
The Standard Water-Tube Boilers adopted for the United States Emergency Wooden Steamships are described and illustrated (from *International Marine Engineering*) in 'Engineering' Nov. 9, 1917.

Waste Heat Boilers.

See p. 2184.

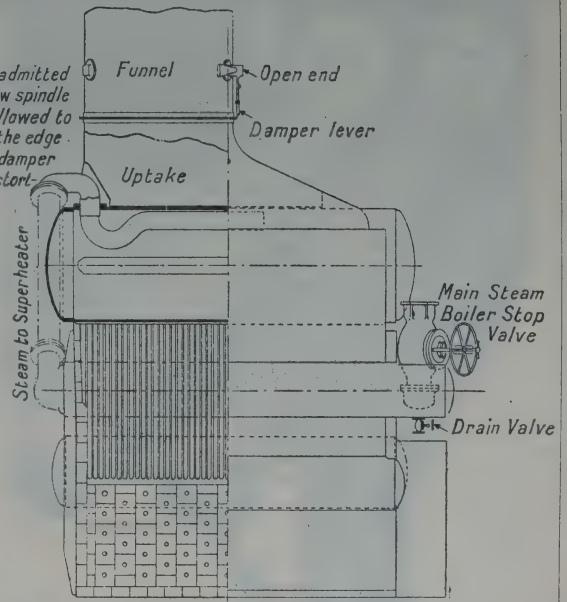
THE YARROW PATENT WATER-TUBE BOILER WITH SUPERHEATER AND CONTROL DAMPER.

il Fuel Burning.)



Transverse Sectional Elevation.

FIG. 30.

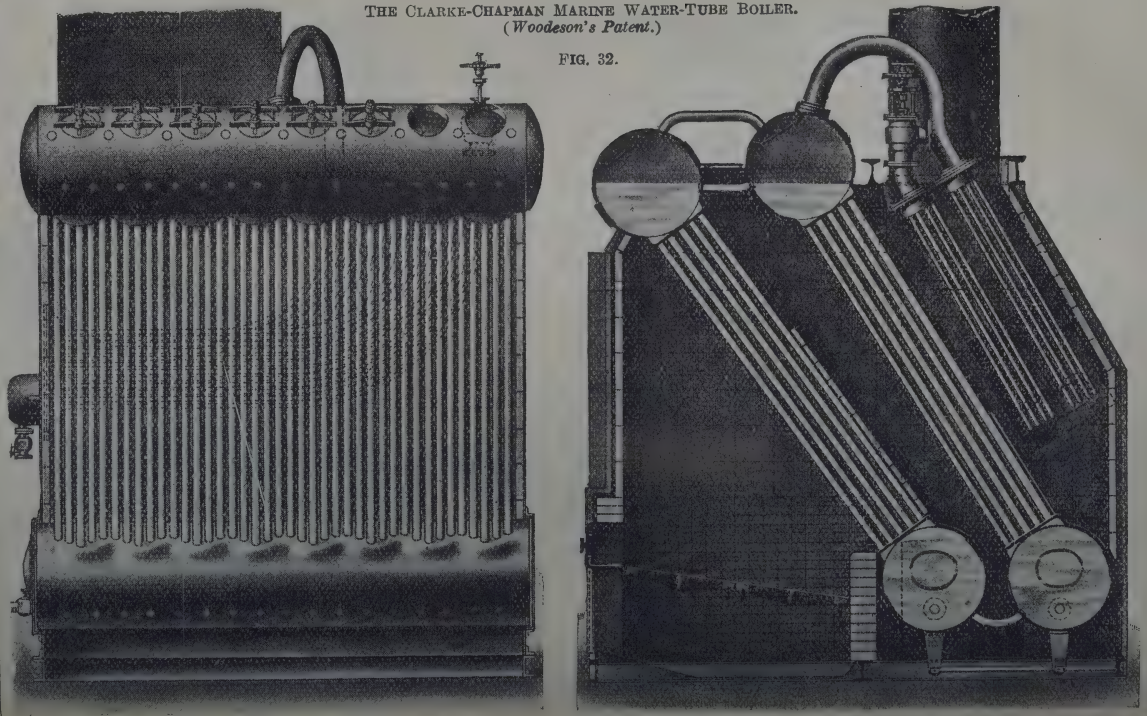


Half Side Section. Half Side Elevation.

FIG. 31.

THE CLARKE-CHAPMAN MARINE WATER-TUBE BOILER.
(Woodeson's Patent.)

FIG. 32.



THE NICLAUSSE BOILER.

FIG. 33.

Life of Marine Boilers.

The life of a marine boiler depends to a certain extent on the care and attention bestowed on it during the first few months of its existence, provided that the plates have been properly treated at the building of the boiler—that is, all mill scale removed and the plates kept dry and free from atmospheric corrosion. The mill scale, if not removed, has a very irritant action on the clean metal of the boiler, and is most hurtful to the plates if allowed to remain on them. The greatest care and attention is needed for the first period of working of new boilers to keep the new metal free from corrosion. It is advisable on the first voyage to put into the boilers, before closing them up, 5 lbs. of lime per 1,000 i.h.p., and afterwards for a period of about six days 2 lbs. of lime per day per 1,000 i.h.p. should be passed through the hotwell as milk of lime, and 1 lb. of lime per day per 1,000 i.h.p. during the remainder of the voyage.

Rules and Regulations with reference to Boilers of Steamships.

STANDARD CONDITIONS FOR THE DESIGN AND CONSTRUCTION OF MARINE BOILERS.

A set of rules has been framed and agreed to by representatives of the Board of Trade, Lloyd's Register of Shipping, the British Corporation for the Survey and Registry of Shipping, and the Bureau Véritas International Registry of Shipping, and recommended for favourable consideration and adoption. An abstract of these rules is given on pp. 1625–1633.

Boiler Casings.

The casings of both the Babcock & Wilcox and Yarrow boilers are constructed of light steel plates and angles, and designed to avoid distortion due to the high temperature of the gases with which they are in contact. In way of the furnaces the casings are lined with brickwork, other parts of the casings are lined with asbestos millboard or some other non-conductor, to prevent radiation of heat to the stokeholds. In the Babcock & Wilcox type of boiler, wide use is made of 'Cellinsulate,' a special form of non-conductor which possesses greater resistance to heat transmission per unit of weight than any other form of lagging.

MARINE SUPERHEATERS.

'M.L.S.' MARINE SUPERHEATERS.

(*The Superheater Company, Limited, London and Manchester; 'Schmidt' and 'Robinson' Patents.*)

The types of superheaters manufactured for marine boilers consist in principle of a series of loops or elements of solid cold-drawn steel tubing inserted in the smoke tubes of the cylindrical

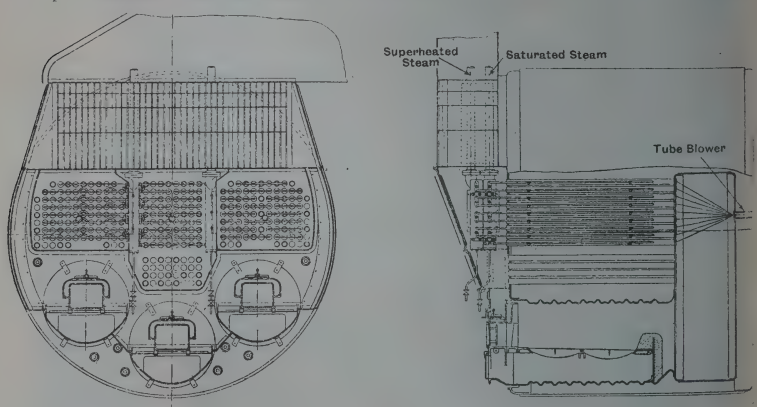
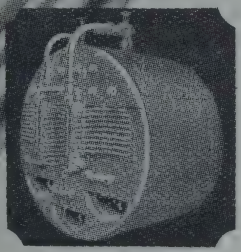


FIG. 34.—Three-Furnace Boiler, Forced Draught, with 'M.L.S.' Superheater.

boiler and connected to suitable headers or collectors placed vertically in front of the boiler between the nests of smoke tubes. The saturated steam from the boiler stop valve enters the saturate

The M.L.S. Superheater



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WATER TUBE BOILERS
55FT MOTOR CRUISER
COASTAL MOTOR BOAT
MOTOR VAN
MOTOR OMNIBUS

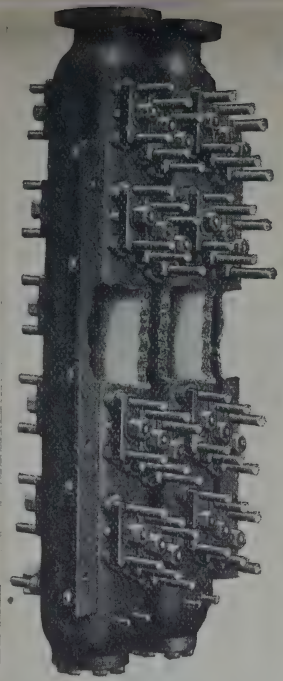


FIG. 35.—'M.L.S.' Forged Steel Header, Type 'S.'

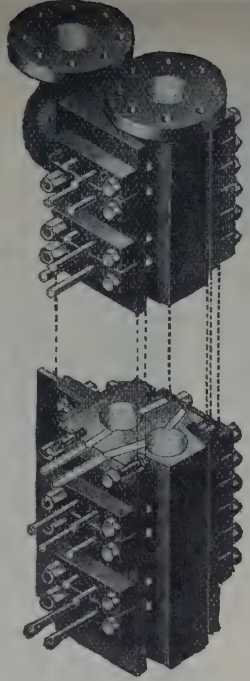


FIG. 36.—'M.L.S.' Solid Steel Header, Type 'RB.'

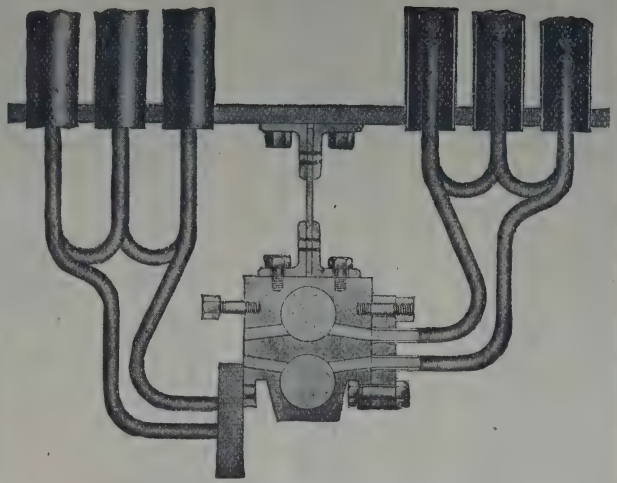


FIG. 37.—'M.L.S.' Element Attachment, Type 'RB.

steam header, the steam circulates through the elements and returns superheated to the super heated steam collector, and thence to the prime mover. The elements are, therefore, in the direc path of the gases flowing from combustion chamber of boiler to smoke-box. (See fig. 34, p. 2396.

The elements are made from solid cold-drawn steel tubing, and the return bends are made b the 'M.L.S.' Integral Machine Forged Return Bend Process, by which these bends are mad integral with the tubing itself and electric or oxy-acetylene welding avoided, thereby prolongin the life of the element and providing a clean, smooth surface, both internally and externally.

'M.L.S.' Superheater, Type 'S.'

In this type of superheater the headers or collectors, fig. 35, are pressed steel forgings; the are of plain rectangular design, with a minimum wall thickness of one inch (1"), homogenou throughout, and of uniform smooth internal and external finish, free from scale or other impurity

The saturated and superheated collectors are entirely separate; they are attached to th partition plate of the boiler smoke-box by means of angle irons.

Fig. 38 shows the method employed for attaching the superheater element ends to the heade Collars are expanded on the element ends, and these collars fit into machined recesses in th headers, where a steam-tight joint is made with a jointing ring. The collars are held in plac by a drop-forged clamp or dog, each dog securing two collars. This arrangement provides fo accessibility and easy withdrawal of elements, at the same time making a perfectly steam-tigh joint.

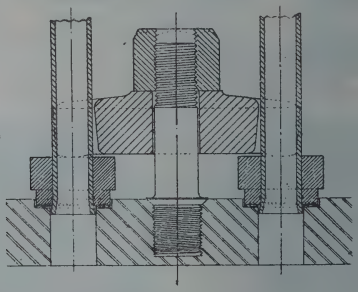


Fig. 38.—'M.L.S.' Element Attachment, Type 'S.'

'M.L.S.' Superheater, Type 'RB.'

In this design the arrangment of the superheater is similar to that previously described, bu the single superheater header embodies two longitudinal passages, one for saturated and th other for superheated steam. The header, fig. 36, is made from one solid mild steel billet, th two chambers being bored longitudinally therein; a cast steel elbow is fitted on the back an connected with one of the chambers, this elbow being for the attachment of the saturated steam pipes.

A flange is also welded on to the header to take the superheated steam-pipe outlet.

The superheater elements are expanded into flat steel flanges, fig. 37, and the sides of the and of the headers are carefully machined, so as to provide a very efficient joint.

The flanges are provided with a bolt hole at the front and a slot at the rear, and are secured to the header by a stud and bolt in such a manner that by removal of the bolt at the front and slackening the nut of the stud the elements can be easily slid in or out of position.

The elements are again made with return bends integral with the tubing itself, by the 'M.L.S.' Integral Machine Forged Return Bend Process.

'M.L.S.' Superheater, Type 'RX.'

This arrangement of superheater is similar to type 'S,' but the superheater headers are so designed that the ends of the superheater elements are expanded directly therein.

The headers are made in steel castings having transverse saturated and superheated compartments. Front openings are provided for internal examination and to allow for the expanding in and driving out the superheater elements from the side walls of the header; these front openings are closed by mild steel cover plates.

The integral superheater elements are made with return bends integral with the tubing itself, by the 'M.L.S.' Patent Machine Forged Return Bend Process.

The 'North Eastern' Superheater.

This superheater is specially designed for the Scotch (or cylindrical) type of boiler, this type being the universally adopted boiler for the mercantile marine.

The superheater, fig. 39, consists of headers arranged in pairs between the nests of boiler tubes.

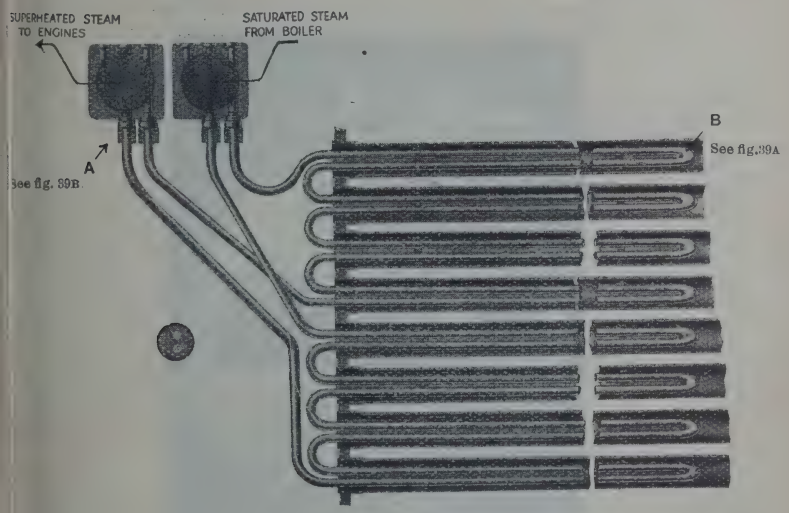


Fig. 39.—The 'North Eastern' Superheater.

These headers, which are fitted in the smoke box and attached to the boiler end, comprise saturated steam headers and superheated steam headers, the saturated being connected by pipes to the boiler stop valve, and the superheated by pipes, so as to deliver superheated steam to the engines.

THE 'NORTH EASTERN' SUPERHEATER.

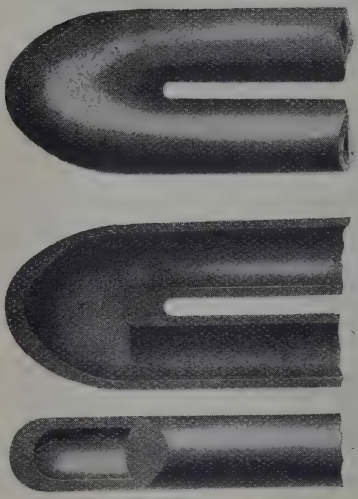


FIG. 39A.

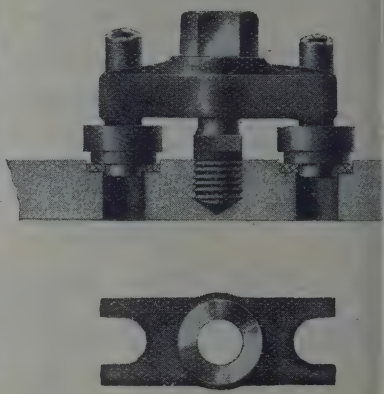


FIG. 39B.

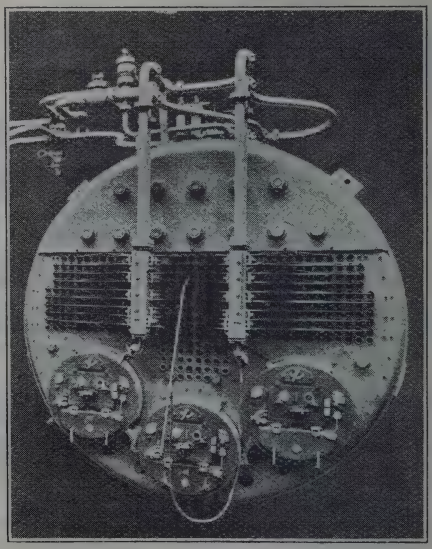


FIG. 39C.

The superheater tubes, or elements, are connected between the saturated and superheated headers and consist of a series of small steel tubes of ' U ' form carried into and out of the boiler tubes. A number of these ' U ' tubes, generally about four, are coupled in series between a saturated and its corresponding superheated steam header.

Where the ends of the elements project into the boiler tubes, and are subject to intense heat, the ends of each pair of tubes are fitted with a special steel cap, fig. 39A, welded to the tubes by oxy-acetylene welding. The end of the element where joining the header, fig. 39B, is fitted with a special form of joint, consisting of a collar fixed to the end of the tube, which collar fits into a recess in the header where a steam-tight joint is made with a jointing ring. The collars are held in place by means of special steel dogs or clamps, each clamp securing a pair of collars, and screwed down to the header by means of a stud and nut.

The general arrangement is shown by fig. 39C.

Oil Fuel.

The advantages of fuel oil as compared with coal are as follows :—

(1) Reduction in weight and space occupied by the boiler installation.

(2) Increased evaporation of water per lb. of fuel in the ratio of about 14 : 9 as compared with good quality coal.

(3) Utilisation of remote parts of the ship and of constricted spaces, such as the double bottoms, for stowage of fuel.

(4) Less manual labour and greater rapidity in stowage.

(5) No reduction in speed due to cleaning fires, difficulty in trimming coal from remote bunkers, or exhaustion of stokers.

(6) Reduced wages bill for boiler room staff, no trimmers, and comparatively few attendants for the burners being required.

(7) A prompt and effective control of the steam output due to the mechanical supply of the fuel, permitting of more rapid changes of speed than is the case with coal.

(8) Absence of smoke if air supply is properly controlled.

(9) No trouble due to accumulation of ashes ; ash expellers or ejectors are dispensed with.

(10) In the case of naval vessels, fueling can readily be carried on at sea.

Both water-tube and cylindrical boilers are now adapted for burning oil fuel, the direct-pressure system being the one most generally in use for naval and mercantile service.

Pressure pumps fitted in the boiler rooms have suctions from the oil tanks, and discharge at a pressure of from 50 to 150 lbs. per sq. in. through cold filters having fine mesh wire gauze lids; from thence the oil passes through a tubular heater, the oil being inside the tubes and heating steam outside. The temperature of the oil is raised to about 150° Fah. in the heater, and before finally reaching the burner it is passed through a second, or so-called hot, filter.

It is necessary to heat the oil in order to reduce its viscosity so that it can be atomised and forced through the fine passages of the burner, which are so designed as to give it a rapid whirling effect due to centrifugal force when liberated through tangential passages at the lip of the burner, and thus reduce it to a fine spray of conical formation. The air supply to the burner passes through directing slots cut in a steel truncated cone, 12 to 15 ins. diameter and about 16 ins. long. The burner is fitted at the centre of the entrance to the cone, and the admixture of the air passing through the slots with the oil spray from the burner produces almost perfect combustion.

In the case of naval vessels the closed stokehold system is adopted, the air pressure in the boiler rooms being controlled to suit the output of the burners. For cylindrical boilers in merchant steamers the Wallsend-Howden system (page 2148) with open stokeholds is now in extensive use. The arrangement of burners and air cones is similar to that described above, but the air supply is heated by the waste gases, as in the ordinary Howden forced draught system (page 2111) applied to coal burning. Each burner can pass from 400 to 600 lbs. of oil per hour, and it is possible to burn about 13 lbs. per cubic foot of combustion chamber. The area of the furnace front limits the number of burners which can be fitted, and it is desirable that the volume of the combustion chamber should be as large as possible.

(See also pp. 2135, 2435.)

EVAPORATORS.

For Fresh Feed Make-up Water for Boilers.*

With the high pressures of steam (usually from 150 to 200 lbs. per square inch) now carried steam boilers for use with modern triple-expansion and other engines, it is found necessary to

* Also used in connection with distilling condensers for producing fresh drinking water instead of the old way of distilling from the donkey boiler.

provide fresh feed-water for the make-up, in order to prevent the great deposit of scale on the heating surfaces which results from these high temperatures.

The quantity of auxiliary feed-water required amounts to from 1 to 5 tons per 24 hours per 1,000 h.p.

To provide this, evaporators have come into general use.

In these evaporators the sea water is boiled by the heat from steam passing through tubes

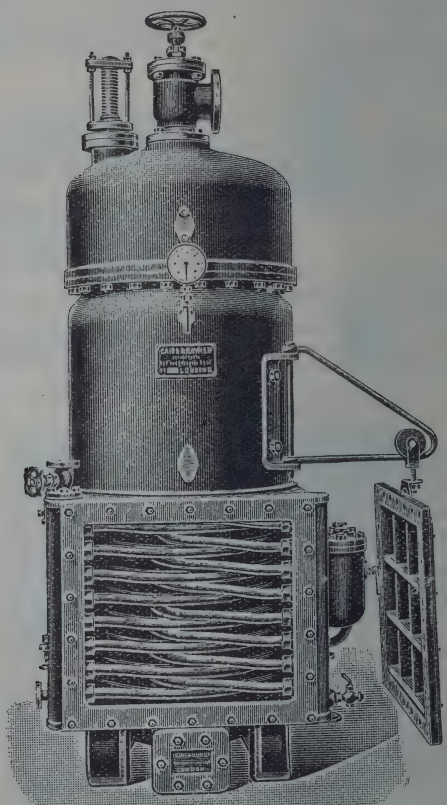


FIG. 39D.

immersed in the salt water. The condensed steam from these tubes is usually drained back t the condenser or hot-well, and so back to the boiler, and the secondary steam produced from th sea water is led to the main condenser, and is there condensed along with the exhaust steam fro the engines, and thus delivered to the boiler as fresh feed-water.

The scale formerly left in the boilers is deposited in the evaporators, which are arranged so a to be easily cleaned when necessary.

The Caird and Rayner Automatic Evaporator.

(Caird & Rayner, Commercial Road, London.)

In this evaporator, shown in general view by fig. 39D, page 2402, live steam is led from the boilers through a series of coils of solid-drawn copper-tube. Sea water being admitted to surround the coils, and automatically maintained at a constant level, is by the heat of the steam within them converted into vapour, which rises to the upper part of the evaporator, and is led hence to the condenser, where, mingling with the condensed steam from the engines, it provides the required auxiliary feed in the form of distilled water, which is pumped into the boilers by the ordinary feed pump.

The form of the heating coils is a very special feature of this evaporator, as by this their self-cleaning property is secured. The helical form gives them greater elasticity, as they expand and contract with the varying temperatures to which they are subjected in working, and especially so each time the brine is blown out and a fresh charge of cooler water admitted. This action causes the scale, which is naturally deposited on the coils, to be thrown off from time to time, and fall to the bottom of the evaporator, from which it is easily removed. This self-cleaning property of the coils, by which the heating surface is kept practically clean, secures the continued efficiency of the evaporator. The ends of the coils are connected to pockets on each side close to the front of the evaporator, so that the door can be removed, and all the joints that are subjected to primary steam pressure can be tested in full view. The pockets have suitable divisions cast in them to regulate the flow of steam through the coils suitable for the pressure of steam to be used.

An automatic feed ensures that the level of the water to be evaporated is maintained at a constant level, and also that it shall be impossible that, through any accidental neglect or carelessness, the sea water can accumulate so as to fill the evaporator and pass over into the condenser.

A series of baffle plates, specially arranged in the upper part of the shell, ensures that no priming shall take place.

In ships where there are many auxiliary engines at work, the exhaust steam from them is economically used in these evaporators on a system patented by Caird and Rayner, which has been adopted by the British Admiralty in their ships.

The exhaust steam is maintained at a pressure of about 25 lbs. by a loaded valve on the main exhaust pipe, so that any excess over that pressure can pass direct to the auxiliary condenser.

By this arrangement distilled water is obtained without any expenditure of fuel whatever.

The evaporators are usually worked under a vacuum into the auxiliary condenser, the degree of vacuum in the evaporator being regulated by a specially-designed control valve.

The evaporators will produce from 1 up to 100 tons of fresh water per 24 hours, according to size.

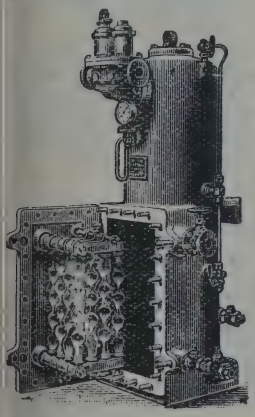


FIG. 40.—The Row Evaporator.

The Row Evaporator.

In the Row Patent Evaporator (*Royles, Ltd., Irlam, near Manchester*), the peculiar indented tube is a distinctive element in its construction. It is found that this form of tube surface casts its scale very readily and is otherwise highly efficient as an evaporating surface. Fig. 40 shows one of these evaporators open for cleaning. All the tubes are erected upon the inside surface of the door so that when this latter is opened, which is done without breaking any pipe joints, all the tube surface is accessible for cleaning. The evaporator is fitted with the usual complement of fittings, and is very compact and efficient. It is made in seven sizes, to produce from 2½ to 30 tons per 24 hours.

The Weir Vertical Type Evaporator.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

This evaporator, fig. 41, is of the vertical type. The shell and dome are of the best close-grained cast iron. The heating surface is formed of heavy solid-drawn copper tubes attached to the inlet and outlet chambers by means of hollow conical couplings. The tube space is separated from the steam space by a deflector. The arrangement of this deflector allows the steam to rise, but

throws down the water so that it is returned again to the water space. With this arrangemen it is almost impossible to make the evaporator prime under anything like reasonable limits. Th usual mountings consist of steam inlet valve, vapour outlet valve, feed check valve, brine valve drain valve, and coupling to hot-well, blow-off cock, safety valve, gauge glass fittings, pressur gauge, compound gauge, salinometer valve, and gunmetal feed pump to work off the main engin levers.

Heating Tubes.—In the latest designs the heating tubes are arranged in elements, each element consisting of a single tube coil with special hollow couplings on inlet and outlet ends in the same plane. These hollow couplings pass through a steam chamber cast on the back or side of the evaporator, and are secured in place from the outside by means of a cap nut on the ends of each coupling. The outlet opening from the tubes is of smaller diameter than the inlet, with the exception of that in the lowest or drain tube, which is the same area throughout, and through which any steam passing through the smaller outlets from the tubes is again returned through the evaporator along with the water of condensation and drained to the hot-well. By this means the pressure in the stand-pipe chamber at the outlet end is always lower than in the chamber at the inlet end, and a constant current is kept up through all the tubes, thus preventing any accumulation of air and water.

Each element or tube can be taken out separately for cleaning, and in this way the cleaning can be more expeditiously and thoroughly done.

The arrangement also provides a means of keeping two or more elements as spares. These can be quickly substituted for elements requiring cleaning, and the evaporator set to work again while the dirty tubes are being scaled. The tube attachments are strong and substantially made, and are kept tight by screwing up from the outside against a strong shoulder on the inner portion of the coupling.

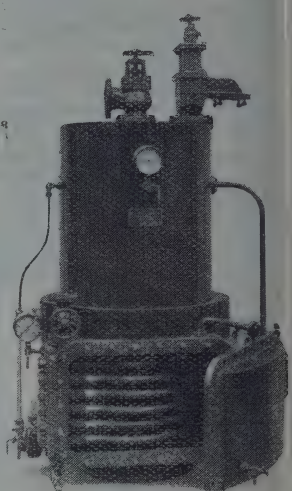


FIG. 41.

Automatic Feeding and Continuous Brining.—A water jet is so arranged as to induce the flow of brine from the evaporator and discharge the mixture overboard at any suitabl level. Sea water at a sufficient pressure is obtained by a connection from the sanitary tank, which is placed at a height sufficient to give the necessary head. As the evaporator feed is now usually obtained from the same source, to permit of automatic feeding through a feed regulator, an effective and simple combination is obtained whereby the minimum of piping i required and the feed and brining arrangements may be made integral with the evaporator.

Condensers and Water Heaters.

THE WEIR 'UNIFLUX' CONDENSER.

This design of condenser, introduced in 1909, has since become extensively adopted in thi country for naval and high-class merchant steamers, and the high vacua attainable by its adop tion when working in conjunction with the Weir 'Dual' type of combined wet and dry air pump has been an important factor in the improved efficiency of steam turbines.

The construction of the condenser introduces no novel features except as regards the pear shape of shell which has been designed with the object of causing the exhaust steam to flow ove the tubes at a uniform velocity without short circuiting, the steam inlet being arranged as fa from the air-pump suction as possible.

The 'Dual' air-pump is of the beam type having one steam cylinder and two pump barrels one pump for air and vapour and the other for water, air and vapour. Cold injection water i introduced at each stroke into the dry-air pump barrel to condense the vapour and cool the air and in order to avoid the expansion of the air present in the water filling the clearance space o the dry pump at the moment of discharge the dry-air pump is arranged to discharge below th head valves of the wet-air pumps.

The combination of improved design of air-pump and condenser in conjunction with an in creased supply of circulating water has resulted in a reduction of the condensing surface from 20 to 25 per cent. as compared with the condensing plant previously fitted.

THE WEIR DIRECT CONTACT FEED-WATER HEATER.

This system consists in taking a portion of the steam from the low-pressure receiver of the engine and utilising it to heat the feed water on its passage to the boiler. In actual practice on board ship, this steam is also supplemented by the exhaust from the auxiliary engines.

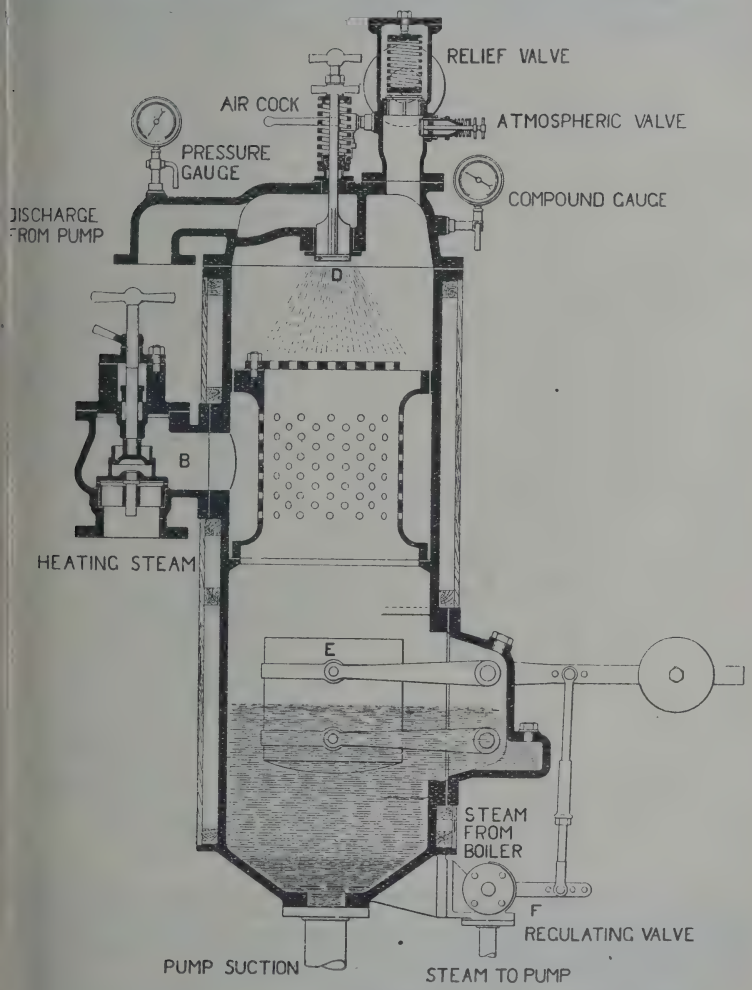


FIG. 41A.

Fig. 41A shows a sectional view of the heater. The heating steam is taken from the low-pressure casing of the main engine, and the exhaust of the auxiliary engines is also led into the heater through the non-return valve B on the side of the apparatus. A perforated cylindrical

waist piece forming an annular steam space round the heater, and surmounted by a conical spra
piece, also perforated, is fitted to ensure the uniform mixing of the steam and water. A Wei
direct-acting feed pump, or the main engine feed-pump, delivers the feed water into the heate
through the spring-loaded valve D on the cover. The feed water is forced through this valve in
thin sheet, and is instantly heated by contact with the steam. The water is further broken u
into fine spray by passing through the conical spray piece, thereby bringing the greatest possibl
surface into contact with the steam. As the pressure in the heater is generally much less tha
that of the entering water, the effect of this lowering of the pressure, and sudden heating of th

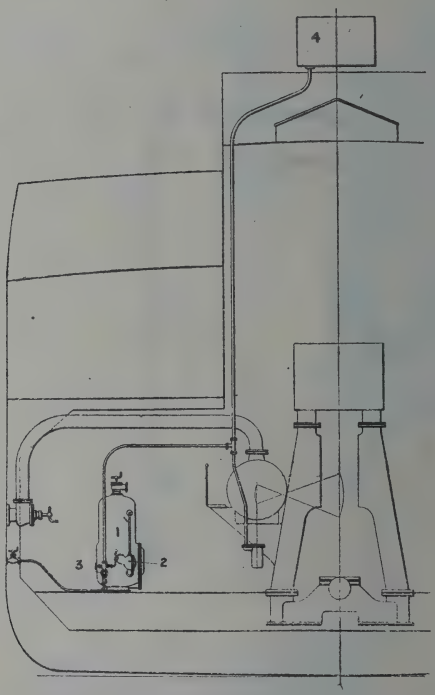


FIG. 42.—Arrangement on board ship of Evaporator with 'Weir' Feed Regulator and Brine Ejector.

1. Evaporator.
2. Feed Regulator.
3. Brine Ejector.
4. Sanitary Tank.

water, is to liberate the air in the water, and this is removed to the condenser, or to the atmospher
by a small cock K on the air vessel placed on the top of the heater. (In the case of twin-scre
vessels fitted with one feed heater, the lever cock on the heater air dome is coupled up to bot
condensers by a T piece.) The feed water is thus rendered non-corrosive, and falls to the botto
of the heater at the boiling temperature corresponding to the pressure.

The combination, fig. 42, of the automatic regulating gear with the heater is a special featu
of the Weir apparatus. The float E shown in the lower part of the heater is a pan, with wate
tight bottom and sides, but open on the top. It is suspended on two levers, so as to move up an
down with a parallel motion; the top lever spindle is carried through the door at one end, and
balanced by a lever and weight. The float is always full of water, and the weight is adjusted

balance when one-half is immersed in water. The weight lever is connected by a rod to another lever, which actuates the throttle valve F and controls the supply of steam to the pump drawing from the heater. When the water in the heater rises, the float is raised, and the throttle valve opened, and, when the water level is lowered, the float follows, and the valve is closed ; the level of the water is thus kept constant in the heater, and the pumps are completely filled with water.

When feed heaters are placed on the discharge side of the feed pump they are necessarily subjected to the boiler pressure, and must therefore be of a very substantial character. Such heaters are always of the surface type. Messrs. Weir have two special designs of heater of this class—the 'Multiflow' and the 'Uniflux.'

As affecting the engines, it is found that this system secures a fuel economy of from 5 to 8 per cent., according to the steam pressure carried, and the number of expansions in the engine.

The heater has been fitted by Messrs. G. & J. Weir Ltd. to over 4,000 vessels.

Air Pumps.

Paragon Air-Pump.

(G. & S. Weir, Ltd., Cathcart, Glasgow.)

This air-pump is a development of the well-known Dual Air-Pump, and is giving the same steadfast reliability in marine work that was characteristic of the Dual type of pump. It has been adopted by the leading steamship companies, and is shown in fig. 42A.

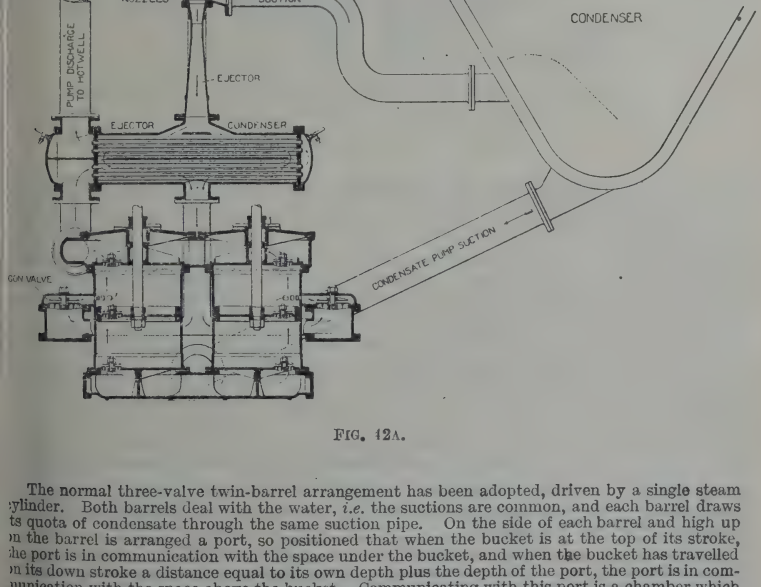


Fig. 42A.

The normal three-valve twin-barrel arrangement has been adopted, driven by a single steam cylinder. Both barrels deal with the water, *i.e.* the suctions are common, and each barrel draws its quota of condensate through the same suction pipe. On the side of each barrel and high up on the barrel is arranged a port, so positioned that when the bucket is at the top of its stroke, the port is in communication with the space under the bucket, and when the bucket has travelled on its down stroke a distance equal to its own depth plus the depth of the port, the port is in communication with the space above the bucket. Communicating with this port is a chamber which houses a non-return valve of a design similar to the pump valves. A branch pipe connects the two chambers with the augmentor condenser outlet. The augmentor condenser is of the tubular

type with brass tubes ferruled into brass tube plates. The augmentor is fitted to the top of the augmentor condenser, and discharges into same. The steam discharged by the augmentor is condensed on the outside of the tubes by the condensate, which is discharged through the tubes by the air-pump; the heat in the augmentor discharge therefore is conserved in the condensate, which results in the economy of the apparatus being good. The steam nozzles are of the convergent divergent type, similar to those fitted to the air ejector.

This pump is capable of maintaining the highest vacua, and has a large air handling capacity for the size of the pump.

Experiment has shown that on a 19 in. × 15 in. pump the fall in vacuum was only 0·4 in. Hg, when a ¼ in. diameter air leak nozzle was opened admitting air to the condenser.

Bearings.

The Michell Bearing.

Michell Bearings (thrust and journal) are largely used in modern marine practice, and are manufactured by Michell Bearings, Ltd., Newcastle-on-Tyne. There are in the British Navy alone ships aggregating over ten million horse-power fitted with main thrust blocks of this type,

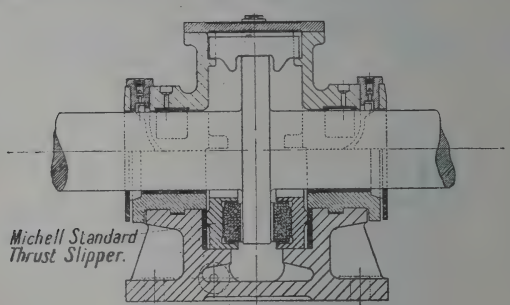


Fig. 43. Michell Slipper Type Thrust Bearing

and in passenger and merchant ships the Michell Thrust Block is commonly used, both for reciprocating engines and steam turbines.

A standard thrust block used for light craft of all kinds is shown in fig. 43. This is self-lubricating, and can be arranged upon an extension of the engine-bed or upon a separate seating immediately aft of the crankshaft coupling. The oil level in the thrust block is usually kept just above the under-side of the shaft. The bearing surfaces are lubricated by the thrust collar carrying oil upon its edge, and the oil is scraped from this by the scraper at top, thus giving a continuous cascade of oil on the pads. The pads are so pivoted that a film of oil is led into the space between pad and thrust collar, and this oil film can withstand a heavy pressure. A feature of the bearing is that as the speed increases, the pressure per square inch can be increased.

Michell thrust blocks have a single collar shaft with a series of pivoted pads arranged forward and aft, and it will be noticed from the illustration that the pads need only be in the bottom half of the bearing. Thrust blocks, however, can be designed to utilise an existing multi-collar thrust shaft.

Large engines are usually fitted with a thrust block arranged for continuous oil circulation, and in these blocks the upper as well as the lower portion of the body sustains thrust load. Oil is introduced into the space behind the pads and compelled to travel radially across the thrust faces. This oil can be cooled and used over and over. In these blocks the upper and lower parts of the body are keyed together, and liners for adjustment are fitted behind each of the rings which carry the pads.

The Michell principle is also applied to journal bearings, and fig. 44 illustrates one as fitted to a marine oil engine. When speeds are high the ring lubrication is replaced by a continuous supply of oil from a pump. It will be noticed that the oil is taken on to the shaft by means of a ring, and this ring is always kept in a central position, even if the ship pitches, as the central part of the oiling ring is guided by grooves in rollers arranged upon the shaft.

Considerable economy in length is effected by this bearing, as a pressure of about 500 lbs. per square inch projected journal area is satisfactorily carried at any speed.

The pivoting principle, upon which all Michell bearings work, ensures, perhaps, the nearest approach possible to perfection in lubrication. Astonishingly high pressures are quite safely

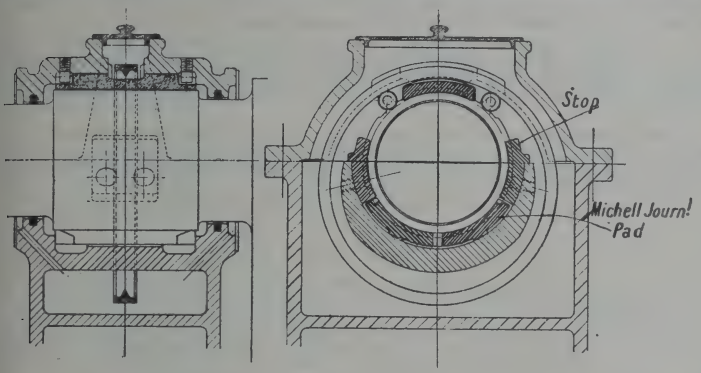


FIG. 44.—Michell Journal Bearing for Marine Oil Engine.

carried (under test as much as 5 tons per square inch has been successfully imposed), whilst speeds of any magnitude may be run by regulating the quantity of oil supplied. High speed is an advantage, inasmuch as oil film thickness increases with the speed.

MARINE DIESEL ENGINES.

Contributed by A. P. Chalkley, B.Sc., A.M.Inst.C.E.
Author of 'Diesel Engines for Land and Marine Work.'
Revised by James Thomson, M.I.N.A.

The Diesel engine as designed for marine work differs in no essential principle from the stationary type; with each manufacturing firm there are certain modifications and peculiarities of construction. On the whole the two-stroke-cycle single-acting engine is considered to have best prospects for the future, but for the very large engines for marine purposes the double-acting two-stroke-cycle motor is expected to give best results, whilst a number of firms still adhere to the four-stroke-cycle single-acting principle for moderate powers.

The superiority of the Diesel engine for marine work in certain cases is not entirely due to its fuel economy. This must always be an uncertain matter, dependent on the relative prices of the fuels. The consumption of oil with a Diesel marine engine is practically the same as for the stationary type, and, generally speaking, with oil of a net calorific value of about 18,000 B.Th.U. per lb. or 10,000 calories per kg. the fuel consumption for marine work may be taken as 0·40 lb. per b.h.p. hour for the main propelling engines. Unlike reciprocating steam engines, and steam turbines, the larger Diesel engines possess practically no advantage over smaller ones. It is usually estimated that the weight of fuel consumed by a Diesel marine engine is ½ that required for a vessel equipped with small reciprocating steam plant burning coal and about ⅓ for double-reduction geared turbines with oil fuel boilers, making allowance for standby losses, etc., and it has been found that this estimate has been well borne out in practice, although owing to the difference in efficiency between large and small steam engines and turbines it cannot apply absolutely.

The fuel consumption of large steam turbine plants with superheat and modern appliances has been reduced so much that fuel rates and first cost, etc., must be carefully considered before deciding whether Diesel or steam turbine machinery is the most suitable for the required service.

Among the most important advantages of the Diesel engine for marine work is the reduced space occupied by the propelling machinery and bunkers. This permits of greater cargo-carrying capacity, or a smaller vessel for the same cargo, with a corresponding reduction of the cost of the hull, although at the present time the cost of a Diesel engine is in excess of a steam engine and boiler plant. A vessel equipped with Diesel engines has from 10 to 15 per cent. extra cargo-carrying capacity as compared with a steam engine, and this is materially increased if the amount

of fuel carried is reckoned on the basis of the same radius in both cases, when considerable extra bunker space is rendered available for cargo in the Diesel ship. With special precautions, moreover, the fuel oil can easily be carried in the double bottom of the ship, which allows a further gain in space. In war vessels the advantage of the economy in fuel with Diesel engines will no doubt be utilised by increasing the possible radius, which may be taken at 3 times that of a steam vessel with geared turbines owing to the relative high economy at lower powers, this being a feature of the Diesel engine as compared particularly with the steam turbine.

In a Diesel ship the number of attendants in the engine room required is less than in a steam vessel, being usually in the neighbourhood of $\frac{2}{3}$. Firemen are entirely dispensed with, the handling of fuel is easy, rapid, and clean, whilst the astern power is equal to the ahead, which is not the case in turbine vessels. A list of engine room staff for various motor ships is given on page 2435.

For the same speed a single screw vessel equipped with Diesel engines usually requires slightly more power than when propelled by a steam engine for similar conditions, as the revolutions are too high for the most efficient propeller, but this does not apply to multiple screw ships when the speed exceeds 12 knots.

The weight of Diesel machinery for large powers is usually greater than steam turbine machinery.

Types of Marine Diesel Engines

There are three distinct types of Diesel marine engines, two of which have already been largely constructed and put into actual service, whilst of the third type comparatively few are in service. The first two are the single-acting engines of the four-stroke-cycle and two-stroke-cycle type respectively, whilst the third is the double-acting engine. A vessel has been completed recently with a twin screw set of vertical engines of the four-cycle double-acting type of 18,000 B.H.P.

The four-stroke-cycle motor is slightly more efficient, but the two-stroke-cycle single-acting engine has the advantage of reduced weight and space, simplicity in reversing arrangements and cheapness of manufacture. It necessitates the employment of scavenge pumps which reduce the overall efficiency of the motor. Larger powers can be developed in single cylinders, and although the limit is not yet certain, it is anticipated that 3,000 h.p. can be produced from a single cylinder. Up to the present 2,000 B.H.P. is the highest power that has been attained in a single-acting two-stroke-cycle motor per cylinder.

The reason for the employment of the double-acting two-stroke-cycle engines is to obtain the maximum power per cylinder. The chief difficulty encountered with the double-acting engine is to get rid of the heat in the cylinder, and there is also the question of the most convenient method of operating the valves in the bottom cover of the cylinder. It is stated that these troubles have now been satisfactorily overcome.

As regards the two-stroke-cycle single-acting type, the chief difference in the design of different manufacturers, apart from details of the reversing gear, is in the method of the provision of the scavenge air. In some engines scavenge valves are employed, fitted in the cylinder cover, and through these the scavenge air enters the cylinder, whilst in other types ports are provided at the bottom of the cylinder usually extending half-way round the circumference, opposite the ports for the discharge of the exhaust. Scavenging through ports presents some difficulties in regard to cleaning out all parts of the cylinders thoroughly, and various arrangements are employed to make it more efficacious, some of these being described later. With valves, the scavenging is excellent, but the valves must be large, and they add to the complication of reversing. The scavenging pumps usually work at a pressure of 2 to 6 lbs. per square inch, above atmosphere, and the power they absorb is from about 5 to 10 per cent. of the output of the engine. The power developed by a single-acting two-stroke cycle Diesel engine is about twice that of a four-stroke cycle engine of equal cylinder dimensions.

The question of reversing Diesel engines is not one of particular difficulty, the only requirement being a variation in the time of opening of the different valves. In the four-stroke-cycle engine this includes the exhaust valve, which is omitted in the two-stroke-cycle type, whilst if in the latter scavenge ports are provided, the matter is further simplified by the absence of scavenge valves. There are various methods of reversing, which, however, practically do not differ at all in principle, the arrangement being to alter the times of openings of the various valves relative to the crank shaft. In one arrangement which is commonly employed, a single cam shaft is provided on which are fixed two separate sets of cams, one for the ahead motion and one for the astern, each valve thus being capable of operation by either of the two cams. For reverse running the cam shaft can slide in a longitudinal direction, and this motion brings the astern set of cams underneath the levers operating the valves, so that the valves are thus set for going astern. Before the cam shaft can be moved, the rollers of the valve levers have to be moved clear of the cams in order to let them pass under.

A second method of reversing consists in having two separate cam shafts, on one of which the cams for ahead running are mounted, and on the other those for the reverse, and either cam shaft is set in a position for its cams to actuate the valve levers, according as it is required to run ahead

or astern. There are various other means adopted for reversing, such as by a rotation of the cam shaft relative to the crank shaft, and utilising the same cams for both directions which necessitates special setting of these cams. In another design a combination of this method and the first is adopted, whilst there are certain other special arrangements, one of which is described later.

Burmeister & Wain Type.

The engine designed and constructed by Messrs. Burmeister & Wain, of Copenhagen, and by Messrs. Harland & Wolff, may be taken as a typical four-stroke-cycle marine Diesel motor. It is built with six or eight cylinders, according to the power, the engines of the 'Glenapp' and several other boats having each eight cylinders, and developing about 2,600 i.h.p. at 115 revolutions per minute.

As is now common in most Diesel engines, and will, no doubt, be generally adopted in the future, external crossheads with water-cooled guides are employed, which, although increasing the height, are of considerable advantage in dismantling and for facility of inspection. An enclosed crank chamber is used, but at front and back there are readily removable covers.

The engine may be considered as arranged in two sets of four cylinders, which is convenient for the placing of the valve gear and manœuvring mechanism described later. The valves are fitted in the cylinder cover, as is generally the case, and each cylinder has a starting air valve, fuel inlet valve, exhaust valve, air inlet valve, and relief valve. The cam shaft carrying the cams which operate the levers controlling the valves is not situated on a level with the top of the cylinders, as is common in many four-cycle engines, but at about half the height of the engine. Each of the valves, except the relief valve, has two separate cams for its control on the cam shaft, one for ahead and one for astern running. In order to reverse the engine, the valve levers are lifted and the cam shaft moved longitudinally a distance equal to the cam width, so that, on dropping the valve levers once more, they are now immediately above the astern cams and are in a position for running in the opposite direction. The sliding of the cam shaft is accomplished by means of a disc carried on it, which moves in a slotted drum on an auxiliary shaft, the slot slanting from left to right. The auxiliary shaft can be turned by means of an air motor controlled from the starting platform, and in turning the cam shaft moves to the left or right, according to the direction of rotation of the auxiliary shaft. The actual operation of the valves from the cams is carried out by having long hollow vertical rods, whose upward and downward motion causes the rocking levers at the top to actuate the valves. It may be mentioned that, contrary to usual practice, the injection valves open inwards towards the cylinders. The drive of the cam shaft is through helical gearing and a vertical intermediate shaft, direct from the crank shaft. Sometimes a direct gear drive is adopted.

The question of the number of fuel pumps for pumping the oil to the injection valves is somewhat controversial, the majority of manufacturers preferring to have one pump per cylinder, whereas others think it desirable to minimise the number as far as possible. A small hand pump is employed for pumping the oil up to the valves when required, the usual overflow cocks being fitted.

In most Diesel engines, the governor controls the amount of fuel admitted to the cylinder by acting upon the suction valves of the fuel pump, and holding them open a longer period during the pressure stroke, if it is required to reduce the oil supply. In this engine the control is from the starting platform and a governor is fitted, which is only for the purpose of preventing the speed rising above the designed revolutions per minute, by cutting off the fuel altogether in all cylinders but one. Forced lubrication is adopted for the engine, and the oil is water-cooled and circulated continuously.

There have been some very distinct modifications with the later and larger type of motor. Eight-cylinder sets are now built developing 3,200 i.h.p., having a cylinder diameter of 740 mm. (29 ins.) and a stroke of 1,100 mm. (43¼ ins.). This is by far the largest output for a single-acting four-cycle marine motor that has yet been attained, although cylinders of greater dimensions are now being built. With an efficiency of 80 per cent. the corresponding brake horse-power is about 2,600. The speed of revolution is 115 per min., and the consumption of the engine is 0·32 lb. per i.h.p., or about 0·4 lb. per b.h.p. A vertical three-stage air compressor is driven direct off the main engine, each compressor being capable of supplying the injection air under normal conditions. A separate fuel pump is provided for each cylinder. Oil or sea-water is used for piston cooling. It may be mentioned that some designers prefer to avoid the use of sea-water for cooling purposes owing to the possibility of deposit, but the matter is largely an open question. The whole of the arrangements for operating the valves and reversing are the same as in the smaller motors, except that the camshaft, instead of being driven by two long horizontal rods, is in this case operated through spur gearing from the crankshaft, three intermediate spur wheels being provided between the crankshaft and the camshaft. It is claimed with this design that there is less likelihood of any variation in the setting of the cams due to wear and other causes.

In fig. 45 (p. 2412) a section is given of a 2,000 b.p. Burmeister & Wain motor of the latest type, whilst figs. 46, 47 (pp. 2413, 2414) give illustrations of the control arrangements for this motor.

Engines of the Burmeister & Wain double-acting type have been constructed for a twin-screw installation of 18,000 b.h.p. with chain-driven camshaft four-stroke-cycle double-acting engines, having eight cylinders in each set and working at 125 revolutions per minute. The air compressors are independent of the main engines and driven by separate Diesel engines. The main

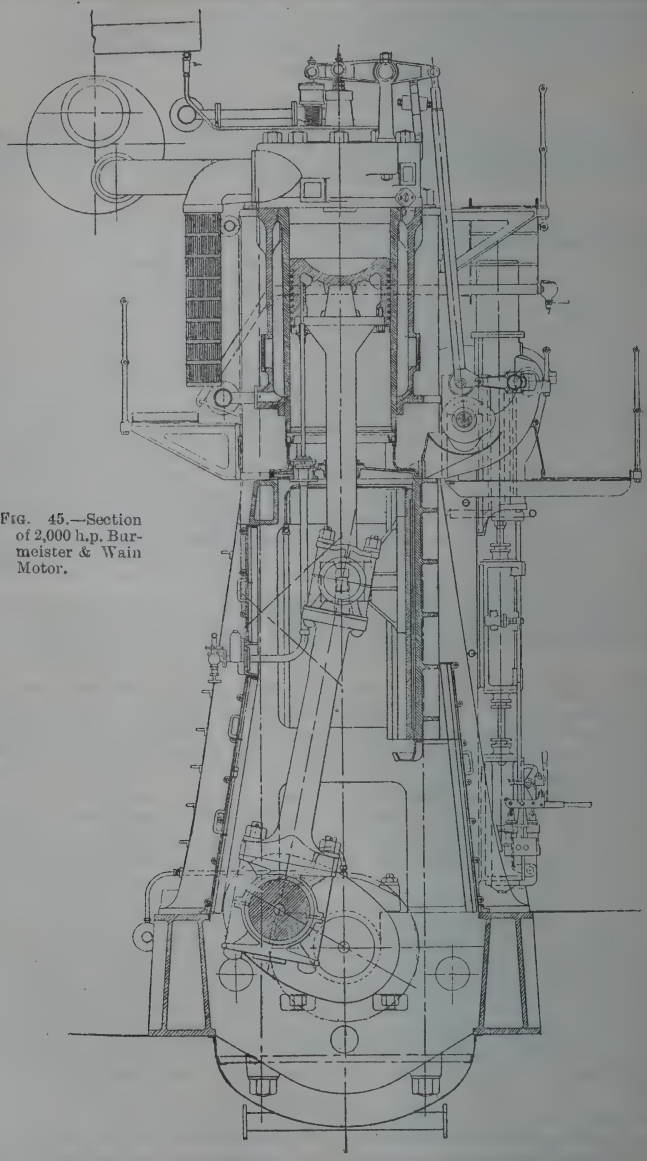


FIG. 45.—Section of 2,000 h.p. Burmeister & Wain Motor.

BURMEISTER & WAIN MARINE DIESEL ENGINE.

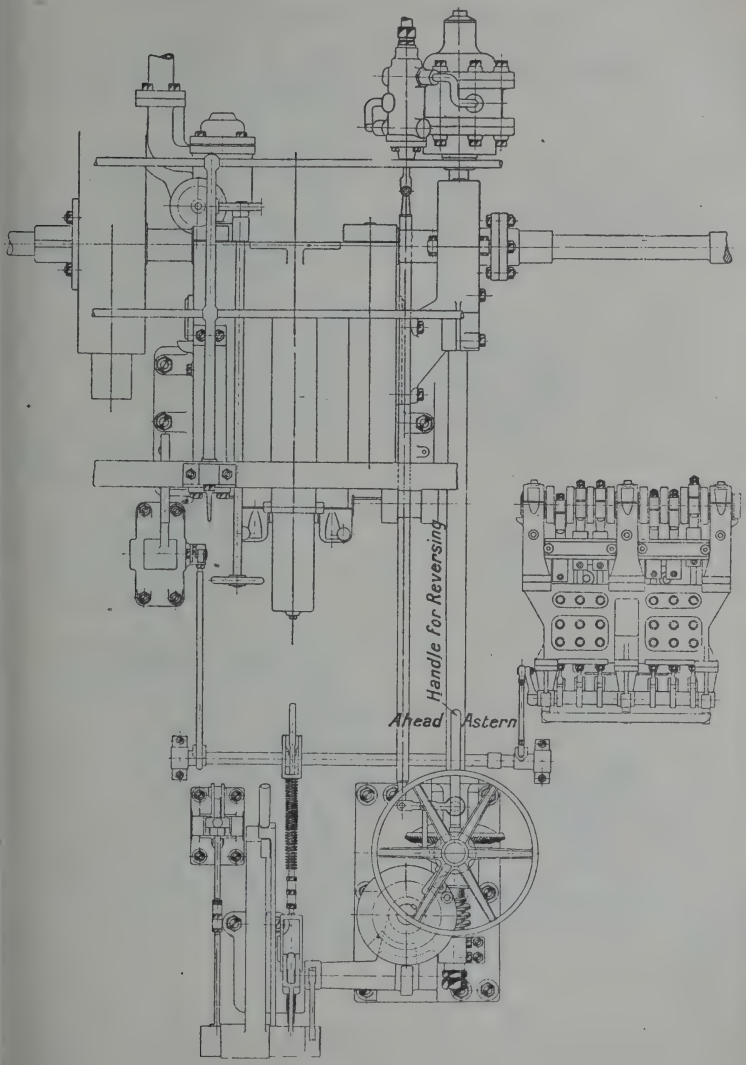


FIG. 46.—Details of Control Arrangements. Front View.

BURMEISTER & WAIN MARINE DIESEL ENGINE.

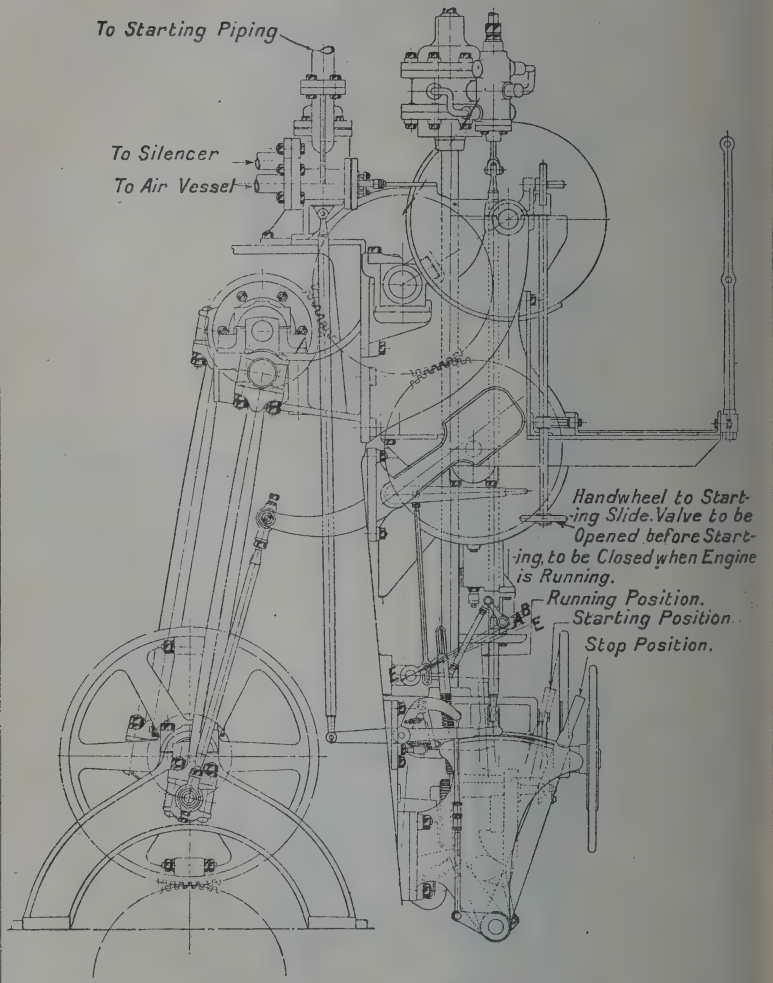


FIG. 47.—Details of Control Arrangements. Side View.

engines are of the piston-rod type, having a gland in the cylinder bottom, and the pistons are cooled by oil. The camshafts are driven by chain drive.

Messrs. Harland & Wolff manufacture a long-stroke slow-running engine which is specially suitable for slow-speed cargo boats.

North-Eastern Diesel Engine—Werkspoor Type.

The first engine of this type was constructed by the Werkspoor Company of Amsterdam, and installed in the *Vulcanus* in 1910. North-Eastern Marine Engineering Co. was the first of British marine engine-builders to take out a licence to build this type of engine, since when engines varying from 1,000 b.h.p. up to 4,000 b.h.p. have been built, both for British and Continental owners, with very successful results.

SINGLE-ACTING ENGINES.

The motor, fig. 48, p. 2417, is usually of six cylinders, and, except for a few special features, is of the standard single-acting four-stroke type of engine.

The chief point of difference lies in the cylinder construction, the North-Eastern-Werkspoor engine having a continuous cooling surface from liner to crown of cylinder, this construction giving highly efficient cooling to the combustion chamber, there being no liner joint to interfere with the circulation. The arrangement also allows the valves to be spread further apart, giving more space for circulation between the valve ports.

The pistons and cylinders are inspected from below, a very simple arrangement being provided for this purpose.

Another point of difference lies in the arrangements for operating the valves and the method of reversing. There is one camshaft on which the cams for ahead and astern working respectively are mounted in pairs for air starting, fuel injection, induction, and exhaust. This shaft does not move in a fore-and-aft direction during reversal, but the lever which transmits the motion from the cam to the valve is mounted eccentrically on the reversing shaft. The axis of the eccentrics and the shaft on which they are mounted are not parallel, so that when the shaft is rotated through an angle of 180° the rollers are lifted from one set of cams and placed on the other.

The camshaft is driven by connecting rods from cranks on a countershaft to cranks on the camshaft, the countershaft being driven by spur gearing from the engine crank shaft. This is a totally distinct method from that already described, in which the camshaft is moved longitudinally, and illustrates the diversity of the arrangements which may be employed for reversing Diesel engines.

A light type of engine is built with the cylinders entirely supported by steel columns and diagonals, but the standard design has the cylinders supported on cast iron 'A' frames, the cylinder beam, columns, and bedplates being held together by heavy through-bolts running from top to bottom of the engine.

The main running gear has forced lubrication, and is totally enclosed in an oil-tight casing with large doors, particularly easy to remove.

The compressor is of the three-stage type, usually direct driven from the forward end of crank shaft.

DOUBLE-ACTING ENGINES.

The 'North-Eastern-Werkspoor' Double-Acting Diesel engine is a new type which has been jointly developed by Werkspoor and the North-Eastern Marine Engineering Co., Ltd.

A sectional elevation is shown in fig. 48A, p. 2417.

The upper portion of the cylinder and the arrangement of the main running gear is of normal single-acting design. A feature is the lower combustion chamber so arranged that combustion takes place in a separate chamber away from the piston rod, which therefore runs very cool and under easy conditions.

The compression pressure in the bottom cylinder is only 250 lbs./sq. in., so that this cylinder requires to be pre-heated to give the necessary compression temperature. This is done by running the engine as a single-acting unit and passing the exhaust gases from the top cylinder through the inlet valve into the bottom cylinder for about five minutes before putting the fuel on. The mean pressure on the top of the piston is about 90 lbs./sq. in. and on the bottom about 65 lbs./sq. in.

The engine is of extremely simple and accessible design, the piston being examined by lowering the bottom portion of the cylinder and thereby exposing the piston.

This engine is built in powers up to 1,000 b.h.p. per crank, the engines at present under construction having six cylinders, and are capable of maintaining 4,000 b.h.p. continuously at sea.

Engine.	B.H.P.	Diameter	Stroke.	R.P.M.	No. of Cyls.
North-Eastern-Werkspoor (Single-Acting)	1,100	22·0	39·4	125	6
North-Eastern-Werkspoor (Single-Acting)	2,300	28·7	51·2	93	8
North-Eastern-Werkspoor (Double-Acting	4,000	32·3	59·0	90	6

NORTH-EASTERN FOUR-STROKE SINGLE-ACTING DIESEL ENGINE.
(8 cyl. 730 dia. × 1,300 stroke.)

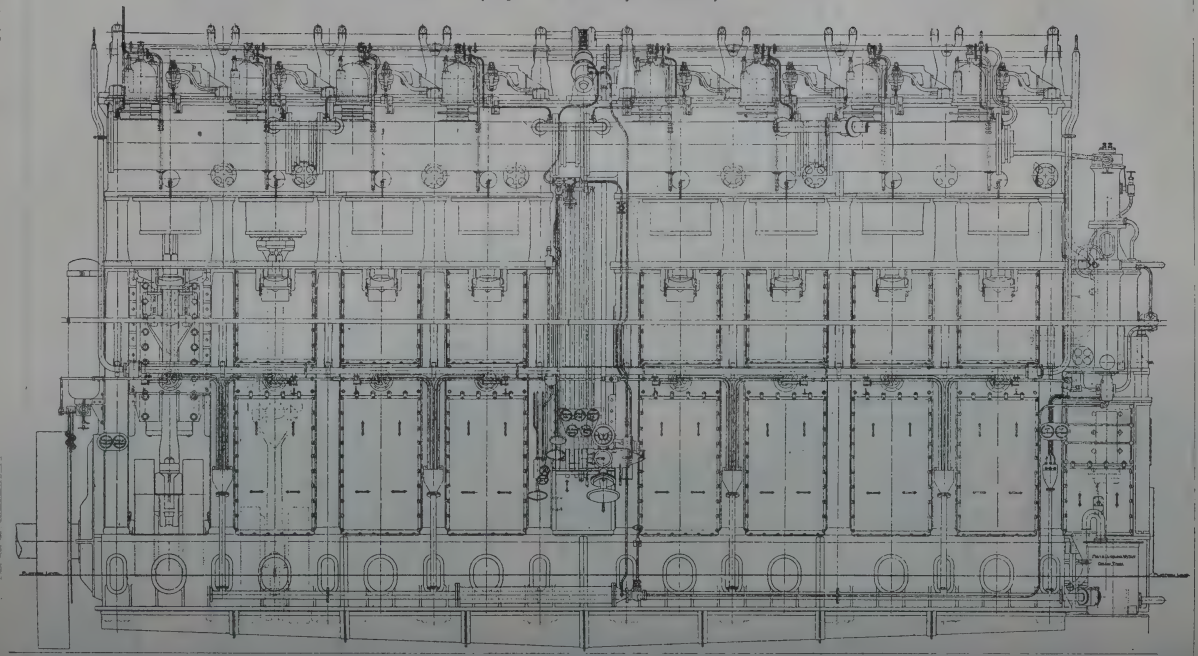


Fig. 47A.

NORTH-EASTERN MARINE DIESEL ENGINE.

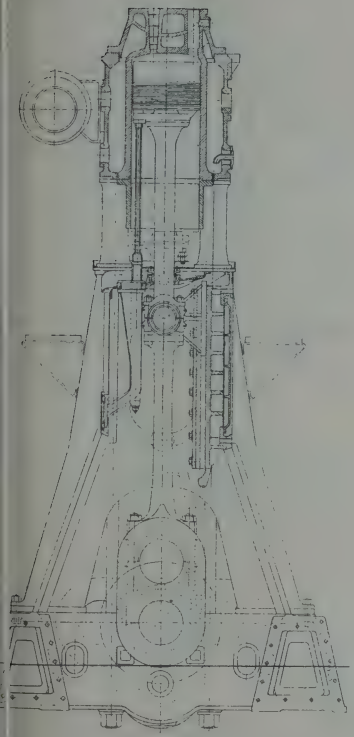


FIG. 48.—Sectional elevation of North-stern-Werkspoor. Single Acting Engine our-stroke).

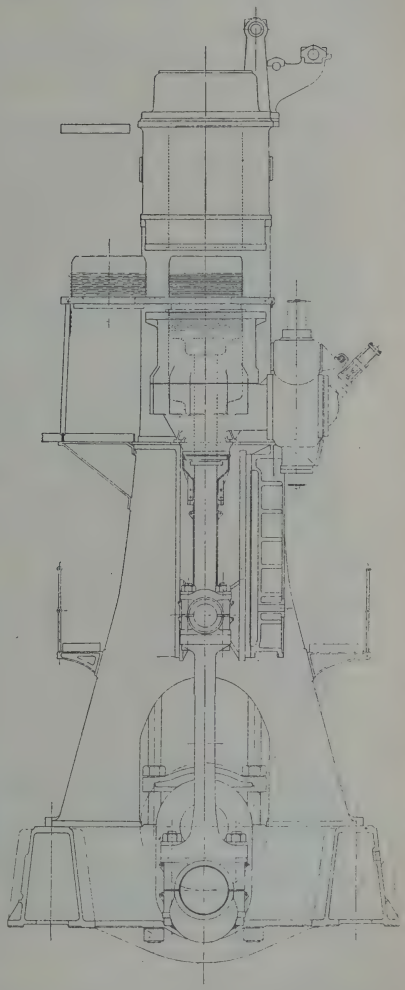


FIG. 48A.—North-Eastern-Werkspoor Four-Stroke Double-Acting Engine: method of with-drawing piston.

Sulzer Marine Diesel Engines.

Messrs. Sulzers' experience of both four-cycle and two-cycle engines has led them to adop the two-cycle engine for all marine work, and they have standard designs of 4, 6, and 8 cylinde marine engines developing from 300 to 7,200 b.h.p., the latter being a unit of 8 cylinders, or 90 b.h.p. per cylinder.

The Sulzer two-cycle engine has important differences from the other engines described Chief amongst these is the method of scavenging through a double row of ports, the upper ro of which is above the exhaust port opening and is controlled by means of a valve.

On the downward stroke of the piston, the upper row of scavenging ports is first uncovered but the valve controlling these ports remains shut and the exhaust commences to take plac only when the piston has descended further and uncovered the exhaust row of ports.

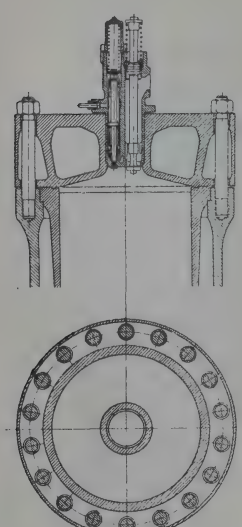


Fig. 49.

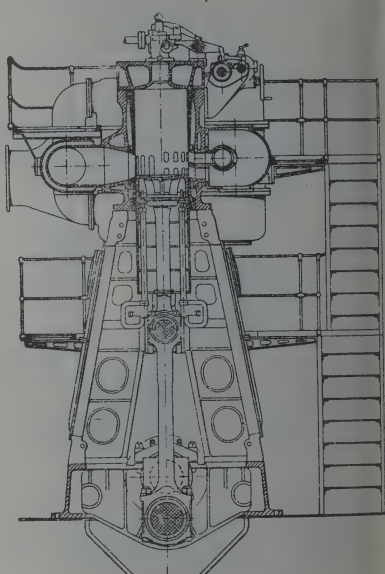


Fig. 50.

Scavenging commences as soon as the lower row of scavenging ports is uncovered and co tinues through both rows of ports, the control valve for the upper ports having been open by the pressure of the scavenging air, and air is admitted through the upper ports to the cylinde after the exhaust ports are closed, as long as the scavenge air pressure exceeds the pressure in t cylinder.

Not only is the scavenging much improved in this manner, but it will be seen that it is possib to obtain a supercharge of air, *i.e.* a slight increase above the atmospheric pressure in the cylind at the commencement of compression.

Messrs. Sulzers have found that the good combustion obtained by this method of scavengin and also the simplicity of the cylinder cover design (fig. 49) enables them to maintain with safe a higher mean pressure in their two-cycle engines than in four-cycle engines.

The power for a given size of cylinder on the Sulzer two-cycle type is more than double t power of a similar size cylinder on the four-cycle type, both being assumed to run at the sa piston speed.

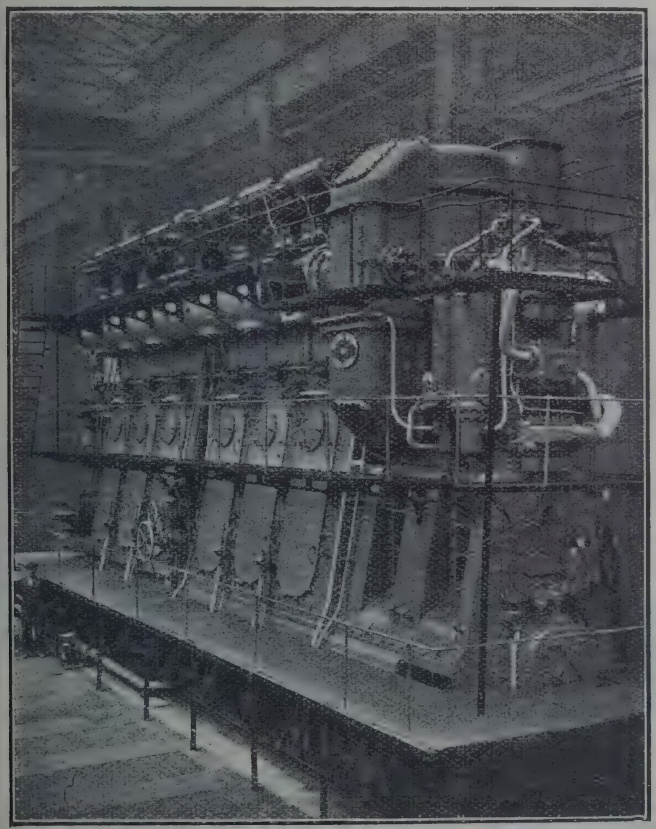
The fuel consumption is also practically the same as the best four-cycle engine when worki under service conditions, *viz.* 0·42 lb. per b.h.p. hour, including scavenge blowers.

Fig. 50 shows the section through working cylinder of a standard Sulzer Marine Engine 1,350 b.h.p. running at 110 r.p.m.

THE WALLSEND SLIPWAY & ENGINEERING COMPANY, LIMITED

Head Office & Works—Wallsend-on-Tyne.
London Office—30 Great St. Helen's, E.C.3
Liverpool Office—Cunard Building.

GRAVING DOCK
540 *feet long.*



Wallsend-Sulzer Diesel Engine on test bed.

Makers of Steam Reciprocating, Turbine and Internal Combustion Engines. Licensees and Manufacturers of Oil Burning Installations.

F. 2418

DOXFORD OIL ENGINE

DOUBLE ACTION OPPOSED PISTON in the most SIMPLE FORM

250,000 HORSE POWER Built and Building

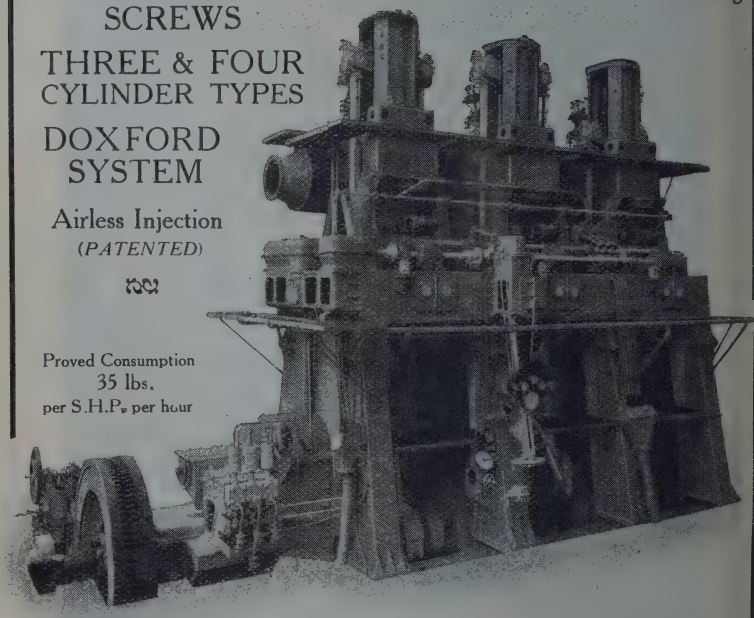
SINGLE and MULTIPLE SCREWS

THREE & FOUR CYLINDER TYPES

DOXFORD SYSTEM

Airless Injection
(*PATENTED*)

Proved Consumption
35 lbs.
per S.H.P.e per hour



WILLIAM DOXFORD & SONS LTD.
SUNDERLAND

Grams: 'Doxford, Sunderland. 'Phones: 1800, 1, 2, 3

F. 2419

The double row of scavenge ports and the control valve for the upper ports are seen on the ght (fig. 49), while the exhaust ports and exhaust collector are on the left. The valve shown is the rotary type, but in the latest designs automatic lift valves are used, the action being as ready described.

The engine shown is provided with a direct driven scavenging pump fitted between the h.p. r compressor at the end of the engine and the main engine cylinders.

In the latest type of engine, the scavenging pumps are in the form of independent rotary owers electrically driven. This is an advantage from the constructional point of view, and ie arrangement has the further gain that the scavenging pump may be speeded up indepen- ently of the main engine when it is desired to increase the power. This does not involve any crease in the size of the electric generating sets where electrically driven winches are installed, these latter are only running in port when the scavenging pump is idle.

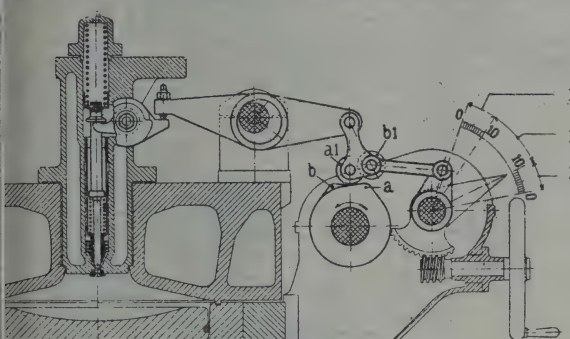


FIG. 51.—Sulzer Reversing Mechanism.

The engine illustrated, when made with separate turbo-blowers, develops 1,500 b.h.p., orking at approximately the same indicated mean pressure and piston speed as the 1,350 b.h.p. gine with reciprocating scavenge pumps.

Reversing is carried out with a minimum requirement of power, and is effected by bringing second set of rollers and cams into operation (fig. 51). Each starting and fuel valve there- re has one cam and roller, a and a^1, for running ahead, and another, b and b^1, for running astern. ie hand wheel shown in the above illustration brings a and a^1 or b and b^1 into operation in cordance with the required direction of running.

The weight complete of Sulzer Diesel Marine Engines is approximately 2 cwt. per h.p., i.e. h.p. per ton.

Submarine engines of Sulzer two-cycle type have been built developing 4,000 h.p. in 8 cylinders, ese engines being the most powerful marine Diesel engines in the world of the light type.

The first large passenger liner driven by Diesel engines is the *Aorangi*, which has engines of e Sulzer type, manufactured by the Fairfield Shipbuilding and Engineering Co., Ltd., at Govan.

THE 'DOXFORD' ENGINE.

Messrs. Wm. Doxford & Sons, Ltd., have completed a number of motor vessels, and there are w built and building an aggregate b.p. of 350,000, consisting of four-cylinder types, quadruple rew, 15,000 i.h.p., twin screw, 5,500 i.h.p. @ 95 revs., single screw, 6,000 i.h.p. @ 95 revs., and ree-cylinder types, single screw, 2,650 i.h.p. @ 90 revs., all of the opposed piston two-stroke pe operating on the Doxford system of airless injection.

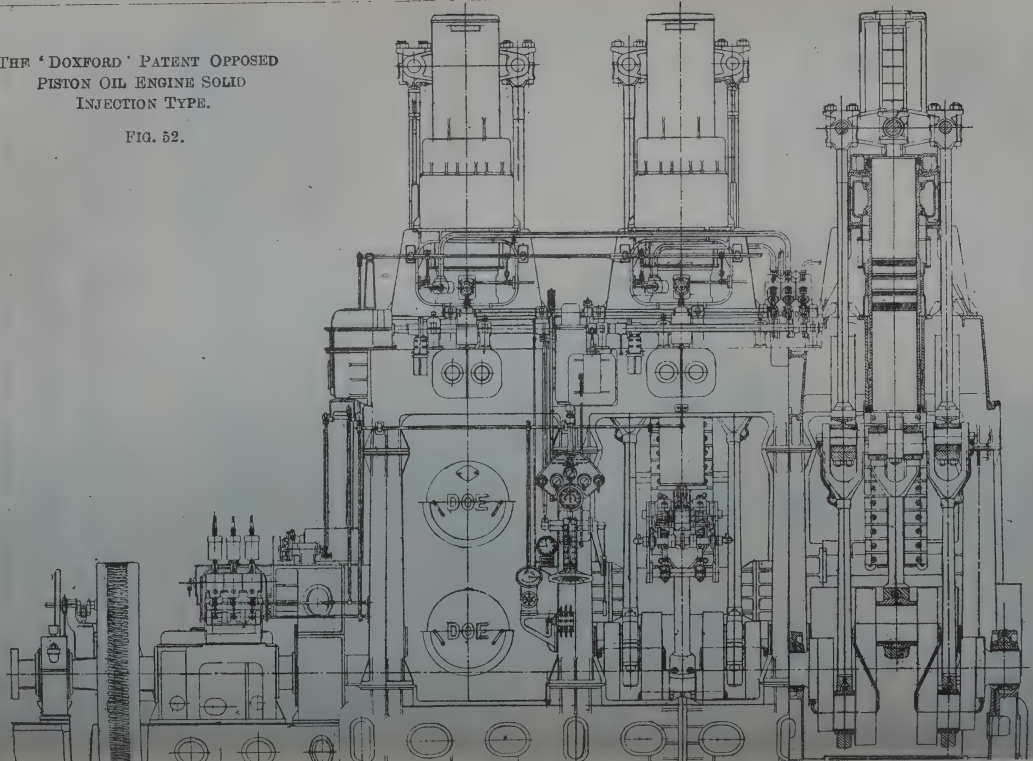
Fig. 52, p. 2420, shows the three-cylinder type of engine, in each cylinder of which there are two stons acting outwards. The lower piston is coupled by crosshead and connecting rod to a crank low the centre of the cylinder, and the upper piston acts upwards to a transverse lever above it, tending fore and aft beyond the walls of the cylinder, and coupled by two side connecting rods to o cranks, one on each side of the centre crank, but arranged in line diametrically opposite to it.

The fuel is injected between the pistons when they are close together, and when combustion kes place the pistons are driven apart, thus exerting an almost perfect turning moment on the ankshaft, without reactional load on the main bearing or the framework of the engine.

The products of combustion are exhausted through ports round the whole circumference at e top of the liner, which ports are controlled by the upper piston. At the end of the stroke, rresponding ports are uncovered by the lower piston in the bottom end of the liner, to control ie scavenging air, thus the entire cylinder is scavenged on the 'Uniflow' principle; the covering

THE 'DOXFORD' PATENT OPPOSED PISTON OIL ENGINE SOLID INJECTION TYPE.

FIG. 52.



f these ports at the beginning of the return stroke traps the containing air, which is thus com-ressed ready for the injection of the fuel and repetition of the cycle.

Fuel injection is on the Doxford ' Solid Injection ' principle, and the fuel oil is injected trans-ersely across the cylinder in the form of a fan, from each valve placed diametrically opposite, ie fan forming a curtain right across the combustion space. The air which is entrapped between he two pistons receives through suitably arranged ports a rotating motion whereby the air fed through the curtain of fuel oil, so that very efficient combustion is obtained without the il impinging on to the piston or cylinder walls. The two pistons are, moreover, hollow, and orm between them practically a complete spherical space, the surfaces of which are kept at 000° F., thus greatly assisting the burning of the heaviest grades of boiler oil.

The elimination of exhaust and induction valves, with their liability to defects, is a great dvantage, and in dispensing with the cylinder cover many defects of jointing and cooling are bviated. Also, the absence of the high-pressure compressors removes the most delicate part of Diesel engine, and the danger from possible explosions is completely avoided.

The valve gear is very simple, consisting of one camshaft in front and one at the back of the ngine. Both are driven by spur and bevel wheels direct from the thrust shaft. The front amshaft has two sets of cams for the fuel and air starting valves for ahead and astern running, ither of which is brought into operation by sliding the cam shaft by means of a hand lever. When oing ahead, the front and back fuel valves are in operation, but when going astern only the ront fuel valves come into use, giving approximately 60 per cent. of full power, which is equal o the resistance obtainable from the propeller. A hand-wheel controls the air-starting valves nd the fuel valves. By rotating the hand-wheel, the air-starting valves are brought into contact ith their cams, and air is admitted to the respective cylinders. By a further rotating of this and-wheel, the air-starting valves automatically come out of action and the fuel valves are rown into use, and by further rotating the hand-wheel, the speed and power of the engine is egulated. The small hand-wheel controls the suction valves of the fuel pump for regulating the equired fuel oil pressure.

An Aspinall governor operates the injection fuel valves, and at the same time acts upon the uel pump suction valves ; thereby racing under any condition is completely prevented.

The cylinder liners and pistons are all cooled with fresh water, and forced lubrication is employed n the crank chamber throughout.

Messrs. Doxford have run extensive trials on one of their four-cylinder 3,400 i.h.p. engines, ubmitted to the Trial Committee appointed by the Naval Arch. and Inst. of Mech. Engrs., and ave proved a consumption of ·4 lbs. per b.h.p. on ·96 British Mexican fuel oil, and a mechanical fficiency of 89 per cent. More recent test-bed results on a three-cylinder engine of 2,200 i.h.p., 90 evs., have given the fuel consumption as ·375 lbs. per b.h.p. on ·89 Anglo-Persian oil.

Messrs. Doxford claim to be the first to introduce aboard vessels centrifugal treatment of uel oil, thus enabling shipowners to burn any brand of fuel oil that may have to be taken aboard.

The Neptune Marine Oil Engine.

(Messrs. Swan, Hunter, & Wigham Richardson, Ltd., Wallsend-on-Tyne.)

The engine as shown by figs. 53 and 54 is of the reversible, two-cycle, single-acting, port cavenging type, and is arranged to be built with four, six, or eight cylinders, the scavenging umps and bilge pumps being situated at the back of the engine and driven by levers from the ngine crossheads. The compressor is driven from an extension of the crankshaft at the forward nd of the engine.

The engine embodies all the principal details of the original Neptune design in that built-p crankshafts, crossheads, guide plates, and connecting rods having double top end bearings re employed. Particular attention has been paid in this design to the accessibility of the engine, hich is, together with the above features, essential to marine engine design.

The crankshaft is designed 10 per cent. stronger than is necessary to comply with Lloyds equirements, and is of the built-up pattern in two interchangeable portions, and is drilled for onveying the lubricating oil to the top and bottom end bearings and to the guide shoes.

The main bearings are circular on the bottom, so that they can be withdrawn for examination ithout disturbing the crankshaft.

The crossheads are arranged to take the double top end bearings of the connecting rods and he links for driving the scavenging pumps. An extension on each end is provided to take the uide shoes. The ahead and astern guide shoes are arranged to have the same area of bearing urface, the reason being that in a two-cycle single-acting engine, the load from the piston is lternately on the ahead and astern faces for alternate strokes. In addition to this the position f the guide shoes makes a very open and readily accessible engine. The guide plates are il-cooled on the surface, and together with the guide shoes, are adjustable.

The piston rod is secured to the crosshead at one end, and is arranged with a flange at the other end to receive the piston.

The piston skirt is separate from the piston, and is attached to the lower part of th piston rod.

The piston is fitted with an inner casting both of which are of simple construction. The objec of this casting is to ensure an effectively cooled piston and to make the inside of the piston readil accessible for cleaning purposes.

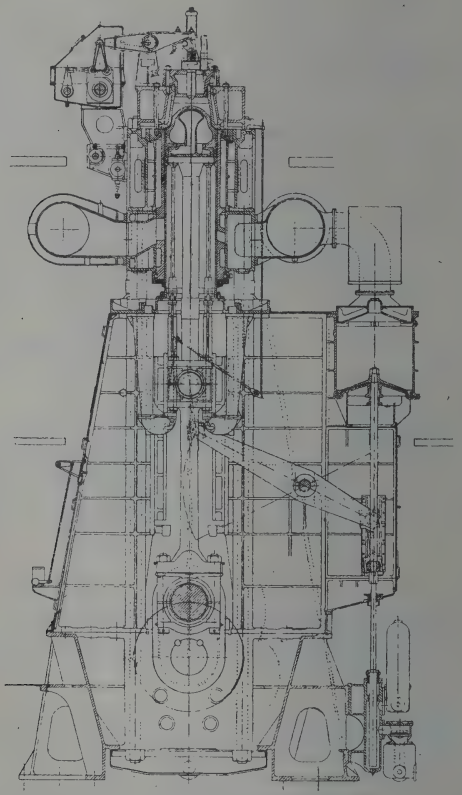
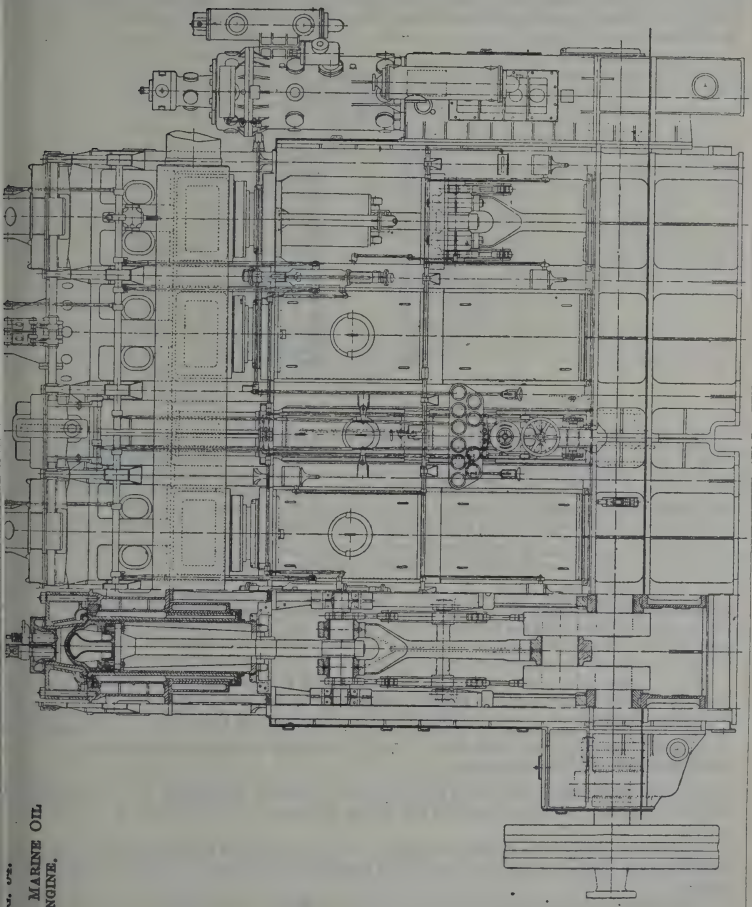


FIG. 53.—Neptune Marine Oil Engine.

The pistons are cooled by means of sea or fresh water as required. The water is admitted t and discharged from the pistons through telescopic tubes and pipes, large air vessels being fitted t prevent water hammer. To obviate any possibility of the water leaking into the lubricating o in the crank case, the piston water service gear is provided with a double stuffing box, having drain led away to the bilge. A wiper ring and inverted funnel are fitted to the telescopic rod abov the stuffing box, in order to collect any water which may be adhering to the rod after passing th stuffing box.

As the success of two-cycle, port scavenging engines depends largely on efficient scavenging



NEPTUNE MARINE OIL ENGINE.

exhaustive experiments were carried out with various shapes of piston tops and scavenging ports, with a view to obtaining the most efficient form of scavenging possible. As a result of these experiments a symmetrical shape of the piston top and a special construction of the scavenging ports has been adopted.

The design of the cylinders and cylinder covers, as shown in fig. 55, is such as to allow all metal subject to high temperatures free expansion in every direction, and to reduce all heat stresses to a minimum. The cylinder is made in two castings, A and B. A is a beam connecting the cylinders together: it takes the load of combustion transmitted through the cover and cover casing F, and is not in any way exposed to the heat of combustion. The lower casting B, which is bolted to the beam A, contains the scavenging and exhaust passages, the latter being efficiently water-cooled.

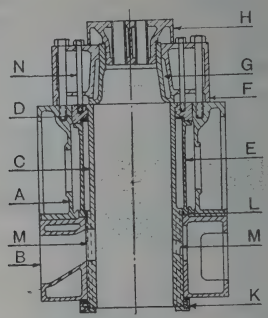


FIG. 55.

The liner C is arranged inside the two castings A and B, and is secured in position by a sandwich plate D. The sandwich plate is cast on the liner some distance below the upper flange, and is cut away to form a single ring. By this means an undesirable thickness of metal at the top of the liner, which gives rise to excessive heat stresses, is avoided, the metal being as thin as is consistent with the required strength. The sandwich plate is attached to the cover casing F by the studs N, thus making the joint between the cylinder liner C and the cover liner G.

This construction allows free expansion of the liner and makes possible a very simple design of liner in that part which is subjected to the highest temperature.

In order to avoid having a water joint in way of the ports, a water jacket E is bolted to the sandwich plate, making a joint at its lower end above the ports. A hollow collecting ring K is attached to the bottom of the cylinder liner. The circulating water passes from this ring through holes M in the ribs of the liner in way of the ports and into the cylinder jacket. This arrangement provides a very efficient means of cooling the liner in way of the exhaust ports.

The cylinder cover casing F is provided with a liner G which is free to expand in an upward direction, and is of such a design that the stresses due to heat are reduced to a minimum. It is so arranged that the liner can be easily withdrawn for cleaning purposes. The liner G has one central hole at the top, which is arranged to take the cover H, containing the necessary fuel starting and escape valves. The cover is designed to allow of free expansion of that part which is exposed to the combustion gases.

The cylinder liner, cover liner, and cover are all water cooled, the water joints being so arranged that they are not exposed to the action of the heat and pressure of the combustion gases.

Steel bolts connect the cylinders through the columns to the bedplate and take the whole of the tension loads due to combustion, the cast-iron columns being designed for compression only.

The camshaft is driven from the centre coupling of the crankshaft by means of gear wheels, eccentrics, and rods. The rods are in two sets connected by levers mounted on an intermediate shaft. All the bearings are adjustable. This gear is the usual Neptune practice and has been adopted in preference to skew gearing, owing to the unsuitability of the latter for marine purposes.

The camshaft is fitted with ahead and astern fuel and starting cams. The cam rollers are carried on links, there being one roller to each cam. Each link carries one ahead and one astern

oller. The engine can be run either in the ahead or astern direction by placing the link so that he ahead or astern rollers are in operation. These links are controlled by a handwheel at the ontrol station. The lift of the fuel valves is regulated by this gear so that when the engine is unning slowly a saving of injection air is effected. Compressed air for starting and reversing urposes is admitted to the cylinders through a valve in the cylinder cover. The fuel and starting alve levers are mounted on eccentrics, the positions of which are regulated from the control tation by means of levers operating through a servomotor. It is so arranged that the fuel valves nd starting valves cannot be in operaton at the same time. It is also arranged that when starting r reversing the engine the fuel pumps are out of operation. One half of the cylinders can be un on compressed air while the remainder are being supplied with fuel.

The fuel pumps are driven from the cam shaft driving gear, and are situated at the back of the ngine on the level of the control station. A separate pump is arranged for each cylinder. The ever used for disengaging the fuel valves is connected to the suction valves of the fuel pumps o that the pumps will be out of action at the same time as the fuel valves. A governor is fitted o operate the cut-out valves on the fuel pumps.

The control station is situated on the lower platform, and is so arranged that the engine can e easily operated by one man. In a central position are two levers for operating the fuel and tarting valves, each lever serving three cylinders. As previously stated, arrangements are ade so that it is impossible for the starting and fuel valves to be open together. The method of tarting up the engine is to admit starting air to one half of the cylinders while fuel s being supplied to the remainder. As soon as the engine is running the cylinders which were n air are put on to fuel. A reversing wheel is situated near to these levers, and arrangements re made so that the engine cannot be put over from ahead to astern or *vice versa* except when hese levers are in the ' stop ' position. Hand gear is also fitted for the control of the injection ir and fuel pumps, and, together with the telegraph and gauges, is arranged in close proximity o the starting levers.

A system of forced lubrication is arranged, the engine being entirely enclosed. A trough is tted under the bedplate to collect the lubricating oil flowing from the bearings, which is drained nto tanks situated in the double bottom of the ship. These tanks are separated from the ship's ide to prevent any possibilty of sea-water leaking into the oil.

Lubricating oil coolers, filters, and strainers are provided in the system.

The compressor is of the three-stage, single-acting type, each stage being provided with a traight tube intercooler and separator. A crosshead and guide shoe is provided to take the ide loads and to allow of the pistons being outside the crank case.

The necessary bilge and sanitary pumps are provided, and are so arranged that any one pump an be used for either purpose, and so enable one pump to be overhauled while the other is in use.

When a flywheel is provided, it is fitted at the after end of the crankshaft, the weight being aken by a special bracket which is bolted to the bedplate, and fitted with a bearing similar to he main bearings. A turning gear is provided which can be driven by a steam engine or electric notor, according to requirements.

Air for injection and starting purposes is stored in bottles situated in a convenient part of he engine-room.

The McLagan Double-Acting Sliding-Cylinder Two-Stroke Cycle Diesel Engine.

This is a three-cylinder unit engine with a cylinder diameter of 24½ ins. and a stroke of 44 ins. he designed power being 2,000 b.h.p. at 100 r.p.m., although during the trials it has been tested t 2,100 b.h.p., and could be rated at this output with a moderate and permissible mean effective ressure. The average m.e.p. at 2,000 b.h.p. is about 88 lbs. per sq. in., and the mechanical fficiency 72 per cent. The fuel consumption is ·448 lb. per b.h.p.-hour.

By the sliding cylinder design, the rubbing speed scarcely exceeds 500 ft. per minute between iston and cylinder. Not only are scavenging valves avoided and a very fine scavenging effect rovided (the scavenging air sweeps through from the top and bottom of the cylinder to the entre), but the piston rod does not pass through the bottom cylinder cover, with the result that. he fuel valve can be located centrally, and the problem of packing does not arise.

In effect, there are two separate cylinders in each line, with a space between them for the ovement of the crosshead pin. These two cylinders are joined together by ties arranged on pposite diameters, and at the top and bottom of the ties are spherical washers, so that the ylinders are free to adjust themselves independently. The actual distance moved by the cylinders about 13 ins., and they slide over the top and bottom cylinder covers. At the top the cylinder over is supported by an entablature, which itself is carried on columns extending from the

bedplate to the entablature. Below the bottom of the cylinder is another entablature, carried by brackets from the frames, and these support the lower cylinder cover, both covers being provided with gastight rings.

The scavenging air is delivered from a double-acting pump driven from the crankshaft at the after-end of the engine into the front engine columns, which are hollow and connected by piping, thus acting as receivers. Suitable branches with glands are provided, allowing the admission of the scavenging air through the pipes on the cylinder which slide within the branches mentioned. In the cylinder at the top and bottom are ports which are uncovered as the cylinder moves downwards and upwards respectively. On the downward stroke the scavenging air sweeps through the cylinder from the top to the centre, the exhaust gases being discharged through the branches and the common pipe, giving connection to the main exhaust manifold with a sliding joint and gland. There are, of course, belts of exhaust ports around the cylinder, these being uncovered by the relative movement of the piston and cylinder.

Only two valves are needed, one for fuel admission and the other for starting air. They are to the right and left of the centre-line of the cylinder respectively, each inclined at an angle of about 45 degrees with the vertical. Only one hole is required (for the fuel valve), as the starting air enters through an annulus around the inner combustion space end of the fuel valve.

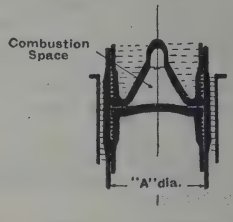


FIG. 56.

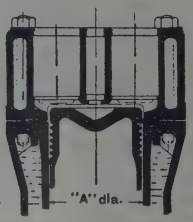


FIG. 57.

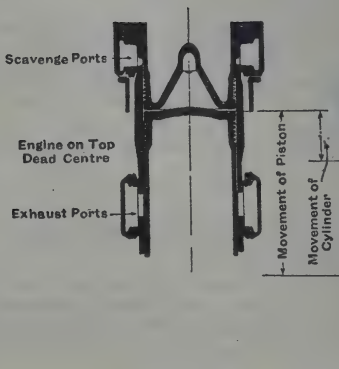


FIG. 58.

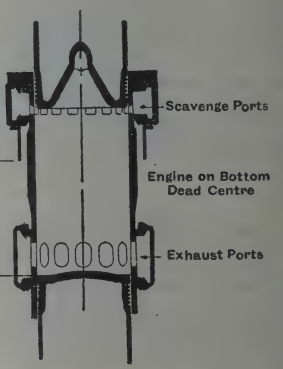


FIG. 59.

The exceptional freedom of the cylinder cover and liner to expand, and the very efficien cooling of the liner, are shown in fig. 56. Fig. 57 shows an ordinary four-cycle cover.

Figs. 58 and 59 show the relative movement of the cylinder and piston, the former being a the inner dead centre, the latter at the outer dead centre. The actual rubbing speed of the pisto rings on the cylinder is materially less than the absolute speed of the piston; at a speed of 10 revolutions per minute the rubbing speed is 508 ft. per minute, which is much less than is usuall found in large Diesel engines, and should have the effect of reducing appreciably the wear on th cylinder and piston rings.

The total length of the engine to the end of the thrust block is about 30 ft. The height from the bottom of the bed-plate is about 29 ft.

Fresh-water cooling is used for pistons, cylinders, and covers, and is to be circulated around a fresh-water cooler in the ship.

The weight of the complete engine is about 220 tons, which compares with a 2,000 b.h.p. four-cycle single-acting motor at about 370 tons for the same normal speed. It is intended to reduce the weight to 200 tons.

The Camellaird-Fullagar Engine.

Cammell, Laird & Co., Ltd., Birkenhead, have developed the Fullagar engine for marine work, and make various sizes of engines of the two-stroke cycle, opposed piston Diesel type with the oil fuel injected by compressed air.

The principal features of the design are: the elimination of the cylinder cover, the provision of a plain cylinder liner, the straight-through scavenge from end to end of the cylinder, the perfect balance of the reciprocating parts provided by the opposed pistons, one connecting-rod and one crank per cylinder.

A 1,000 b.h.p. engine is illustrated in fig. 60. There are four cylinders, in each of which the upper piston of one cylinder is connected to the lower piston of the other cylinder by external tie rods and crossheads, so that each crank receives two impulses per revolution. The horizontal component of the pull of the tie rods is taken up by guides at the top and bottom of the cylinder. The upper crossheads are enclosed and form scavenge pumps, compressing to 1½ to 2 lbs. per sq. in. The pistons uncover air and exhaust ports at opposite ends of the cylinders, and excellent scavenging is obtained.

The Fullagar design enables double the power to be produced in the same space compared with ordinary Diesel engines, and a lighter weight per h.p. As the forces and reactions are largely self-contained by the moving parts, very little load comes on to the framework of the engine, and the construction can be correspondingly light. For marine work the engines have the great advantage of being able to run at a slow speed, also they are very accessible for overhauling.

The 1,000 h.p. engine has cylinders 18½ ins. diameter by 25 ins. stroke, and the speed is 110 r.p.m. Fresh water or sea water cooling is adopted in the jackets and pistons. The starting and fuel valves are in the centre of the cylinder, between the pistons, and are operated by a horizontal cam-shaft driven by skew gearing from a vertical shaft operated by crank-shaft. Governing is effected by controlling the lift of the suction valves on fuel pump in the manner usual with Diesel engines, and to reverse the direction of rotation it is only necessary to turn the hand wheel to set the vertical shaft for the ahead or astern position.

In addition to the M.V. *Malia*, which has two 1,000 b.h.p. sets of the type just described, the following have been constructed by the firm or their licensees: two single-screw vessels engined with six-cylinder sets of 3,000 b.h.p., one with a six-cylinder engine of 1,500 b.h.p., and one with a six-cylinder set of 2,500 b.h.p. All these are now in service, and a further six-cylinder set of 2,500 b.h.p. is now being installed in a Japanese vessel.

See also p. 1948.

The 'White' Diesel Engine.

The Diesel engines made by Messrs. J. Samuel White & Co., Cowes, were first used for submarines, and they are now supplied for all marine purposes.

One of the White 450 b.h.p. two-stroke cycle engines was subjected to severe tests in order to prove its capabilities as regards power, flexibility, and endurance. A 72-hour full load trial was satisfactory, and it was proved that the engine did not require vigilant attention. The exhaust was practically invisible. At the end of this run the engine was slowed down to two-thirds speed and manœuvring trials were conducted. It was seen that 14 cubic feet of air at 700 lbs. per sq. in. was sufficient for starting and reversing the engine 42 times, the pressure of air going down to 90 lbs., which was insufficient for starting.

As an example of flexibility, the tests to determine the minimum speed consistent with smooth running of the engine are interesting. The speed was gradually reduced from 400 down to 50 r.p.m. with suitable power and without alteration to fuel pumps, etc. It was found that 50 r.p.m. could be maintained without fluctuations, and with a steady blast pressure of 630 lbs. per sq. in.

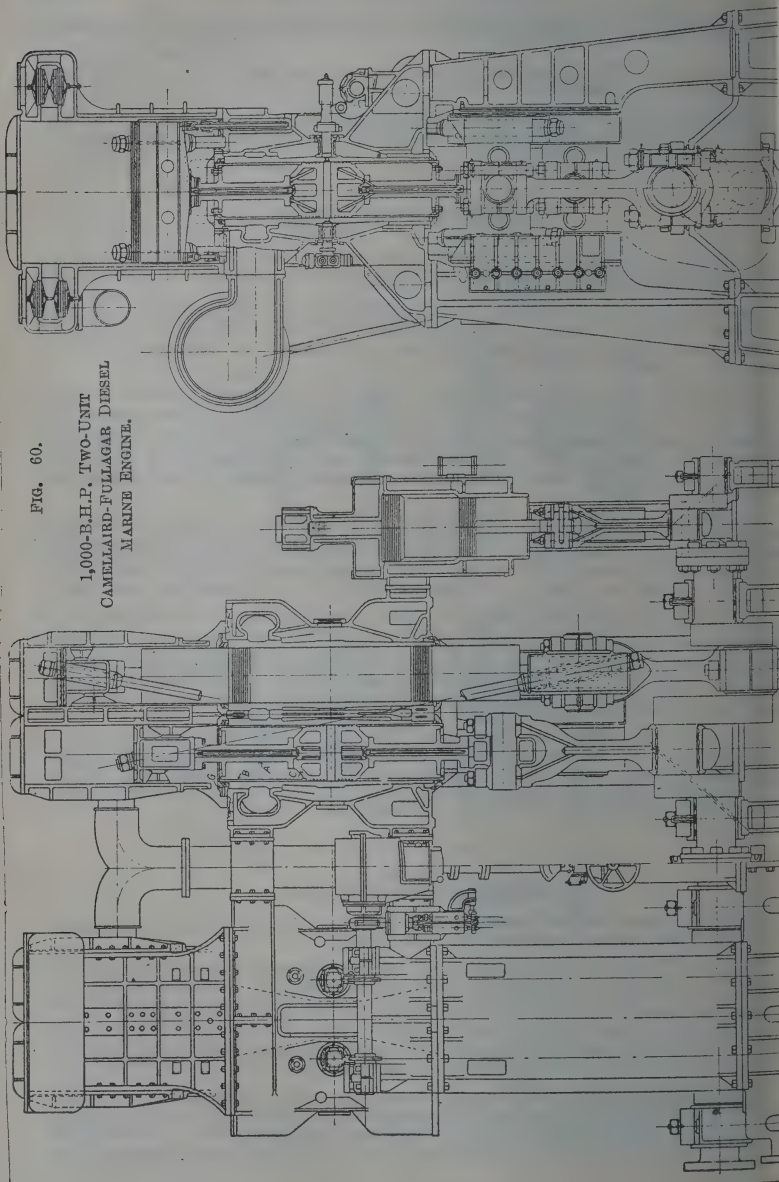


FIG. 60.

1,000-B.H.P. TWO-UNIT CAMELLAIRD-FULLAGAR DIESEL MARINE ENGINE.

SWAN, HUNTER & WIGHAM RICHARDSON,

LIMITED,

WALLSEND-ON-TYNE.

BUILDERS
AND REPAIRERS OF
SHIPS AND ENGINES
OF ALL CLASSES.

—FLOATING DOCK—
SPECIALISTS.

BUILDING BERTHS for ships
up to 1,000 ft. in length.

MARINE ENGINE WORKS
with an aggregate capacity of
450,000 H.P. a year.

NEPTUNE, WALLSEND-SULZER,
and BARCLAY CURLE-DOXFORD

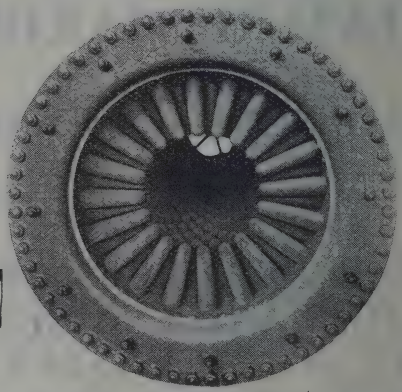
DIESEL ENGINES

Head Office: WALLSEND-ON-TYNE
Telephone: Wallsend 112. Telegrams: 'Swanhunter, Wallsend.'

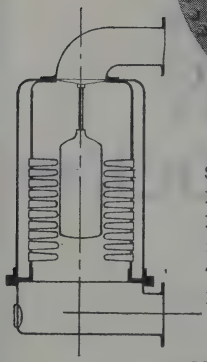
London Office: 21 RUSSELL SQUARE, W.C.1.
Telephone: Museum 6851. Telegrams: 'Swanhunter, Phone, London.'

Clarkson Silencer-Boiler

End view with

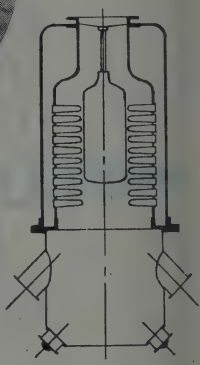


Centre core removed



SILENCER BOILER FOR 1 ENGINE TYPE BEGAT

SILENCER BOILER FOR 2 ENGINES WITH 2 OIL BURNERS TYPE BEGATOO



SEE EDITORIAL PAGES 2184, 2185, 2186.

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Specified for a further 21 Sea-going Vessels
Saving £4 to £5 per 1000 B.H.P. per day.

Please give exhaust pipe diameter

The Clarkson Thimble Tube Boiler

COMPANY LIMITED,

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The White engines are vertical, with stepped pistons, the working piston having a clearance of about 0·024 in. and relying for gas-tightness wholly upon its rings, while the lower portion fits the cylinder liner and takes the side thrust of the connecting-rods; this lower portion is always comparatively cool, and hence is easily kept effectively lubricated. An important feature of the latest design is the rotating scavenge valves, the sleeve within which they work forming part of the reversing mechanism of the engine.

The Beardmore Diesel Engine.

Messrs. Beardmore & Co., Dalmuir, manufacture the Tosi design of Diesel engine, of which large numbers have been supplied for submarines and other work. The engines are of the four-stroke cycle type, and are very economical, the full load fuel consumption being only 0·4 lb. per b.h.p. hour.

The engines are of the enclosed design and are noteworthy for the elegance of their appearance. They are made in a number of sizes up to 4,000 b.h.p. Before standardising the four-stroke cycle engines, Messrs. Franco Tosi constructed a two-stroke cycle engine, so that they could make comparative tests. The latter engine had six cylinders and developed 1,300 b.h.p. when running at 300 r.p.m. The results of the tests showed that their eight-cylinder 1,450 b.h.p. engine was much more economical in fuel.

The outstanding feature of the Tosi design is a director valve fitted in conjunction with a combined valve in the cylinder head, which alternately admits air to the cylinder and allows the exhaust gases to escape from it, depending on the position of the director valve. In this way the cylinder valve is kept cool and free from carbon.

The latest Beardmore engines are arranged for supercharging.

Double-acting Beardmore-Tosi engines have been installed in the converted steamer *Wulsty Castle*, driving the propeller shaft at 80 r.p.m. through Vulcan hydro-mechanical gearing, the engine speed being 250 r.p.m.

See also p. 1944.

Other Types of Marine Diesel Engines.

Among the other British makers of Diesel engines for marine work are Harland & Wolff, of Belfast, the North British Diesel Engine Works, Glasgow, and Scotts Shipbuilding Co. All of these makers are well known in marine engineering and, in their manufacture of Diesel engines, uphold the high traditions of British marine practice.

There are various other types of Diesel engines, but although they differ in some details from the engines already described, the points of difference are not usually important. In the single-acting two-cycle engine of the Maschinenfabrik Augsburg Nurnberg A.G., a stepped piston is adopted, the scavenge pumps being directly below the working cylinders. This arrangement has the advantage of occupying less floor space although the height is greater. The motors are not so accessible, but the amply dimensioned gudgeon pin is kept cool, and there is a large guide surface. With the large low-speed engines of the open crosshead type, scavenge pumps are driven off the extended crankshaft, or by rocking levers. Four-cycle engines are also built by the M.A.N. Co.

A double-acting two-stroke engine of 15,000 h.p. has been constructed by M.A.N. for a land installation, and the motor liner *Augustus* is fitted with four such engines, each developing up to 3,000 s.h.p. A feature of this engine is that the scavenge ports are at the same side of the cylinder as the exhaust ports and are uncovered by the piston after the exhaust ports are fully open.

In the low-speed, two-stroke-cycle engines constructed by Messrs. Krupp, of Kiel, the general design is similar to the Carels type, except for some slight modification in the reversing gear, whilst for high-speed engines employed in submarines enclosed engines are constructed. These are made up to 1,000 h.p. and have a scavenge pump at each end and an air compressor in the centre. A section through a Krupp-Diesel slow-speed engine of 1,150 b.h.p. is shown in fig. 61.

One of the most interesting of the large Diesel engines that has been developed during the last few years is that of the F.I.A.T. Company of Turin. This is of the two-cycle type, and it is of especial interest in that after experience with two-cycle motors with valve scavenging the newer types are provided with ports in the cylinder walls for the admission of the scavenging air.

The scavenge ports are uncovered by the piston before the exhaust ports and are fitted with automatic disc valves. Marine Diesel engines of this design have been built in power up to 3,200 h.p. in six cylinders.

A development of the past year or so which seems likely to have a marked effect on the question of the manufacture of small internal combustion motors is the low-powered type of Diesel marine engine built by the Polar Company of Stockholm. It is of the four-cycle non-reversible type running at about 550 r.p.m. and is made in 1, 3, 4, 6 and 8 cylinders, each cylinder having an output of 12½ h.p. It is so far as possible totally enclosed and the construction is perfectly standardised. A reverse gear of the ordinary type has to be employed with engines of this design, since they are not made reversible as are the larger sets.

THE KRUPP MARINE DIESEL ENGINE.
(1,150 b.h.p.)

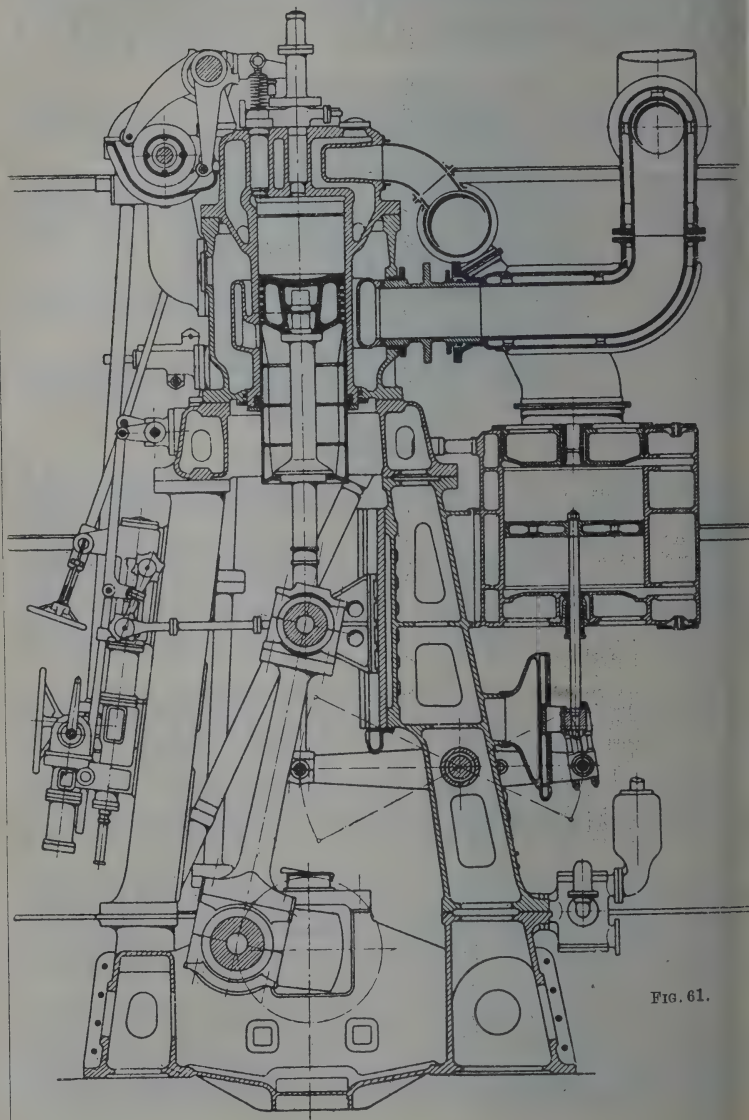

FIG. 61.

Diesel Engines for Submarines.

Practically all the European and American navies are now solely relying upon Diesel engines r the propulsion of submarines on the surface. These motors are of totally distinct type from ıose of the ordinary marine engine owing to the necessary high speed in order to reduce the eight sufficiently. They usually run at 400 to 500 r.p.m., and they are now constructed in ›wers up to 1,300 b.h.p. In the German and several other European Navies the Krupp two- ·cle engine was employed, and also that of the M.A.N. Co., which is likewise of the two-cycle ngle-acting type. The former is a six-cylinder machine with two scavenge cylinders in the ntre driven direct off the crankshaft, whilst in the latter the scavenge pumps are arranged rectly beneath each working cylinder. The air pumps for air injection are also driven off the igine, so that it is practically self-contained. The weights of these motors are low, and usually mewhere in the neighbourhood of 50 to 60 lbs. per b.h.p. For the British Navy the ickers type is usually employed, which is a four-cycle twelve-cylinder motor of about 1,200 b.h.p. ı this engine, solid injection of fuel is always adopted—that is, the injection by mechanical means stead of compressed air. The advantage of this is that no air compressor is required, which is ry desirable in a submarine. Although the engine as a Diesel engine is not quite so efficient as ith air injection, the absence of air compressor renders the overall economy about the same as in her types of motors. It is doubtful, however, whether such heavy fuel may be satisfactorily nployed as with the other engines, and Broxburn shale oil is generally used in these submarines. wo-cycle engines have also been designed for operation with mechanical injection.

Other types of Diesel engines are now used in British submarines, and one of the first of the ›o-cycle types to be employed for the purpose is the F.I.A.T., which was installed in the first bmersible built by Scott's Shipbuilding and Engineering Co. In this engine the scavenge ımps are arranged beneath the working cylinders as with the M.A.N. engine previously men- ›ned, the pistons being stepped in the ordinary manner. Other types of two-stroke Diesel otors will be installed in British submarines, if they have not already been so fitted.

In order to keep the piston speed of submarine engines within the limits which it is not sirable to exceed (from 900 to 1,100 ft. per min.), it is usual to make the ratio of the stroke to e bore very much less than with the ordinary mercantile type of motor. Frequently the stroke made equal to the diameter of the cylinders, and is very seldom more than 10 per cent. greater. this way it is possible to construct Diesel for submarine purposes almost equal from the point view of reliability to the slow-running types. High-speed engines of 1,300 h.p. have been ınstructed for installation to submarines, and others of over 2,500 b.h.p. in eight cylinders ıve been designed, and are possibly now being built for the same purpose.

A particularly important type of submarine Diesel engine is illustrated in fig. 62. This is Sulzer motor as employed in several navies, and mainly follows along the lines of the slow eed mercantile Diesel motors built by the same firm and described in the preceding pages. ıe most notable feature is that port scavenging is employed and the method of introduction an extra supply of scavenging air through valve controlled auxiliary ports is the same as the larger sets. It had been thought that the high speed of rotation (350–500 r.p.m.) might nder this system inefficient for submarine engines, but this does not appear to be the case. ›tors of this design are being built in powers up to 4,000 b.h.p. per engine.

In their latest submarine motors the F.I.A.T. Company have also adopted the port scavenging rangement, and engines of 1,300 h.p. in eight cylinders built according to this principle have ready been installed in Italian submarines.

Output, Dimensions, and Weights of Diesel Marine Engines.

The design of Diesel engines in regard to the main dimensions of cylinders, etc., is not yet a very definite or exact basis, mainly owing to the variations of mean effective pressure in e cylinders, and the uncertainty regarding the best speed of revolution. The output of a linder varies with the diameter, the stroke, the mean effective pressure, and the speed of ·olutions. In general terms it may be expressed as follows:

B.H.P. = KD^2LNn, where K = a constant; D = diameter of cylinder; L = stroke of ıton; N = revolutions per min.; n = number of cylinders.

Taking the dimensions of the cylinders in inches it is found that for four-cycle engines the lue of K varies between ·00007 and ·00009, a good average figure being

$$K = \cdot00008.$$

For two-cycle engines the value is between ·000125 and ·000155, the average being

$$K = \cdot00014.$$

As the mean effective pressure varies between 70 and 105 lbs. per square inch, and is some- ›es higher, it is evident that cylinder dimensions are no absolute criterion of the exact output a Diesel engine at a constant speed of revolution.

The piston speed in two- and four-cycle engines is approximately the same, namely, about 3 4 metres per sec., or 580 to 780 ft. per minute, with the ordinary marine motors. It does not ·an exceed these limits, except in high-speed engines of the type employed in submarines,

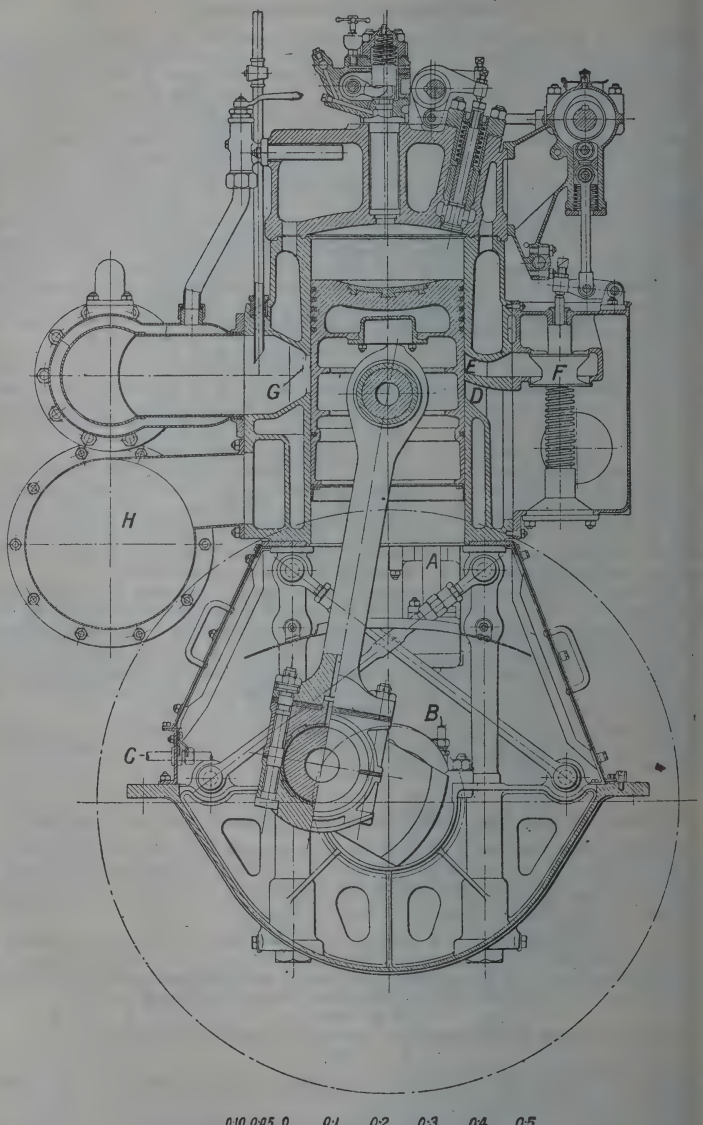

FIG. 62.—SULZER SUBMARINE DIESEL ENGINE.

when it may be as much as 1,100 ft. per minute. In the Burmeister and Wain double-acting four-cycle type the piston speed is about 1,200 ft. per minute.

The ratio of stroke to bore is a matter of wide variation, and in some cases is as low as 1·3 and others as high as 1·8. This latter figure is common in two-cycle motors with valve scavenging. Some types of four-cycle motors have a ratio of 1·4 and others 1·8.

The weight of Diesel marine engines varies as a rule between 200–300 lbs. per b.h.p., but is reduced to 60–70 lbs. per b.h.p. in submarine motors. Four-cycle engines are heavier than two-cycle, but the difference is not very marked, except in special cases, average figures being 300 lbs. and 250 lbs. respectively. This includes air compressors, scavenge pumps (in two-cycle motors) and various bilge, oil, and circulating pumps driven direct by the engine.

Weir High Pressure Air Compressors.

(G. & J. Weir, Ltd., Cathcart, Glasgow.)

Fig. 63 shows a typical Weir three-stage, single-acting, twin-crank, motor-driven air compressor, for a delivery pressure of 1,000 lbs. per sq. in. In this machine the first and second stages are formed by means of a differential type piston, the air passing from the first stage of compression through the first stage intercooler and thence to the annular space forming the second stage. After second stage compression and cooling, the air passes to the third stage situated at top of the machine, where, when third stage compression is completed, the air is delivered through the after-cooler and oil and water separator.

The coolers are of the tubular type, the air passing through copper tubes expanded into rolled brass tube plates. Arrangements for the longitudinal expansion of the tube units are provided, and all troubles associated with tube packings are completely eliminated.

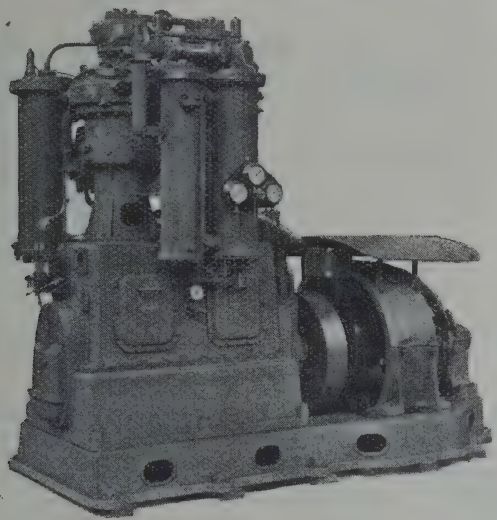

Fig. 63.

The pistons are of high-grade cast iron fitted with cast-iron rings of the Ramsbottom type. With the perfected lubricating and cooling arrangements in the Weir compressor, the wear on these cast-iron rings over long periods of running is practically negligible, the tool marks being visible after years of running.

The air valves are of special design, the valve plates being made in a steel alloy, heat-treated to obtain the correct degree of hardness. The lift of the valve is exceedingly small, preventing undue shock and noise and obtaining a high degree of efficiency. As a special precaution the valve seats are made in mild steel perforated with small holes, this type being superior to the usual cast seat with annular slots, as the former design makes it practically impossible for fragments of a broken valve to enter the cylinder with destructive effect. The assembled valve units are arranged round the cylinder heads in such a manner as to reduce the cylinder clearance to a minimum, and give a resultant high volumetric efficiency.

The motion work generally is robustly designed to meet the high stresses generated in r ciprocating air compressor machinery. The crank webs and connecting rod jaws are cut fro solid mild steel forgings and machined all over. The crosshead and piston rod are forged one piece, and tapers are provided on the rod to take the pistons.

As in best modern practice, forced lubrication is applied to all bearing surfaces, the cran case bearings being served through a special system of oil ducts by an oil pump of the oscillatin disc type. Cylinder lubrication is effected by a mechanical sight feed lubricator, feeding minu quantities of oil at the correct points on the cylinder walls, and maintaining the thin even film so necessary with comparatively high-temperature conditions.

The balancing of these compressors has received careful consideration, the weights in all cas being designed to effectively balance the forces set up by the reciprocating parts.

The circulation of the water spaces is carried out by a plunger type water-pump driven fro the compressor crankshaft. This pump is of a very compact and positive design, and has a cas iron body and gun-metal plunger with valves of the Kinghorn type.

The foregoing description is typical of compressors largely supplied for motor ship auxilia duties, viz. Diesel engine air-blast injection, manœuvring, etc.

Compressors dealing with oxygen and other industrial gases for delivery pressure ranging 6,000 lbs. per sq. in. are constructed, and may be arranged for drive either by electric moto independent steam engine, tandem steam engine, or oil engine.

Power of Diesel Marine Engines.

The following table gives details of the dimensions and powers of some of the types of Dies marine engines as now built :—

Engine.	B.H.P.	Diam.	Stroke.	R.p.m.	No. of Cy
Sulzer	4,000	28	39	110	8
Polar	800	15·7	21·25	165	6
Burmeister & Wain (Single Acting)	1,100	20·5	28·5	140	8
" " (Double Acting)	9,000	33	59	125	8
Werkspoor	1,100	22	39·4	125	6
Carels	1,800	23·5	43·2	90	6
"	1,500	20	36·4	120	6
Krupp	1,150	17·3	31·4	130	6
Burmeister & Wain (Single Acting)	1,150	21·3	28·6	140	8
Carels	900	17·6	22	234	4
Werkspoor	600	15·75	27·625	160	6
"	400	15·75	27·625	160	4
Polar	350	11·4	11·8	500	6
Fullagar	1,000	18·5	25·5	110	4
Doxford	2,900	22·75	45·5	87	4
"	2,200	22·75	45·5	90	3
"	1,850	21·25	42·5	90	3
"	5,000	26·75	53·5	90	4
M.A.N. (Double Acting)	7,000	27·5	47·2	125	6

Diesel Marine Engines in Service.

Motor ships have now been in operation for some considerable time, and it is possible to in what manner the chief defects have developed. At first the four-cycle engines proved m satisfactory, probably owing to the fact that more experience had been gained with this type motor previously for land work ; but the two-cycle engine is now quite as reliable in every respe due to recent developments. In the two-cycle engines the chief difficulty encountered was t cracking of cylinder covers which occurred with many engines, but the Sulzer cover is immu from this trouble, owing to the single opening for central valve. Cast steel, which was employ in some instances, has now been abandoned entirely in favour of cast iron, and with a pro mixture it is probable that the cracking of covers will in future be avoided. Air compress have in some instances given rise to difficulty, whilst in the four-cycle motors, as might ha been anticipated, the exhaust valves have required special attention.

The 1922 report of *Lloyd's Register of Shipping* devotes considerable attention to the de lopment of the Diesel oil engine. Several vessels of considerable size fitted with Diesel engi were built during the war to the Society's class by Messrs. Harland & Wolff and by Mess Burmeister & Wain, of Copenhagen. Until recently the largest Diesel engines fitted in a merchant vessel were the twin screw engines made by Messrs. Harland & Wolff, of Glasg for the motor vessel 'Glenapp,' of 7,374 tons gross, built in 1918 by Messrs. Barclay, Curle Co., Ltd. The Fairfield Shipbuilding & Engineering Co. completed a large passenger and ca vessel in 1924, with four screw engines of 12,000 b.h.p. of the Fairfield Sulzer type. The 'Aoran is 600 ft. long, with a service speed of 17 to 18 knots. This vessel is on service between Cana and Australia, and has conclusively demonstrated that the Fairfield Sulzer Diesel engine entirely satisfactory for propelling ocean liners.

The following table of typical vessels illustrates the advance which has taken place in the construction of Diesel engines :—

Name.	Tons.	Twin or Single Screw.	Date of Construction.	Cylinders.		Stroke.
				No.	Diam.	
'Vulcanus'	1,179	Single	1910	6	15½	23
'Selandia'	4,950	Twin	1912	16	20⅞	28
'Juno'	2,345	Single	1912	6	22	39½
'Siam'	5,296	Twin	1913	16	23½	31½
'Fiona'	5,219	"	1914	12	29½	43 5/16
'Panama'	5,239	"	1915	12	24 13/16	37 13/16
'Glenamoy'	7,269	"	1916	12	26¾	39 3/4
'Glenauy'	5,075	"	1917	12	24 13/16	33½
'Glenapp'	7,374	"	1918	16	29½	43 5/16
'Aorangi'	18,500	Four	1922	24	27½	39
'Asturias'	22,000	Twin	1925	—	—	—

There were recorded 2,343 motor vessels in Lloyd's Register, 1926, of which 134 have tonnages ranging from 1,000 to 2,000 tons, 128 at 2,000 to 4,000 tons, 185 at 4,000 to 6,000 tons, and 177 from 6,000 to 10,000 tons, and 15 above 10,000 tons.

Oil Fuel for Diesel Engines.

(See also FUELS Section, page 2135.)

The fuel most commonly used in Diesel engines is that known as the residual oil, which is obtained by the process of distilling the crude oil when the lighter spirits are carried over, and the residual remains. Some crude oils are, however, directly used in Diesel motors, and in particular Texas oil, which does not contain sufficient proportion of petrol and other lighter oils to warrant its distillation. The only oil fuel which is unsuitable for employment is that from an asphaltum base, and it is for this reason that Mexican fuel oil is not as a rule employed for these motors without special treatment. Besides Texas oil, that from the Californian, Persian, Trinidad, Galician, Roumanian, and Russian oilfields is satisfactory for use in Diesel motors. Tar oil, which is obtained from the distillation of tar, is also very largely utilised in Germany, where the duties on imported oils are excessive, and often render the employment of Diesel engines unprofitable. Tar oil has a higher specific gravity than the petroleum fuel (usually in the neighbourhood of unity or slightly over), and has a lower calorific value, so that the consumption of an engine using this fuel is greater than when running on the ordinary oil. It is very viscous and, therefore, often requires heating, whilst some slight modifications have usually to be made in the fuel injection arrangements in order that an engine should run quite satisfactorily on tar oil. The usual method is to allow the injection of a small quantity of a lighter fuel oil before the main body of the tar oil passes into the cylinders through the pulveriser. It is claimed, however, that some motors run without any modification whatever, but this should not be taken as a general statement.

For information relating to Diesel engines for land installations, see page 1939.

ENGINE ROOM STAFF FOR MOTOR SHIPS.

Vessel.	Engine Room Staff.	
	Engineers and Electricians.	Greasers, Mechanics, Donkeymen, etc.
'Conde de Churruca'	4	5
'Handicap'	8	6
'Glenapp'	11	6
'Glenluce'	10	(?)
'Lobos'	11	9
'William Penn'	3	9
'Asia'	9	4
'Ossag'	7	4
'Magvana' and 'Melma'	12	17
'Seminole'	8	(?)
'Domala'	12	24 (Natives)
'Aorangi'	19	—

COMPARISON OF MACHINERY FOR A CARGO SHIP DRIVEN BY A TRIPLE-EXPANSION RECIPROCATING STEAM ENGINE AND BY AN OIL-DRIVEN DIESEL ENGINE.

Dimensions of ship 360 ft. by 48 ft. by 29 ft.

Speed		13 knots.	
E.H.P.		1,500	
Diesel Engine—			
Revolutions		100	
Propulsive efficiency		·51	
B.H.P.		2,950	
Weight of 6-cylinder single-acting 2-cycle engine		290	tons
Weight of boiler 5 ft. by 10 ft. high, with water uptakes and funnel		10	,,
Diesel electric generators		40	,,
Electrically-driven auxiliaries		30	,,
Silencers, piping and other fittings in engine-room		100	,,
Shafting propellers and other tunnel weights		70	,,
Tons		540	
Steam Engines—			
Revolutions		60	
Propulsive efficiency		·50	
I.H.P.		3,000	
Weight of engines and boilers, etc.—			
(*a*) with Howden draft at 5·5 I.H.P. per ton		545	tons
(*b*) ,, natural ,, 5 ,,		600	,,
Length of machinery spaces except bunkers—			
Oil engine		60	ft.
Steam engine, Howden draft		50	,,
,, natural ,,		65	,,

			Per h.p. per hour. Lbs.	Per day Tons.
Fuel Consumption	Oil Plant	Main engine	oil ·43	13·6
		Auxiliary machinery, electrically driven	·04	1·4
		Total	·47	15·0
	Steam Plant	Main and auxiliary machinery	coal 1·7	55
Engine Room Complement	Oil Engines:	Engineers	6	14
	,,	Greasers	8	
	Steam Engine:	Engineers	4	30
	,,	Greasers	6	
	,,	Stokers and Trimmers	20	

LLOYD'S RULES FOR MARINE INTERNAL-COMBUSTION ENGINES. See page 1975.

Metals for Propellers.

A properly designed bronze screw will give a very marked increase of speed (as much as *half a knot*) as compared with an iron or steel propeller, this being due to reduced scantlings, smoother surfaces, etc. Whilst the efficiency of a bronze screw continues unimpaired, that of an iron or steel propeller diminishes, through the pitting and corroding of its surface. In the case of solid screws the reduction in weight as compared with a cast-iron screw ranges from 10 to 20 per cent.

Nearly all vessels of any size or pretension are now fitted with bronze propellers. The metal has a tensile breaking strength of about 32 tons per square inch with about 20 per cent. elongation, and a transverse strength of over 7,500 lbs. per square inch. All warships as well as many merchant steamers are fitted with bronze propellers. Cast-steel propellers cost about twice as much, and bronze propellers about six times as much, as those of cast iron.

The *Bull's Metal Company* have with great success combined the study of Bronze Propeller designs with that of material, manufacture, and finish, large numbers of ordinary Bronze Propellers having been replaced with Bull's Metal propellers, giving, it is stated, a very material increase in speed on a reduced consumption of coal.

The *Delta Metal Co. Ltd.*, supply their special corrosion-resisting 'Delta' propeller bronze for casting propellers and propeller blades.

(See also Section XL, METALLURGY, p. 2715.)

BULL'S METAL & MELLOID CO.

LTD.,

Telegram Address: 'Melloid, Yoker.'
Telephone Nos {182 Clydebank. 183 ,,

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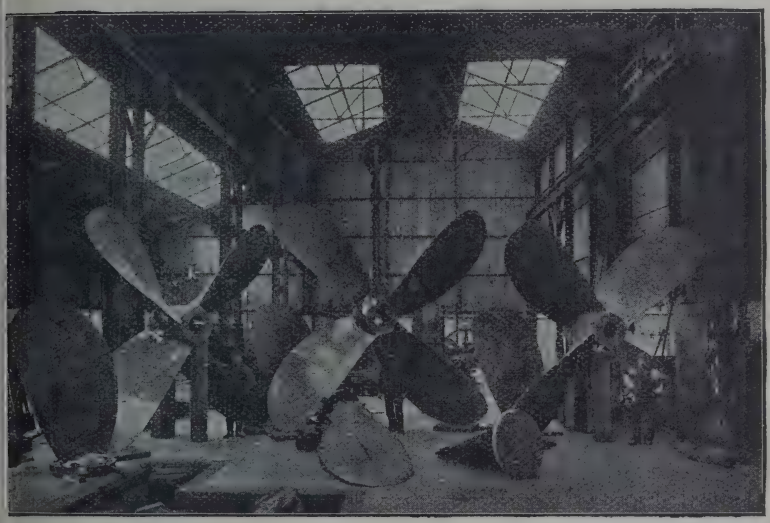

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Pump Rods, Valve Spindles,
Bars, Forgings, Bolts, Nuts, Castings.

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Piston Cooling Tubes, Boiler Stays, Beater Bars, Bearings, Glands,
Bars, Forgings, Slide Valves, Piston Rings, Etc., Etc.

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F. 2436

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Elements of Propulsion.

If a vessel (without propeller) moving at a speed of V feet per minute experiences a total resistance of R pounds, a force R must be applied continuously by means of a thrust or tow-rope pull in order to overcome the resistance and maintain the speed. The power required is RV foot-pounds per second and is called the Tow Rope Power or Effective Power.

$$\text{Effective Horse Power, E.H.P.} = \text{R.V.} \div 33000 = \cdot 00303 \text{ R.K.}$$

If the thrust is delivered by a screw propeller working behind the ship, it is found that the action of the propeller increases the resistance. This increase is called the 'Augment of Resistance.' T, the total thrust of the propeller, must therefore be equal to R + Augment = R + A, and T − A = R. The augment of resistance can therefore be regarded as a deduction from the thrust: it is alternatively called the 'Thrust Deduction' and is written A = tT, where t is the 'Thrust Deduction Fraction.'

$$T - tT = T(1 - t) = R$$

$(1 - t)$ is called the Thrust Deduction Factor.

If a vessel is being towed at a speed of K knots, the skin friction sets the adjacent water in motion, and at the stern there will be found a 'wake' current moving in the same direction as the ship at some speed W knots. The stern, and with it the propeller, will therefore be moving at a speed K — W relatively to the wake water, and this speed is called the 'Speed of Advance.' Froude compares wake speed with speed of advance, and writes W = ω (K − W) = ωK'.

$$\text{Wake fraction} \quad \omega = \frac{W}{K - W} = \frac{W}{K}$$

$$\text{Wake factor} \quad 1 + \omega = \frac{K}{K - W} = \frac{K}{K}$$

$$\text{Wake per cent.} \quad 100\omega.$$

Taylor compares wake speed with ship speed, and writes—

$$\omega = \frac{WK}{K}$$

$$\text{Wake fraction} \quad \omega = \frac{W}{K}$$

$$\text{Wake factor} \quad 1 - \omega = \frac{K - W}{K} = \frac{K'}{K}$$

$$\text{Wake per cent} \quad 100\omega.$$

If a propeller having a pitch P and making N revolutions per minute is working behind a ship and producing a thrust T with a torque Q in the shafting just forward of the propeller, the ship's speed being K and the speed of advance of the propeller K' = K − W, the work obtained will be RK (E.H.P.) and the work expended 2πNQ, which we can call the 'Received Horse Power Behind' R.H.P.$_b$. The efficiency η is therefore $\frac{\text{E.H.P.}}{\text{R.H.P.}_b} = \frac{RK}{\text{R.H.P.}_b} = \frac{T(1 - t) \times K' (1 + \omega)}{\text{R.H.P.}_b}$.

TK' is called the 'Thrust Horse Power' (T.H.P.) and the product $(1 - t)(1 + \omega)$ the 'Hull Efficiency,' being the product of one factor $(1 - t)$ representing the effect of the propeller on the hull and another $(1 + \omega)$ representing the effect of the hull on the propeller. If we write—

$$\text{Hull Efficiency} = h = (1 - t)(1 + \omega)$$

we have

$$\text{Screw Efficiency Behind} = \eta = \frac{\text{T.H.P.}}{\text{R.H.P.}_b} h.$$

Now if the same propeller be mounted on a shaft alone, without ship or model, and run in open water at the same revolutions N, and its speed of advance adjusted until it gives the same thrust T, we can fairly assume that the speed of advance so found must be the same as the speed of advance when in place behind the ship. We are thus able to determine the wake speed. The torque is not necessarily the same as when behind the ship, though it is usually not very different, so we call the power in the shaft 'Received Horse Power in the Open,' R.H.P.$_o$, and the 'Efficiency in the Open,' $\odot$, is $\frac{TK'}{\text{R.H.P.}_o} = \frac{\text{T.H.P.}}{\text{R.H.P.}_o}$.

The ratio $\frac{\text{R.H.P.}_o}{\text{R.H.P.}_b}$ is called the 'Relative Rotative Efficiency,' r.

Finally therefore, we can write—

$$\eta = \frac{\text{T.H.P.}}{\text{R.H.P.}_b}\,h = \frac{\text{T.H.P.}}{\text{R.H.P.}_o} = \frac{\text{R.H.P.}_o}{\text{R.H.P.}_b}\,h = \odot\, rh,$$

or screw efficiency behind = screw efficiency in open × relative rotative efficiency × hull efficiency.

S.H.P., the 'Shaft Horse Power' (or B.H.P., the 'Brake Horse Power'), is the power in the shafting just abaft the engine. The shaft line efficiency l is the ratio $\frac{\text{R.H.P.}_b}{\text{S.H.P.}}$. The mechanical efficiency of the engine m is the ratio of S.H.P. to the indicated horse power (I.H.P.).

$$\therefore \quad \text{S.H.P.} = m \times \text{I.H.P.}$$

$$\text{R.H.P.}_b = l \times \text{S.H.P.} = l \,.\, m \,.\, \text{I.H.P.}$$

$l \times m$ is the 'Transmission Efficiency,' $f = \frac{\text{R.H.P.}_b}{\text{I.H.P.}}$.

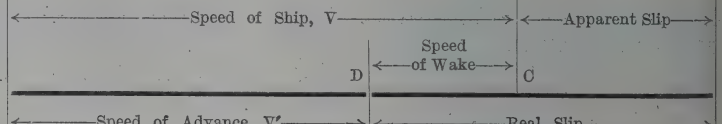
The overall propulsive efficiency or propulsive coefficient, ϵ,

$$= \frac{\text{E.H.P.}}{\text{I.H.P.}} = \frac{\text{E.H.P.}}{\text{R.H.P.}_b} = \frac{\text{R.H.P.}_b}{\text{I.H.P.}} = \eta f = \odot\, rhf.$$

η is sometimes called the 'Quasi-Propulsive Coefficient.'

A propeller having a pitch P and making N revolutions per minute would advance a distance PN if there were no slip. On account of slip, however, it actually advances a lesser distance V' called the 'speed of advance.' The difference is called slip, so that slip = PN − V', and the 'slip ratio' $s = \frac{\text{PN} - \text{V}'}{\text{PN}} = 1 - \frac{\text{V}'}{\text{PN}}$. If the thrust is T and the torque Q, the efficiency $= \frac{\text{TV}'}{2\pi\text{NQ}} = \frac{\text{TP}\,(1-s)}{2\pi\text{Q}}$.

When attached to a ship the apparent speed of advance is the ship's speed K knots or V feet per minute, where $\text{V} = 101\frac{1}{3}\text{K}$. The apparent slip is PN − V. On account of the presence of the wake stream, however, the true speed of advance of the propeller through the water surrounding it is K − W(= K') knots or V' (= $101\frac{1}{3}$K') feet per minute, and the real slip is PN − V'. Let AB represent to scale the 'Speed of the Propeller':



AC the speed of the ship V, and CD the speed of the wake.

$$\text{Then apparent slip ratio} = \frac{\text{CB}}{\text{AB}}$$

$$\text{Real slip ratio} = \frac{\text{DB}}{\text{AB}}$$

$$\text{Froude's wake fraction} = \frac{\text{DC}}{\text{AD}}$$

$$\text{Taylor's wake fraction} = \frac{\text{DC}}{\text{AC}}$$

(*W. J. Luke.*)

Law of Comparison for Model Propeller Experiments.

If a model propeller $\frac{1}{n}$th of the size of the ship's propeller is run at $\sqrt{n}$ times the revolutions and its speed of advance adjusted so that both screws are working with the same slip ratio, the thrust

of the ship's propeller will be n^3 times that of the model, the torque n^4 times, the powers $n^{3\frac{1}{2}}$ times, and the efficiencies equal.

	Model Propeller	*Ship's Propeller*
Diameter	d	$D = nd$
Pitch	p	$P = np$
Revolutions	r	$R = n^{-\frac{1}{2}} r$
Speed of Advance	v'	$V' = n^{\frac{1}{2}} v'$
Slip Ratio, s	$1 - \frac{v}{pr}$ =	$1 - \frac{V'}{PR}$
Thrust	t	$T = n^3 t$
Torque	q	$Q = n^4 q$
THP = U	$\frac{tv'}{33000}$	$\frac{TV'}{33000} = n^{3\frac{1}{2}} \frac{tv'}{33000}$
RHP = P	$\frac{2\pi vq}{33000}$	$\frac{2\pi RQ}{33000} = n^{3\frac{1}{2}} \frac{2\pi vq}{33000}$
Efficiency	$\frac{tv'}{2\pi rq}$ =	$\frac{TV'}{2\pi RQ}$
ρ_U (Rho-U)	$\frac{ru^{\frac{1}{2}}}{v'^{2\frac{1}{2}}}$ =	$\frac{RU^{\frac{1}{2}}}{V'^{2\frac{1}{2}}}$
ρ_P (Rho-P)	$\frac{rp^{\frac{1}{2}}}{v'^{2\frac{1}{2}}}$ =	$\frac{RP^{\frac{1}{2}}}{V'^{2\frac{1}{2}}}$
δ (Delta)	$\frac{dr}{v'}$ =	$\frac{DR}{V'}$

The last three functions are the same for all similar propellers working at the same slip ratio. ρ_U and ρ_P depend on revolutions, power and speed, which are given quantities in the initial stage of propeller design. The results of systematic propeller experiments are usually plotted on some function of Rho as base, since this is independent of diameter. For each of a series of pitch ratios, a curve of efficiency and a curve of some function (such as δ) involving the diameter are plotted, from which the most suitable diameter and pitch ratio can be found for the given power, revolutions, and speed of advance. Taylor has published four 'Rho-delta' diagrams obtained by combining and averaging his own propeller experiments with those of Froude, Durand, and Schaffran. These were reproduced in *The Shipbulder*, January 1925.

Metals for Marine Engines.

Delta Bronze Nos. I. and IV. alloys (see Index), Phosphor bronze, and Phosphor white lining metal No. II. are especially suitable for various parts of marine engines: the latter metal (phosphor white) has a higher fusing point than good Babbitt metal, thus allowing a bearing to heat without causing the metal to melt, a matter of some importance at sea.

Delta Bronze No. IV., a malleable bronze of great strength and tenacity, is specially adapted to replace steel in cases where a material of the highest corrosion-resisting qualities is desired. For this reason it is employed on a very large scale in the form of forgings or extruded or rolled rods, etc., for air and circulating pump rods, shafts, plungers, spindles, thrust block bolts and other parts of marine engines. For particulars of corrosion-tests, see p. 284.

Phosphor-bronze sheet is superior to copper in withstanding the action of sea-water. In a comparative experiment made at Elankenberghe, lasting over a period of six months, between the best English copper and phosphor bronze, the following results were arrived at: the loss in weight due to the oxidising action of the sea-water averaged for copper 3·058 per cent., while that of the phosphor bronze was only 1·158 per cent.

For lining bearings, crank-pin bushes, and other parts, exclusive of crosshead bushes, the following alloy has been found to give good results after extended experience in hard ocean steaming :—12 parts tin, 1 part copper, 1 part antimony, mixed in the following way : 6 parts tin alloyed with 1 part of antimony, and 6 parts tin with 1 of copper, and the two mixed together. For lining crosshead brasses the following harder alloy has been found to give good results : 85 per cent. tin, 5 per cent. copper, and 10 per cent. antimony.

The *Eyre Smelting Co., Ltd.*, who have made a special study of bearing metals for marine engines, supply a particular alloy of white metal which is stated to give good results in the big end bearings of Diesel engines. For the small end bearings the company supply a mixture of phosphor bronze, which is largely used in this country and on the Continent.

Painting Ships' Bottoms.

Ordinary oil paints are not suitable for this purpose, particularly because the drying of each coat of oil paint takes a longer time than owners can afford to allow vessels to remain in dock ; besides, these paints possess little or no power to prevent fouling. The practice, therefore, is to use what are termed ' compositions,' which are usually applied in two coats.

The composition paints have to be used in combination. The anti-corrosive, as a preservative and insulating coating, should be applied when the bottom is well scraped and dried. The anti-fouling composition contains powerful poisons and can be applied almost immediately after the primary coating, and the vessel can be floated as soon as the painting is completed, although it is desirable to allow the compositions a few hours to harden before the vessel enters the water.

It is very important to remove all rust or scale on the plates, as when such is not done corrosion is likely to continue beneath the surface and will eventually throw off any paint that can be applied. The ingredients in the best compositions are very expensive and are consequently not used to any extent in the manufacture of the cheaper brands.

The careful *stirring* up of these compositions is an essential point too often overlooked. The more valuable ingredients are heavy, and tend to form a sediment at the bottom of the drums, which requires to be carefully worked up. Much also depends upon careful painting—a thing which is unfortunately very difficult to arrange for in many of the dry docks owing to hurried and inefficient work.

Concrete Vessels.

A concrete weighing but 110 lbs. per cub. ft. and having a crushing strength after 28 days of 4,000 lbs. per sq. in., has been employed in the construction of reinforced concrete vessels of large tonnage, in America, for the United States Government. The aggregate itself, although light and cellular in structure, is not porous. The lighter quality will actually float on water, and as a test the United States Shipping Board authorities kept an amount of aggregate floating in water for some months, and it was demonstrated that the absorption was very small.

The aggregate is made from clay, calcined in kilns in a similar manner to that employed in the manufacture of bricks, the fundamental difference being that the heat (about 2,000° F.) is applied in a comparatively short time of 30 hours. This relatively sudden application of heat causes the material to swell, forming a clinker. The clay may be pressed into bricks and partially dried and stacked in kilns in the ordinary manner, care being taken to provide sufficient room around the bricks for expansion during burning. The size of the brick adopted in the United States is 8½ ins. by 4½ ins. by 2¾ ins. During burning, the bricks run together and form a solid mass of clinker, which is allowed to cool for about 3 days, in order to ensure a high degree of toughness. The cooling of the material is then completed by water, which causes the mass to split into pieces suitable for handling, and it is also found that this greatly facilitates the unloading of the kilns. The material may also be calcined in cement rotary kilns, the clay in this case being pressed into lumps of suitable size.

After burning, the product is crushed to the desired size. During the operation a proportion of the lightest aggregate is reduced to dust. This, however, is used to take the place of the sand or crushed stone in ordinary concrete, the constituent parts being carefully selected and graded. Light pneumatic hammers are used to vibrate the shuttering during ramming, materially assisting the flow of the concrete around the steel reinforcement, and producing a dense and impermeable material.

A number of reinforced light concrete oil tankers and cargo steamers of 7,500 tons deadweight have been under construction in various parts of the United States. These vessels are 434 ft. long. (*W. L. Scott, ' Engineering.'*)

When wood is used as a reinforcing material for concrete it should be impregnated with magnesium chloride, and the wood must be so placed that any change in the cross-sectional area does not affect the durability of the structure. If the latter precaution is overlooked the concrete may crack. Small strips of wood are better than larger ones, and rushes appear to be excellent for the purpose, especially for thin-walled structures such as ships.

(*Beton u. Eisen.*)

Lloyd's Rules for Ferro-Concrete Vessels.

No definite rules have as yet been formulated, but in regard to the quality and testing of steel to be used for reinforcements these are the same as given in Section 3 of the Rules of the Society, for Steel Ships. The cement should comply with the requirements of a recognised standard specification for Portland cement or the equivalent thereto. In the matter of the preparation of the concrete, the proportions of the cement, sand, and aggregate have been left to the individual constructors to submit their proposals for the consideration of the Committee, as these depend to some extent on the local facilities for obtaining sand and gravel, the quality of which varies in different districts.

In the design of vessels to be built of ferro-concrete, it is considered that concrete is incapable of withstanding any of the main tensional stresses, and the steel reinforcements embedded in the concrete must therefore be of sufficient strength to take up all the tensional stresses produced in the structure due to strain from longitudinal bending.

Lloyd's Tentative Regulations for the Application of Electric Arc Welding to Ship Construction.

(Abstract.)

Before welding, the surfaces to be joined must be fitted close to each other.

All butt and edge connections are to be lapped or strapped.

With lapped connections the breadths of overlaps of butts and seams and the profiles of the welds are to be in accordance with the following table :—

Thickness of plate. Inches.	Width of overlap seam and butt. Inches.	Throat thickness. Inches.
·40 and under	2¼	·28
·60	2½	·38
·80	2¾	·48
1·00	3	·50

Intermediate values may be obtained by direct interpolation, and for thicknesses below ·40 the throat thickness is to be about 70 per cent. of the thickness of the plate.

See also ' Electric Welding,' p. 2766.

SECTION XXXVII

GAS AND GASWORKS

GENERAL PRINCIPLES GOVERNING THE SIZE AND CAPACITY OF APPARATUS—COMPOSITION OF VARIOUS GASES — CONDENSATION, PURIFICATION, STORAGE — RETORTS—TAR DISTILLATION—WATER GAS—COMPLETE GASIFICATION — CYANOGEN — BENZOL RECOVERY — SULPHATE OF AMMONIA—FLOW OF GAS IN MAINS—GAS TESTS —ACETYLENE GAS—PETROL AIR GAS.

(Contributed by Alwyne Meade, A.M.Inst.C.E., author of 'Modern Gasworks Practice.')

SECTION XXXVII

GAS AND GASWORKS—GENERAL PRINCIPLES GOVERNING THE SIZE AND CAPACITY OF APPARATUS—COMPOSITION OF VARIOUS GASES—CONDENSATION, PURIFICATION, STORAGE—RETORTS—TAR DISTILLATION—WATER GAS—COMPLETE GASIFICATION—CYANOGEN—BENZOL RECOVERY—SULPHATE OF AMMONIA—FLOW OF GAS IN MAINS—GAS TESTS—ACETYLENE GAS—PETROL AIR GAS.

(Contributed and revised by **Alwyne Meade, A.M.Inst.C.E.**, author of '**Modern Gasworks Practice.**')

Parliamentary.

The public supply of gas in this country is governed largely by local Acts, but in general by the Gasworks Clauses Acts of 1847 and 1871, the Sale of Gas Act of 1859, and the Gas and Water Works Facilities Acts of 1870 and 1873, and most recently by the Gas Regulation Act (1920). London companies are, in addition, under the regulations of the Metropolitan Gas Act (1860). Under the Public Health Act of 1875, the local authority may become its own gas supplier, or may purchase an existing undertaking by agreement. Thus gasworks are controlled by—

(*a*) Statutory companies.

(*b*) Non-statutory companies.

(*c*) Local authorities.

The supply of gas in Scotland is, for the most part, in the hands of the local authorities. In England local authorities predominate as owners in the counties of Yorkshire and Lancashire, and in the North generally, but in the Home and Southern counties private ownership is the general rule. In addition to the Acts named above, the supply of gas in Scotland is governed by the Gas Acts of 1864 and the Burghs Gas Supply Acts of 1876 and 1893.

The obligations of the gas undertakings in the way of standards of quality were somewhat modified by an order made by the Minister of Munitions in June, 1918, as to the manufacture and production of gas, compliance with which order by the gas undertaking protected the undertaking from any forfeiture for failing to comply with its statutory obligations with regard to the illuminating power or the calorific power of the gas supplied, provided that in any event gas of a lower calorific power than 450 B.Th.U. gross was not supplied to the consumers.

It may be said that a new era in the supply of gas was marked by the introduction of The Gas Regulation Act of 1920. The commodity is no longer sold on a basis of cubic feet, but in terms of 'Therms.' In other words, the consumer now pays for the useful energy only, i.e. British Thermal Units; accordingly, the incombustible constituents in gas have no longer any commercial value. The standard 'Therm' is equivalent to 100,000 B.Th.U. Thus, if 10,000 cubic feet of gas are registered on the consumer's meter, and the 'declared' or normal calorific power of the gas is 500 B.Th.U. per cubic foot, then the number of B.Th.U. consumed is 5,000,000, or 50 Therms.

The main provisions of the Act are as follows :—

(*a*) The obligation to charge consumers on the heat unit basis.

(*b*) The adjustment of the 'standard' or 'maximum' price (on the heat-unit basis) t meet the additional expenses of manufacture and distribution arising from post-wa conditions.

(*c*) Powers are given to the Board of Trade to limit the proportion of inert constituen in the gas, if thought fit; but the committee appointed to examine the question incombustibles recommended that no limit should yet be imposed.

(*d*) There is an obligation to supply gas at 2 ins. water pressure in mains or services 2 ins. diameter and upwards.

One of the most noteworthy provisions of the Act is the latitude which is given to gas unde takings in connection with the quality of gas supplied. The old standard of illuminating powe has completely given way to calorific power, and the producer is permitted a free choice in th type of gas he distributes. He must, however, declare at what calorific power he is prepare to supply, consumers' appliances must be adjusted by him to consume the 'declared' variety gas to the best advantage, and, in order to preclude excessive fluctuations in quality, certai penalties are imposed when the heating value falls below a prescribed limit. As regards th machinery for carrying out the Act, powers are given to the Board of Trade to grant facilitie which in the past have entailed formal application to Parliament.

An important feature of the Act is that it empowers the Board of Trade to make amendin orders revising the standard or maximum price if at any time it is shown to the satisfaction the Board that the costs incidental to the production and supply of gas have substantially altere by reason of circumstances beyond the control of the gas undertakings. The effect of this wa experienced some few years ago in the London area, when on the application of the Londo County Council the standard prices of certain undertakings were substantially reduced. Mo recently, however, on the application of certain gas undertakings themselves, increases in standar prices have been approved, and in addition Bills have been introduced which permit of the pay ment of a minimum dividend irrespective of the price of gas.

The Act prescribes that the quality of the gas distributed shall be determined by a calorimete of the recording type which gives a continuous record of heating value. For some years recordin calorimeters were not insisted on, and the system of periodical spot testing is still generally i force. The Gas Referees, however, commenced to prescribe the installation of recording calor meters in certain cases as from the commencement of 1928, the two calorimeters specified for th purpose being the Fairweather and the Boys.

A non-statutory company operates as the result of established practice, or under the goodwi of the local authority. Its position is in many respects similar to that of a statutory company but before opening roads for the laying of mains permission must be obtained from the distric or county authority.

Statistics of Gas Undertakings in Great Britain and Ireland.

The following table shows the total number of gas undertakings which have existed in th United Kingdom during various years since 1901. It should be noted that the total number separate undertakings has undergone decrease during the last twenty years, this being due to th policy of amalgamation which still continues. It is noticeable, too, that while undertaking owned by private companies and individuals have undergone a decrease, those owned by loca authorities have increased, showing the tendency for the town authorities to take over unde takings from private ownership.

Year.	Owned by Companies & Private individuals.	Owned by Corporations & Local Authorities.	Total Number of Undertakings.
1901	1,349	265	1,614
1905	1,330	285	1,615
1907	1,322	297	1,629
1908	1,322	296	1,628
1909	1,330	296	1,626
1910	1,339	302	1,641
1911	1,320	308	1,628
1912	1,316	311	1,627
1915	1,281	320	1,601
1916	1,263	323	1,586
1917	1,256	322	1,578
1918	1,252	325	1,577
1919	1,252	325	1,577
1921	1,229	330	1,559
1922	1,220	321	1,551
1924	1,155	331	1,487
1926	1,134	332	1,466

The largest gas undertaking in the world is the Gaslight & Coke Co. of London. This Company distributes more energy per annum than all the public electricity supply stations in Great Britain added together. The third annual report of the Electricity Commissioners shows that the authorised electricity undertakings of the United Kingdom generated, in the year ending March 1923, 4,600 million Board of Trade units of electricity, or 15,690,600 million B.Th.U. (156·906 million therms), while the Gaslight & Coke Co. supplies its consumers annually with over 235 million therms.

The largest gasworks in the world is the Beckton station of the above company. During a year, over a million and a quarter tons of coal are carbonised at this works, and the maximum daily output of gas amounts to over 70 million cu. ft. The Beckton works were opened in 1870, and have a total area of 475 acres. There are 14 retort houses on the works, and the water-gas plant is capable of an output of 27 million cu. ft. per day. There are upwards of 50 miles of standard gauge railway on the works, and the rolling stock consists of some 14,000 wagons and 40 locomotives.

Number of Gasworks in Great Britain.

In 1927 (the last year for which statistics are available at the time of publication) the total number of gasworks in operation in Great Britain was 1,450. The total is made up as follows:

In England and Wales—	
Companies and privately owned	875
Local authorities	246
In Scotland—	
Companies and privately owned	171
Local authorities	70
In Ireland—	
Companies and privately owned	70
Local authorities	18
	1,450

Gas Made in Great Britain.

The quantity of gas made in Great Britain during 1926 was 296,082 million cu. ft. This was 4·3 per cent. in excess of that made in 1925, which again exceeded that made in 1924 by 3·1 per cent. The increase in 1926 was entirely due to the increased make of water gas, a rather smaller quantity of coal gas being made in 1926 than in 1925. Only 16,564,000 tons of coal were carbonised in 1926, as compared with 17,031,000 tons in 1925; but 1,436,000 tons of coke for water gas, and 97,703,000 gals. of oil were used in the past year, as against 1,153,000 tons and 51,383,000 gals. in 1925. The residual products in 1926 included 11,177,000 tons of coke and breeze, and 187,546,000 gals. of tar, showing reductions of 221,000 tons and 6,613,000 gals. as compared with 1925.

The total number of gas consumers throughout Great Britain is approximately 9,000,000.

The capital employed by the statutory gas undertakings alone amounts to some 150,000,000*l.*, and the total length of street mains employed runs to some 45,000 miles.

Consumption of Gas per Head of Population.

In the larger towns the average consumption of gas per head of population varies from 6,000 to 10,000 cu. ft. per annum. In smaller towns it ranges between 2,500 and 7,500 cu. ft. Gasworks statistics are, however, generally based on the consumption per consumer, which figure, for consumers through ordinary meters, approximates to 42,000 cu. ft. per annum, and 15,000 cu. ft. for those taking the gas through 'slot' meters. In addition, there will be an appreciable consumption for public lighting, and about 5 per cent. of the whole output will be written off as 'unaccounted for.' In straggling districts with long lengths of mains the latter figure may reach so much as 10 per cent. Taking the country as a whole, the average consumption per consumer at the present time works out at almost exactly 30,000 cu. ft. (say 150 therms) per annum.

Capital Expenditure on Gasworks.

This item varies considerably in accordance with the size of the installation and the price of labour and materials. In pre-war times, however, a concern promoted for the erection of a modern works with the accompanying distribution plant found it possible to complete the scheme for 600*l.* per million cu. ft. sold per annum. For smaller country works, the outlay was very much greater, varying from 750*l.* to 1,000*l.* per million cu. ft., or even more.

The following figures show the approximate capital employed (neglecting nominal additions) in 1926 in the case of representative undertakings:—

	Per million cu. ft. per annum.		Per million cu. ft. per annum.
Gaslight & Coke Company	429*l.*	Bristol Gas Company	408*l.*
Croydon Gas Company	537*l.*	Birmingham (Corporation)	266*l.*
Brighton & Hove Gas Company	429*l.*		

It is, perhaps, more accurate nowadays to rate capital expenditure on the therm basis in lieu of the cubic foot basis. As an example of how this method compares with the figures given on p. 2447 it may be mentioned that the capital of the Gaslight & Coke Company is now 1*s.* 9*d.* per therm, and that of the Croydon Gas Company 2*s.* 2*d.* per therm.

It is a somewhat surprising fact that at the present day the expenditure on the district mains, etc., is generally rather greater than that laid out in the erection of the works. Of the total outlay approximately 55 per cent. will be expended on the district, 38 per cent. on the works, and the remainder on Parliamentary, promotion, and engineers' expenses.

General Rules relating to Capacity of the Apparatus, etc.

LAND.

The area of land required for the erection of the works will amount to at least 2½ acres per million cubic feet of gas per maximum diem.

(NOTE.—The make of gas per maximum diem is calculated by dividing the total annual production by the factor of 240.)

RETORT HOUSE.

Dependent upon the size of the unit, i.e. the number of retorts set in each arch or section. The make per retort per 24 hours for different types of units is given in the following table :—

STOP-ENDED OR 'SINGLE' RETORTS.

	Therms per diem.
Length 9 to 10 ft., section 15 ins. round	15 to 20
,, 10 ft., section 16 ins. round	20 to 27
,, 10 ft., section 21 ins. by 15 ins. dee	35 to 45
,, 10 ft., section 22 ins. by 16 ins. dee	

'THROUGH' RETORTS.

	Therms per diem.
Length 20 ft., section 24 ins. by 16 ins. dee	90 to 100
,, 20 ft., section 22 ins. by 18 ins. oval	90 to 105

A later development is the short 'through' retort, 12 to 16 ft. in length, while a 21-ft. retort is now sometimes employed.

VERTICAL RETORTS.

	Therms per diem.
Woodall-Duckham type	150 to 450
Glover-West type	120 to 300
Chamber ovens	500 to 600

The gas yield from vertical retorts is extremely flexible, very much depending upon the proportion of steam admitted and the class of coal carbonised.

COAL STORAGE.

In the present day, owing to uncertainty of delivery and such causes, it is advisable for gasworks to keep in hand much larger stocks than were thought necessary some years ago. No undertaking can now afford to risk three weeks' storage, although this is a usual and sufficient allowance for that kept under cover. When ground area is available large stocks may be arranged for out in the open. The calculation of the stock of coal in hand may be performed by assuming that one ton of average gas coal occupies from 42 to 43 cub. ft. For the convenience of dealing with stocks of other materials used on gasworks the following figures are given :—

One ton of	coke occupies	85 cub. ft. (average).
,, ,,	broken coal occupies	40 ,,
,, ,,	cannel coal occupies	35 to 45 cub. ft. (varies considerably).
,, ,,	anthracite coal occupies	35 to 39 ,,
,, ,,	breeze occupies	60 to 65 ,,
,, ,,	lime occupies	42 ,,
,, ,,	oxide of iron (Dutch)	45 ,,
,, ,,	ditto (prepared)	41 ,,
,, ,,	sulphate of ammonia	47 to 48 ,,
,, ,,	ashes	50 ,, (about).
,, ,,	Portland cement	23 to 26 ,,
,, ,,	loose earth	28 to 30 ,,

CONDENSERS.

Water condensers are now largely used in preference to atmospheric types. Many of the ıtter kind are, however, still in use, and are not without their recommendations. Rules for ondenser capacity vary to some considerable extent, and there is by no means agreement on he subject. The following are given as representing the average practice :—

Atmospheric condensers.—Allow 5 sq. ft. of atmospheric condensing surface per 1,000 cub. ft. f gas made per diem.

Water condensers.—Allow 3 sq. ft. of surface per 1,000 cub. ft. per diem.

In using the first of these two rules it must be borne in mind that the figure arrived at includes in addition to the areas exposed by the actual condenser) the area of all piping between the outlet of the hydraulic main and the inlet of the condenser. In making calculations the actual urface to be considered is that with which the gas is in contact. Thus, when the gas travels nside a tube the interior surface must be taken, and when outside the exterior surface is onsidered.

Water condensers are of two distinct types :—

(*a*) Multitubular condensers.

(*b*) Water-tube condensers.

In the first type the gas passes through the tubes, which are surrounded by a water jacket. In the second type the water is within the tubes and the gas around them. As to which type s chosen depends entirely upon the conditions of working. When any deposit is likely to take place it is preferable to have this within the tubes which may be readily cleaned. Thus, when muddy water alone is available there should be no hesitation about adopting the water-tube type. On the other hand, when the gas dealt with is likely to be particularly dirty or to contain a large quantity of heavy tar vesicles the multitubular type is to be preferred. Condensers for carburetted water-gas are invariably of the water-tube type. As regards general dimensions the height of the apparatus should be from two to five times the diameter; 3-in. tubes are preferable for the larger condensers, but 2-in. pipes will suffice for those of smaller design. The ratio of the length of the tube to its diameter should be within the limits of 80 to 1, otherwise the tube loses in structural stability. In the direction of the number of tubes to be employed a good basis to work upon is that of arranging the tubes so that they occupy about 18 per cent. of the total area of the tube-plate. For water-gas condensers this may be increased to 25 per cent.

EXHAUSTERS.

In a works of from 4 to 6 million cub. ft. capacity per annum the saving to be effected by the installation of exhausters is problematical, after consideration has been given to interest on capital and running costs. Over six millions capacity the advantages of the machine are unquestionable. In the smaller works (from 15 to 20 million cub. ft. per annum) driving is nearly always carried out by means of a gas engine, the same engine providing power for operating tar, liquor, and other pumps. The effective hourly capacity of an exhauster is guaranteed by the makers. For the capacity of a four-blade machine, however, the following formula may be taken; it is not to be recommended when dealing with very large or very small exhausters :—

$$Q = 65D^2LN;$$

where,

Q = cub. ft. passed by the exhauster per hour; D = inside diameter of outer drum in ft.; L = length of drum in ft.; N = number of revolutions per minute.

This gives the gross capacity. To arrive at the nett capacity, about 20 per cent. must be deducted (for 'slip') from the figure obtained.

On the larger works it is usual to maintain a vacuum of about 4 ins. of water at the exhauster inlet. At the outlet, the pressure to be overcome varies in accordance with the resistance offered by the apparatus following and the quantity of gas passing at the time. As a general rule the total back-pressure may vary between 8 and 10 ins. on a small country works to as much as

50 ins. of water on the largest plants, but under average conditions the following pressures wi approximate to those found at the different portions of the apparatus :—

Retorts	Level gauge.
Hydraulic main	½ in. to 1 in. vacuum.
Exhauster inlet	4 ins. vacuum.
,, outlet	30 ins. pressure.
Tar extractor, outlet	26 ins. ,,
Washers, outlet	24 ins. ,,
Scrubbers, outlet	22 ins. ,,
Purifiers, outlet	9 ins. ,,
Station meter, outlet	8·5 ins. ,,
Holder, inlet and outlet	8·5 ins. ,,

It will be seen from the above that the forcing of the gas through the dry purification materia and the raising of the holder bell account for by far the greatest portion of the work agains back-pressure which the exhauster is called upon to perform.

Running Speed.

The speed at which the exhauster operates should be gauged, not by a consideration of th revolutions performed per minute, but by the peripheral speed of the tips of the blades. Thi speed should be approximately constant for all sizes of exhausters, and should lie within th limits of 650 to 850 ft. per minute.

Lubrication.

This is a point requiring the most careful attention. Much depends upon the type of lubrican made use of, the best being a mixture of refined creosote and a mineral oil. These should b admixed in the proportion of one part of creosote to three parts of mineral oil. A vegetabl oil should not be used, as this will tend to thicken the tar inside the drum.

In modern practice there is a tendency for the ordinary rotary blade type of machine to giv way to the newer high speed turbo-exhauster working on the fan principle and providing larg clearances. An advantage attached to this type of machine is that it has some considerabl volumetric capacity per unit of floor-space occupied. The construction consists of an oute case provided internally with two or more impellers which rotate on a common axis, but i distinct cells. The gas is passed from cell to cell in series until it is discharged from the machin at the requisite pressure, the pressure obtained being dependent upon the size and speed of th impellers.

WASHERS AND SCRUBBERS.

Washers.

The capacity of the wet purification plant depends very largely upon the type of apparatu employed, whether mechanical or merely static. Mechanical washer-scrubbers are now largel used, while of the static washers the well-known Livesey type has few rivals.

Rules for Capacity.—For washers of the Livesey and similar types allow one-seventh to one fifth of a cubic foot capacity per 1,000 cub. ft. of gas passed per maximum diem.

For mechanical washer-scrubbers an allowance of one-half to three-quarters of a cubic foo capacity per 1,000 cub. ft. of gas per diem may be made.

Scrubbers.

Some works are provided with scrubbers of the tower type only, and have no separate wash ing vessels. In such cases the size of the scrubbers and their number may be based on th following rule :—

Allow 10 cub. ft. of capacity per 1,000 cub. ft. of gas dealt with per maximum diem. When the scrubbers are operated in conjunction with mechanical washer-scrubbers the above allowance may be reduced to from 5 to 6 cub. ft. When Livesey and such washers are employed prior to the scrubbers, the latter should have a capacity based on 6 cub. ft. of volume pe 1,000 cub. ft. of gas per diem.

Washing and scrubbing capacity is greatly dependent upon the manner in which condensation is carried out. Extremely effective condensation will be the means towards reducing the usua wet purification allowances by nearly 50 per cent.

Horse-Power Required to Drive Washer-Scrubbers.

The following figures refer to the power necessary for the modern vertical type of machine. The horizontal machines of similar capacity will usually require one or two horse-power less :—

500,000 cub. ft. capacity per diem	4 H.P.
1,000,000 ,, ,, ,,	5 H.P.
2,000,000 ,, ,, ,,	7 H.P.
3,000,000 ,, ,, ,,	10 H.P.

It is advisable to allow a small margin (about 20 per cent.) above these figures for emergencies.

If the power employed is electricity, and this is obtainable for a halfpenny per unit, the cost of driving amounts to about 0·033*d*. per 1,000 cub. ft.

The ratio of the height to the diameter of tower scrubbers varies between 2½ and 5 to 1. In exceptional instances, however, it may be so much as 7 to 1, particularly in the case of scrubbers of small capacity. When the diameter becomes greater than 30 ft. the flat cast-iron top is inclined to sag. In such cases it may be found advisable to provide a domed top having a rise equivalent to one-sixth of the diameter, and made from steel.

As regards the material employed for packing, Livesey has given the following figures relating to the area of wetted surface exposed to the gas :—

	Sq. ft. per cub. ft. of Scrubber Capacity.
Coke	8½
Drain pipes, 3 ins. diameter	17
,, 2 ins. diameter	21
Boards on edge	31

Boards on edge, although expensive in the first instance, are to be preferred to any other type of packing. They conform to no hard and fast rule as regards size, but the following will afford satisfactory results :—

6-in. boards, ¼ in. thick, laid ¾ in. apart.
11-in. boards, ⅛ in. thick, laid ½ in. to ¾ in. apart.

WATER REQUIRED.

The amount of water required to effect wet purification depends very largely on the type of apparatus, but very variable results are found. As an average it may be taken that the water admitted to the final scrubber will vary between 10 and 13 gallons per ton of coal carbonised. It has been found that with a modern form of vertical washer-scrubber the whole of the ammonia can be removed by admitting only 3¾ gallons of water per ton of coal carbonised.

DRY PURIFICATION PLANT.

Capacity of the dry purifiers depends upon the extent to which purification is carried. Nowadays it is customary to remove sulphuretted hydrogen alone, but if lime purification (for the removal of carbon disulphide) is resorted to it is advisable to employ rather larger vessels. It is always as well, however, that the vessels should be too large rather than too small, for the first cost increases but slowly as compared with the capacity, and purification charges undergo considerable reduction as the unit capacity becomes greater. For oxide boxes the following rule may be taken :—

For a set of four purifiers allow *for each box* an area of 0·5 sq. ft. per 1,000 cub. ft. of gas to be dealt with per maximum day. If lime is to be used this figure should be increased to 0·6 sq. ft., or 0·65 to 0·7 if no catch boxes are available.

Hunt's rule for the total amount of purification space required, i.e. the combined area of all boxes, says that 20 to 30 sq. ft. per ton of coal carbonised per maximum day should be allowed.

As regards the purifying capacity of oxide of iron it may be taken that one ton will purify about two million cubic feet of gas before it is finally spent.

In order that the oxide of iron in the dry purifiers may be retained in an alkaline condition it is not advisable to remove the whole of the ammonia from the gas. The usual practice is to permit 1 grain of ammonia per 100 cu. ft. of gas to remain as a minimum.

Purifiers are invariably square or rectangular in shape and are constructed from cast-iron plates bolted together. In one or two isolated instances reinforced concrete vessels have lately been experimented with.

As regards the necessary thickness of the cast-iron plates the following figures may be taken as indicative of the general practice :—

Purifiers up to 10 ft. square	⅝ in. plates.
,, ,, 20 ,, ,,	11/16 in. ,,
,, above 20 ,, ,,	¾ in. ,,

The flanges are usually cast ⅛ to ¼ in. thicker than the body. The smallest vessels are usually 4 ft. deep, while the largest sizes vary from 6 to 8 ft. in depth. The following rule is suggested for ascertaining the required depth :—

$$\text{Depth in feet} = \sqrt[4]{\text{Total superficial area}} \times 1{\cdot}1.$$

The depth as given may be taken to the nearest foot. For smaller purifiers, i.e. up to 100 sq. ft. in area, multiply by 1·3 instead of 1·1.

PURIFIER CONNECTIONS.

The diameter of the connecting mains is most readily and accurately computed from th following formula :—

$$\text{Diameter of pipe in ins.} = \sqrt{\text{area of each box in sq. ft.}}$$

For small purifiers (up to 60 sq. ft. area) the result can be taken as it stands, but fo medium size boxes deduct 16 per cent., and for large vessels 25 per cent.

CONSTRUCTIONAL NOTES.

From the point of view of economy water-lute purifiers should be so constructed that th lute is portion of the side plate itself and not a distinct unit. This method of constructio facilitates erection and is less costly in the first place. The depth of the lute is usually half th depth of the side plate, but the depth of water obtainable must in all events be sufficient to with stand the greatest pressure which is likely to prevail within the box. The covers of purifier are invariably made from wrought iron or steel plates, usually about $\frac{1}{4}$ in. in thickness. The are either flat or slightly curved, but in either case some form of trussing or stiffening is necessary and strong curbs should be provided when the vessel is of any size. In modern purifiers the water lute principle is largely abandoned, and dry-luted covers are provided. These possess many advantages over the older method, chiefly in the direction of initial outlay, whilst they combin greater durability with increased safety. Moreover, owing to the lighter construction of th covers the lifting apparatus may be less cumbersome and costly. A gastight joint between cove and box is usually ensured by inserting a strip of rubber or tallowed hemp between the paralle flanges, the two flanges being afterwards pulled together by means of special fasteners or ordinary bolts.

For carburetted water gas purifiers the capacity allowed should be rather greater than is th case with purifiers used in connection with coal gas. A satisfactory allowance is 0·8 sq. ft. pe 1,000 cub. ft. of water gas per maximum day.

STORAGE CAPACITY.

The holder capacity necessary is somewhat dependent upon whether or not the works i provided with a water gas plant. If such a plant is available the storage allowed for need no exceed 18 hours maximum make, but if there is no water gas to fall back upon provision shoul be made for 21 to 24 hours maximum production. In years gone by it was customary to provid considerably greater storage chiefly on account of the heavy fluctuations in output. The levelling up of the hourly load-curve has, however, had a marked effect in the direction of diminishing the quantity of gas kept in hand.

PROPORTIONS OF GASHOLDERS.

Single lift height = 0·3 to 0·4 of diameter.
Multiple lift height = 0·6 to 1·0 of diameter.

In computing the capacity of a holder the volume enclosed by the crown is neglected, as th gas contained therein is not available for distribution. Accordingly

$$\text{Capacity in cub. ft.} = \cdot 7854 \times \text{diameter in ft.}^2 \times \text{height in ft.}$$

With multiple lift holders the capacity of each lift should be estimated separately by applying the above formula to each section.

DEPTH OF LIFTS.

Each lift will be approximately of equal depth.

RISE OF CROWN.

The greater the rise the stronger will be the crown. The dome should conform to a segmen of a sphere. Normally, the rise will range between $\frac{1}{15}$th to $\frac{1}{20}$th of the diameter, but when trussing is employed it may be less than when the plain crown only is used.

The cubic capacity of the crown space may be found from the following :—

$$\text{Volume in cub. ft.} = \cdot 5236 R \left(R^2 + \frac{3D^2}{4} \right)$$

where,

R = rise of crown in ft.;
D = diameter of top lift in ft.

The depth of each lift should never be less than one-seventh of its diameter, otherwise locking or tilting may occur. In general, the proportion varies between one-fourth to one-fifth of the diameter.

The crown sheeting of gasholders varies from 14 gauge to 10 gauge (about $\frac{5}{64}$ in. to $\frac{1}{4}$ in.), but much depends upon the size of the holder.

The side sheeting varies from 12 gauge to 10 gauge, but curb or cup and grip rows are thicker, $\frac{1}{4}$ in. to $\frac{3}{8}$ in. Top lift sheets are usually thicker than those of succeeding lifts, often about 8 gauge.

The thinner sheets of the bell are generally riveted up cold with $\frac{1}{2}$ in. rivets at a pitch of 1 in. to $1\frac{1}{4}$ in. All rivets above $\frac{1}{2}$ in. must be driven hot.

In the gas holder recently built for the Gartson station of the Liverpool Gas Co., wrought-iron plates are used, as these are less liable to corrode than plates of mild steel. The gasholder, which is of the spirally guided type, is 150 ft. in diameter and has a total height of 148 ft. The iron plates have a tensile strength of 21 tons per sq. in. and an area reduction of 18 per cent. with the fibre, and 18 tons per sq. in. with an area reduction of 8 per cent. across the fibre.

(*Machinery, April* 2, 1925.)

GASHOLDER TANKS.

Steel tanks have many advantages over the masonry variety, and cast-iron as a material for this purpose may now be looked upon as obsolete.

The thickness of plate required may be calculated as follows:—

$$T = \frac{PD}{2fe},$$

where,

T = thickness of the plate in ins.;

D = diameter of the tank in ins.;

f = allowable working stress (usually $5\frac{1}{2}$ tons per sq. in.);

e = the efficiency of the vertical riveted seams. This will range up to 90 per cent. for large holders. For small holders it will vary between 75 and 85 per cent.;

P = the pressure due to the water in lbs. per sq. in.

The latter may readily be found from the following:—

$$P = WD,$$

where,

W = the weight of a cub. ft. of water = 62·4 lbs.;

D = depth below the surface of the section under consideration.

As regards the apportionment of the cost of gasholders, the following figures represent normal conditions:—

	Per Cent. of Total Outlay.
Bell, complete	35 to 45
Guide framing	18 to 23
Tank (steel)	35 to 45

Single lift holders (up to about 50,000 cub. ft.) cost in pre-war days from 25*l.* to 28*l.* per 1,000 cub. ft. If of the spiral type the outlay would be reduced by 25 per cent. Two lift holders (about 250,000 cub. ft. capacity) ranged from 16*l.* to 20*l.*; or, if spirally guided, about 10*l.* per 1,000 cub. ft. capacity. Holders varying from 2 to 3 million cub. ft. capacity cost from 9*l.* to 12*l.* per 1,000 cub. ft. The large 12-million holder at the East Greenwich Works cost five guineas per 1,000 cub. ft. capacity, whilst a $10\frac{1}{2}$-million holder at Manchester worked out at 5*l.* per 1,000 cub. ft.

CALCULATION OF PRESSURE THROWN.

The pressure thrown is dependent upon the weight of the floating portion and its diameter. It may be found as follows:—

$$\text{Maximum pressure (ins. of water)} = \frac{549W}{D^2},$$

where,

W = weight of bell and water in lutes, in tons;

D = diameter of holder in ft.

When dealing with a multiple lift holder take the mean diameter.

Size of Works Mains.

No hard and fast rules are adhered to, but the following will form a guide as to the averag conditions :—

Size of Works.	Suitable Size for Mains. Ins. Diam.
3 to 4 million cub. ft. per annum.	5
6 to 10 ,, ,,	6
15 to 25 ,, ,,	8
30 to 45 ,, ,,	10
55 to 90 ,, ,,	12
100 to 150 ,, ,,	15
200 to 300 ,, ,,	18
350 to 450 ,, ,,	20 to 21
500 to 600 ,, ,,	24
600 to 900 ,, ,,	30

Composition of Various Gases.

Per Cent. by Volume.	Coal Gas.	Carburetted Water Gas	'Blue' Water Gas	Mond Gas.	Suction Gas.	Dowson Gas.
Hydrogen	49·0	35·0	52·0	26·0	16·0	20·0
Carbon Monoxide	9·0	32·0	38·0	15·0	31·0	24·0
Carbon Dioxide	2·5	4·5	4·5	12·0	3·0	6·0
Methane	27·0	13·0	1·0	3·0	nil	1·0
Heavy Hydrocarbons	4·0	10·0	nil	nil	nil	nil
Nitrogen	8·5	5·5	4·5	44·0	47·0	49·0
Candle Power	14·0	18·0	nil	nil	nil	nil
Calorific Power, B.Th.U. gross	550	580	300	165	160	155

Calorific Value of Various Fuels and their Cost per Therm.

The following table (compiled by G. Evetts) gives the calorific value of various fuels, and th lost per therm (100,000 B.Th.U.). The cost must only be regarded as the prime cost of a ther used in such a manner that the heating power can be developed :—

	Calorific Value B.Th.U.	Cost.	Cost per Therm Pence.
Coal	13,000–15,000 per lb.	36*s.* per ton	1·4
Coke	11,500–13,500 per lb.	30*s.* per ton	1·35
Coal Gas	400–560 per cu. ft.	10*d.* per therm	10·0
Electricity	3,440 per unit	2*d.* per unit	58·2
Petrol	19,500 per lb.	2*s.* per gall.	16·6
Fuel Oil	18,000 ,,	5*l.* per ton	3·0
Motor benzole	19,000 ,,	2*s.* per gall.	14·2
Alcohol	12,000 ,,	5*s.* ,,	62·0

Composition of Coal and Coke.

Per Cent.	Anthracite Coal.	Average Gas Coal.	Average Gas Coke.
Carbon	94·0	80·0	88·0
Hydrogen	2·5	5·5	0·2
Oxygen	0·25	8·8	traces to 3·0 (varies considerably)
Nitrogen	0·5	1·5	2·0
Sulphur	0·5	0·8	1·0
Ash	2·25	3·4	5·8
Calorific Power, B.Th.U.	15,500 per lb.	14,800 per lb.	13,500 per lb.
Volatile Matter	8 per cent.	30 per cent.	1 per cent.

Products of Distillation.

One ton of average gas coal will yield (approximately) the following products :—

Gas	13,000 cub. ft., or approximately 70 therms.
Coke	12 to 13 cwts., excluding breeze.
Breeze	1 cwt.
Tar	9 to 11 gallons.
Ammoniacal liquor	32 to 40 gallons at 8 ozs.
Sulphate of ammonia	24 to 28 lbs.
Sulphur	5 to 7 lbs.
Cyanogen (HCN)	4 lbs.
Virgin liquor	10 to 12 gallons.

The yield of gas as given above is the normal quantity of straight coal gas obtained, but it should be borne in mind that the modern vertical retort in which 'steaming' is employed will give a yield of from 85 to over 100 therms per ton of coal.

(The sulphate of ammonia is obtained from the ammoniacal liquor, and not in addition to it. The virgin liquor is included in the figure given for total yield of ammoniacal liquor. The figure given for sulphur is that which may be recovered during purification of the gas, and does not include the quantity remaining behind the coke.)

The approximate distribution of the elements of the original coal, and the manner in which each exists after the process of carbonisation, is illustrated in the following table :—

One ton of coal, consisting of :—

	Lbs.
Carbon, 1,792 lbs., distributed as—	
Coke	1,385
Breeze	107
In gas, as CO and CO_2	30
In gas, as hydrocarbons	130
In tar	122
As scurf, cyanide, etc.	18
Hydrogen, 123 lbs., distributed—	
In gas and tar	98·5
As ammonia	1·0
As water	18·5
In coke	5
Oxygen, 197 lbs., distributed—	
In gas, as CO, CO_2, and combined in tar	49
As water	148
Nitrogen, 34 lbs., distributed—	
In gas (free)	11·8
In coke	14·1
In tar (combined)	1·0
As ammonia	5·8
As cyanogen (total HCN 4 lbs.)	1·3
Sulphur, 18 lbs., distributed—	
As gaseous impurities and in liquor	6
In coke	12
Ash remaining in coke and breeze	76
Total	2,240

Amount of Coke Used as Fuel.

The quantity of coke used for heating the retort benches varies in accordance with the system of firing adopted. There are three types of firing now in common use, namely :—

(*a*) Direct-fired settings.
(*b*) Semi-gaseous settings.
(*c*) Gaseous-fired settings.

In addition, some works employ external producers, in which the producer gas is generated in a producer of special design situated away from the retorts, and forming a central source from which all the settings are supplied. At the Fuel Research Station at East Greenwich blue water gas is employed for heating a setting of vertical retorts.

The following shows the amount used :—

	Per cent. of the original weight of coal carbonised.
Direct-fired settings	28
Generator settings	15 to 18
Regenerator settings	11 to 14
Vertical retorts :—	
(*a*) Intermittent types	16
(*b*) Continuous types	11½
Outside producers	13 to 16

With modern systems it should be possible actually to sell 10 cwts. of coke per ton of coal.

See also ' Coke as Boiler Fuel,' p. 2088.

Composition of the Producer Gas.

The following is the average composition under good conditions:—

	Per-cent. by volume.
Carbon monoxide	25
Carbon dioxide	5
Hydrogen	6
Methane	1
Nitrogen	63

(Oxygen should be absent, for its presence indicates an excess of primary air.)

The analysis of the waste gases emitted from the retort setting should approximate to the following :—

	Per cent. by volume.
Carbon monoxide	19
Oxygen	0·4
Nitrogen	80·6

(The presence of carbon monoxide in the waste gases is indicative of a deficiency of secondary air, and is wasteful in firing. The oxygen, if above 0·5 per cent., denotes an excess of secondary air.)

Gasworks Temperatures.

	F.°
Retorts	1800 to 2100
Ascension pipes	200 to 300
Foul main (inlet)	140
Condensers (inlet)	125
,, (outlet)	75 to 85
Washers and scrubbers (outlet)	60
Purifiers (inlet)	60
,, (outlet)	65
Holders	60

The modern combustion chamber temperature rarely, if ever, exceeds 2800 F.° The prevailing temperature of the fuel-bed is in the neighbourhood of 1800 to 1900 F.°

Before the introduction of the regenerative system, one of the chief causes of the loss of heat arose from the escape of the waste gases of the producer at unnecessarily high temperatures. In such cases the normal temperature at which the gases are allowed to leave the settings is in the neighbourhood of 1700 to 1800 F.°, but by the transference of the sensible heat from these gases to the inflowing secondary air the temperature of the waste gases has, in the modern regenerator, been reduced to 600–800 F.° before their escape is permitted. In the ordinary way, the secondary air approaches a temperature of 1800 F.° before combustion.

Grate and Chimney Area.

The grate area of the retort bench producer must in all cases be ample, so as to ensure a steady travel for the air passing through the fuel. When the ordinary horizontal fire-bar grate is employed the recognised modern rule for grate area is as follows :

Allow one-tenth square foot of grate area for every lineal foot of retort in the setting. Thus for a through setting of ten 20-ft. retorts, this gives a total grate area of 20 sq. ft. Another

but less common rule, is that which gives the allowance as 1 sq. ft. of area for every 8 lbs. of coke consumed by the furnace per hour. As the actual consumption of coke (which is shot into the producer hot) is somewhat difficult to compute, the rule is not readily applied.

The ordinary horizontal form of bar grate is now rapidly giving way to the sloping form of grate. The original sloping arrangement consisted of a number of flat plates placed progressively in the manner of a stairway, cooling being effected by a small stream of water which was permitted to drop from step to step. The latest development is the Grille grate, which is composed of a number of independent components set together so as to form an interlocking grille. The grate is made entirely from special cast iron, and embraces a series of hanger bars, which are hung from specially shaped cross-bars. When in the working position each hanger is automatically locked, so that it cannot be displaced during the process of cleaning the fire, while at the same time, should it be necessary to remove any one of the hangers, this may readily be done by applying a slight forward movement to the lower end. The grate is employed in conjunction with a supply of steam, and the formation of clinker is practically avoided, the inert matter coming down in the form of a fine dust.

The rule given above for grate area does not apply when grates of the sloping type are employed, for, owing to the more favourable conditions of the base of the fuel bed, the circulation of primary air is uninterrupted by layers of dead matter. With the Grille type of grate the following rule may be employed :—Allow 0·6 sq. ft. of sloping superficial area per 10 lineal ft. of retort in the setting.

Flue and chimney area is calculated by allowing 1½ sq. ins. of area per lineal foot of retort in all those settings which depend upon the flues and chimney under question. Thus, if a retort bench consists of eight settings, each containing ten 20-ft. retorts, the area required would be 16½ sq. ft.

In large retort houses the height of the chimneys varies from 50 to 70 ft. The chief considerations to bear in mind are the heights of adjoining buildings, also the avoidance of down-draughts and the effect of shifting winds. It is not advisable to connect a chimney to a greater number of retort beds than ten, for above this number its dimensions become unwieldy. Circular chimneys, except for vertical retort installations, are now almost things of the past. The rectangular chimney with an external batter is most commonly employed. The batter usually varies between the limits of 1 in 36 to 1 in 40. Retort house chimneys are usually braced for their entire height; the general methods being to run angle-iron up each corner, the angles being held in position by tie bands placed at intervals of about six feet. An inspection door should be left at the base of the shaft for cleaning purposes. As regards material of construction, stock bricks may be employed for the external courses, but a lining of fire bricks in the interior is essential. Very frequently the whole chimney is constructed from fire bricks, in which case no lining is, of course, necessary. The volume of gas drawn up a chimney increases in proportion to the square root of its height; thus any increase in height produces only a comparatively small change in this respect. On the Continent it is occasionally found that a separate chimney is installed for each retort setting, but the idea is confined almost wholly to stop-ended settings. The construction of retort bench shafts should be such that the cross sectional area, in spite of the batter, is constant throughout the whole height. This may readily be arranged for by reducing the thickness of the brickwork from the bottom upwards.

Proportions of Horizontal Retort Benches.

The following normal dimensions are given as exemplifying the usual proportions of various types of retort houses and benches :—

(*a*) Single retort bench, 10-ft. retorts :—

	ft.	ins.
Width of bench	12	6
At back of bench	1	6
In front of bench	18	0
Total width inside houses	32	0

The height of the retort house to the eaves would be 20 ft., and the height of the retort bench from ground level 11 ft.

(*b*) Through retort bench, hand charging and discharging—

	ft.	ins.
Width of bench	20	0
Each side of bench, 20 ft.	40	0
Total width of house	60	0

The height of the retort houses to eaves, if house of the stage type, would be about 35 ft.; if of the subway type 8 to 10 ft. less. The height of the retort bench from base of producers to top of brickwork about 20 ft., if retorts set in three tiers.

(*c*) Through bench, mechanical charging and discharging—

	ft.	ins.
Width of bench	20	0
Charging side of bench	23	0
Discharging side	17	0
Total width of house	60	0

The height of the bench from base of producers to top of brickwork would be about 25 ft if retorts are set in five tiers. The height of the house (stage type) to eaves would be abou 40 ft. if continuous coal hoppers overhead were included. As an approximate rule for ascertain ing the height of the bench from charging floor to top of brickwork, allow 29 ins. for each tie of retorts. The width of the main setting arch will be, for two rows of retorts, from 7 ft. 9 ins to 8 ft. 9 ins.; for three rows of retorts, 8 ft. 6 ins. to 9 ft.

RETORTS.

Vertical Retorts.

Modern vertical retorts are of three types, namely, (*a*) continuous; (*b*) intermittent; (*c*) continuous-intermittent. The best known examples of the continuous type are the Woodall Duckham and Glover-West systems.

WOODALL-DUCKHAM SYSTEM.

Length of 5½ ton retorts is 25 ft. The shape of the retorts is rectangular tapered, their dimensions at the top being 4 ft. 3 ins. by 7 ins., and at the bottom 5 ft. 3 ins. by 18½ ins. Each retort will carbonise from 4½ to 5½ tons of coal per diem, and it is usual for two or four of them to be erected in one unit. The coke is extracted by a revolving rake device which makes one revolution in from 50 to 70 minutes, and the speed of extraction of the coke regulates the speed of inflow of coal at the top of the retort. The coke, after extraction, drops into a receiving hopper which is emptied about every three hours. The power required to drive the mechanical portion amounts to approximately 1·8 b.h.p. per ton of coal per maximum day. The largest type of retort made will carbonise up to 7½ tons of coal per day.

GLOVER-WEST SYSTEM.

In this system the retorts are elliptical in shape, having a taper towards the bottom. The system has recently undergone considerable development by the introduction of what is known as the 'Leigh' type of retort, which is fitted at the base with a large steaming chamber. In this way it has been possible greatly to augment the proportion of steam admitted to the retort, with the result that the yield of gas per ton of coal has been greatly increased. The retorts are set in units of 2, 4, or 8, and they are made in three sizes, the particulars in connection with which are given in the following table:—

	Type I.	Type II.	Type III.
Shape of retorts	Elliptical.	Elliptical.	Elliptical.
Breadth and width of retorts	40″ × 10″ to 46″ × 18″	33″ × 10″ to 39″ × 18″	24″ × 10″ to 30″ × 18″
Length of retorts	21 ft.	21 ft.	16 ft.
Coal throughout per diem (without steaming)	4 tons	3 tons	2 tons

ADMISSION OF STEAM.

The process of admitting steam to the base of the retort has now become the standard practice in connection with carbonisation in vertical systems. Blue water gas is thereby generated *in situ*, and besides increasing the yield of gas and therms per ton of coal carbonised, some noticeable augmentation of the liquor and tar yields has resulted. The effect of steaming is well illustrated by the following results obtained at the Fuel Research Station at East Greenwich with Mitchell Main gas coal:—

	Cub. ft. of gas per ton of coal.	Calorific Value B.Th.U. (gross).	Therms per ton of coal.
Without steaming	13,100	544	71·26
Steaming (20·53 per cent.)	22,580	460	103·86
,, (30·03 per cent.)	25,610	432	110·63

Fireclays as used on Gasworks.
See Section XX., p. 534.)

Retort Bench Fittings.

The following may be taken as giving the approximate size of ascension pipes necessary with horizontal retorts :

Works making under 10 million cub. ft. per annum . . . 5-in. pipes.
" " between 10 and 200 million cub. ft. per annum 6-in. "
" " above 200 million cub. ft. per annum . . 7-in. "

The above refer to retorts having an ascension pipe at both ends. If a single pipe is used it should not be less than 8 ins. in diameter.

Joints for Ascension Pipes.

These must on no account be made with lead. Rust joints are to be preferred to any others, although they may entail no little labour when having to be cut out. To prepare the material for these joints, cast-iron borings should be damped down with gas liquor; the mixture is then rammed well down into the joint space. When the bench is at work the heat soon hardens off the joint. If borings cannot be obtained, a serviceable joint may be made from the following :

Ewell brick dust . . . . . 1 part.
Slaked lime . . . . . 2 parts.

This is rammed into the joint dry, no moistening being necessary.

For the joints between the cast-iron mouthpiece and the fireclay retort the following may be used :—1 part of cast-iron borings to 2½ parts of fireclay. This mixture is then damped down with a solution of sal ammoniac. The amount of sal ammoniac required is about 1 lb. to every cwt. of the fireclay and borings. Ammoniacal liquor may be used in lieu of the sal ammoniac, but the latter is to be preferred, as a more complete rusting action is thereby set up.

Hydraulic Mains.

These are now of two types, i.e. :

(*a*) Distinct mains, one to every retort bench, on either or both sides.
(*b*) Continuous mains, one uninterrupted main extending over a number of settings.

The latter type have their advantages as regards initial cost, but distinct mains are otherwise to be preferred owing to the greater ease with which they are adjusted. In addition, by their use a single setting may be readily shut down and isolated.

The gas take-off from the hydraulics should be arranged from the cover of the box, rather than from the side, as is so frequently found.

Foul Main.

The size of the foul main must depend upon the combined areas of all pipes leading into it. Generally speaking, the following sizes are those prevailing, and which may be safely applied.

Capacity of Bench per 24 hours.	Size of Foul Main.	
	If one.	If two.
50,000 to 100,000 cub. ft.	6 ins. to 9 ins.	—
100,000 to 500,000 cub. ft.	12 ins. to 15 ins.	—
1 million to 1¾ million cub. ft.	18 ins.	14 ins.
2 million to 3 million cub. ft.	24 ins.	18 ins.

Another rule is that which states that the foul main (if it delivers all the gas) should be 25 per cent. of the area of the main works connections.

The modern practice is to construct the foul main from lap-welded steel plates or solid drawn tubes in lieu of cast-iron pipes. When steel is used, however, some form of expansion joint should be introduced, for the main is liable to undergo some considerable expansion when the settings are fired up from cold. With the cast-iron main, the lead joints at the spigots will be sufficient to cope with any change of length, and flange joints should therefore be avoided unless some form of expansion joint is inserted.

Tar and Liquor Removal.

The method employed for removing the tar and liquor condensed out of the gas in the hydraulic main is of extreme importance, for if an efficient principle is not employed endless trouble results in the shape of pitched-up hydraulics, stopped ascension pipes and tar mains, and considerable loss of ammonia. The tar-tower system has been regarded as one of the best methods and is a considerable improvement on the older systems. The objection to the tar-tower, however, is that it is not automatic in action, requiring periodical 'running-off,' during which process there is every possibility of temporarily unsealing the dip-pipes. One such method is the 'Reflux' system, which is entirely automatic. The system separates tar and liquor while hot, and effects the continuous circulation of hot liquor in the hydraulics, which presents many advantages from the point of view of practical working.

Retort House Governors.

The retort house governor is a more or less essential auxiliary of the modern retort house. I differs from the station governor in that, whilst the latter is employed with the object of reducin pressure, the retort house governor is interposed for the purpose of reducing the intensity c vacuum created by the exhauster. Thus the governor ensures a constant vacuum in the hydrauli main, whatever the volume of gas coming away from the coal charges may be. The intensity c vacuum required is obtained by loading the bell on similar lines to those employed with th station governor. The best place for the governor is on the top of the retort bench, as close n to the end of each section of the foul main as possible, for it is not so sensitive when interpose at the inlet or outlet of the condenser as is occasionally found. By-passes should be fitted to th governor, for it will require cleaning out about every four months.

Cost of Manufacturing Coal Gas

The cost of manufacturing towns' gas depends primarily upon the capacity of the works, it geographical position relative to suitable coalfields, and the character of the plant in use. It mus be borne in mind, too, that the actual cost of production (*i.e.* cost into gasholder) represents onl about one-half of the ultimate selling price, the remainder being accounted for by the cost of dis tribution, overhead charges, dividends, etc. In considering a normal case of an undertakin supplying about 1,000 million cu. ft. of 500 B.Th.U. gas per annum, the manufacturing cost would be approximately as follows, assuming that coal gas only was produced :—

	Cost per 1,000 cu. ft.	Cost per Therm.
Coal	26*d.*	5·2*d.*
Less Residuals	17*d.*	3·4*d.*
Net cost of coal	9*d.*	1·8*d.*
Purification	0·5*d.*	0·1*d.*
Salaries and wages	3·5*d.*	0·7*d.*
Wear and tear	7·5*d.*	1·5*d.*
Net cost of gasholder	20·5*d.*	4·1*d.*

Gasworks Conveyors and Elevators.

The formula given below may be taken as giving a useful guide as to the capacity of bucke conveyors :

$$\text{Capacity} = \frac{S \times B \times W}{96{,}768 \times P} \text{ tons per hour,}$$

where,

B = capacity of buckets in cub. ins. ;
S = speed of conveyor in ft. per minute ;
W = weight per cub. ft. of substance carried (see page 2448) ;
P = pitch of buckets in ft.

The horse-power required to operate elevators and conveyors may be readily arrived at by adopting a coefficient of friction in accordance with the conditions under which the machine is working.

Let M = the weight of material carried in lbs.
W = the weight of the moving parts in lbs.
K = the coefficient of friction.
S = the speed of the conveyor or elevator in ft. per minute,

then, for

(*a*) Vertical elevator :

$$\text{H.P.} = \frac{M \times S}{33{,}000} + \frac{K \times S(M+W)}{33{,}000};$$

(*b*) Inclined elevator :

Let a° = the angle of inclination with the horizontal, then,

$$\text{H.P.} = \frac{M \times S \times \sin a^\circ}{33{,}000} + \frac{K \times S(M W) \cos a^\circ}{33{,}000};$$

(*c*) Horizontal conveyor :

$$\text{H.P.} = \frac{K \times S(M+W)}{33{,}000}.$$

As regards the value of K, the following figures may be taken :

0·15 for metal sliding on metal ;
0·07 to 0·8 ,, ,, (well lubricated)
0·25 for wood sliding on wood.

Purification of Coal Gas.

The purification of coal gas is carried out in two stages, namely, by means of wet purification in the washers and scrubbers and afterwards in the dry purifiers. During the wet purification of the gas the alkaline ammonia is made use of for removing a portion of the acidic impurities, sulphuretted hydrogen and carbon dioxide. The two last-named are, therefore, absorbed with the formation of certain salts, which are themselves soluble in water. The resultant solution consists of water containing a certain proportion of these salts, and is known as ammoniacal liquor. In crude coal gas the ammonia content is usually in the neighbourhood of 1·5 per cent. by volume, and of this amount from about one-third to one-half will have been deposited prior to the gas reaching the wet purification plant. Hunt has given the following figures for the distribution of ammonia :

	Per cent. of total.
Ammonia removed by condensation	42·7
,, ,, first scrubber	43·3
,, ,, second scrubber	14·0

When gas containing carbon dioxide and sulphuretted hydrogen comes in contact with a solution of ammonia both acid and normal salts are formed. Thus we have :

(*a*) $2NH_3+H_2O+CO_2=(NH_4)_2CO_3$ (normal) (*c*) $2NH_4OH+SH_2=(NH_4)_2S$ (normal) $+2H_2O$
(*b*) $NH_3+H_2O+CO_2=NH_4HCO_3$ (acid) (*d*) $NH_4OH+SH_2=NH_4HS$ (acid) $+H_2O$

Composition of Gas Liquor.

The ammonia present in gas liquor is combined in two distinct ways. In the first place it is present as easily decomposible compounds, such as carbonates and sulphides, and secondly, as more stable compounds which will only undergo decomposition by heating in the presence of a caustic alkali. In general, the final mixture of gas liquor obtained consists of from 75 to 80 per cent. of the more unstable salts, i.e. 'free' ammonia, whereas the remaining 20 to 25 per cent. is made up of the more stable salts, i.e. 'fixed' ammonia. The possible constituents of gas liquor are enumerated below, although it must be borne in mind that any one sample of liquor will seldom contain all of the compounds given. In fact, some of those included are only met with on rare occasions.

Water, containing in solution:

Ammonium carbonate	'Free' ammonia.	Ammonium chloride	'Fixed' ammonia.
,, bicarbonate		,, sulphocyanide	
,, carbamate		,, sulphite	
,, sulphide		,, thiosulphate	
,, hydrosulphide		,, sulphate	
,, cyanide		,, ferrocyanide	
,, polysulphide		,, acetate	

Also phenols, amines, and other nitrogenous bodies.

The amount of ammonia in gas liquor is in reality quite small, and varies between 1·5 and 3 per cent. In general, it will be apportioned as follows :

	Per cent.
'Free' ammonia	1·2 to 1·6
'Fixed' ammonia	0·3 to 0·4

The following figures relate to sulphuretted hydrogen and carbon dioxide :

	Per cent.
Carbon dioxide in gas liquor	1·3 to 2
Sulphuretted hydrogen	0·1 to 0·6

The distribution of the total ammonia in gas liquor varies, of course, to some considerable extent. The following table, however, refers to the average solution :

	Per cent. of total ammonia.
Ammonium sulphides	6
,, carbonates	74
,, chloride	15
,, sulphocyanide	1·75
,, thiosulphate, sulphite, etc.	3
,, sulphate	0·25

The most effective manner of operating the washing and scrubbing plant is to ensure that the gas on first entering the apparatus is treated with the strongest liquor available. In each succeeding vessel the washing liquor employed becomes gradually weaker and weaker until, in the final scrubber, clean water should be employed. Where circumstances permit, it is preferable that the first washer should be operated with the liquor from the hydraulic main, for in this way both CO_2 and SH_2 may be considerably reduced.

The amount of water which must be added for the purpose of wet purification seems to vary to some considerable extent in accordance with the conditions prevailing. The writer has

found with Durham coal that the ammonia may be completely removed in ordinary coke-fille tower scrubbers by adding from 10 to 13 gallons per ton of coal carbonised. When mechanica washer-scrubbers are in use the quantity of water required will be considerably less, probably n more than 4 gallons per ton of coal.

Mr. Thos. Glover states that the liquor distributed per sq. ft. of cross sectional area of th scrubber should be 0·145 gallon per minute. This is less the quantity of clean water added t the final scrubber.

Ammonia Lost.

The quantity of ammonia lost in the direction of that permitted to go forward from the fina scrubber may be conveniently calculated as so many gallons of 10 oz. liquor.

$$\text{Quantity of 10-oz. liquor lost per week (in gallons)} = \frac{\text{Total grains of ammonia passing forward from scrubber per week.}}{1{,}522}$$

Impurities in the Gas at various stages.

	Grains per 100 cub. ft.
Outlet of condensers—	
Ammonia	200 to 300
Sulphuretted hydrogen	600 „ 900
Carbon dioxide	900 „ 1,400
Sulphur compounds	35 „ 45
Hydrocyanic acid	60 „ 80
Naphthalene	20 „ 25
Inlet of purifiers—	Grains per 100 cub. ft.
Ammonia	nil to 1·5
Sulphuretted hydrogen	450 „ 700
Sulphur compounds	35 „ 45
Hydrocyanic acid	50 „ 70
Carbon dioxide	750 „ 1,150
Outlet of purifiers—	Grains per 100 cub. ft.
Ammonia	nil
Sulphuretted hydrogen	nil
Carbon dioxide	750 to 1,150
Sulphur compounds	35 „ 45
Hydrocyanic acid	nil „ 10

(The last three named above may all be removed, or partially removed, by the employment of special processes, but in the majority of gasworks such processes are not resorted to.)

Removal of Sulphuretted Hydrogen.

Sulphuretted hydrogen is now almost universally removed by means of oxide of iron in one its forms. Natural ferric oxide (bog-ore) is still largely employed for the purpose, although i recent years various artificial preparations have found a good deal of favour, chiefly owing t their lower cost. The natural bog-ore is chiefly obtained from deposits in Holland, Belgium, an Ireland. In the dried state its composition varies between the following limits :

	Per cent.
Hydrated ferric oxide (Fe_2O_3, H_2O)	60 to 65
Organic matter	15 „ 25
Silica	3 „ 6
Alumina	1

The active material in bog-ore and artificial preparations is not actually the iron oxide, bu the oxide plus a certain quantity of water of combination, *i.e.* a hydrated ferric oxide. I addition to this moisture the material as used should contain a further quantity of water, usuall from 20 to 30 per cent. The artificial oxides are employed with a similar degree of moistur The made-up or artificial material, if of good quality, is usually rather more active than th natural product, owing to a rather higher content of ferric hydrate, which may reach so much a 70 to 75 per cent.

Reactions during the Removal of Sulphuretted Hydrogen.

The absorption of SH_2 by the active oxide occurs in two distinct ways :

(*a*) $Fe_2O_3, H_2O + 3H_2S = Fe_2S_3 + 4H_2O$.
(*b*) $Fe_2O_3, H_2O + 3H_2S = 2FeS + S + 4H_2O$.

In the first instance ferric sulphide is formed, whilst secondly the result is ferrous sulphi and some free sulphur.

When spent and inactive the material is removed from the purifier and subjected to the process of revivification, or exposure to the air, when the sulphides are oxidised to oxides and the material is ready for further use. The following are the revivifications reaction :

(*a*) $2Fe_2S_3 + 3O_2 + 2H_2O = 2Fe_2O_3, H_2O + 3S_2$.
(*b*) $4FeS + 3O_2 + 2H_2O = 2Fe_2O_3, H_2O + 2S_2$.

Oxide is generally laid in the purifiers on grids to a depth of from 8 to 10 ins. In some works, however, it is still customary to employ deep layers of as much as 30 ins. This is particularly the case in those purifiers in which hurdle grids are made use of.

A space of at least two inches should be left between the top of one layer and the base of the sieves or grids of the layer immediately above. Oxide as it becomes fouled increases in bulk, hence this precaution. Partial revivification *in situ* is nearly always arranged for in present-day systems. This is effected by admitting a small measured quantity of air to the purifiers along with the gas. The air may be taken from a small compressor and forced into the box, or may be injected by means of steam. In other cases, it is sucked in with the gas through a pipe attached to the main on the inlet side of the exhausters. When air is admitted at some point prior to the washers and scrubbers it should not be overlooked that undesirable reactions may be set up in the wet purification plant.

It is generally understood that the material in any one purifier cannot simultaneously extract sulphuretted hydrogen and undergo revivification. The assumption is not entirely accurate, but the process of sulphiding takes place at a very much more rapid rate than does the oxidation effect.

If the capacity of the purification plant is not ample the full effect of the admitted air will not be realised. For the most effective results a slight excess of air above that theoretically required (as determined from the SH_2 present) should be admitted.

When air is admitted to a purifier a rise in temperature of about 5 degrees Fahr. will usually be found as the gas passes from inlet to outlet. The air acts, of course, as a diluent, and therefore a careful check must be kept on the quantity admitted with the gas. As regards the effect of the air in this direction the following may be quoted :

Audouin and Berard found that 1 per cent. of air reduces illuminating power by 6 per cent.

	Per cent.
2 per cent. of air reduces illuminating power by . .	11
3 „ „ „ „ . .	18
4 „ „ „ „ . .	26

Würtz has stated that

3 per cent. of air causes	15·69 per cent. loss in light.
5 „ „	24·0 „ „

Dr. W. B. Davidson, in more recent experiments, has found the following results :

			Per cent.
1 per cent. of	oxygen	reduces candle power by .	3
1 „	„	„ calorific power by .	1
1 „	nitrogen	„ candle power by .	2·8
1 „	„	„ calorific power by .	1
1 „	carbon dioxide	„ candle power by .	3·5

Lime Purification.

Prior to the year 1905 lime purification for the removal of carbon dioxide and sulphur compounds other than sulphuretted hydrogen was in almost universal use. To-day, purification by this method is met with only in isolated instances.

Lime in the slaked condition is an active absorbent of sulphuretted hydrogen and carbon dioxide, and—after special treatment—is capable of removing carbon disulphide. The following reactions occur during the process of purifying by means of lime :

(*a*) Removal of carbon dioxide—

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

(*b*) Removal of sulphuretted hydrogen—

$$Ca(OH)_2 + 2SH_2 = Ca(SH)_2 + 2H_2O.$$

(*c*) Removal of CS_2.

It must be borne in mind that slaked lime in itself has no action upon carbon disulphide. The active medium which accounts for the removal of the CS_2 is now generally supposed to be calcium hydroxyhydrosulphide. This is prepared by sulphiding the slaked lime, in other words by admitting gas containing sulphuretted hydrogen to the vessels which are destined to

remove the CS_2. Carbon disulphide certainly cannot be absorbed according to the following equation, which has been so often set down as illustrating the reaction:

$$CaS + CS_2 = CaCS_3.$$

Veley has laid down the following theory as to the actual reactions which occur:

(1) Calcium hydrosulphide is formed in the first place—

$$Ca(OH)_2 + 2H_2S = Ca(SH)_2 + 2H_2O.$$

(2) By the addition of water or oxygen the hydrosulphide is converted into hydroxyhydrosulphide—

$$(a)\ Ca(SH)_2 + H_2O = CaOH,SH + SH_2$$

or

$$(b)\ 2Ca(SH)_2 + O_2 = 2CaOH,SH + 2S.$$

(3) The carbon disulphide and hydroxyhydrosulphide then react as follows:

$$(a)\ 2CaOH,SH + CS_2 = SH_2 + Ca(OH)_2,CaCS_3$$

or

$$(b)\ 3CaOH,SH + CS_2 + H_2O = 2SH_2 + (Ca(OH)_2)_2,CaCS_3.$$

When gas is manufactured and is to be freed from the whole of its impurities it is usual to instal a system in which oxide of iron and lime are used in conjunction. Many methods of operating for this purpose are employed, but one of the most common systems is that generally known as the 'Beckton' method. It consists in the main of four sets of purifiers operated in rotation:

First Set, Lime.—These remove the whole of the CO_2 and some SH_2, which is afterwards displaced by CO_2. Some CS_2 is also absorbed.

Second Set, Oxide.—These remove the whole of the SH_2, including any which may be displaced from the lime in the previous set.

Third Set, Lime.—This lime has been previously 'sulphided' and removes the bulk of the CS_2. It will not remove the whole of this impurity.

Fourth Set, Oxide.—These vessels remove any SH_2 which is disengaged from the third set.

Cost of Purifiers.

It is difficult to give any reliable figure, based on each 1,000 cub. ft. capacity, for the cost of purifiers, for everything is dependent upon the size of the vessel. The larger the box, the lower the cost per unit of capacity. As regards the distribution of the cost, the following is illustrative of normal conditions with a medium size installation:

	Per cent. of total expenditure.
Purifying boxes	50
Covers (dry lute)	15
Lifting apparatus	4 to 6
Grids	6 to 10
Connections and valves	20 to 30

Castings for the boxes, in normal times, cost from 10*l.* to 11*l.* per ton. The covers cost from 17*l.* to 19*l.* per ton. As regards valves, it is usual to base these per inch of diameter. The following figures are approximate pre-war costs:

	Per inch of diameter.
Ordinary rack and pinion valve	1*l.*
Centre valves	9*l.*
Weck's valves, and such types	10*l.* 10*s.*

Removal of CS_2 by Hot Purification.

Owing to the uncertainty and expense of lime purification for the removal of sulphur compounds other methods of effecting the same end have recently been introduced. The most important of these is the Carpenter-Evans system of hot purification, which is now in everyday use at some works. The principle of the process consists in converting the CS_2 into sulphuretted hydrogen, and then removing the latter by means of ordinary oxide of iron purification. The gas, after being purified from SH_2 in the usual way, is passed into special chambers containing a catalyst heated to a temperature of about 800°F. The CS_2 is thereby decomposed according to the following reaction:

$$CS_2 + 2H_2 = 2H_2S + C.$$

The catalytic agent employed consists of fireclay balls about 1 in. in diameter impregnated with nickel reduced from the chloride. The free carbon resulting from the reaction is left behind in the catalysing apparatus, and after about thirty days' run it is necessary to remove it. This is carried out by the process known as 'aeration.' Air is pumped through the catalyser tubes at a definite rate thus burning out the carbon and disposing of it as carbon dioxide. The aeration

process on the larger plants usually occupies about one week, after which the apparatus is again ready for work. When starting and stopping special precautions have to be taken to ensure immunity from explosion. The effect of the process on the general composition of the gas seems to be but slight; as an instance the following figures, given by Dr. Carpenter, are quoted:

Analysis of Gas.	Before Treatment.	After Treatment.
CO_2, per cent. by volume	1·44	1·45
Heavy hydrocarbons	3·55	3·63
Oxygen	0·33	0·06
Carbon monoxide	8·16	8·03
Methane	26·85	27·26
Hydrogen	54·19	54·25
Nitrogen	5·48	5·32
Illuminating power	14·70	14·70
Calorific power (Gross, B.Th.U.)	590·0	594·40

Cost of Purification.

The present-day cost of operating the Carpenter-Evans system of purification is shown in the following table:—

	Pence per 1,000 cubic feet.
Fuel (coke @ 42*s.* 6*d* per ton)	0·2550
Conveying coke and cleaning producer	0·0240
Power	0·0129
Labour and chemical supervision	0·1180
Repairs and maintenance	0·1649
Capital charges	0·1967
Total	0·7715*d.*

Purification by means of Charcoal.

Mr. W. Gordon Adam has introduced a method for removing carbon disulphide and thiophen by passing the gas, after washing and scrubbing, through animal or wood charcoal in a granulated state. The impurities (including naphthalene) are afterwards removed from the charcoal in an unchanged condition by the application of heat, a temperature of about 300° C. being sufficient. After this treatment the charcoal is ready for further use, and is employed in a purifying vessel of ordinary construction. The prevention of ethylene absorption is effected by curtailing the quantity of charcoal used—in other words, by increasing the space-velocity above that at which ethylene is extracted.

Removal of Naphthalene.

During recent years it has become usual to employ special naphthalene solvents, to the action of which the gas is subjected before travelling to the district mains. Paraffin, water-gas, tar, and anthracene oil have all proved effective, particularly the latter. In general the gas will contain, if no special treatment is accorded it, from 6 to 12 grains of naphthalene as it leaves the works. Butterfield has pointed out that a million cubic feet of gas cooled from 68° to 50°F. may deposit about 14 lbs. of naphthalene. The introduction of carburetted water gas has to a certain extent lessened the naphthalene evil, although its effect in this direction is somewhat erratic. As regards the methods of washing with solvents, the most ready plan to adopt is that of treating the gas in a Livesey or mechanical washer just prior to its entering the holders.

Carburation with the aid of solvents was introduced by Botley, who injected, by means of a special spray, about 4 gallons of thoroughly atomised paraffin oil per million cubic feet of gas. Botley found that petroleum oil was more suitable for the purpose than spirits such as benzol. Leather made use of a creosote oil for washing the gas, but owing to the 'stripping' properties of this oil he took the precaution to pre-benzolise it first. The practice of Ferguson Bell is somewhat uncommon. The gas whilst in a warm state is washed with warm tar, and at the outlet of the wet purification plant it is further treated with a naphtha oil.

Recovery of Cyanogen on Gasworks.

Cyanogen is a subsidiary by-product which is only recovered on the largest of works. The maximum amount which can be obtained from a ton of coal is about 1½ lbs. of hydrocyanic acids or about 10,000 grains. The processes now employed recover the hydrocyanic acid either as ammonium sulphocyanide or as sodium ferrocyanide (prussiate of soda). The most readily applied method is that operating on the polysulphide principle. In this system the gas, prior to washing and scrubbing, is passed through a special vessel (of the nature of a small purifier

containing a layer of spent oxide of iron about 2 ft. in depth. Above the oxide material sprays are arranged around the box, and the oxide is periodically sprayed with water or weak cyanide liquor. The gas, containing hydrocyanic acid, passes upwards through the layer of oxide and comes in contact with the polysulphide solution trickling through the mass. The hydrocyanic acid combines with the ammonium polysulphide and yields ammonium sulphocyanide according to the following equation :

$$(NH_4)_2S_2 + HCN = NH_4SCN + NH_4SH.$$

The spent oxide used in the process should contain about 50 per cent. of sulphur, and it is a surprising fact that although sulphur is required for the completion of the reaction the spent oxide, when removed from the vessel after working for about three months shows little or no loss in sulphur, while occasionally some slight increase may be found. Accordingly, the process would be of a continuous nature were it not for the fact that the physical nature of the oxide gives rise, after a time, to excessive back-pressure, when the only remedy is the substitution of a fresh layer. Figures obtained in practice show that one ton of spent oxide is capable of removing the cyanide evolved from 350 tons of coal.

The Recovery of Crude Benzol.

While the 'stripping' of gas for the recovery of the aromatic series of hydrocarbons has been carried out in the case of coal gas produced on coke-oven works for some years, the practice has only recently been introduced in gasworks, primarily as a means of meeting the demand for certain essential war products. The coal gas, either in the semi-crude state (*i.e.* after the wet purification plant) or when completely purified, is subjected to washing with a solvent which absorbs the benzene hydrocarbons but which has no effect on the remainder of the constituents. The solvent employed consists usually of a coal-tar distillate known as 'green oil,' although other substances, such as creosote, blast-furnace oil, or crude petroleum, may also be employed. The oil, after having been in contact with the gas, is said to be benzolised, when it may contain up to 5 per cent. of benzene hydrocarbons, according to the extent to which 'stripping' is carried. The benzolised oil is then passed through a series of vessels comprising the distilling plant in which the benzene hydrocarbons, with some light naphthas and a small proportion of naphthalene, are driven off and separated from the wash-oil. The benzene vapours thus obtained are condensed and collected as a crude spirit, while the wash-oil, having been 'debenzolised,' is cooled and once more employed for treating the gas. In general, it is customary to recover from normal coal gas from 1½ to 2½ gallons per ton of coal carbonised, depending upon the amount of aromatic hydrocarbons contained in the original gas and the proportion of these which it is deemed advisable to extract. The crude spirit will vary in composition, but in general about 65 to 70 per cent. will distil over up to 120° C., and 80 per cent. up to 160° C. The portion which distils over will consist of about 80 per cent. of benzol and 15 per cent. of toluol, the remainder being xylol. The amount of wash-oil employed for extraction per ton of coal carbonised undergoes considerable variation in accordance with the taste of the responsible engineer. It may be said, however, that it should never be less than 60 gallons per ton of coal, while it may be so much as 100 gallons. Water in the wash-oil is strongly to be guarded against, and should never exceed 1 per cent. by volume if effective results are to be obtained. Temperatures play an important rôle in the process, and it may be said that the scrubber should never exceed about 70° F., and as regards the temperature of the debenzolised oil a good rule to observe is that of maintaining the oil about 5° F. above the temperature of the gas. Now that the demand for explosives has ceased many gas undertakings have discontinued the recovery of benzol.

There can be no question, however, that experience with benzol stripping has shown that a valuable effect results so far as naphthalene is concerned. On quite a number of works it has, therefore, become a common practice to wash the gas with oil, the primary object being, not the recovery of benzol, but the reduction of naphthalene. Green oil of the usual kind may be utilised for the purpose, but gas oil has in many cases been found to be superior.

Tar Distillation.

(Contributed by Harold Moore, M.Sc., A.I.C., F.C.S.)

The yield of coal tar depends very largely upon the volatile content of the coal; but, in addition, it is considerably affected by the design of the retort. Retorts in which heating is conducted gradually, and which ensure the rapid removal of the volatile products from the heat zone, yield the largest quantities of tar. The nature of the tar depends, to a slight extent, upon the type of coal used, but is much more seriously affected by the carbonising conditions. A rapid rise in temperature, with a high maximum temperature, tends to produce tar high in specific gravity, high in viscosity, rich in free carbon, and mainly consisting of aromatic hydrocarbons. Gradual heating, low maximum temperature, and rapid removal of the volatile products result in brown mobile tars, comparatively devoid of free carbon and rich in aliphatic hydrocarbons.

Horizontal retorts subject the coal to a very rapid heating with a high maximum temperature, whilst the volatile products have to pass along the heated retort walls, whereby they undergo cracking. The result is a viscous tar, rich in free carbon. Horizontal retort tars frequently

contain over 20 per cent. They possess a specific gravity of about 1·2. In continuous vertical retorts the coal is slowly passed from the cool zone into a hotter zone, undergoing gradual heating, whilst the volatiles are removed from the cooler end of the retort, and, therefore, are not so liable to undergo cracking. The resulting tar possesses a specific gravity of about 1·08, and about 1 to 8 per cent. of free carbon. Inclined retorts give products of intermediate composition; whilst coke ovens yield tars of very varied composition, depending upon the design of the ovens.

Special processes for the low-temperature carbonisation of coal, such as the Coalite and Premier Tarless systems, yield brown low-gravity tars in which free carbon is almost entirely absent. Gas works and coke ovens supply nearly all the tar produced in this country. Tar produced in gas works is accompanied by ammoniacal liquor, and requires settling out previously to distillation. The tar in distillation is usually divided into the following fractions in English distilleries:—

	Temperature.	Approx. Yield.
1. Crude naphtha	Up to 110° C.	3 per cent.
2. Light oil	110° to 200° C.	7 ,,
3. Crude carbolic oil	200° to 240° C.	7 ,,
4. Creosote oil	240° to 270° C.	15 ,,
5. Anthracene oil	270° to finish	10 ,,
6. Residuum of pitch	—	58 ,,

The finishing-point of the distillation is decided by the quality of pitch desired. The yields of the above products vary, of course, with the nature of the tars, horizontal retort tars yielding a residue of about 65 per cent. of pitch, whilst vertical retort tars give only about 50 per cent. of pitch. The benzene and toluene are mostly present in the crude naphtha fraction, the yield of benzene being about 2 gallons to the ton of tar. They are separated by distillation combined with washing with dilute alkali, which removes phenols, cresols, and other acidic bodies, followed by washing with dilute acid, which removes pyridine, quinoline, and other basic substances, and are finally refined by treatment with strong sulphuric acid, which removes certain sulphur-containing compounds and a portion of the unsaturated hydrocarbons originally present in the tar. Similar processes of refining are adopted for other fractions, though the strong acid treatment is usually applied only to the benzene, toluene, and solvent naphtha-containing fractions. The most common grades of these three distillates are sold under the names of 90*s.* benzol, 90*s.* toluol, and 90*s.* xylol. The 90*s.* benzol distils 90 per cent. of its volume at 100° C. by the tar distillers' retort test; 90*s.* toluol yields 90 per cent. at 120° C. by the same test; whilst 90*s.* solvent yields 90 per cent. at 160° C. The solvent fraction consists mainly of the three isomeric xylols. Naphthalene and anthracene are removed from the higher boiling fractions (naphthalene mainly from the carbolic oil fraction, anthracene from anthracene oil) by cooling and decantation, or by cooling and filtration.

The limiting temperatures of the fractions are liable to alteration, depending upon market conditions, whilst the distillation is frequently stopped at an earlier stage than that indicated in the above table, in order to yield a soft residue known as treated or refined tar, which is used for tar spraying on the roads. A soft finished residue is also frequently sold as pitch-creosote mixture, and used for the fuel market.

Benzol is mainly used for motor fuel, together with a considerable quantity of the toluol, though smaller amounts are employed in the synthetic chemical industry. Carbolic acid (phenol) and cresylic acid (cresols), obtained by alkali washing, both find their main market for the manufacture of disinfectants. Creosote oil is used for timber preservation and as fuel. The use of creosote as fuel is somewhat intermittent, depending upon the price of petroleum. Pitch is mainly used for road repairing, but also for many other purposes, a considerable amount being consumed for electric insulation.

WATER GAS.

Manufacture of Water Gas.

Water gas, which is employed as an auxiliary to coal gas in gasworks, is now usually of the 'blue' type, although in some instances oil enrichment has again been resorted to owing to the very considerable drop in the price of oil. The composition of these two gases has already been given on pp. 2177, 2454. The reactions occurring in the generator of the water gas plant are as follows:

$$(a)\ C + 2H_2O = CO_2 + 2H_2.$$
$$(b)\ C + H_2O = CO + H_2.$$

The carbon dioxide produced in the lower portion of the fuel bed according to equation (*a*) is then reduced to carbon monoxide on passing through the remainder of the fuel bed:

$$(c)\quad CO_2 + C = 2CO.$$

The extent to which the reaction (*b*) takes place depends largely upon the temperature prevailing in the lower part of the fuel bed.

As the above reactions are of an endothermic nature the heat of the fuel bed is gradually absorbed, accordingly this is replaced at intervals by the process of blowing. The reaction occurring during the 'blow' is of an exothermic nature, being simply as follows:

$$C + O_2 = CO_2.$$

All practical water gas plants are now operated on the intermittent principle of providing for short periods of a gasmaking 'run' and a 'blow.' In the more common carburetting plant the 'run' continues for 5 or 6 minutes, and is followed by a 'blow' extending for 3 or 4 minutes. In certain forms of plant intended entirely for the production of 'blue' gas the blowing period is generally of much shorter duration, lasting for about 70 to 90 seconds. The primary object of the 'blow' is to convert the coke direct into CO_2, thereby liberating the maximum quantity of heat, but this condition is never attained in practice, some CO being always present. The CO, in the enriching plants, is made use of for heating up the subsequent apparatus in which enriching takes place. In some of the later forms of 'blue' plants (in which no enriching vessels are required) the CO is employed for the purpose of raising the steam required during the 'run.' The average composition of the 'blow' gases issuing from the top of the generator is as follows:

Carbon monoxide	17 per cent. by volume.
Carbon dioxide	10 " " "
Nitrogen	73 " " "

Traces of hydrogen, methane and sulphuretted hydrogen may also be found. The CO is at a maximum, and the CO_2 at a minimum, during the first minute of the 'blow,' and as the period proceeds the CO undergoes reduction while the CO_2 increases in quantity.

As regards temperatures the generator should, at the commencement of the 'run,' be worked up to 2,000F.° By the time that the 'run' is completed the temperature will have dropped by from 300° to 500°. Owing to this fact the quality of the water gas undergoes gradual deterioration from the commencement of the 'run' onwards; thus at the end of the first minute of the 'run' the CO_2 content will only amount to some 2 per cent., whilst at the end of the fifth minute it may amount to from 7 to 8 per cent. The temperature of the carburettor and superheater varies in accordance with the type and quantity of oil in use at the time. Under normal conditions the following will apply:

Carburettor	1350 to 1400 F.°
Superheater	1400 to 1450 F.°

For the manufacture of carburetted water gas the materials required are as follows:

Coke	35 to 41 lbs. per 1,000 cub. ft. of gas;
Oil	about 2½ gallons per 1,000 cub. ft. of 18 candle gas;
Steam	27 to 30 lbs. per 1,000 cub. ft. of gas.

The cost of carburetted water gas is mainly influenced by the current value of the enriching oil utilised. To-day, blue water gas is a far more common and important product, so that many plants formerly utilised for producing carburetted gas are now employed for the production of blue gas only. The present-day cost of manufacturing blue gas is as follows:—

BLUE WATER GAS: COST OF MANUFACTURE (1925).

	Per 1,000 cubic feet.	Per therm.
	d.	*d.*
Coke, generator	6·0	2·0
Coke, for steam	3·0	1·0
Water, for steam	0·15	0·05
Wages	3·5	1·16
Maintenance	2·5	0·84
Purification	0·5	0·16
Establishment charges	0·75	0·25
Total	16·40	5·46

The impurities in water gas consist of carbon disulphide and sulphuretted hydrogen, which are present in the following quantities:

	Grains per 1,000 cub. ft.
Sulphuretted hydrogen	110 to 120
Carbon disulphide	10 to 15

As regards water gas tar, S. Carter has given the following analysis:

Specific gravity	1·0665
	Per cent.
Benzol	1·11
Naphtha	2·33
Creosote oil	21·35
Naphthalene	4·09
Anthracene oil	15·91
Pitch	56·70

The Complete Gasification of Coal.

Now that the choice of the quality of gas to be distributed rests with the gas engineer instead of being stipulated by Parliament, a certain amount of interest has been displayed in the process known as the complete gasification of coal. By this is meant the treatment of the coal under such conditions that no solid residue other than ash remains. Complete gasification may, of course, be carried out in two ways, namely, by treating the coal in two stages for the production, firstly, of straight coal gas, and secondly, of blue water gas in distinct plants, the two gases being subsequently mixed either in the crude or purified state. The alternative is to employ plant of special design in which the above two processes are carried out simultaneously.

From the standpoint of gas production, the two methods may be contrasted as follows:—

A. Dual Process.

	B.Th.U.
1 ton of coal yields—	
13,000 cubic feet of straight coal gas @ 520 B.Th.U. =	6,760,000
and 11 cwts. surplus coke.	
11 cwts. coke yields—	
20,500 cubic feet of blue gas @ 300 B.Th.U. =	6,150,000
Total yield in gaseous form from 1 ton of coal. =	12,910,000

B. Single Process.

	B.Th.U.
1 ton of coal yields—	
50,000 cubic feet of mixed gas @ 370 B.Th.U. =	18,500,000

The composition of the gas obtained from the modern single-stage complete gasification plant is as follows:

	Per Cent.
Hydrogen	51·0
Carbon monoxide	30·0
Methane	8·0
Unsaturated hydrocarbons	1·4
Carbon dioxide	4·6
Nitrogen	5·0
Oxygen	trace
Yield per ton of coal (cubic feet)	50,000
Calculated calorific power (gross)	370
Therms per ton of coal	185

SULPHATE OF AMMONIA.

Average commercial salt contains:

Ammonia	from 24¼ to 25¼ per cent.
Equal to	
Nitrogen	20·2 to 20·8 per cent.
Free acid	0·4 per cent.
Moisture	2 to 3 per cent.

Materials required for the manufacture of 1 ton of sulphate of ammonia:

Liquor, approximately	3,400 gallons of 8 oz. strength.
Acid "	18 cwts. at 80 per cent. strength.
Lime "	3 cwts.

The sulphate of ammonia recovered per ton of coal varies in this country between 24 ar 28 lbs.

Equation for formation :

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4.$$

Gallons of liquor × ounce strength × 0·0823 = lbs. of sulphate.

The total quantity of ammonia products (mainly sulphate of ammonia) produced in Englan Scotland, and Wales in 1923, was 425,590 tons.

CONCENTRATED LIQUOR.

The exigencies of the war were responsible for a new gasworks product in the form concentrated and purified ammoniacal liquor. This product contains about 25 per cent. ammonia, while the sulphuretted hydrogen is reduced to 0·5 per cent. by volume. The co centrated liquor is prepared by passing the ordinary liquor from the storage well through desulphurising column in which the carbon dioxide and sulphuretted hydrogen are remove the purified liquor being afterwards concentrated in a special still. With the war ended th majority of these plants have been shut down. During 1923 the quantity of concentrated liquo made in Great Britain was equivalent to 39,071 tons of sulphate of ammonia.

USEFUL MEMORANDA.

1 in. of mercury = 0·490 lbs. per sq. in. ; 1 in. of water = 0·0361 lbs. per sq. in. 1 lb. per sq. in. = 27·7 ins. of water.

A British Thermal Unit is the amount of heat required to raise 1 lb. of pure water 1° Fahr correctly, from 39·1° Fahr. to 40·1° Fahr.

A Calorie is the amount of heat required to raise 1 kilogramme of water 1° Cent. : correct from 0° to 1° Cent. This is the *large* calorie, which is the unit employed on gasworks.

1 British Thermal Unit	= 0·252 calories.
1 Calorie	= 3·968 B.Th.U.
1 Therm	= 100,000 B.Th.U.
Therms	= cu. ft. × calorific value per cu. ft. ÷ 100,00
Cu. ft.	= therms × 100,000 ÷ calorific value per cu. f

CALORIFIC VALUE OF VARIOUS GASES.

South Met. Co.	560 B.Th.U. per cu. ft.
Gas Light & Coke Co.	500 ,, ,,
Commercial Gas Co.	500 ,, ,,

200 cu. ft. of Gas Light and Coke Co's. gas = 1 therm.

CALORIFIC POWER OF VARIOUS SUBSTANCES.

	B.Th.U. per lb.		B.Th. per l
Coke-oven coke	14,436	Petrol, specific gravity 0·684	20,9
Peat, 5 per cent. water	9,900	Shale oil	18,2
Wood, pine	9,153	Blast-furnace oil	16,0
,, oak	8,316	Heavy tar oil	16,0
Petroleum, American	19,627	Coal gas tar	15,5
,, Texas	19,242	Alcohol, absolute	12,9
,, Russian	19,440		(*Lewes.*)

At normal temperature and pressure 32 cu. ft. of coal gas (14 candle power) weig approximately 1 lb.

1 cu. ft. of coal gas (14 candle power) at N.T.P. weighs ·03125 lb.
1 ,, blue water gas ,, ,, ·0376 lb.

GASWORKS TERMS.

A barrel of tar	25 gallons	A fodder of lead	19½ cwts.
A butt of liquor (Usually 8 oz. strength)	108 ,,	A hundred of deals	120 in numbe
A bushel of coal	80 lbs.	A load of lime (A bushel = 70 lbs.)	32 bushels
A bushel of coke	45 lbs.	A long thousand of slates	1,200 in numb
A chaldron of coal (Varies according to locality)	25½ cwts.	A seam of glass	120 lbs.
A chaldron of coke (Varies according to locality)	12½ cwts.	A short ton (American)	2,000 lbs.
A cord of wood	128 cub. ft.	A tonne (French)	2,204·6 lbs.
		A ton of freight	40 cub. ft.
		A truckload of bricks	About 3,300 in numb

VOLUMES OF OXYGEN AND AIR REQUIRED FOR COMBUSTION OF ONE VOLUME OF COMBUSTIBLE GAS.

Combustible Gas.	Oxygen.	Air containing 21 per cent. Oxygen.	Volume of Products of Combustion.
Hydrogen . .	0·5	2·38	1 vol. H_2O
Carbon Monoxide	0·5	2·38	1 vol. CO_2
Marsh Gas . .	2·0	9·52	1 vol. CO_2, 2 vols. H_2O
Ethylene . .	3·0	14·28	2 vols. CO_2, 2 vols. H_2O
		Incomplete Combustion.	
Marsh Gas . .	1·5	7·14	1 vol. CO, 2 vols. H_2O
Ethylene . .	2·0	9·25	2 vols. CO, 2 vols. H_2O

High Pressure Lighting.

For high-pressure lighting the cost of compressing the gas only amounts to from 2½ per cent. o 4 per cent. of the total cost of the gas consumed, which is very small when it is compared with he extra light obtained.

With a water-driven compressor, from 250 to 300 gals. water are required per 1,000 cubic feet as compressed to, say, 9 ins. pressure; with a gas-driven plant, 12·4 to 13·4 cubic feet per 1,000 ubic feet compressed to same pressure.

Compressing coal gas reduces the illuminating value until, with a pressure of 200 lbs. per q. in., the loss is 16 per cent.

(See also 'LIGHTING,' Section XXXVIII., Part III., p. 2521.)

Incandescent Burners.

The Bunsen burners used for incandescent lighting should give a flame with a green inner cone nd not a violet one, so as to show that the proportion of air used for primary combustion is as arge as possible. This ensures an intense heat in the flame, which intensity adds greatly to the ight emitted by the burner. This intensity of flame is obtained in the high pressure systems, which are now becoming so general for street and shop lighting, by increasing the pressure of this as to about 2 lbs. per sq. in., and when this is used with an inverted mantle of a much longer hape than the ordinary low pressure ones, the rush of gas at this high pressure at the nipple causes he full quantity of air required for combustion to be drawn in at the base of the burner mixing ube and so give a flame of the highest intensity. This flame only gives off the same heat per ubic ft. of gas as an ordinary Bunsen burner, but the heat is concentrated and the flame is much naller. If the quantity of air induced by the current of gas into the mixing tube is 2½ times that f the gas there will be a lilac inner cone, and the hottest part of the flame will be about 2,800°F., nd the mantle will then show about 20 candles per cubic ft. of gas consumed. If 3½ times of ir are induced, a green inner cone will be noticed, and then the flame will be about 3,000°F., and 0 candle power per cubic ft. of gas obtained.

Products of combustion must be conveyed away and not allowed to enter at the primary air ole of the Bunsen burner. The air used there should contain the full proportion of oxygen to nsure proper combustion. Mantles must fit the flame, or, inversely, the flame must fit the mantle. s then it will be in the hottest part of the flame which is at the outside where the C in the gas s combining with the O_2 of the air to form CO_2 with the evolution of the heat. As the flame is ollow, if the mantle is smaller than the flame it will be in the cooler region of the flame where the as is not being fully burned. Upright burners give their greatest light horizontally, inverted urners downwards. Shades for gas lights should be at 45° with the horizontal, not 60° or 70° s usually adopted, when very little light is reflected.

The best effects are obtained with burners which permit of the adjustment of both air and as. These burners should be adjusted from time to time. The burner should be thoroughly leaned out each time a mantle is fixed.

Incandescent Mantles.

Mantles are made from cotton, ramie, or artificial silk knitted into a 'stocking' or hose about ins. in diameter. This stocking is thoroughly washed and dried. Then it is saturated with a olution of nitrate of thorium and 1 per cent. of nitrate of cerium. After the stocking has been ashed and dried, it is either cut to proper size and impregnated with the thorium solution, or

is first impregnated and then cut to the required lengths. The impregnated stockings, after being cut and dried, are sewed at one end with asbestos thread so as to form a head provided with a loop, which serves to hold the mantle in process of manufacturing and when in use on the burner. Then the impregnated stocking is hung on a wire by the asbestos loop, and heated in a gas flame of the Bunsen type. This is done in order to burn out the thread. The next process is called the shaping. The mantle now consists only of ashes of thorium (oxide of thorium), and is carefully held over a high pressure Bunsen flame, and gradually given the right shape, at the same time being hardened. As soon as the mantle is shaped and hardened it is practically completed, but in order to protect it from breakage it is 'dipped' in a stiffening solution. There are many forms of 'dip,' but the one most used is made of soluble cotton (gun cotton) dissolved in good alcohol and acetone. To this mixture castor oil and shellac are added.

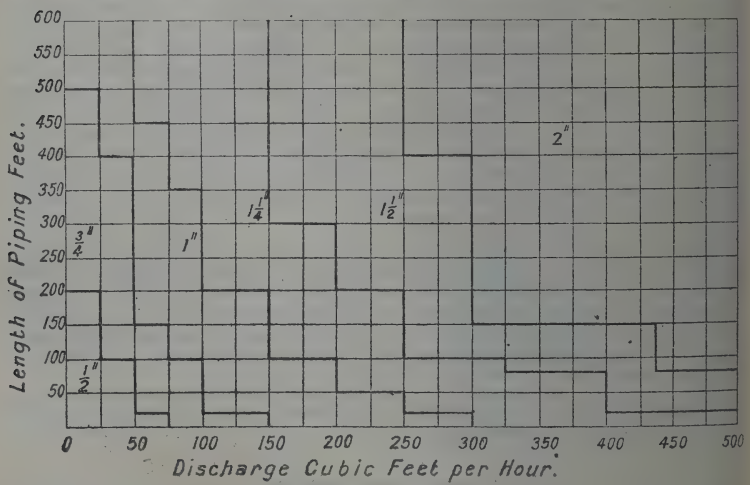
Gas versus Electricity.

The inverted incandescent gas lamp requires 47 B.Th.U. per candle-power hour obtained. The one-watt electric lamp requires 54 B.Th.U., and the ½-watt lamp 31 B.Th.U. A considerable proportion of gas burners consist of the upright type, which are less efficient, requiring 82 B.Th.U. per candle-power hour. The average may be taken at 64 B.Th.U. per candle-power hour. High-pressure incandescent burners reduced the heat consumption to 23 B.Th.U. per candle-power hour and flame arcs in electric lighting use only 15 B.Th.U. At about 75 per cent. of full load a gas engine of the ordinary type would deliver to the consumer as actual or brake horse-power 11 per cent. of the heat used at the gasworks, while an electric motor would deliver, also as brake horse-power, only 6·8 per cent. of the heat used at the electricity generating station. The efficiency of the gas power production and distribution was thus over 1·6 times that of the electricity system.

(*Sir Dugald Clerk.*)

Gas Piping.

In the following diagram the point of intersection of consumption in cub. ft. per hour and length of pipe falls into an area indicating size of pipe for the work.



The diagram shows the size of pipe for the conveyance of a given quantity of gas. It is based on a fall of pressure between the extreme ends of the pipe of $\frac{5}{10}$-inch water gauge, and for

ordinary low-pressure gas supply it would not be desirable to have a drop greater than this. The diagram does not provide for piping smaller than $\frac{1}{2}$ in. because generally sizes smaller than this are only used for the branches to pendants or other apparatus consuming less than 25 cub. ft. per hour. Up to 10 cub. ft. per hour $\frac{1}{2}$ in. pipe is sufficient and for 10 to 25 cub. ft. $\frac{3}{4}$ in.

WEIGHT OF WROUGHT-IRON GAS PIPES.

Bore in inches	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$
	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	
Outside diameter	$\frac{17}{32}$	$\frac{11}{16}$	$\frac{27}{32}$	$1\frac{1}{16}$	$1\frac{11}{32}$	$1\frac{11}{16}$	$1\frac{29}{32}$	$2\frac{5}{32}$	$2\frac{3}{8}$	$2\frac{5}{8}$
	3	$3\frac{1}{4}$	$3\frac{1}{2}$	4	$4\frac{3}{8}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	
Threads per inch	19	19	14	14	11	11	11	11	11	11
	11	11	11	11	11	11	11	11	11	
Weight in lbs. per ft.	0·38	0·58	0·81	1·16	1·60	2·36	3·00	3·60	4·10	4·60
	5·33	5·84	6·33	7·16	8·05	9·08	10·17	11·49	12·57	

WEIGHT OF CAST-IRON GAS PIPES.

Bore, in inches.	Thickness of Metal.							
	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
	Lbs. per Lineal Foot.							
2	8·7	12·3	16·1	—	—	—	—	—
3	12·4	17·1	22·2	—	—	—	—	—
4	16·1	22·1	28·3	—	—	—	—	—
5	19·8	26·9	34·4	42·3	—	—	—	—
6	23·4	31·9	40·6	49·7	—	—	—	—
7	27·1	36·8	46·7	56·8	—	—	—	—
8	30·8	41·6	52·8	64·3	—	—	—	—
9	34·4	46·0	58·9	71·7	—	—	—	—
10	—	51·4	65·1	79·0	93·3	—	—	—
11	—	56·4	71·0	86·4	101·8	—	—	—
12	—	—	77·3	93·7	110·4	127·4	—	—
14	—	—	89·6	108·4	127·5	147·0	—	—
15	—	—	—	115·7	136·1	156·8	—	—
16	—	—	—	123·1	144·7	166·6	—	—
18	—	—	—	139·9	161·8	186·2	—	—
20	—	—	—	—	178·9	205·8	260·3	—
22	—	—	—	—	—	225·4	284·8	—
24	—	—	—	—	—	245·0	309·3	—

The weight of two flanges or one socket may be reckoned weight of 1 foot.

AVERAGE WEIGHTS OF GAS PIPE CONNECTIONS.

Internal Diameter.	Tees.			Collars.			Syphons.			Caps.		
	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.	Cwts.	Qrs.	Lbs.
2	0	1	17	0	0	12	2	0	14	0	0	9
3	0	2	11	0	0	25	2	0	25	0	0	16
4	0	3	9	0	1	5	2	1	4	0	0	21
5	1	1	0	0	1	22	4	0	14	0	1	2
6	1	2	0	0	2	0	4	1	7	0	1	13
7	1	3	21	0	2	20	4	1	25	0	1	21
8	2	1	21	0	3	7	4	2	7	0	2	3
9	2	3	14	1	0	11	4	2	14	0	2	24
10	3	2	11	1	0	14	4	3	25	0	3	5
12	4	2	7	1	2	7	6	1	0	1	0	14
14	6	3	7	2	0	0	7	0	7	1	1	25
15	7	0	18	2	1	0	7	0	7	1	3	7
16	8	1	7	2	2	14	7	2	25	1	3	14
18	9	1	21	3	0	14	11	1	0	2	1	11
20	10	1	14	3	1	4	12	2	14	2	1	25
24	16	3	0	5	0	0	13	0	0	3	1	7

Flow of Gas in Mains.

Pole's Formula.

Let Q = the discharge of gas in cub. ft. per hour.
d = the diameter of pipe in inches.
p = pressure of gas in inches of water,
s = specific gravity of gas, air being 1
l = length of pipe in yards.

then,

$$Q = 1350d^2\sqrt{\frac{p\,d}{s\,l}};\quad d = \sqrt[5]{\frac{Q^2 s\,l}{(1350)^2 P}};\quad p = \frac{Q^2 s\,l}{(1350)^2 d^5};\quad l = \frac{(1350)^2 d^5 p}{Q^2 s}.$$

Unwin's Formula for High Pressure Gas Mains.

Let D = diameter of pipe in ft.
S = specific gravity of gas (air being 1).
L = Length of pipe in ft.
P_1 = initial pressure in lbs. per sq. inch absolute.
P_2 = final pressure in lbs. per sq. inch absolute.
C = coefficient of friction $= 0{\cdot}0044\left(1+\frac{1}{7D}\right)$.
U_1 = initial velocity of gas in feet per second.
U_2 = final velocity of gas in feet per second.
W = area of pipe in sq. ft.
Q = discharge in cub. ft. per hour,

then,

$$Q = 1{,}323{,}250\sqrt{\frac{P_1^2 - P_2^2}{P_1^2}\cdot\frac{P_1^2}{P_2^2}\cdot\frac{D^5}{CSL}};\quad U_1 = 468\sqrt{\frac{D}{CSL}\cdot\frac{P_1^2 - P_2^2}{P_1^2}};\quad U_2 = \frac{P_1}{P_2}U_1.$$

Table of Constants for Friction in Gas Mains.

Diameter of Main in Ins.	Diameter of Main in Ft. = D.	Area of Main in Sq. Ft. = W.	Value of C = Coefficient of Friction $= 0{\cdot}0044\left(1+\frac{1}{7D}\right)$
2	0·166	0·022	0·0082
3	0·250	0·049	0·007
4	0·333	0·087	0·0063
5	0·417	0·136	0·006
6	0·500	0·196	0·0057
7	0·583	0·267	0·00554
8	0·666	0·349	0·00537
9	0·750	0·442	0·00527
10	0·833	0·545	0·00515
12	1·000	0·785	0·005
14	1·166	1·069	0·00492
15	1·250	1·227	0·00488
16	1·333	1·396	0·00485
18	1·500	1·767	0·0048
20	1·666	2·182	0·00475
21	1·750	2·405	0·00473
24	2·000	3·142	0·0047

(*Professor Unwin.*)

Everite Gas Piping.

(*Bell's Poilite and Everite Co., Ltd., Southwark St., London, and Peter St., Manchester.*)

Everite piping is specially manufactured for the gas industry, and all the usual accessories can be obtained, including flue pipes, bends, bafflers, cone caps, etc., etc.

Gas Pressures.

Generally, gas pressures (in a factory, for example) are sufficiently constant for the correct working of gas-consuming apparatus, but occasionally owing to piping being of insufficient size a variation in the consumption will cause a variation of pressure. The best remedy is to relay or supplement the piping in the building, but, as a temporary measure, governors can be installed on any apparatus which needs a fairly constant supply of gas. The Stott, Peebles, Tilley, Sugg, and Williams governors are typical of this appliance. They maintain a constant pressure on their outlet regardless of wide variation at the inlet.

Gas Meters.

Size of Meter.	Normal Capacity.	Safe Maximum Capacity.
Lights.	Cub. ft. per hour.	Cub. ft. per hour.
5	30	60
10	60	100
20	120	200
30	180	300
50	300	450
60	360	480
80	480	600
100	600	750
150	900	1,100
200	1,200	1,500
250	1,500	1,900
300	1,800	2,300
400	2,400	3,000
500	3,000	3,700
600	3,600	4,500
800	4,400	6,000
1,000	5,000	7,500

It is desirable that the normal capacity should not be exceeded for continuous working, as there will be some risk of the meter breaking down and the supply of gas temporarily stopped. If additional gas-consuming apparatus is installed a larger meter should, if necessary, be used.

Gas Tests.

Gas Tests as Prescribed by the Metropolitan Gas Referees.

As gas is now sold on the 'Therm' basis, the determination of calorific power is the most important of the official tests. Illuminating power, however, is frequently required as a matter of interest rather than importance, and for this reason the test is given below.

(1) *Illuminating Power.*

Although calorific power is taking the place of illuminating power as a standard of quality, the latter test is still carried out in many instances.

This test is made by a photometric comparison between (*a*) a standard Argand burner called the Metropolitan Argand Burner No. 2, of which a part section drawing is given in fig. 1;

(*b*) a standard flat-flame wing burner $\left(\text{Bray's } \frac{G}{L} \text{ 5 ft. } \frac{15}{10}\right)$ having a slit 0·028 in. wide, and a 10-candle power standard lamp burning a mixture of pentane and air. The standard lamp is shown in fig. 2. A is a receptacle subdivided by seven alternate partitions which do not extend the full width of the chamber; so that air, drawn in through the cock S^1, by means of which the supply is regulated, is caused to traverse the surface of the liquid, with which the chamber is filled to about two-thirds of its height, eight times. The mixture of gas and air passes through the cock S^2 to a burner B, consisting of a steatite ring pierced with thirty holes between 1·5 and 1·25 mm. in diameter. The flame is viewed through a mica window in G. Careful adjustments are made to regulate the height of the flame and the concentricity of the chimney D.

The pentane for the lamp is prepared and tested in the following manner:—Light American petroleum, such as is used for making air-gas, is rectified by three successive distillations, at 15° C., 50°, and 45°. The distillate is shaken up from time to time, during two periods of not less than three hours each, with one-tenth its bulk of (1) strong sulphuric acid, (2) solution of caustic soda. After this it is again distilled, and that portion which comes over between the temperatures of 25° and 40° is collected. This consists chiefly of pentane, with small quantities of other homologues the presence of which does not affect the light of the lamp.

The density of the liquid pentane at 15° C. should lie between 0·6235 and 0·626 compared with water of maximum density.

Any admixture with pentane of hydrocarbons having a higher photogenic value, such as benzene or amylene, must be avoided. The presence of these may be detected by the following test:—Pour into a stoppered 4-oz. bottle of white glass 10 c.c. of dilute nitric acid, specific gravity 1·32; add 1 c.c. of a dilute solution of potassium permanganate (1 gr. in 200 c.c.). Pour into the bottle 50 c.c. of the sample of pentane, and shake strongly during five successive periods of 20 seconds. If there is an admixture of as much as ½ per cent. of amylene or benzene, the pink colour will disappear.

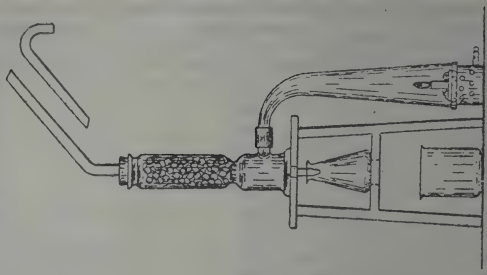


FIG. 3.

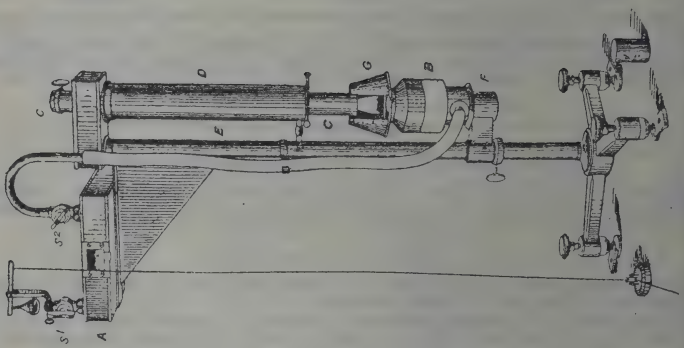


FIG. 2.

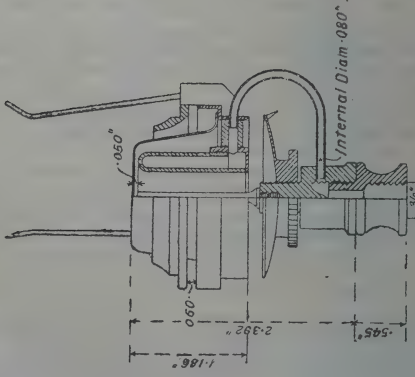


FIG. 1.

The photometric comparison is made by producing equality in the illumination of a white paper screen by shifting the test burner nearer to or further from the screen; the result, after applying barometric and temperature corrections, is expressed to the nearest hundredth of a candle.

(2) *Test for Sulphuretted Hydrogen.*

The gas is passed through a glass vessel in which are suspended strips of bibulous paper moistened with a solution of 6·5 grams acetate of lead crystals in 100 c.c. water. The gas having been turned into the vessel long enough to sweep out the air, is ignited at the issuing orifice, and when it has burned for three minutes one of the slips is compared with a slip similarly moistened but not exposed to the gas. The gas is taken as exhibiting a trace of H_2S if the exposed is unmistakably darker than the unexposed slip.

(3) *Tests for other Sulphur Compounds.*

Ten cubic feet of gas is burned in a Bunsen burner at the rate of ·5 cubic foot of gas per hour. The stem of the burner is surrounded with about 2 ounces of sesquicarbonate of ammonia, and the combined products of combustion and volatilisation are collected by means of a trumpet

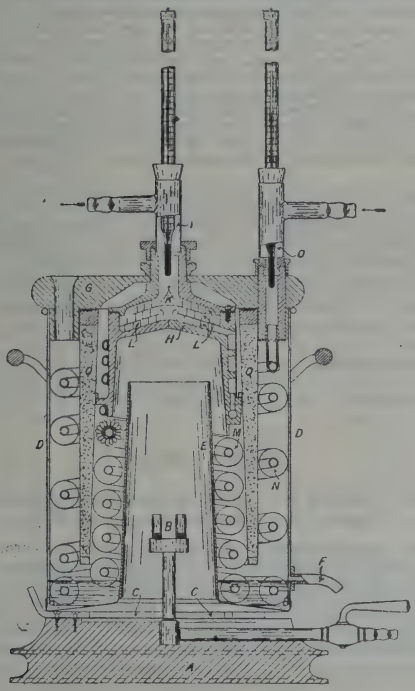


FIG. 4.

glass fitted over the burner and salt, an air-way being provided for the burner in the stand upon which it is placed (see fig. 3). The products are condensed as far as possible in the upper glass vessel, which, to aid the condensation, is filled with a number of glass balls about .5 mm. in diameter. The distillate, collected in a beaker placed beneath the bottom orifice of the condenser as shown, is poured, together with the washings of the trumpet and condenser, into a measure glass. A sample $\left(\frac{1}{n}\text{th part}\right)$ of the liquid is treated with hydrochloric acid in a covered beaker until there is an excess of acid, and then raised to boiling point; an excess of a barium

chloride solution is added, and the boiling continued for five minutes. After standing for a time barium sulphate settles; the latter is filtered off and washed with hot distilled water, in order to remove all traces of ammonium and barium chlorides. (A sample of the washings is tested for this in a test tube with silver nitrate, the washing being continued until no cloudiness is produced by the nitrate.) The filter paper with the barium sulphate is heated in a weighed platinum crucible until the paper is removed. When cool the crucible is placed in a desiccator over strong sulphuric acid and again weighed. The number of grains of barium sulphate thus obtained, multiplied by $\frac{11n}{8}$ (n being the quantity of liquid under test as above), gives the grains of sulphur per 100 cub. ft. of gas. This figure is corrected for barometric and temperature variations as in the case of the illuminating power test.

(4) *Tests for Calorific Power.*

These are carried out by observations taken by means of the special calorimeter illustrated in fig. 4, in which water flowing at a calibrated rate is heated by a double burner consuming the gas at a rate of $\frac{1}{12}$ cub. ft. per minute. The calorimeter having been set up, the burner lighted, and the water flow adjusted, the heating is allowed to proceed for not less than half an hour. Four readings of the inlet thermometer and fifteen readings of the outlet thermometer are taken at periodic intervals, during which the discharged water is collected in a measuring vessel and the operation timed by means of a chronograph. The temperature of the air about the apparatus, the gas in the meter, and the effluent gas are also observed. The mean of the four readings of the inlet temperature is subtracted from the mean of the fifteen readings of the outlet temperature, and the difference is multiplied by 3 and by the number of litres of water collected. The product is divided by a tabular number.* The difference in degrees Centigrade of the temperature of the effluent gas and of the surrounding air divided by 6 is added to the result previously found if the effluent gas is the warmer of the two, or subtracted if the effluent gas is the cooler. The result is the gross calorific power of the gas in calories per cubic foot (c).

In addition to the foregoing, the amount of condensed water resulting from the combustion of the gas is measured. For this purpose the condensation water is led into a flask not less than 20 minutes after the calorimeter has been set up. The amount collected in not less than 30 minutes is measured, the time of collection being accurately noted on the chronograph. The number of cubic centimetres collected is multiplied by the number of seconds and by the number 1·86 (a). The number of seconds during which the condensed water is collected is multiplied by the tabular number (b). The first product (a) divided by the second (b) and subtracted from the gross calorific power (c) gives the net calorific power in calories per cubic foot. The gross and net calorific power in British thermal units is obtained by multiplying the corresponding numbers of calories by 3·968.

The meters used for these tests are of the 'wet' type, having a calibrated capacity of $\frac{1}{12}$ cubic foot per revolution of the drum. The drum carries an index-hand moving over a dial divided into 100 divisions, and the meters are provided with a thermometer for measuring the normal gas temperature.

ACETYLENE.

(Contributed by the late Professor Vivian B. Lewes, F.C.S., F.I.C.) Revised by Charles Bingham, C.E.

Acetylene, which is a gaseous compound of hydrogen and carbon, represented by the formula C_2H_2, is a colourless gas with a density of 0·92. As ordinarily prepared, it has a strong and very penetrating odour, but when purified from minute traces of other gases, invariably present with it in its crude state, has a not unpleasant ethereal odour. It can be converted into a liquid at a pressure of 21·53 atmospheres, at a temperature of 0° C., and liquefies under ordinary atmospheric pressure when cooled to a temperature of −82° C. The critical point of the gas is 37° C., and at this temperature the pressure has to be raised to 68 atmospheres for its liquefaction.

Acetylene is readily soluble in water, which at normal temperature and pressure takes up about its own volume of the gas; its solubility in other liquids is given in the following table:

100 Volumes of		Volumes of Acetylene.	100 Volumes of		Volumes of Acetylene.
Brine	absorb	5	Fusel oil	absorb	100
Water	,,	110	Benzene	,,	400
Alcohol	,,	600	Chloroform	,,	400
Paraffin	,,	150	Acetic acid	,,	600
Carbon disulphide	,,	100	Acetone	,,	2,500

* The tabular number depends upon the barometer reading and the normal temperature of the gas passing through the meter.

Extended researches by Bistrow and Liebreich upon the toxic properties of acetylene show that it acts upon the blood in much the same way as carbon monoxide, but exhaustive experiments show that it is less poisonous than ordinary coal gas.

Acetylene forms compounds of an explosive character with copper and silver, and at first this was thought to be a great drawback to its general use; but experience has shown that these fears were unfounded, and that brass gas fittings, when gas-tight, can be used with perfect safety.

Acetylene, when heated, polymerises, like most hydrocarbons, i.e. it is partly or wholly split up, and the resulting gas is usually a mixture of acetylene itself and poorer gases, such as hydrogen, methane, etc., while tarry compounds and even solid carbon are formed, if the heating is carried far enough.

This is a matter of the utmost importance to acetylene users. For lighting purposes, it means that a poor light is given; for oxy-acetylene welders it means that the temperature at the blowpipe is reduced considerably, indeed in some cases it has proved impossible to make satisfactory welds, owing to the poor quality of the gas.

These troubles arise almost exclusively with water-to-carbide generators, which are often faultily designed, so that overheating is bound to occur.

Experiments lately carried out by the French Acetylene Office have shown that polymerisation starts in an ordinary commercial generator at about 130° C., *i.e.* at a much lower temperature than was originally believed to be the case. Unfortunately many generators sold in this country act by driving the water away from the carbide container, when a certain amount of gas has been generated, leaving the live carbide surrounded by a mass of moist lime sludge, which is again surrounded by a blanket of acetylene. Acetylene, however, is a far poorer conductor of heat than water. At the instance of the writer, the heat conductivity of acetylene was ascertained by the National Physical Laboratory, we believe for the first time. It was found to be 0·000043 c.g.s., or only about one thirty-second of that of water. If, therefore, decomposing carbide is surrounded by acetylene instead of by water, only about 3 per cent. of the heat is carried off in a given time, which could be carried off by water, and the writer has seen sludge become actually visibly red under such conditions.

It is therefore of the utmost importance that acetylene users should be careful to see that they select acetylene generators in which there is always an ample supply of water in constant contact with the carbide, or constantly surrounding the carbide containers. It may also be pointed out that the better the carbide is, the more quickly it is attacked by water and, in consequence, the greater the quantity of heat liberated in a given time by its decomposition.

A new type of acetylene generator which differs radically in its generating chamber from anything previously used, although of extremely simple construction, has been put on the market in this country. The system has been in considerable use for about two years, and has given complete satisfaction.

In contact with air acetylene inflames at a temperature of 480° C. and burns with a flame which, when properly spread out so as to obtain a large quantity of oxygen, emits more light than any other gaseous compound of carbon and hydrogen.

Gas.	Candle hours per 5 cub. ft.	Carcel hours per cub. metre.	Gas.	Candle hours per 5 cub. ft.	Carcel hours per cub. metre.
Methane	5·2	3·5	Propane	56·2	40·0
Paris gas	13·2	9·6	Ethylene	70·0	49·0
London gas	16	11·5	Butylene	123·0	86·0
Ethane	35·7	25·0	Acetylene	240·0	168·0

Professor Clowes has shown that acetylene has a wider range of explosibility when mixed with air than any other combustible gas, the limits in percentages being as follows:

	Per cent.		Per cent.		Per cent.
Acetylene	3 to 82	Carbon monoxide	13 to 75	Methane	5 to 13
Hydrogen	5 to 72	Ethylene	4 to 22		

Acetylene is made commercially by acting upon a compound known as calcium carbide (CaC_2) with water, when acetylene gas is liberated and calcium hydrate (slaked lime, $Ca(HO)_2$) is formed.

Calcium carbide is made by fusing together very pure coke (or high-carbon anthracite coal) and very pure lime by the intense heat of the electric furnace. No other way of heating the mixture to the required temperature has yet been discovered, although many attempts have been made; for instance, by the use of the oxy-acetylene blowpipe.

Acetylene generators, in which the interaction of the calcium carbide and water to generate the gas takes place, may be either automatic or non-automatic. In the former class, devices are used to stop the generation of the gas automatically, by cutting off the supply of water or the supply of carbide, thus doing away with the need of a large store-holder for the gas, whilst in the non-automatic class the action is allowed to continue until all the carbide is decomposed, the gas being stored in a holder from which it is used as required.

In making acetylene, water may be brought in contact with the carbide either by adding it to the carbide, or by adding the carbide to water.

The overwhelming majority of acetylene generators in practically all countries are now constructed on the water-to-carbide system.

Of late years the automatic type of apparatus for the generation of acetylene has almost entirely superseded the non-automatic type, owing to the very large quantity of acetylene now being required for the oxy-acetylene welding process.

Experience has shown that automatic generators can be constructed with a high factor of efficiency, while the capital outlay per unit of gas generated is considerably less than in the case of non-automatic apparatus.

Owing also to the much smaller space occupied by the automatic type, it has also been found much more convenient for private use.

Until comparatively recent times, the pressure customary in acetylene generators was from 4 to 8 inches water-column, these limits having been found to give the most satisfactory results for lighting purposes. The advent of the oxy-acetylene welding blowpipe, however, soon caused experiments to be made with higher pressures, with the most favourable results. To-day the general tendency in most countries is to have the acetylene under slightly higher pressure than the oxygen in the welding blowpipe, it being claimed that less oxidation of the metal took place under these conditions and that there was less chance of the right proportion of the two gases being interfered with by accidental obstruction in the blowpipe, and, lastly, there was less tendency for the flame to flash back.

In consequence of this movement, the Governments of the United States, Canada, Switzerland, and Denmark now allow a maximum pressure of 1 atm. in acetylene generators for welding, and Germany is on the point of adopting this maximum pressure also. Very interesting details of tests have been published by the Government Bureau of Standards in the United States.

The oxy-acetylene blowpipe has been most successfully used for a considerable time for case-hardening various parts of machinery, and in particular the gear-wheels and other parts of motor cars. Lately a most important development has taken place in this direction, the blowpipe having come into the most extensive use, not only for cutting and repairing rails, but for applying an exceedingly hard surface, to a depth reaching even the high figure of ¼ inch and more to the entire rail system of electric tramways.

The improvement shown in the wearing properties of rails is shown by the following figures:

	Wear of rails in 12 months.		No. of cars
	Untreated.	Treated.	carried.
Bristol	0·045	0·0157	300,000
Liverpool	0·030	0·0125	200,000

The rails are hardened *in situ*, without otherwise interfering with the track in any way.

When acetylene first made its appearance, its use was confined almost entirely to lighting detached buildings, motor-cars, and cycles.

The advent of electric sets materially reduced the field for acetylene for lighting purposes, but recently there has been a decided revival in this direction, owing to the enormously increased construction of houses of the bungalow type, large numbers of which are situated so far from a centre of supply of coal-gas or electric current that the cost of laying the necessary supply pipes or cables makes the capital outlay too great, in view of the modest requirements per bungalow.

In such cases the very low capital outlay required for an acetylene outfit, its extreme simplicity, and the beautiful light it gives, have made this form of lighting extremely popular.

The use of the oxy-acetylene blowpipe has continued to increase during the past year; indeed these and other applications have so greatly extended the use of acetylene that whereas the consumption of carbide before the war amounted to about 28,000 tons, it rose in 1925 to 40,000 tons per annum. There was a set-back, owing to the difficulties in the coal industry, but at the time of writing a consumption of approximately 40,000 tons a year has again been reached.

The use of acetylene in other directions than as a combustible again made great strides in the past year. One of the most interesting new derivatives is the 'Meta' block, which has been placed on the market by a Swiss firm. This block resembles in appearance solidified methylated spirit, but in its properties it is greatly superior, inasmuch as the block does not liquefy when burning, nor evaporate even if exposed to the air for many months.

Acetylene as obtained from ordinary generators contains a certain amount of impurities. The use of the acetylene blowpipe for welding high-class steels has shown more and more clearly the necessity for removing these impurities from the gas, a purification which can easily be effected by the use of such purifying materials as catalysol, heratol, etc.

One pound of commercial calcium carbide, when acted upon by water, yields on an average about 4·5 cub. ft. of the gas.

Before the war the price of carbide was about £12 10*s.* per ton, packages included. The price is now about £16 to £18 in the United Kingdom, while it is still higher in many of the countries producing it.

Dissolved Acetylene.

By an Order in Council issued in 1897 the compression of free acetylene was made illegal, but further orders were issued in 1901 and 1912 exempting the process now known as 'dissolved acetylene.' This is acetylene thoroughly purified and washed, and compressed into steel cylinders previously filled with a porous mass and having a fixed quantity of acetone added. Acetone is a liquid hydrocarbon, having the property of absorbing 25 times its own volume of acetylene at one atmosphere and 15° C.

For each additional atmosphere of pressure, the same proportion of gas is absorbed, but an lowance has, of course, to be made not only for the volume occupied by the porous filling of ıe cylinder, but, in addition, in order to allow for expansion, so that it is customary to charge ıese cylinders with only 43 per cent. of acetone.

A cylinder will therefore in actual practice contain about 100 times its own volume at 10 mospheres pressure and about 150 times at 15 atmospheres pressure.

In order to show the enormous capacity for storing light obtained in this manner, it may mentioned that the standard oil-gas cylinder in use on railways has a capacity of 14 cub. ft. atmospheric pressure. As the oil-gas is usually compressed to 12 atmospheres, this gives gas volume of 168 cub. ft., which, if filled with oil-gas, will supply eight burners using 2 ft. r hour and burning eight hours per day, for about a day and a half. If this cylinder were led with porous material and acetone in the manner described above, and charged with acetylene 15 atmospheres, its capacity would be 2,100 cub. ft., or sufficient to supply eight acetylene rners of 1 cub. ft. each (giving a most brilliant light), for about thirty-three days (basing on ght hours' lighting per day), before the cylinders would require to be re-charged.

The possibility of obtaining acetylene in compressed form opens up a very wide field for the pansion of its utility.

The tests carried out by the Home Office Authorities before issuing the exemption order of 01 were exhaustive, and furnished satisfactory proof of the safety attending the process of nufacture and the use of the cylinders.

Storage of Dissolved Acetylene.

Acetylene dissolved in acetone and stored, under a pressure not exceeding 225 lbs. per sq. in. a vessel filled as completely as possible with some porous substance is not deemed an ex- sive, and can therefore be manufactured, stored, and used without risk of infringing the plosives Act.

(See also 1919 Order in Council, 'Dissolved Acetylene.')

Porous Material.—Various types of filling are in use and appear to give satisfaction. In s country the Kapok filling, patented by *Allen-Liversidge, Ltd.*, is chiefly in use. The porosity the material should not exceed 80 per cent. The material should completely fill the receptacle, l should contain no pockets or cavities.

The Solvent.—Acetone is the most suitable commercial solvent, but substitutes for acetone ıld be permitted. The solvent should not completely fill the porosity of the material under r rise of temperature likely to be met with in practice.

Pressure Allowed.—The pressure can be 225 lbs., provided the cylinders used are of the solid wn type, the pressure to be measured at 60° F.

The Cylinders.—The cylinders should be made of mild steel containing not more than 0·25 cent. of carbon and not more than 0·05 per cent. each of phosphorus and sulphur. The test ssure should be four times the working pressure, and should be maintained for not less than een minutes. All cylinders should be annealed, but the use of fusible plugs, at present npulsory on acetylene cylinders, should be discontinued, as they are apt to become loose and, ther, in the event of fire occurring, may actually lead to the fire being augmented.

It is not considered necessary to impose any conditions as regards the retesting of acetylene inders beyond requiring them to be thoroughly examined visually at intervals. The form of sting to which oxygen and other cylinders are subjected cannot readily be applied to tylene cylinders with their content of porous material and solvent.

Acetylene Lighting.

For the illumination of buildings, towns, and large areas by acetylene, generators of some able type are in general use.

Dissolved acetylene is used successfully from an economical and efficient point of view for ıy purposes where a constant supply of acetylene is required, and is particularly adaptable re space available for the apparatus is strictly limited.

In the matter of motor vehicle lighting it has been very extensively adopted. A cylinder taining acetylene absorbed in acetone under pressure and of convenient size is attached to footboard or other suitable position on the car. Such a cylinder contains a sufficient supply ıcetylene to meet the requirements for the lighting of the necessary lamps. The time for ch the supply is available is variable according to the rate of consumption; the pressure of in the cylinder is reduced by an automatic governor or regulating valve, and the supply in service pipes is maintained at a constant pressure to the lamps.

The standard automobile cylinders contain 20 cub. ft. and 40 cub. ft. of dissolved ylene, and by the exchange system originated by the manufacturers it is possible for s to obtain refills at practically all important garages throughout the country.

Larger vehicles, such as motor omnibuses, mail vans, motor lorries, etc., may be equipped outfits of larger capacity to meet the requirements of any particular case.

Another recent departure is the manufacture and circulation of cylinders containing dissolv acetylene of such capacity to meet the demands of motor cyclists. These cylinders a standardised and contain 5 and 10 cub. ft. of acetylene and, as with the standard cylind for automobile work, they may be exchanged throughout the country.

For buoy and coast lighting dissolved acetylene has many advantages. The purity of t gas in this form, which is assured before compressing, gives the light increased brilliance a greater penetrating power, hence a shorter light period can be employed than with any oti illuminant. Various special apparatus are in use, in which flashes of long or short duration obtained by automatic means, the light being extinguished between the flashes instead of obscu (a small bypass burner remaining alight), thus economising gas. In some cases a flash of short duration as one-tenth of a second is obtained, with perfect accuracy and flame. By mea of this economical consumption and the great storage capacity of a comparatively small cylind a gas supply for periods as long as 12 months can be easily carried on a buoy, no attention bei required until the gas is exhausted, when the cylinder is disconnected and replaced by a full o The cylinders may be arranged in the form of a battery where larger consumption is involved.

Owing to the smallness of space required for acetylene in this form it is particularly adapta for lighting railway coaches, yachts, and small craft. The effect of atmospheric temperat on the gas in this form is almost negligible, and other advantages are obtained by reason of purity of gas and the elimination of handling carbide, water, waste and residue, and by the f that the gas in this form can be stored indefinitely without deterioration.

The applications of this form of acetylene are ever increasing, and it has been recently appl with success to cinematographs, searchlight, signalling and projection work, where a small a compact plant consistent with efficiency is required.

The most recent application for illuminating purposes is that of its adoption for portable ha lamps for mining and other similar purposes.

Lately acetylene buoys have commenced to displace other forms of coast-lighting to a v considerable extent. Such buoys take a very large charge of calcium carbide, usually one two tons. They are entirely automatic, require practically no attention, and as they run for to twelve months before requiring recharging, they form an exceedingly economical means f coast and harbour-lighting. Another great advantage is the fact that the light can recognised at a much greater distance than that of the oil, or oil-gas, buoys previously used.

(See also pp. 1553, 1559.)

PETROL AIR GAS.

(Contributed by E. Scott-Snell, A.M.S.E.)

Petrol gas is made by impregnating air with the vapour of petroleum spirit, this mixture be sent through pipes in the usual way for combustion with incandescent mantles. The essen features of an apparatus for producing this gas are an air compressor, a carburettor—in wh the air and petrol are brought into contact—and a gas-holder from which the pipe service is In automatic apparatus, *i.e.* machines in which gas is made according to the demand, the hol is also used as a governor for controlling the supply of air and petrol to the carburettor. relative proportions of air to petrol are very important: in fact, upon the relation of these in dients, and the constancy of this relation under varying load and climatic conditions, the suc or failure of any apparatus must depend. As a mantle is used for light-giving, a flame is requi at the burner which shall give the highest possible temperature, *i.e.* the amount of air mi with the petrol vapour must be such as to completely combust it. With the more volatile sp mainly hexane (C_6H_{14}), used for making this gas, complete combustion is assured when appr mately two volumes of vapour are mixed with 98 volumes of air. This is calculated from typical equation $2C_6H_{14}+19O_2=12CO_2+14H_2O$ representing the combustion of the chief c stituent of light spirit. At present, opinion seems to be divided as to the advisability of send such a mixture—which from its composition is obviously an explosive one in a confined sp such as a gas-holder—through the system. It is found, however, that when the percentag vapour in the mixture exceeds 4½ per cent., e.g., a 5 per cent. or 6 per cent. mixture, the ga incombustible without the addition of further air, and in the better class machines advantag taken of this fact to make a slightly richer gas than 4½ per cent., diluting it with the extra required for complete combustion by the aid of Bunsen burners.

The air-compressing apparatus of a petrol gas machine may be actuated by any motive po but as the work of forcing the gas through the pipes is comparatively light, nothing more powe than a hot-air motor or wound-up weights is usually required. In a good apparatus, the rela amounts of air and petrol are mechanically measured before passing to the carburettor, so t constancy of mixture is obtained under all conditions of temperature within wide limits. W other means are adopted, such as leading the air across a bath of petrol, selective evapora takes place, producing erratic results, the make of gas varying with every change of temperat In fact, attempts to make apparatus of this sort automatic almost inevitably end in failure.

Petrol gas is probably one of the safest lighting mediums known, by reason of the small compass over which mixtures of petrol vapour and air are explosive (1½ per cent. to 4½ per cent.. c.f. acetylene 3·3 per cent. to 52·3 per cent., coal-gas 7·9 per cent. to 19·1 per cent.) and the fact that over 90 per cent. of the escaping gas from any leak is air. It is also non-asphyxiating.

The gas varies in calorific value according to the proportions of the mixture and the spirit used, but a 6 per cent. mixture from 0·680 sp. gr. petrol has a gross calorific value of nearly 300 B.T.U. per cubic foot. Although this is a comparatively low figure, cooking and heating can be efficiently performed with suitably proportioned burners.

One gallon of light spirit gives 5,000 candle-power hours (Lewes). With petrol at 1*s.* a gallon this is equivalent to 2·4*d.* per 1,000 candle-power hours. The Government tax of 3*d.* per gallon is remitted when petrol is used for purposes other than propelling road vehicles.

Petrol gas can be stored almost indefinitely over water, but since a small 'Bijou' mantle requires anything from 4 to 12 cub. ft. per hour (according to whether a 6 per cent. or 2 per cent. mixture is used) the storage of any reasonable quantity of the gas entails the use of very large holders. Hence the advantage of the weight-driven type of automatic generator.

Attempts are being made to effect economy by using the less volatile petrols of 0·720 to 0·760 sp. gr. for lighting purposes, such as are in general use for motor cars. The physical characteristics of these spirits, however, are such that they do not lend themselves readily to cold carburation, for either considerable quantities will pass through the carburettor unvapourised, or if heat is used to evaporate them, heavy condensation is unavoidable in the pipe service, which must necessarily be very carefully laid to provide for it.

An explosive (or 'weak') mixture in the pipes and holder is unavoidable if heavy spirits are used, since they are not sufficiently volatile to allow of the use of a 'rich' mixture. See also Wescott-Snell on 'Petrol Air Gas,' Soc. of Eng. Journal and Trans., March 1911; Illuminating Engineer's Soc. Journal and Trans., February 1913.

Heating Value and Candle-Power of Petrol-Air Gas.

According to *The Snercold Engineering Co.*, as the result of tests of a variety of different brands and grades of petrol, the fair average heating value of a gallon of petrol is 143,500 B.Th.U., and the maximum candle-power hours that can be obtained under the best conditions is 6,025. The following table shows different mixtures in percentages of petrol vapour used; for calculation purposes the heating value has been taken as 143,000 B.Th.U., and the candle-power hours as 6,000 per gallon.

TABLE SHOWING VARIOUS MIXTURES OF PETROL-AIR GAS.

Mixture Percentage of Petrol Vapour.	Gallons per 1,000 Cubic Feet of Gas.	Heating Value B.Th.U. per Cubic Foot.	Cubic Feet of Gas to the Gallon.	Candle-power Hours per Cubic Foot.
6	2·184	312	458·3	13·104
5½	2·0	286	500	12·0
5	1·82	260	555	10·92
4½	1·638	234	612	9·828
4	1·4638	208	687·5	8·7828
3½	1·274	182	785·7	7·644
3	1·092	156	916·6	6·552
2½	0·91	130	1100	5·46
2	0·728	104	1375	4·368
1½	0·546	78	1833·2	3·276

The heating value of coal-gas varies from 420 to 550 B.Th.U. per cubic foot according to the source of supply.

THE SNERCOLD PETROL-AIR GAS PLANT.

In this plant a 5½ per cent. mixture is generated. The carburettor will vaporise petrol in very cold weather without the application of warmth; in it, the temperature of evaporation falls below as 49° of frost (−17° F.), which is well below the lowest winter temperature in this country; for this reason condensation is impossible with the apparatus. The arrangement extracts the moisture from the air, which is carefully kept from contact with water, and thus the air on carburation is dry; hence it always absorbs the correct proportion of petrol, and a uniform gas is produced without possibility of variation. The air cannot obtain more than the predetermined quantity of petrol, while from the design of the carburettor it must take all that is supplied. When no gas is being consumed the apparatus is entirely inactive.

THE WELLS LIGHT.

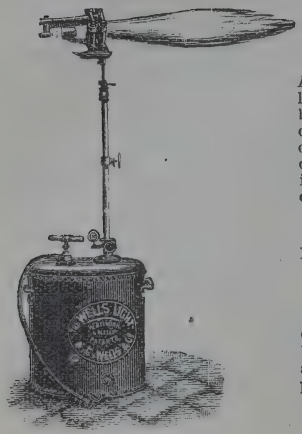


FIG. 5.

Wells Light (*A. C. Wells & Co., Midland Road, St. Pancras, London, and Manchester*), fig. 5, is a portabl light, up to 3,000 candle-power, produced from oil spra blown horizontally ; the flame is quite unaffected by win or rain. The arrangement is self-contained, and th containing vessel can easily be charged with oil and a during working, while accessibility of all parts for clean ing, combined with strength and simplicity, are feature of the lamp.

The most useful sizes are as follows :

		Ins.	In
No. 0, 500	candle-power ; size of tank	13½ × 9	
„ 1, 500 and 1,500	„ „ „ „	16 × 1	
„ 3, 2,500	„ „ „ „	24 × 1	

The Wells Light has been adopted by more than Governments, for military and naval purposes, and al by the principal Railway Companies in England ar abroad. The Wells Light principle is also applied powerful Heating Plants, Road Drying Appliances, Brazi Outfits, &c.

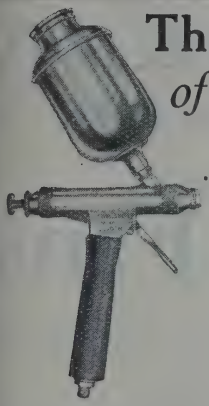
(For ' LIGHTING,' see Section XXXVIII., Part III., p. 2521.

HEAT TREATMENT OF GAS CYLINDERS.

(*Second Report.**)

In view of experiments made by the Gas Cylinders Research Committee the Committee agr that the periodical re-heat treatment of carbon steel gas cylinders which have not been obvious damaged, serves no useful purpose, and they recommend that the practice be discontinued.

* ' Periodical Heat Treatment.' Published for the Department of Scientific and Industri Research by H.M. Stationery Office. Price 2s. 6d. net.



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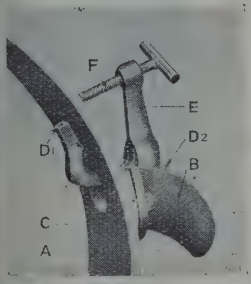

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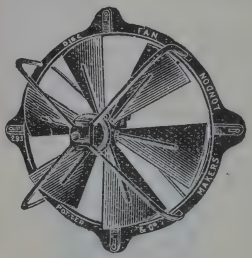

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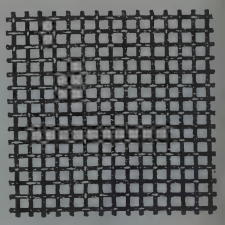

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SECTION XXXVIII

PART I

HEATING BY HOT WATER, STEAM, GAS, &c.—DRYING
(pp. 2487–2508)

PART II

VENTILATION (pp. 2509–2520)

PART III

LIGHTING (pp. 2521–2543)

PART IV

FIRE EXTINCTION—FIRE-RESISTING BUILDINGS
(pp. 2545–2549)

SECTION XXXVIII

PART I

HEATING.

(Revised by J. Roger Preston, Member of the Council of the Institution of Heating and Ventilating Engineers.)

General.

The unit of heat or British Thermal Unit (B.Th.U.) is the heat required to raise the temperature of 1 lb. of water 1° F.; the unit of surface is the square foot; the unit of pressure is the pound per square inch; the unit of temperature is the degree Fah. Air may be expressed in cubic feet or in pounds weight, and Table A shows how these are convertible.

TABLE A.

Air Temperatures.	12°	22°	32°	42°	52°	62°	72°
Relative Volume of dry air at given temperatures (Volume at 32° F. = 1) . . .	·960	·980	1·00	1·02	1·04	1·06	1·08
Weight per cubic foot in pounds	·0842	·0824	·0807	·0791	·0776	·0761	·0747

NOTE.—The volume of 1 lb. of dry air at 32° F. = 12·38 cub. ft. For any other of the above temperatures, multiply by the relative volume.

OPEN FIRE GRATES.

It would seem that the open fireplace is not the criminally wasteful contrivance that it is commonly supposed to be, and that the 'well' type of fireplace is open to criticism. 'The pleasant British practice of sitting round the open fire,' says the Fuel Research Board Report, 1918–19, 'is amply justified from the scientific point of view, when we know that so much as one-fifth of the total heat of the coal is immediately available for absorption by the sitters if they constitute themselves into a sufficiently close screen around the fire.' In addition to the directly measured radiant heat, the open fire, it seems, is to be credited with heat conducted, radiated, and convected from the fireplace, chimney, and walls to an extent which is such that all together some 60 to 70 per cent. of the heat of the coal is utilised in warming the room and the general fabric of the building.

The following hints as to the best method of altering ordinary house fire-grates, so that they will be more effective and economical, have been circulated by the Royal Institute of British Architects: 'Line your grates with fire-bricks. See that the fire-bricks are high enough to stand up above the fire. Take care that the back brick leans forward and is not more than 4 ins. from the front bars. Fill in the space at the back with fire-clay. See that your register is open not more than one-fourth of its full capacity. If you have no register, partially close the chimney opening with another fire-brick. Fill in the front space beneath the grate with a movable piece of metal. If you cannot do this, put a small fire-tile in the bottom of the grate.'

It must be remembered, however, that the above efficiencies are only obtainable under the most favourable conditions ensuring the proper combustion of the fuel.

Heat Losses.

When a room is maintained at a higher temperature than the surrounding air, there is always a loss of heat through the windows, walls, air-change, etc. Modern practice demands that these losses shall be estimated as accurately as possible; a few of the most useful factors concerned are given below:—

Brick wall 12″ thick	. .	0·30	B.Th.U. loss per F. deg. diff. per sq. ft. per hour	
Brick wall 18″ thick	. .	0·24	,, ,, ,, ,,	
Without plaster 12″ thick	.	0·34	,, ,, ,, ,,	
Without plaster 18″ thick	.	0·26	,, ,, ,, ,,	
Concrete wall 4″ thick	. .	0·53	,, ,, ,, ,,	
Concrete wall 8″ thick	. .	0·40	,, ,, ,, ,,	
Single window	. . .	1·06	,, ,, ,, ,,	
Double window	. . .	0·76	,, ,, ,, ,,	
Air	. . . . .	0·019	,, ,, ,, cu. ft. ,,	

Thus with an inside temperature of 70° F. and an outside temperature of 30° F., the loss per sq. ft. per hour in the case of a single window would be

$$1{\cdot}06 \times (70 - 32) = 40\text{B.Th.U.}$$

The following are some of the channels through which heat may be lost:—

Gases of high calorific value escaping to the chimney unburnt.
Flue gases passing away at high temperatures.
By radiation and convection from uncovered pipes and fittings in Boiler House.
,, ,, ,, ,, ,, in Trenches.
,, ,, ,, ,, ,, in Basements.
,, ,, ,, ,, ,, on Roof.
Steam blowing away into atmosphere.
Condense water cooling in collecting well, etc.
Leakage from, and the cooling of air in, ducts where heated at intake.
Heated air passing away without doing any useful work.
Excessive heating of rooms.
Normal heating of rooms where not in use.
Leakage from air flues.

Reliable comparison of existing work can only be made after exhaustive tests, as owing to conditions varying so much, comparison can easily be misleading, a careful theoretical test balance would be more reliable than an incomplete one of existing conditions.

Care in design at every point to prevent waste, makes a very important whole in large buildings.

Economy.

The most economical system is that which wastes the least heat and costs the least in attendance and upkeep, providing the initial cost is reasonable.

Direct radiation plants are the most economical. Systems where the air is fully heated at the intake and distributed by ducts throughout the building will obviously have a rather high fuel consumption.

As a distributing medium, hot water comes the first, except where exhaust steam is available; there is not a great deal of difference between water and steam, providing that each is the best of its kind.

Cost of Heating.

The warming of the air costs much more than moving it; where it would take 2*d.* to move 1,000,000 cubic feet, it would cost 12·5*d.* to heat it from 30° to 60° F.

Heating Systems.

The heating medium may be either water, steam, or gas. In the case of water and steam these may be distributed in various ways, as follows:—

Water	Low pressure gravity circulation.
	Forced or induced circulation by accelerators.
	Various automatic induced.
Low-pressure steam.	Condense through traps (live-steam or exhaust-steam).
	Vacuum systems.
	Automatic vapour systems.

Heating by Hot Water.

Gravity Circulation.

For installations not exceeding, say, 5,000 sq. ft. of radiating surface, where upkeep and attention are serious items, and the building is suitable, this system is very satisfactory, and, if no exhaust steam is available, for economy it cannot be beaten.

Arrangements of Circulation.

The two-pipe method was at one time nearly universal. The single pipe has taken its place to a great extent, but a combination of the two is most general. The 'drop' system gives a very rapid circulation.

The following points require to be borne in mind:—Short circuits, dips and air-pockets, size and lengths of mains.

Size of Mains.

The first thing to decide is the maximum drop in temperature to be allowed between the flow and return; a small drop is desirable, but not always practicable, 20° may be taken as a standard. The following formula agrees very well with practice:—

$$U = \left[\left(16{\cdot}353 \frac{\left(H - \frac{S_1 H}{S_2} \right) 12D}{L} + 0{\cdot}00665 \right)^{\frac{1}{2}} - 0{\cdot}0816 \right] D^2 1224F,$$

where,

H = height of circulation in feet; S_1 = specific gravity of water in flow pipe; S_2 = specific gravity of water in return pipe; L = equivalent length of pipe in feet (bend. say. 12 diameters); D = diameter of pipe in inches; F = drop between flow and return in degrees; U = British Thermal Units per hour.

The rapidity of circulation in vertical pipes often increases at a greater rate, owing to bubbles of steam forming.

The above formula gives B.Th.U., but the curves on the following diagram, fig. 1, are in sq. ft. of radiation, calculated on an average of 160 B.Th.U. per ft. of radiating surface.

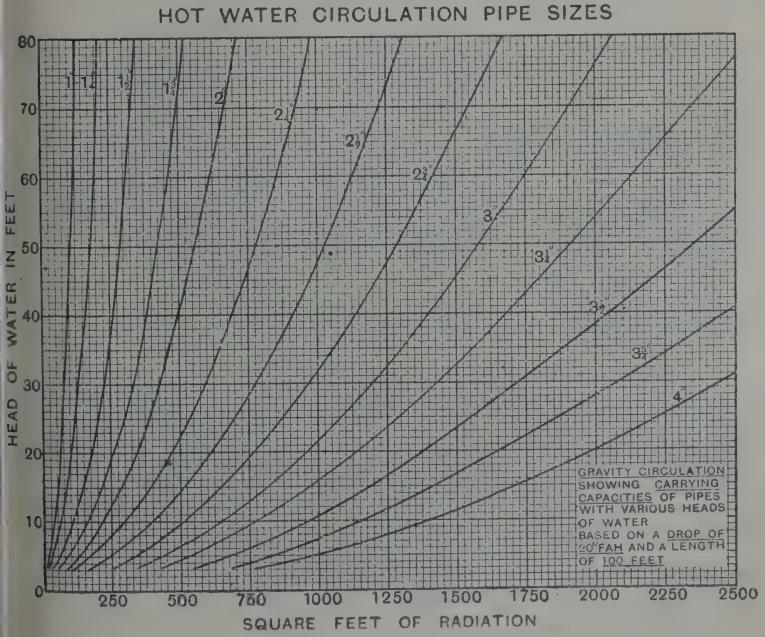


FIG. 1.

For short pipes, such as connections to radiators, a liberal allowance should be made to make up for velocity loss at entry and through connections; these have a considerable effect, so that apart from having a well-designed scheme, it is necessary to have an intelligent fitter.

TABLE OF FACTORS FOR DIFFERENT LENGTHS OF MAINS.

Length of Main. Ft.	Factor.
50	1·5000
100	1·0000
150	0·8125
200	0·7000
250	0·6125
300	0·5375
350	0·4875
400	0·4500
450	0·4375
500	0·3875

For different lengths of mains, multiply the heating surface from fig. 1 by the factor given.

CIRCULATION BY ACCELERATORS.

In large buildings where the radiation is extensive and at many different levels, pumps may be employed to circulate the water; this allows of smaller mains, owing to the higher velocities obtained. The piping may be arranged either on the one-pipe or two-pipe system. With the one-pipe, practically only the mains are under the influence of the pump, though there is a little pull on the branches, due to the loss of head on the main between the point where the flow is taken off and the return back.

The number of gallons of water required to supply the heat can be ascertained as follows:—

$$G = \frac{U}{10D},$$

where,

G = number of gallons per hour; U = heat loss in B.Th.U.; D = drop in temperature (F.° allowed between flow and return.

The size of mains depends upon their length, the number of gallons, and the maximum loss of head due to friction to be allowed. A fair velocity in the mains is from 60 to 200 ft. per min., according to the size and length, arranging for the frictional head not to exceed about 20 ft.; this is a point that should be carefully watched, as a contractor may cut down the size of mains to save initial cost, but, as a result, increasing the cost of upkeep.

The friction head and power required may be calculated in the usual manner for cold water.

There are several special types of accelerators on the market, though most centrifugal pumps are suitable, also drum or other pumps may be used if desired.

AUTOMATIC INDUCED CIRCULATION.

Where power is available, a simple accelerator is to be preferred; but there are conditions where an automatic arrangement is an advantage. These utilise the power of steam in some form, either by condensation, a partial vacuum being formed which exerts a powerful pull on the water in the returns, or by the pressure being utilised to lift water from one tank to another at a higher level, the water returning through the circuits by gravity; a separate steam boiler is not always needed, steam being formed in connection with the water boiler.

Apart from the particular apparatus for producing the motive power, the heating system is the same as any other low-pressure system.

Low Pressure Steam Heating.

GRAVITY RETURN.

In this system the condense water finds its way back to the boiler by gravity. The steam may be distributed to the radiators by either the one- or the two-pipe system.

In single-pipe work the steam in the mains travels in the direction of the condense water, but in the risers and branches they meet (except in the drop system), and when starting the heat, noise is created. Where absence of noise is essential at all times, the two-pipe system is preferable; with this arrangement there are two pipes to each radiator, the condense pipes are carried down into a wet return or fitted with an automatic water-seal at the outlet to the radiator.

Size of Pipe.

The size of pipe to supply a given amount of heat at a given point depends upon the length initial pressure, and the maximum loss of pressure to be allowed.

Taking the known formula for steam, and modifying the exponent and value of P, we get the following:—

$$U = \left(\frac{WDP^5}{L\left(1 + \frac{3{\cdot}6}{D}\right)} \right)^{\frac{1}{2}} 10^6,$$

where,

U = British Thermal Units per hour; W = weight of a cubic foot of steam; P = loss of pressure in inches of water; D = diameter of pipe in inches; L = length of pipe in feet.

The results shown in Fig. 2 have been worked out for about 1·3 lb. initial gauge pressure and ins. water gauge drop.

For one-pipe work, multiply B.Th.U. by 0·5.

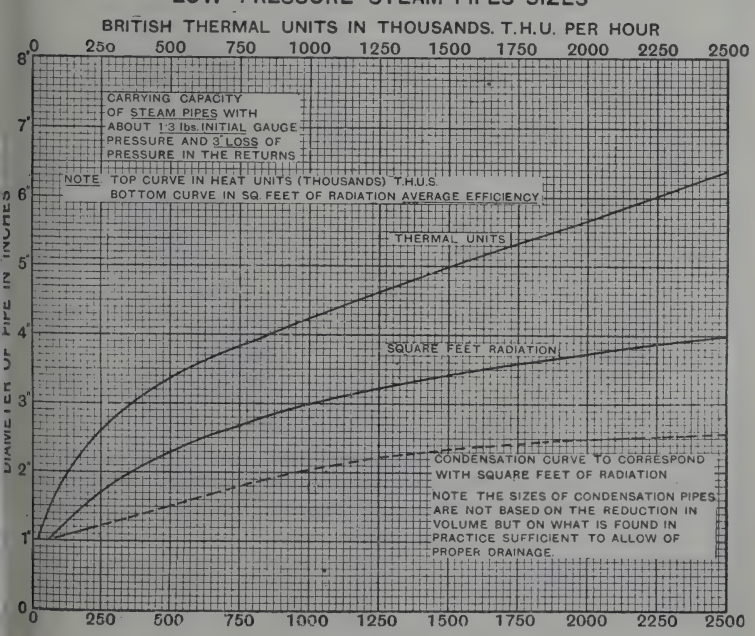


Fig. 2.

Pipe Sizes for Vapour or Low Pressure Steam Systems.

For small work, and ready reference, the following tables may be used; they are based on conservative drop in pressure in all piping; care should be exercised in ascertaining length runs:—

Example.—To find size of main required under the following conditions:—Length of ru 150 ft., with six 90° elbows, and carrying 250 sq. ft. of radiation. From Table I a 2 in. ma approx. is required. Under 2 in. on Table II it is found that each 90° elbow has the equivale resistance of 5 ft. of pipe, or 30 ft. for the six elbows. This makes the total length of pipe equ valent to 180 ft. Checking back under 200 ft. of run (the nearest length to the run desired), is found that a 2 in. pipe will carry 325 sq. ft. of radiation.

Riser sizes are determined in the same way. All lengths to be measured from the boiler.

TABLE I.—MAIN AND RISER SIZES.

Main Sizes.						Riser Sizes.				
	Length of Run in feet.						Length of Run in feet.			
Pipe Size in ins.	200	300	400	500	600	Pipe Size in ins.	100	200	400	600
	Capacities in sq. ft. of direct radiation.						Capacities in sq. ft. of direct radiation.			
2	325	270	220	200	160	¾	25	20	—	—
2½	600	500	420	360	280	1	65	50	35	20
3	1050	850	720	620	560	1¼	120	100	75	45
3½	1560	1250	1050	900	800	1½	200	150	100	70
4	2050	1800	1500	1300	1100	2	400	320	240	175
4½	2800	2400	2000	1725	1500					
5	3800	3100	2600	2300	2000					
6	6000	5000	4300	3700	3300					

Return Main Sizes.		Return Riser Sizes.	
Radiation (sq. ft.).	Size in ins.	Radiation (sq. ft.).	Size in ins.
0–100	¾	0–50	¾
100–400	1	50–200	¾
400–1200	1¼	200–400	1
1200–1800	1½	400–900	1¼
1800–3000	2	900–1500	1½
		1500–3000	2

TABLE II.—PIPE LENGTH IN FEET EQUIVALENT TO RESISTANCE IN ELBOWS.

Pipe Size.	45° Elbow.	90° Elbow.	Pipe Size.	45° Elbow.	90° Elbow.
Ins.	Ft.	Ft.	Ins.	Ft.	Ft.
2	3	5	4	6	13
2½	3	6	4½	8	16
3	4	8	5	10	19
3½	5	10	6	13	23

British Standard Low-pressure Heating Pipes.*

(No. 40—1908.) (*Abstract.*)

For working pressures up to 100 ft. head.

Dimensions of Pipes (fig. 3).

			Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Pipe.	Internal Diameter	A	2	3	4	5	6	7	8	9
	Approximate External Diameter	B	$2\frac{3}{8}$	$3\frac{7}{16}$	$4\frac{15}{32}$	$5\frac{9}{16}$	$6\frac{5}{8}$	$7\frac{11}{16}$	$8\frac{3}{4}$	$9\frac{13}{16}$
	Approximate Thickness	C	$\frac{9}{16}$	$\frac{7}{32}$	$\frac{15}{64}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$
	Diameter of Spigot Bead and Astragal	D_1 D_2	$2\frac{5}{8}$	$3\frac{3}{4}$	$4\frac{25}{32}$	$5\frac{15}{16}$	7	$8\frac{1}{8}$	$9\frac{3}{16}$	$10\frac{5}{16}$
	Projection of Spigot Bead and Astragal	E_1 E_2	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{1}{4}$
	Width of Spigot Bead	F	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$
	Radius of Spigot Bead	G	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{25}{64}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{19}{32}$	$\frac{21}{32}$
	Width of Astragal	H	$\frac{9}{16}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$
	Clearance	I	$\frac{1}{8}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$
	Caulking Space	$E_1 + I$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{17}{64}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$
Socket.	Internal Diameter	J	$2\frac{7}{8}$	$3\frac{15}{16}$	5	$6\frac{3}{16}$	$7\frac{1}{4}$	$8\frac{3}{8}$	$9\frac{1}{2}$	$10\frac{5}{8}$
	External Diameter	K	$3\frac{7}{16}$	$4\frac{9}{16}$	$5\frac{21}{32}$	$6\frac{13}{16}$	$8\frac{1}{16}$	$9\frac{1}{4}$	$10\frac{7}{16}$	$11\frac{5}{8}$
	Thickness	L	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{21}{64}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{1}{2}$
	Internal Depth	M	3	$3\frac{1}{4}$	4	4	$4\frac{1}{2}$	$4\frac{1}{2}$	5	5
	Internal Radius	N	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{19}{32}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$
	External Radius	O	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{15}{16}$
	Diameter of Beads	P	$3\frac{15}{16}$	$5\frac{1}{4}$	$6\frac{13}{32}$	$7\frac{11}{16}$	$8\frac{15}{16}$	$10\frac{1}{8}$	$11\frac{7}{16}$	$12\frac{5}{8}$
	Width of Beads	Q	$\frac{9}{16}$	$\frac{25}{32}$	$\frac{13}{16}$	$\frac{7}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$
	Projection of Beads	R	$\frac{1}{4}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$
	Distance between Beads	S	$1\frac{3}{8}$	$1\frac{7}{16}$	$1\frac{19}{32}$	$1\frac{15}{32}$	$1\frac{11}{16}$	$1\frac{3}{4}$	$1\frac{15}{16}$	$1\frac{13}{16}$
	Distance of Bead from Edge	T	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$
	Taper on End	U	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{8}$
	Width of Rest at Top	V	$\frac{7}{16}$	$\frac{21}{32}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$
	Width of Rest at Bottom	W	$\frac{9}{16}$	$\frac{25}{32}$	$\frac{15}{16}$	$\frac{7}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$

Minimum Weights of Pipes (fig. 4).

Overall Length. Feet.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
3	15	24	32	50	67	86	108	130
6	27	45	61	94	125	160	201	243
9	—	66	90	138	182	234	294	356

All sizes of low-pressure heating-pipes and fittings shall be tested by an internal hydraulic pressure of 100 lbs. per square inch, applied for at least 2 minutes. While under pressure each pipe and fitting shall be struck all over with a hand hammer weighing $\frac{1}{4}$ lb.

* By permission of the British Engineering Standards Association.

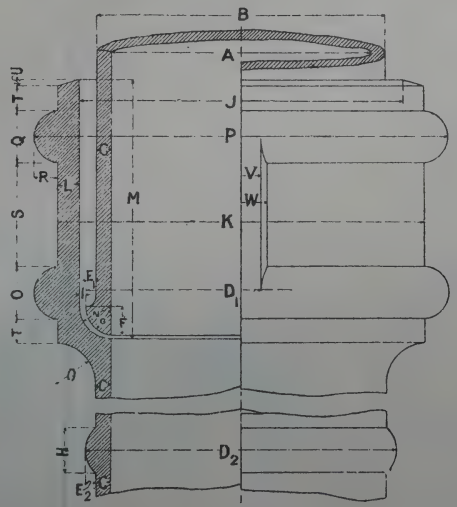


FIG. 3.

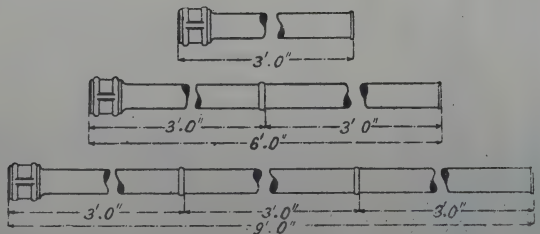


FIG. 4.

Vacuum System.

One of the objections to the ordinary gravity steam work is the difficulty of displacing the air in the radiators, and controlling the heat; this may be overcome by attaching a system of piping to the air valves connected to a small exhausting pump, which draws away the air and forms a partial vacuum; another way is to attach all the condense mains to a pump which will exhaust the air and draw away the condense water, this method is known as the 'Vacuum System.'

The piping is much the same as an ordinary gravity arrangement, except that the mains are rather smaller, and the condense pipes much smaller.

Owing to the thorough circulation of steam, the radiating surface has a high efficiency per sq. ft. per degree difference. It should be noted, however, that this does not materially affect the fuel efficiency.

The success of a vacuum system depends to a large extent on the proper working of the valves which are fixed on the radiators, or wherever condense water is likely to collect.

Plenum System.

'Plenum' is the name given to the system where the air is dealt with at the intake, tempered, washed, heated, and blown into the various rooms in such a quantity as to provide ventilation and make good the heat losses, the size of outlets being so proportioned as to allow of a slight pressure in the building, hence the name 'Plenum.'

The inlets may be from 8 to 10 ft. above the floor level, outlets at floor level on the same side of the room, the initial velocity of the air carrying it across the room, some of it cooling and gradually falling on the way—an extra outlet at ceiling level is advisable, especially if gas is the illuminant. Two ducts are necessary, one for hot and one for tempered or cold air.

NOTE.—Any system where the air is propelled into a building and maintained at a higher pressure than the atmosphere is a Plenum system, though the name is usually associated with downward methods of ventilation only.

Centrifugal fans are the most suitable, as the resistance of the heaters is considerable, apart from the ducts.

There are several special makes, including the multivane types, for which a much higher efficiency is claimed.

For economy a fan should be chosen that will pass the amount of air just running at a suitable speed to overcome the resistance, as the power rises as the cube of the speed, while the output is only directly as the speed.

Heating by Exhaust Steam.

The use of exhaust steam for heating and other purposes such as drying, hot-water supplies, etc., is to be recommended wherever possible, as the adoption of this system enables the latent heat in the steam to be used, whereas this cannot possibly be used for the production of power, and the extension of this system would render many small and inefficient power plants at present in existence more efficient.

For instance, the Technical Advisor to the Coal Controller states that the average thermal efficiency of steam-driven electric power plants at the present time is only 8½ per cent., whereas, if sufficient demand for heat can be found to enable the exhaust steam to be used for heating purposes, etc., the thermal efficiency of these plants might be increased to something like 60 per cent.

The exhaust steam can be either taken direct from the engines and conveyed without back pressure, for considerable distances, by the adoption of a modern vacuum system, or alternatively it can be used to heat water in calorifiers and the water pumped round to the various points where heat is required.

In many institutions, hotels, etc., it is found that there is practically no difference in the coal consumption whether the power is purchased from outside or generated on the premises, as there is a demand for heat all the year round which can be met by the exhaust steam from the power plant, so that the extension of this system to general domestic heating from the existing small power plants would enable these small power plants to run at a greater efficiency than any large condensing plant.

The utilisation of exhaust steam for heating when, as is too frequently the case, there is a back pressure on the engine—does not always result in economy. For assume that at a large works offices are to be warmed, requiring 800 sq. ft. of radiation, which offices are at such a distance from the main engine that a back pressure of 8 to 10 lbs. is required to force the circulation, the engine being 200 h.p. cutting off automatically at one-third of its stroke; the effect of the back pressure in this case would be to decrease the range of expansion to approximately one-half stroke, and presuming the initial pressure to be 80 lbs., and the consumption at one-third stroke to be 25·7 lbs. weight of steam per h.p. per hour, the consumption would be increased to 29 lbs. per h.p. hour, or a total for the 200 h.p., of 200 × 3·3 (the latter figure being the difference in the con-

sumption without and with back pressure) = 660 lbs. of steam per hour. Now as the amount of radiation mentioned would require, at 8 to 10 lbs. pressure, less than 300 lbs. per hour, there is, so far from being an economy, a loss of over 360 lbs. of steam per hour as the result of using the exhaust steam under such conditions of back pressure. Only when it is used without back pressure will the full economy be derivable from the utilisation of exhaust steam for heating.

One square foot of radiation will give off about 250 heat units an hour. One pound of steam an hour will supply about 4 square feet of radiation. A rough-and-ready rule for finding the radiation that may be supplied by an engine is to multiply the horse-power of the engine by 131.

When estimating on exhaust-steam heating, with non-condensing engines, the steam consumption for each indicated horse-power an hour will be about as follows :—

Engine.	Total.	Available for Heating.
Compound automatic	20 lbs.	18 lbs.
Simple Corliss	30 lbs.	27 lbs.
Simple throttling	40 lbs.	36 lbs.
Simple automatic, single valve	35 lbs.	31 lbs.

When exhaust steam is employed as the heating medium it is necessary to extract the grease by means of a separator, so placed as to intercept the grease before the steam enters the heating main. It is also necessary to have an outlet to the atmosphere which should be closed by a valve weighted to open at a pressure of ¼ lb. above the atmosphere, so as not to cause any back pressure. So low a pressure can, however, only be used for circulation when a vacuum return line is maintained, as in the vacuum system, for unless the air is first exhausted from the apparatus, a definite pressure is required to force it out through the air valves. With a vacuum return line no air valves are required on the radiation, and no foul air from the radiators discharged into the rooms.

In steam heating, the temperature depends on the pressure of steam in accordance with the figures given in the following table :—

TABLE OF THE PROPERTIES OF SATURATED STEAM.

Absolute Pressure per Square inch.	Temperatures.	Total Heat of One Pound of Steam from Water at 32 deg. F.	Latent Heat of One Pound of Steam from Water at 32 deg. F.	Weight of One Cubic Foot of Steam.	Volume of One Pound of Steam.	Pressure as shown by Gauge
Lbs.	Deg. Fah.	Units.	Units.	Lbs.	Cub. Ft.	
7	176·9	1135·3	990·0	·01889	52·936	15
7·5	180·0	1136·3	987·8	·02016	49·610	14
8	182·9	1137·2	985 7	·02142	46·686	13
8·5	185·7	1138·0	983 8	·02268	44·097	12
9	188·3	1138·8	981·9	·02394	41·777	11
9·5	190·8	1139·5	980·1	·02547	39·261	10
10	193·3	1140·3	978·4	·02642	37·845	9
10·5	195·6	1141·0	976·7	·02767	36·145	8
11	197·8	1141·7	975·2	·02890	34·599	7
11·5	200·1	1142·4	973·6	·03026	33·045	6
12	202·0	1143·0	972·2	·03137	31·879	5
12·5	204·0	1143·6	970·8	·03260	30·678	4
13	205·9	1144·2	969·4	·03382	29·573	3
13·5	207·8	1144·8	968·1	·03504	28·536	2
14	209·6	1145·3	966·8	·03627	27.573	1
*14·7	212·0	1146·1	965·2	·03797	26·360	0*
15	213·1	1146·4	964·3	·03870	25·843	—
16	216·3	1147·4	962·1	·04112	24·320	1
17	219·6	1148·3	959·8	·04253	23·513	2
18	222·4	1149·2	957·7	·04594	21·766	3
19	225·3	1150·1	955·7	·04834	20·687	4
20	228·0	1150·9	953·8	·05074	19·710	5
21	230·6	1151·7	951·9	·05311	18·828	6
22	233·1	1152·5	950·2	·05549	18·022	7
23	235·5	1153·2	948·5	·05786	17·282	8
24	237·8	1153·9	946·9	·06023	16·603	9
25	240·1	1154·6	945·3	·06259	15·977	10

Approx. inches of Vacuum.

Approx. pounds per sq. inch.

*Atmospheric Pressure.

Details.	Above Atmosphere.								Below Atmosphere.		
Steam pressure	0	1	2	3	4	6	8	10	2	4	6
Absolute pressure	14·7	15·7	16·7	17·7	13·7	20·7	22·7	24·7	12·7	10·7	8·7
Temperature of steam	212	216	219	222	225	230	235	240	204	201	199
Temperature of air	70	70	70	70	70	70	70	70	70	70	70
Temperature difference	142	146	149	152	155	160	165	170	134	131	129
B.Th.U. per min. from 100 sq. ft. rad.	426	438	447	456	465	480	495	510	402	393	387
Total heat in steam above 212°	966	967	968	969	970	971	973	974	964	961	957
Latent heat in steam	966	963	960	958	957	954	950	947	970	979	986
Cubic feet in 1 lb. steam	26·4	24·6	23·2	21·0	20·6	19·5	17·8	16·4	31·9	38·0	47
Cubic feet steam in $\frac{3}{4}$ lb.	17·6	16·4	15·5	14·0	13·7	13·0	11·8	10·9	21·2	25·3	31
Cubic feet steam per min. to supply 100 sq. ft. radiation—air 70°	11·6	10·9	10·3	9·3	9·0	8·6	7·8	7·2	10·8	16·8	20·8
Weight per cubic foot steam—lb.	0·038	0·0387	0·041	0·437	0·046	0·061	0·056	0·0609	0·031	0·026	0·021
Throttling Engine— Radiating surface supplied—sq. ft.	152	146	143	139	136	131	128	126	162	175	188
Automatic Engine— Radiating surface supplied—sq. ft.	134	129	127	122	121	120	119	117	146	151	168
Simple Corliss— Radiating surface supplied per horse-power	114	110	107	104	101	98	96	95	122	127	146
Compound Engine— Radiating surface supplied per horse-power	95	91	90	87	84	82	80	79	104	108	116

Boilers.

If plenty of draught is available, a boiler with a liberal amount of secondary flues and small grate area may be chosen; if the draught is small, one with less flue resistance would be more suitable. It should be of such a design as to allow of proper combustion in the fire-pot, free circulation in the waterways, the lighting, feeding, and ash doors to be well fitted, so as to stop an inrush of air at undesirable points; the general design to allow of clinkering and flue cleaning to be carried out with a minimum of trouble. The catalogue rating should give the number of B.Th.U. given off with a *six hours' firing interval*; *this should be taken from test, not based upon square feet of boiler heating surface, the value of which varies very much with different makes.* The *fuel efficiency* should be stated, and should *not be less than* 60 *per cent.* On testing a well-known sectional boiler, the highest efficiency was found to be at seven hours' firing interval (78 per cent. evaporative test), with a slight drop to four hours (due to loss from high flue temperature) and a quick drop to ten hours (due to incomplete combustion). While in power boilers combustion has received a deal of attention, heating boilers have been neglected in this respect.

Approximate Minimum Size of Boiler House for Different Sized Heating Installations.

Amount of Radiation in Feet Super.	Dimensions of Boiler House.*		
1,000	9 ft. long	5 ft. wide	7 ft. 6 ins. high
2,500	11 ft. „	6 ft. „	7 ft. 6 ins. „
5,000	13 ft. „	9 ft. „	8 ft. „
10,000	14 ft. „	13 ft. „	9 ft. „
20,000	18 ft. „	16 ft. 6 ins. „	10 ft. „
50,000	18 ft. „	32 ft. „	10 ft. „

* Exclusive of fuel space.

If hot water supply, boiler, etc., are required, extra space must be allowed.

Approximate Size of Chimney for Various Sized Installations.

Radiation in feet super.	1,000	2,500	5,000	10,000	20,000	50,000
Size of chimney in inches	9×9	14×9	14×14	21×18	24×24	36×36

The Cochran Hot-Water Boiler.

This boiler (*Cochran & Co., Annan, Limited*) is manufactured in twenty-two sizes corresponding to the range of standard boilers, the essential difference being the considerably reduced height, diameter for diameter, as compared with the steam units.

The 8 ft. 6 in. diameter boiler can be limited in height to 14 ft. should headroom considerations necessitate this.

The range of duties vary from 390,000 to 6,500,000 B.Th.U. per hour reckoned on a two-hourly stoking interval in the case of boilers with two fireholes.

These boilers retain all the constructional advantages of the standard Cochran boiler.* They can be supplied for a working pressure of 100 lbs. per sq. in. (*i.e.* for use with a head of 230 feet of water), and, with reasonable care, will last indefinitely. The Cochran boiler manufacturers claim that as a hot-water unit the arrangement occupies less floor space than any other type of boiler. As compared with cast-iron sectional types, the high efficiency and durability of this boiler are important considerations, while the prices are below those of steel sectional and wrought welded boilers. Also, owing to the entire absence of brickwork setting, etc., they are cheaper than the built-in types of boiler, a feature of importance in large heating schemes.

A fire-box of any capacity can be supplied, but the standard sizes are fully equal to all normal requirements, and to meet 'banked' conditions two fire-doors can be provided.

With regard to the outlet connection at the top of the boiler, it is necessary to submit details of the available head-room and size of flow-pipe in the system, to enable a suitable flanged bend to be supplied. The diameter of the return pipe must also be indicated, in order that a suitable flange connection may be provided. In the absence of this information standard flow and return connections would be supplied; these are made with flanges to B.S. Table No. 1.

The smoke-box of the Cochran hot-water boiler enables the funnel to be taken off in any desired direction relative to an existing system of flues in the building, thus keeping within the height of the boiler, in cases where headroom is limited.

* See p. 1646.

Fuel.

The average calorific value per pound of fuel may be calculated at 12,000 B.Th.U., but of this it is only possible to obtain in the boiler an actual efficiency of 70 to 75 per cent. In other words, 8,000 B.Th.U. would represent the heat available from the boiler per pound of fuel burnt, the coal being of an average quality.

SIZE OF MINIMUM FUEL SPACE REQUIRED FOR VARIOUS SIZES OF HEATING INSTALLATIONS ON A BASIS OF ONE MONTH'S SUPPLY.

Radiation in feet super . . .	1,000	2,500	5,000	10,000	20,000	50,000
Fuel space in cubic feet . . .	500	1,000	2,000	3,800	7,600	19,000

FUEL SPACE REQUIRED FOR GENERAL OFFICE BUILDINGS.

Cubic feet of fuel space = cubic contents of building $\times \frac{6 \cdot 45}{1,000}$.

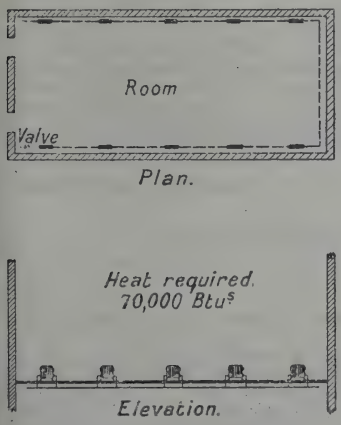
Radiators.

RADIATING SURFACE.

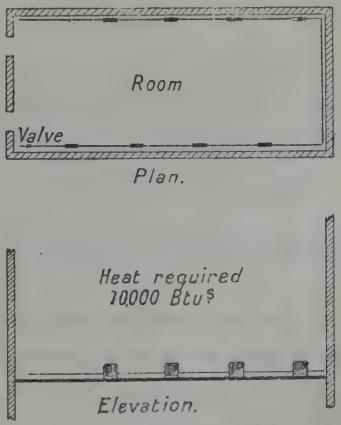
Vertical Loop Radiators are mostly used. Their efficiency varies with the design and size. They should be plain, smooth, and the loops so spaced as to allow of every part being easily cleaned.

Where it is permissible for the pipe supplying the radiators to be above the floor, the initial cost is considerably reduced, as will be seen from fig. 6; this is an important point often lost sight of in considering the cost of a heating installation.

The amount of radiating surface will vary according to the class of surface and its temperature.



Pipes below floor: cost £98.
FIG. 5.



Pipes above floor: cost £73.
FIG. 6.

A recent test carried out by the Research Committee of the Institution of Heating and Ventilating Engineers has shown that a safe figure for modern radiation is 150 B.Th.U. per sq. ft., with a difference of 100° F. between the temperature of the water and surrounding air.

The above figures show the advantage of having the pipe above the floor where permissible.
Note.—Prices fair competitive basis (January 1928).

It has also been proved that the emission varies as the 1·3 power of the temperature difference between the heating medium and surrounding air. This is a very useful factor, as within reasonable limits obtained in general heating the transmission can be found at any given temperature difference.

It will be seen, therefore, that the amount of radiation in any room will vary considerably according to the temperature of the heating medium; for instance, if a room has a heat loss of 100,000 B.Th.U., the amount of surface required for providing a temperature of 60° F. would be:—

Steam at 212° F.	390 square feet of radiation.
Water at 185° F.	510 „ „ „ „
Water at 160° F.	660 „ „ „ „

Fig. 7 shows the variation needed for drop in temperature on a hot water circuit, each room being supposed to have exactly the same heat loss.

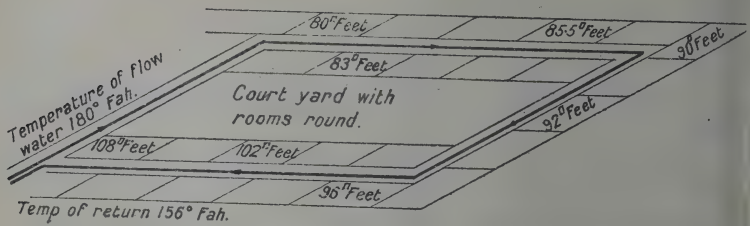


FIG. 7.

The above figure represents a number of rooms which are supplied with a hot water ring main, either forced or gravity circulation; each of the rooms is supposed *to have the same heat loss* (about 14,800 B.Th.U.); the figures show the amount of double col. radiation required, and show the *increase in surface required* due to drop in temperature of the water in main. A total drop of 24 degrees is taken. The chief object of this diagram is to draw attention to a fact which is often given secondary consideration.

NOTE.—It is good practice if possible to arrange the circulations so that the hottest water is at the coldest side of building.

In indirect radiators, the B.Th.U. vary approximately as the square root of the velocity of air passing over the heated surfaces.

AMOUNT OF RADIATION SURFACE REQUIRED IN ROOMS OF AN AVERAGE HOUSE.

Type of Room.	Radiation in Feet Super. per 1,000 Cub. Ft. (To supplement domestic fires.)	Radiation in Feet Super. per 1,000 Cub. Ft. (Without fires in rooms.)
Corner room with large exposed wall and window surface	12	20
Less exposed room	9	15
Passage	—	20
Bedrooms	10	16

Radiating Surface required for Different Classes of Buildings, and Cost of Heating.

Type of Building. (Taking the total cube.)	Average Heating Surface in Feet Super. per 1,000.	Approximate Cost of Heating per 1,000 Cubic Feet.
Churches	12	75 shillings
Hospitals	20	140 "
Block of offices	15	98 "
Public buildings	12	84 "
Factories	7 to 10	47 "
Residences	12	84 "
Small detached residences	15	105 "
Retail shops, etc.	8	52 "

The amounts given include the surface in mains for average work.

These costs, which are based upon present-day prices (January 1928), do not include builders' work, cutting away, making good, etc.

For country work, add 10 per cent. to cover additional allowance to workmen, travelling, and incidental expenses.

Where all pipes are concealed, add 25 per cent.

Approximate Heating Surface required for Horticultural Heating.

Type of House.	Approx. surface in feet super per 1,000 cubic feet.
Houses requiring to be kept at a temperature above 35° in order to prevent frost entering	16
Peach and similar Houses	27
Greenhouses	40
Tomatoes. Vines, etc.	60
Forcing Pits	130

Table of Radiation.

Height of Radiator in Ins.		46	38	36	32	30	26	24	23	20	18
Type.	Length of One Section. Ins.	Heating Surface per Section in Ft. Super.									
Single Column	3	—	3	—	2½	—	2	—	1⅔	—	—
Two Columns	3	5	4	—	3½	—	2⅔	—	—	—	—
Three Columns	2¾	6	5	—	4½	—	3½	—	—	—	2¼
Four Columns	3	—	8	—	6½	—	5	—	—	—	3
Classic 4 Column	2	—	—	3	—	2½	—	2	—	—	1½
Classic 6 Column	2	—	—	4½	—	3¾	—	3	—	—	2¼

To find the space necessary for radiators, multiply the above figures by the number of sections required, adding 8 ins. in length for valve, elbow, union, and bushing.

WIDTH OF RADIATORS AT FEET.

	Ins.		Ins.
Single column	5½	Three columns	10½
Two columns	8⅜	Four „	11

The kind of metal, and the thickness of the latter, of which the radiator is made, has little effect upon the heat transmission, provided the radiator is not painted.

Some recent experiments have proved that painting may affect the radiation as much as 28 %.

The white enamels give rather a better effect (103 %) than a plain unpainted surface (100 %). The ordinary white paints give about 100 %, the greens dropping to 96 %. Copper and aluminium bronzes are the worst, 72 %.

The *thickness of the coat* makes very little difference.

THE WESTINGHOUSE PATENT STEAM RADIATOR.

The Westinghouse Patent Radiator shown in fig. 8 was designed to overcome the disadvantages formerly attendant on the use of steam for heating purposes. Steam enters the radiator at A and passes through the opening in the valve seat B into a distribution pipe C, in the upper side of which a small hole is drilled opposite each column. It then passes up each column as shown

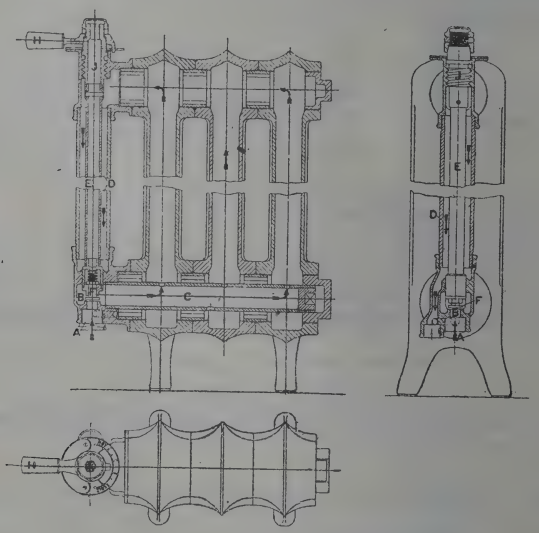


FIG. 8.—The Westinghouse Patent Radiator.

by the arrows and into tube D. This tube contains another tube E of metal with a high coefficient of expansion, and when it reaches a temperature of about 210° F. or any other lower temperature to which it is set, expands and closes the valve F, thus shutting off steam until the temperature is slightly reduced, when the valve again opens.

The temperature of the radiator can be varied as desired up to the maximum by moving the handle H which, owing to the screwed socket J, moves the tube E and valve F nearer to, or farther

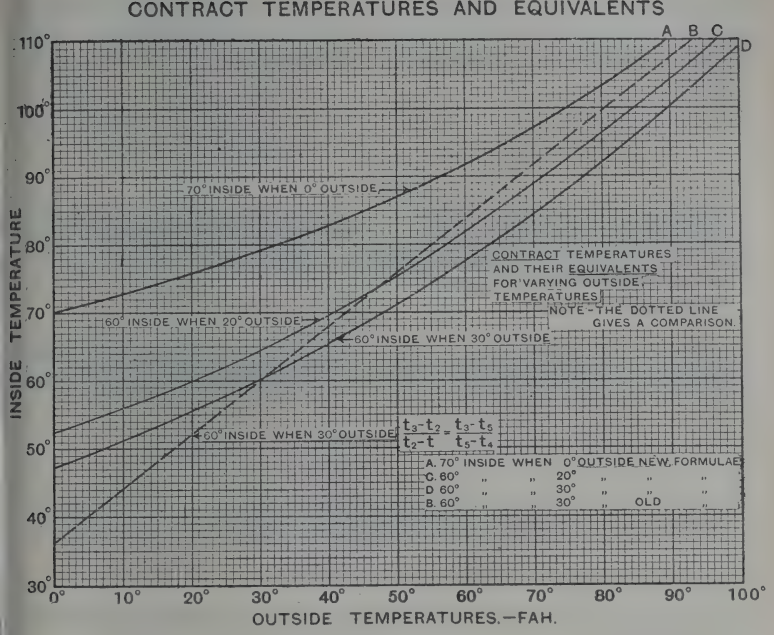

CONTRACT TEMPERATURES AND EQUIVALENTS
A B C D
110°
100°
90°
80°
70°
60°
50°
40°
30°
INSIDE TEMPERATURE
70° INSIDE WHEN 0° OUTSIDE
60° INSIDE WHEN 20° OUTSIDE
60° INSIDE WHEN 30° OUTSIDE
60° INSIDE WHEN 30° OUTSIDE
CONTRACT TEMPERATURES AND THEIR EQUIVALENTS FOR VARYING OUTSIDE TEMPERATURES
NOTE - THE DOTTED LINE GIVES A COMPARISON.
$\frac{t_3-t_2}{t_2-t} = \frac{t_3-t_5}{t_5-t_4}$
A. 70° INSIDE WHEN 0° OUTSIDE NEW FORMULAE
C. 60° " " 20° " " "
D 60° " " 30° " " "
B. 60° " " 30° " OLD "
0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100°
OUTSIDE TEMPERATURES.—FAH.

FIG. 9.

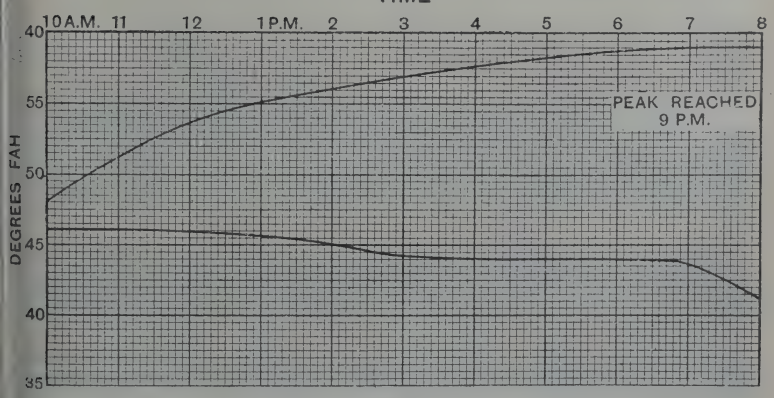

TIME
10 A.M. 11 12 1 P.M. 2 3 4 5 6 7 8
40
55
50
45
40
35
DEGREES FAH
PEAK REACHED 9 P.M.

FIG. 10.

from its seat B, and thus causes the valve to close at a lower or higher temperature as desired. The temperature of the radiator can never exceed 212° F., as the steam inlet is restricted by the valve while the outlet is fully open to the return line, and the steam is entirely therefore condensed in the radiator, only water escaping to the return line. It will therefore be seen that the temperature of the radiator does not depend on the pressure of the steam supply, nor is it affected by the distance of the radiator from the source of supply.

Contract Temperatures and their Equivalents.

(Direct Radiation.)

These, which are of considerable interest to architects and engineers, have been the subject of considerable controversy. Some years ago a Committee of the American Institute of Heating and Ventilating Engineers reported on the subject; in 1903 Mr. Walter Jones gave a paper before the English Institute. Professor Allen's paper on 'The Coefficient of Heat Transmission in Cast Iron Radiation,' June 1908, is one of the most modern.

The expression $$\frac{t_2 - t_3}{t_2 - t} = \frac{t_3 - t_5}{t_5 - t_4}$$

is considerably in error, *even taking into consideration the different coefficients of transmission, extra losses due to increased air changes, etc.* In the discussion on Professor Allan's paper, Mr. C. B. Thompson said he had recently made some tests, but could not get more than 105° F. inside, with an outside temperature of 85° F. and surface that gave 70° inside when 0° outside.

The following empirical formula is found to agree closely with *actual tests* :—

$$t = [t_1^{12} - t_2^{12} + t_3^{12}]^{\frac{1}{12}}$$

where,

t_1 = contract inside absolute temperature F.;
t_2 = contract outside " "
t_3 = existing " " "
t_4 = estimated inside " "

The curves shown in fig. 9 are worked out from the above formula for reference under different contract conditions.

The time factor is an important one, as will be seen from fig. 10, which is from an actual test of a large public building warmed by steam-heated accelerated hot water. The upper curve shows the inside temperature and the lower curve the outside temperature.

Automatic Regulation of Heating Apparatus.

It is very desirable that with hot water or steam installations some arrangement should be made for automatic regulation of the room temperatures independent as far as possible of the human element. The chief drawbacks to regulation of this description have been—firstly, expense; secondly, complicated apparatus requiring skilled attention to ensure the proper efficiency of same. Recently, however, the tendency has been for each room to have its independent automatic regulation instead of being part of a complete system of automatic apparatus, and this tendency has gradually evolved a simpler form of apparatus, some of which are being used with great success at the present time.

In addition to the independent room regulation it is also desirable to have further regulation of the boiler independently, not based on the water temperature of the boiler, but on the variation of the outside temperature; and experience proves that in this country it is preferable to regulate the boiler by means of the outside temperature than by the temperature inside the building.

The Thermutator automatic boiler damper regulator combined with outdoor thermostat, made by *The Drayton Regulator and Instrument Co., Ltd., West Drayton*, for hot-water boilers, operates the draught door in accordance with variation of outdoor temperature. The boiler thermostat is arranged above the boiler in a tube, and can be isolated by closing a cock.

The 'Drayton' A.M. Regulator.

(The Drayton Regulator and Instrument Co., Ltd., West Drayton.)

This regulator, fig. 11, is operated by water pressure. The pilot valve is actuated by metal expansion.

The fig. shows the regulator applied to the control of a water heater, but in place of the diaphragm operated valve, diaphragm operated dampers or other devices may be substituted.

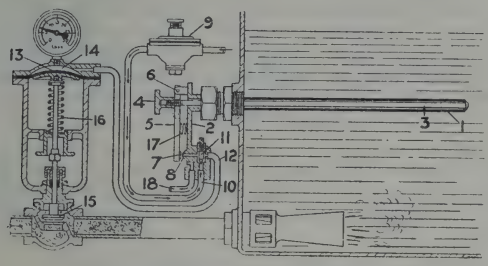


FIG. 11.—'Drayton' A.M. Regulator.

A modified form of this type of regulator is also made for the control of room temperatures.

The great power obtained by the 'Drayton' pilot valve system enables the largest valves or dampers to be operated without loss of accuracy.

HOT WATER SUPPLY.

Hot water supply can be divided into three classes:—

1. Domestic hot water supply suitable for ordinary houses.
2. Hot water supply for institutions, hotels, etc.
3. For industrial work.

Domestic Hot Water Supply.

The general apparatus for this purpose in an ordinary house is a boiler behind the range, a cylinder in a convenient position, and a supply tank. Points which should have attention are as follows:—

Boiler and its flues should be so fixed in the range as to be easily cleaned; also it should have an emptying tap.
Cylinder should be as near the boiler as possible, so as to ensure an easy circulation.
Feed tank should be in an accessible position, and protected from frost.

The fuel efficiency of a range boiler is low, and experience proves that even in quite small houses an independent boiler is more economical. It will be found that the major portion of the fuel used in a range is taken by the boiler, and not by the ovens required for cooking.

Institutions and Hotels Hot Water Supply.

For this class of work where steam is not required for other purposes, independent hot water boilers are the most economical. The type of boiler will depend on the nature of the water; where the water is hard it is desirable to have the boiler of as simple a form as possible, with ample provision for cleaning out, a bolted top being very desirable in this connection. In some cases it may be found necessary to either soften the water or put in a system of secondary heating, in which case the water in the boiler is circulated through a coil which heats the water in a secondary manner. Where the water is not hard, the sectional boilers 'Bower-Barffed' have proved very successful and highly efficient. In domestic supply it is desirable that the cylinder, which would usually be of a horizontal type with dome ends, should be as near the boiler as

possible; from this cylinder, secondary circulations of considerable length may be taken to the various parts of the building, to supply the different fitments. In arranging hot water supply circulations and draw-offs, it must always be remembered that where there is a branch off the circulation, and the tap on the end of that branch is open, water will flow both ways, both from the flow direction and from the return direction, the return, therefore, should connect to the cylinder at a high point. This is most important, and many failures have been due to neglect of this necessary arrangement.

In many cases steam is required, especially in institutions and hotels, for different purposes such as cooking, etc.; in such cases, instead of having a separate hot water supply boiler, it is desirable to heat the water by steam. This is done by means of a calorifier; in principle it is simply a coil of steam pipe enclosed in a vessel of water, the steam being condensed and the latent heat of the same being conveyed through the coil to the water outside. This system also lends itself to thermostatic control. For this class of work it is very necessary that the pipe from the supply tank to the storage cylinder be of ample size. In some installations of a large size it is desirable to do away with the supply tank and simply keep the installation full by means of a pump, the pump automatically starting on a tap being opened. This system has many advantages but is not so well known as the usual one of having a supply tank.

Westinghouse Lavatory Water Heater.

Where a supply of steam is available this heater affords a convenient means of obtaining hot water instantly without the use of hot-water tanks.

Referring to fig. 12, steam enters by a pipe connection, which is in direct communication with chamber B. Cold water enters by a pipe connection which communicates directly with chamber D. Valves E and F are kept closed by springs G and H, when the handle J is in the 'OFF' position.

When the handle is moved to position 'COLD,' the bell crank K pushes open valve F, and cold water only flows through the passage L to the space between the tubes N and M, and thence by pipe connection O to the lavatory basin.

On moving the handle further over to the position 'HOT,' the steam valve E is also opened by the bell crank K pushing against its stem, and steam then flows by passage P to the interior of tube N, and thence to the atmosphere by pipe connection R.

The heat of the steam being transmitted through the walls of the tube N to the water as it flows down the narrow space between the tubes M and N, the water is hot by the time it reaches the outlet N, while the steam in tube N is partially condensed before issuing from outlet R. The spring S returns the handle to the 'OFF' position.

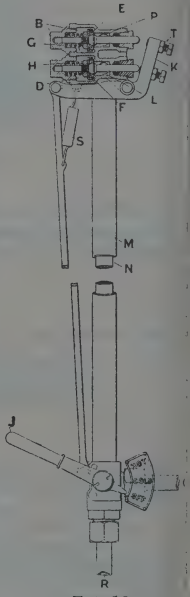


FIG. 12.

Method of ascertaining Heat necessary for a given Supply of Hot Water.

The basis of the calculations is that one British Thermal Unit will raise the temperature of 1 lb. of water 1° F. This figure varies a little according to the temperature of the water, but the variation is so small that for the purpose of hot water supply calculation, it may be neglected.

On the above basis we get the following simple formula—

$$B = \frac{G \times 10 \times T}{H} + R,$$

where,

B = British Thermal Units per hour;
G = gallons of water;
T = degrees it is required to raise the temperature of water;
H = time in hours allowed for obtaining the required temperature;
R = radiation losses from pipes and cylinder, per hour.

Example.

It is required to raise 100 gallons of water from 40° to 150° F. in 2 hours then

$$B = \frac{100 \times 10 \times 110}{2} = 55{,}000.$$

With regard to radiation losses, we may assume the cylinder and pipes loss to be, say, a mean of 10,000 B.Th.U. per hour ; the total B.Th.U. per hour would then be

$$55{,}000 + 10{,}000 = 65{,}000.$$

It is assumed that the circulating pipes and cylinder would be covered with non-conducting material to conserve the heat.

A boiler will transmit on an average from 2,500 to 7,000 B.Th.U. per hour per foot of boiler surface, 2,500 being for secondary flue surface, and 7,000 for fume firepot surface. An average of 5,000 may be taken for an ordinary independent boiler with normal firing. A tube in a well-designed calorifier will transmit from, say,8,000 B.Th.U. per foot at 1 lb. pressure to 37,000 B.Th.U. at 50 lbs. pressure. The pressure of the water surrounding the tubes has quite an appreciable effect on transmission, apart from the temperature of the steam.

Apart from the usual hot water supply in a hospital, a special sterilised supply is required for surgical work in the operating theatres ; steam is generally used for this purpose, and the water is heated to sterilised temperature, or generally boiled, and the apparatus so arranged that the sterilised water does not come into contact with unsterilised water or air before it is delivered at the taps for the use of the surgeon.

Hot Water by Gas.

Gas is often used for the purpose of heating water, especially in small installations, and a very usual application of this, in an ordinary size house, is to connect up the gas-heating boiler to the circulating pipes, so that during the summer when the range is not required (the gas-cooker being used for cooking) the gas-heater boiler can be used when desired. Apart from the geysers, etc., the systems of heating the water are arranged in a general manner, as regards arrangements of circulation, etc. The amount of gas necessary is on the basis of the calorific value per cubic foot. The average calorific value of town gas is, say, about 500 B.Th.U. per cubic foot. Assuming the boilers of the heaters to have an efficiency of 80 per cent., this would mean that 400 B.Th.U. of the 500 should be actually transmitted to the water, so that, taking the amount of water to be heated as mentioned above, namely, 100 gals., to be raised 110°, which requires 65,000 B.Th.U., this divided by 400 will give 162·50 cub. ft. of gas necessary.

Heating Water by Electricity.

For domestic uses, surgical work, industrial, and other purposes, a method of heating water by electricity is very handy ; but there is a disadvantage, it is very expensive if a very large quantity of water is required ; this will be seen from the following :—

The electrical Board of Trade Unit contains 3,411 B.Th.U., and as the efficiency of electrical heating apparatus is very high, it may be considered that 3,000 B.Th.U. of the 3,411 would be transmitted to the water. Again, taking the quantity mentioned above, the amount of electricity required would be 65,000 B.Th.U. divided by 3,000, which gives us 21·7 units of electricity required. With regard to the type of heater, one very handy form, and one easily replaced, is the ' Immersion Heater.'

Industrial Hot Water Supply.

Hot water is required in a great many industries, and the method of heating the same is generally similar to the foregoing methods, although, very often waste heat of the furnaces in various industrial processes can be utilised for heating the boiler. For some requirements such as bottling, washing, etc., where it is desirable to have the water under considerable pressure the closed pump system lends itself to this class of work. (*J. Roger Preston.*)

Heating and Drying.

Not infrequently rooms and chambers are found provided only with steam pipes, which have to do duty at night and in the day time in order to keep pace with requirements. Such rooms

are very bad drying places, and very slow into the bargain because the essential air current is lacking, and failure attends the introduction of a fan under these circumstances, owing to the influx of cold air following its use and lowering the temperature. To be effective the air must be raised to the required temperature before distribution and should act as a vehicle for the conveyance of the heat to and about the drying rooms or chambers.

To derive the maximum benefit from the use of exhaust steam, drying rooms of considerable size should have two or more divisions, as by this means operations may commence in one section soon after starting the engine, and conveniently proceed so that the operators may work in the cool part and finish up within a period of time to coincide with shutting off steam.

The proper temperature to effect rapid and perfect drying varies considerably, and depends upon the nature and texture of the material to be treated. Provided, however, the warm air current is fairly proportioned, then mechanical drying will considerably enhance the value and quality of the work, and vastly expedite and cheapen the process.

Drying Room Temperatures.

Material.	Room Temperature.	Time to dry.
	Mean ° F.	Hours.
Stains and varnish (caskets, pianos, &c.)	110	7
Shirts, flannels, &c. } In drying machine with air circu-	120	½
Blankets } lated internally	120	¾
Cement sacks, on drying horses	120	1
Candied peel, on trays	165	2
Potatoes (steamed), on trays	170	6½
Cabbage and carrots (raw)	140	4½
Apples (sliced) (raw), on trays	175	6½
Hops, on floor in usual kiln	130	12
Retted flax on racks, lightly spread	120	10
Leaf tobacco on racks, lightly spread	135	12
Stem tobacco	180	12
Cinematograph films, on wooden drums	80	½
Millboard sheets, hung from clips	95	10
Ramie fibre, on perforated table	140	10
Earthenware plates, in revolving stove	110	8
Basils and skivers, on frames	75	48
Heavy hides from liquors, on poles { 1st.	atmospheric	100 to 200
Heavy hides from liquors, on poles { 2nd	70	72
Bone glue (thin sheets), on wire trays { 1st	70	100 to 124
Bone glue (thin sheets), on wire trays { 2nd	80	
Wool after scouring, on perforated floor	150	4
Toilet soap in ribbons (Cressonnieres' Patent)	90	½
Hanks, hung on poles	120	2
1½-in. oak or hardwood, piled in stacks	90 to 125	20 days of 10 hours
2-in. to 3-in. oak or hardwood, piled in stacks	90 to 125	3 to 4 weeks.
The following are in tunnel dryers :	Tunnel inlet.	Hours to dry.
Common bricks of easy-drying clay, on trucks	170	30
1-in. air-dried, soft woods, piled on trucks	175	72
1-in. green soft woods, piled on trucks	175	120
Casein, on trays	140	8

(*George H. Gill*, '*Engineering*,' *May* 4, 1923.)

SECTION XXXVIII

PART II

VENTILATION.

(Revised by J. Roger Preston, Vice-President of the Institution of Heating and Ventilating Engineers.)

Amount of Air necessary for Ventilation.

Whenever possible, it is desirable to provide 3,000 cubic feet of air per hour per person for halls, theatres, etc. Owing to the restrictions of cost and building construction, the sizes of the ducts necessary for this amount are rarely attainable, so a more usual figure is 1,800 cubic feet of air per hour per person. The L.C.C. regulations give 1,000 cubic feet of air per hour per person as the minimum amount of air required in buildings licensed by them.

Assuming a building in which there are, say, 3,000 people, and taking the L.C.C. requirements of 1,000 cubic feet per hour, this means about 830 cubic feet of air per second. The velocity permissible in the ducts will depend to some extent on their length, but 15 to 20 feet per second may be taken as a good maximum average. This means that the inlet and distributing ducts should have an area of not less than 50 square feet. As a streamline section must be maintained, it follows that where a change of direction in a duct of this size takes place, considerable space is taken up, and unless provision has been made for same, difficulties may be encountered. Steelwork is often a very important factor, especially in connection with the vertical subsidiary ducts, and is very difficult to modify; this trouble can only be avoided by close collaboration between the various parties concerned in the early stages of the building.

A very important point to bear in mind in the general planning is to allow plenty of room for the engineering equipment and to arrange that every part shall be easily accessible to the engineer in control of the plant. Experience proves that this is most essential, but is often overlooked or sidetracked to make room for something else.

The aim should be to make a system of ventilation as noiseless as possible, though this may not be necessary in industrial work. A good deal can be done by attention to details, but the fundumental factor is to keep low velocities, enabling the fans to run at slow speed, thus saving power. The space required and the initial cost will probably be more than for a system having high velocities, but it cannot be too strongly emphasised that in good class work *low air velocities and slow-running fans are essential to successful ventilation.*

The foregoing statement applies whatever system is adopted, and it must be remembered that *high air velocities and high-speed fans are a source of trouble and expense*, however attractive it may appear at the time to install small trunks that are easily adapted to the building.

Distribution of Air.

Convection currents are a most important factor in ventilation, and should be closely studied. This can conveniently be done either by balanced mica vanes or by blowing air through HCl and NH_4OH, the vapours so formed causing, when mixed, a dense white smoke (not heated). When these convection currents are known it can then be decided whether natural or mechanical methods will be required to give satisfactory ventilation and the best positions for the introduction of the air.

If natural ventilation is utilised, the air should be introduced at low level, preferably behind radiators, and allowed to find its way out at ceiling level.

Three methods of mechanical ventilation are employed, the particular method to be used depending on circumstances.

(*a*) *Mechanical extract* only. Inlets are provided at a low level, preferably behind radiators, the air being extracted by means of a fan at high level. This method is commonly employed in halls seating under 1,000 people, and similar buildings.

(*b*) *Mechanical inlet* only. Inlets are provided at a low level or about 6 feet above floor level. A common distribution is one-third of the total area of gratings at low level and two-thirds at 6 feet up. Outlets are provided through the walls at high level or through the ceiling. This method is employed when fresh air from outside is not otherwise obtainable.

(*c*) *Both mechanical inlet and extract.* The extracts should be as (*a*) and the inlets as (*b*). This method is used for large halls and particularly difficult problems, such as basements and enclosed rooms. The amount of air extracted mechanically is usually 75 per cent. of the air introduced by the inlet fan.

Where circumstances will allow, it is often found an advantage to arrange the distributing ducts, inlets, and outlets in such a way that the direction of air currents in the room can be reversed for different atmospheric conditions and temperatures.

Air-Filtering, Washing and Conditioning.

It is always desirable and frequently essential that the air should be as free from dust and impurities as possible. This dust can be removed by filters and air washers. There are several types of air filters obtainable, but they can be divided into two main groups:

(*a*) *Dry filters.*—These consist of a series of perforated plates arranged so that the perforations are staggered, the plates being covered with a sheet of wadding on the up-stream side for the better collection of the dust. The filtering effect is dependent on the number of plates. To clean, the filter unit is detached from its frame and shaken.

(*b*) *Viscous fluid filters.*—In these, the air passes over a series of plates or troughs coated with a viscous fluid to which the dust adheres. To clean, the filter unit is washed in strong soda water, dried, and then dipped in the viscous fluid and allowed to drain before replacing.

Air washers commonly used consist of a series of fine sprays through which water is pumped, the air mixing thoroughly with this finely divided spray, afterwards passing over a series of eliminator plates which collect the surplus water together with the dust.

The use of dry or viscous filters removes the dust without altering the temperature or humidity of the air, while the air washer varies both the temperature and humidity, thus making it unsuitable for certain purposes although it is frequently advantageous, especially when applied to the ventilation of halls and theatres.

The endeavour to produce a pleasant and healthy atmosphere inside at all times of the year whatever the outside conditions may be, has received a good deal of attention of late years, and in this connection a term *Effective Temperature* has been brought into use. The 'Effective Temperature' is influenced by three factors: (1) Dry bulb temperature; (2) Wet bulb temperature; and (3) Velocity of the air. The most suitable 'Effective Temperature' may vary, according to circumstances, from 60° to 70° F. If, however, it were 90° F. outside, it would be very unwise and actually uncomfortable for people to go into a temperature of, say, 60° F. or even 70° F. In this case, the reduction of the dry bulb temperature by about 10° F. together with a perceptible air movement, would probably give rise to a marked degree of comfort.

Air Cooling.

Air can be cooled by an air washer, but the relative humidity will always rise. In a washer using recirculated water, the heat content will not be substantially changed although a certain cooling effect can be obtained with a consequent rise in relative humidity. The wet bulb temperature is unaffected by this method, so that the cooling is limited by the initial wet bulb temperature and will in practice always be a few degrees above this. Actually it will be found that the dry bulb temperature can be reduced to, say, 75 per cent. of the difference between the wet and dry bulb temperatures.

When artesian well water or some other water having a temperature of 52° F. is obtainable the air can be cooled to about 57° F. with a consequent reduction in the vapour contents of the air should the initial dew-point be above 57° F., which is most probable in hot weather. The air will then be saturated.

When air is required with a lower temperature than can be obtained by the air washer refrigeration will have to be employed. Cooling air is far more expensive than heating, owing to the condensation of the moisture in the air. For general ventilation, the air may be cooled from 10° F. to 15° F., but for industrial purposes, when it is required to have complete control over the relative humidity and temperature, it is usual to cool the air to 35° F. The amount of brine to be circulated should be calculated on a drop of 3° F. The specific heat of brine may be taken as 0·82° F., and in calculating the heat required for the reduction in temperature the condensation of the vapour must not be forgotten. The heat in British thermal units required divided by 12,000, will give the size of plant required in tons of refrigeration per day of 24 hours.

The heat exchange in cooling or heating air over a given range of temperature is not materially different, provided the dew-point is not reached. Should, however, the initial humidity be such that the dew-point is reached in the cooling, another very important factor is introduced, a portion

of the aqueous vapour being condensed and giving up its latent heat in the process. The British thermal units involved in the heat exchange may be ascertained by the following, which is accurate enough for all practical purposes and shows the various points involved :

$$U = \overbrace{L_C (W_1 - W_2)}^{\text{SECTION A.}} + \overbrace{S_v(T_1 - T_2) W_1}^{\text{SECTION B.}} + \overbrace{S_a (T_1 - T_2)}^{\text{SECTION C.}},$$

where,

T_1 = Initial dry bulb temperature;
T_2 = final ,, ,, ,,
W_1 = weight of aqueous vapour per lb. of air at initial temperature T_1;
W_2 = ,, ,, ,, ,, final ,, T_2;
L_C = mean latent heat of vaporisation or condensation at initial dew-point, and T_2;
S_v = specific heat of vapour;
S_a = specific heat of air;
U = B.Th.U.'s to cool 1 lb. of air from T_1 to T_2;

Basic figures to be taken for this and other equations :

S_v = specific heat of aqueous vapour = 0·44;
S_a = ,, ,, air = 0·2415 *;
L_C = latent heat of vaporisation varies from 1073·4 B.Th.U.'s per lb. ar 32° F. to 1052·3 B.Th.U.'s per lb. at 70° F.

Section A is the heat required to be extracted to condense the water vapour.

Section B is the heat required to be extracted to reduce the temperature of the water-vapour contents of the air and is so small that it can usually be neglected.

Section C is the heat required to be extracted to cool the air from T_1 to T_2.

Velocities of Air Flow for Mechanical Ventilation and Flow of Air Through Ducts.

Where silence is essential, the velocities of flow of air in ducts must be kept low, the ideal velocity being from 10 to 15 feet per second, and on no account exceeding 20 feet per second. For factory work speeds up to 30 feet per second are allowable, but this velocity should not be exceeded. In general, the outlets to the rooms (if at low level) should be of such an area that the air issues at a velocity of from 3 to 5 feet per second, as such velocities do not give rise to a sensation of draught. In certain circumstances, however, such as during hot weather, it may be found desirable to direct a flow of air across a room at a velocity of 10 to 15 feet per second, this movement giving a feeling of coolness. (See 'Effective Temperature' p. 2510.) The following table gives the permissible velocities for different parts of the ventilation system. The lower figure refers to ventilation where silence is desired, and the higher gives the maximum permissible for factories, etc.

Fresh air intake	500 to 800 ft. per min.	Main ducts	800 to 1,200 ft. per min.
Heating battery	800 ,, 1,500 ,, ,,	Branch ducts	600 ,, 900 ,, ,,
Filter	150 ,, 350 ,, ,,	Registers	180 ,, 300 ,, ,,
Washer	300 ,, 500 ,, ,,		

The flow of air through a building resembles an electrical circuit, the inlets, outlets, and ducts acting as the resistance, and absorbing some of the aeromotive force. *To ensure an even flow in various ducts requires considerable care*; the resistance must be low, as the initial force in ventilation is small, usually equal to about 0·25 ins. of water, or 17 pneumatic units. In natural ventilation it is much less than this.

In order to obtain an even distribution of air throughout the system, the design of the ducts is very important. Changes in direction and section should be as gradual as possible, particular care being taken to avoid sudden changes. The finish of the ducts should always be of the best, as roughness and irregularities increase immensely the resistance to the flow of air. The ducts are usually made of galvanised iron or in builders' work. When made by the builders the ducts should be lined with glazed bricks, or, if this is too expensive, finished with Keene's cement or some similar hard, smooth finish. It is always advisable to whitewash the latter, as the presence of dust is then easily noticed and more likely to be removed. The importance of the foregoing will be appreciated when it is realised that in mechanical ventilation where silence is essential the fan should not work against a resistance exceeding 1in. W.G. and in other general work it is advisable not to exceed 2in. W.G., except for dust extraction and similar industrial processes.

* 0·238 was at one time the accepted figure for specific heat of air and will be found in many textbooks, but 0·2415, or sometimes 0·2400, is now accepted as the more correct value.

RESISTANCE OF FLOW OF AIR PER 100 LINEAL FEET OF CIRCULAR GALVANIZED IRON TRUNKING.

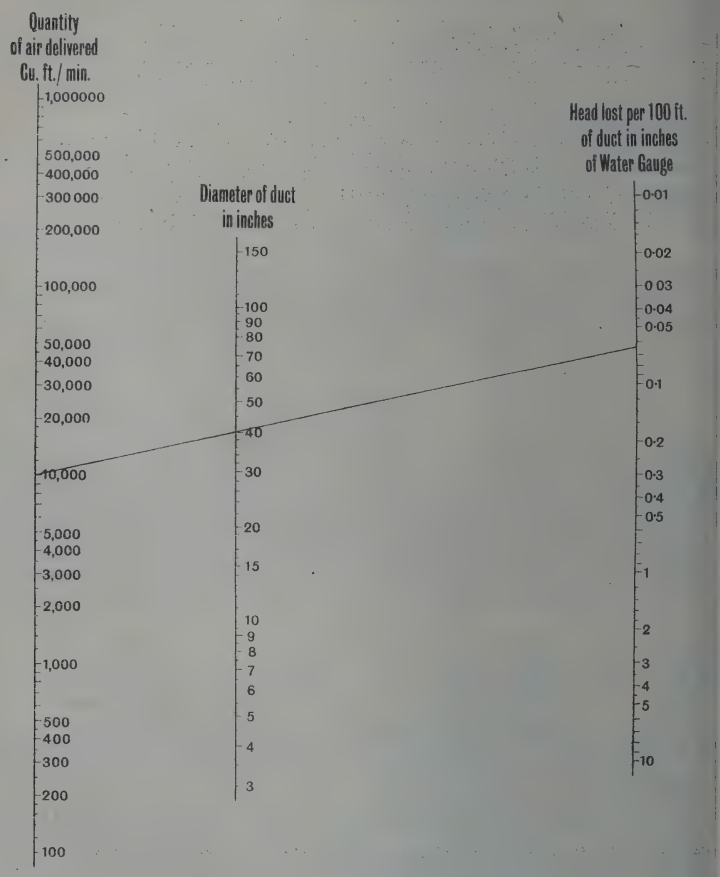


FIG. 1.

EXAMPLE: To find the loss of head in a 40-in. diam. duct carrying 10,000 cu. ft. of air per minute, lay a straight edge as shown connecting 10,000 cu. ft./min. and 40-in. diam., reading the loss of head 0·064 ins., W.G. per 100 ft., on the right.

. There is yet a need for research work in connection with the flow of air in ducts, but the ollowing will be found a useful formula for the flow of air through galvanised iron pipes :

$$C = 39d^{2\cdot5} \Big/ \left(\frac{L}{H}\right)^{\frac{1}{2}}$$

here,

C = cubic feet of air per minute ; L = length of pipe in feet ;
d = diameter of pipe in inches ; H = drop of pressure in inches of water.

The values derived from this formula are shown more conveniently in fig. 1.

For resistance in ducts of other materials than galvanised iron, multiply the result obtained rom the diagram or by the above formula by the following factors :

Smooth concrete . . . . 1·5 Brickwork . . . . . 2·0

When arriving at the total resistance in a duct, allowance must be made for bends and loss ue to entry and egress at registers. The loss of a sharp elbow varies from 30 to 60 diameters. smooth bend 5 diameters and a usual register 80 diameters.

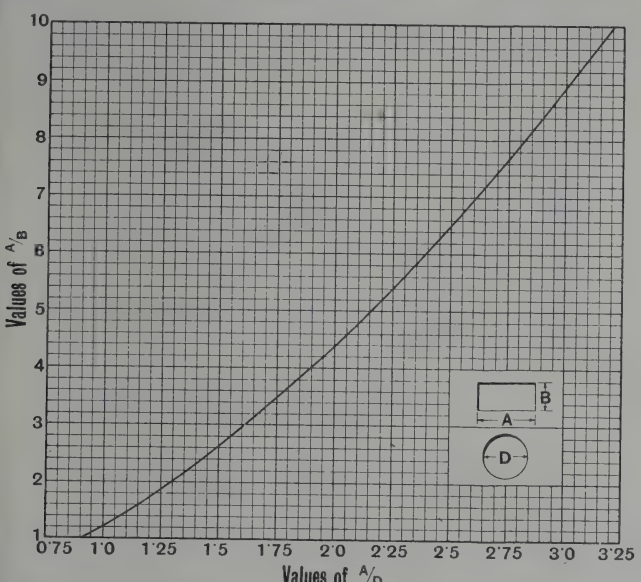


FIG. 2.

Diagram for obtaining equivalent Diameter of Round Duct carrying the same amount of air for the same loss as a Rectangular Duct.

To obtain the total head against which the fan has to work, the velocity head must be added the resistance in the duct ; this is obtained from the following formula :

$$h = \frac{6D \cdot v^2}{gk}$$

ere,

v = velocity in ft. per sec. ; h = velocity head in W.G. ;
g = 32·2 ; D = density of air at temperature required
k = density of water = 62·4 ; = 0·0749 for dry air at 70° F.

All the above is based on circular pipes. In the case of rectangular pipes, find the equivalent

circular pipe to give equal discharge for equal resistance from the following formula, and then use fig. 1 to find the resistance to flow :

$$D = \sqrt[5]{3{\cdot}25 \frac{A^3B^3}{A + B}},$$

where

A = long side of rectangular pipe ; B = short side of rectangular pipe ; D = dia. of equivalent round pipe.

This equivalent diameter can conveniently be found by means of fig. 2.

Movement of Air by Fans.

The choosing of a suitable fan is a most important factor in any scheme of mechanical ventilation.

There are two distinct types of fans used for this work : the propeller and centrifugal, one similar to a ship's propeller, and the other more like a paddle wheel.

A propeller is a very efficient and useful fan if used in the proper way, that is, either with free inlet and outlet, as, for instance, when fixed in a window or wall without any trunking attached, or with short trunking of ample size, causing very little resistance head.

In the average building a fan must run at a low speed to avoid noise. At this speed the efficiency of a propeller fan falls off very considerably against resistance, as will be seen from

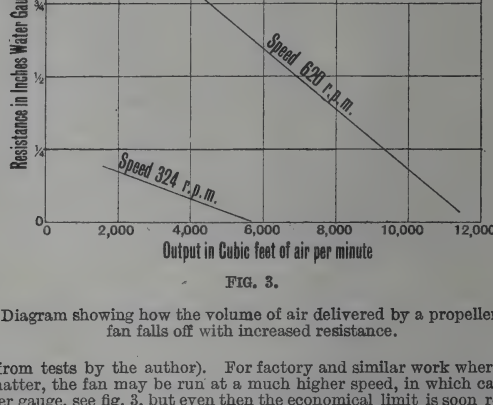


FIG. 3.

Diagram showing how the volume of air delivered by a propeller fan falls off with increased resistance.

fig. 3 (plotted from tests by the author). For factory and similar work where noise and extra power do not matter, the fan may be run at a much higher speed, in which case it can be used at a higher water gauge, see fig. 3, but even then the economical limit is soon reached. It must be remembered also that as the quantity of air decreases, due to resistance, the power increases.

The centrifugal fan can be used up to any reasonable pressure, but for general ventilation where absence of noise and economy of power is desired, it is good practice not to exceed about 1 in. total head (resistance head + velocity head), the filters, heaters, ducts, etc., being designed accordingly.

When the resistance is increased, the amount of air falls—so also does the power taken. At a lesser resistance the volume of air increases—so also does the power.

Should a centrifugal fan and motor be designed for a given resistance, and then the resistance turns out to be less than expected, there is a great danger of the motor being overloaded, unless a specially large one has been installed. To meet this condition, a special fan has recently been put on the market, and the author's experience of this fan so far has been very satisfactory.

The Fan Standardisation Committee of the Institution af Heating and Ventilating Engineers after devoting some five or six years to the study of the subject, has recently issued a very comprehensive report on the testing of fans, terms to be used, and method of cataloguing, etc. to which the reader is referred.

* 'Report of the Fan Standardisation Committee, 1927' (price 2/6). Office of the Institution 12 Russell Square, London, W.C. 1.

Movement of Air other than by Fans.

As the air in a flue such as a chimney or outlet duct from a warmed room is at a higher temperature than the outside atmosphere, its density is less, and the tendency is for it to rise. The resulting velocity of flow varies within wide limits, but is theoretically given by :

$$V = 480 \sqrt{\frac{h\,(T - t)}{t - 460}}$$

where,

V = velocity of air in feet per minute ; T = temperature of heated air °F ;
h = height of flue in feet ; t = outside temperature °F.

The actual velocity is considerably lower in practice, and the result from the above formula should be multiplied by 0·25 to 0·6, according to size, shape, and materials.

In addition to the movement of air due to difference of temperature, the wind has a considerable aspirating effect on a properly designed ventilator.

The following data are taken from some tables in the ' Robertson Ventilation Data Book ' :*

Temperature Difference, Fahrenheit.	Height of Ventilator above intake.	Wind Velocity in Miles per hour. 2	6	10
		Velocity of air exhausted, in feet per minute.		
0°	10′	61·5	185	309
	20′	61·5	185	309
	30′	61·5	185	309
	40′	61·5	185	309
	50′	61·5	185	309
	100′	61·5	185	309
5°	10′	139	262	385
	20′	170	294	416
	30′	195	318	441
	40′	215	337	460
	50′	233	355	479
	100′	300	422	545
10°	10′	170	294	416
	20′	215	337	460
	30′	250	372	496
	40′	279	401	525
	50′	304	426	549
	100′	402	526	650
20°	10′	215	337	460
	20′	279	401	525
	30′	326	449	572
	40′	367	491	614
	50′	402	526	650
	100′	545	670	792
30°	10′	250	372	496
	20′	326	449	572
	30′	386	509	633
	40′	437	560	684
	50′	481	604	728
	100′	655	779	902

Heating units such as gas jets, electric heating, steam or hot water coils, are sometimes used for the purpose of causing an up-draught. These should never be used if any other method is available, as they are very inefficient and costly in up-keep, costing, in the case of steam coils for example, on an average six times that of moving air by fans. (*J. Roger Preston.*)

* H. H. Robertson Co., Pittsburg, Pa., U.S.A.

Blowers and Exhausters.

Sturtevant Blowers and Exhausters.

(Sturtevant Engineering Co. Ltd., London, E.C. 4.)

The design of a fan depends upon the pressure against which it has to discharge. A blower designed for low pressure is not suitable for high, and *vice versâ*. Figs. 4 to 10 show various types.

Fig. 4.

Air Propeller.

For moving large volumes of air from one part to another where the resistance is low. Used for ventilating and exhausting.

Multivane Centrifugal Fan.

For moving large volumes of air against 1 to 4 ins. water gauge. Fan wheel has shallow blades with corrugations to prevent lateral slip. Used for ventilating, drying apparatus, mechanical draught for boilers, etc.

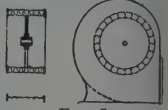


Fig. 5.

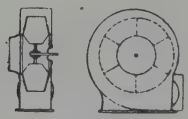


Fig. 6.

Steel Plate Cased Centrifugal Fan.

For air pressures up to 8 or 10 ins. water gauge. The square section steel plate casing is used, but the wheel has deeper blades and side plates (shrouds). Used for dust exhausting, conveying, etc.

Cast Iron Casing Fan.

For obtaining higher pressures up to 15 ins. water gauge, the casing must be more carefully designed and preferably made in cast iron. The wheel is narrower and deeper than that for lower pressures. Used for blowing forges, furnaces, etc.

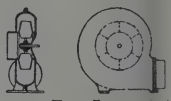


Fig. 7.

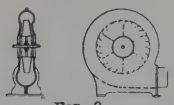


Fig. 8.

High Pressure Fans.

For blowing cupolas, etc., requiring air pressures from 12 to 30 in water gauge. The scroll must be most carefully designed and the wheel have a greater number of blades. For sizes and capacities of this fan see page 2656.

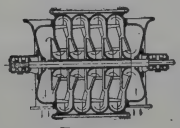


Fig. 9.

Multistage Fans.

For blowing and exhausting air at pressures up to 3 to 4 lbs. per square inch.

Rotary Blowers.

These are used for many duties, for blowing and exhausting air or gases where pressures up to 5 lbs. per square inch are required.

Fig. 10.

Power Variation of a Blower at Constant Speed.

Propeller Fans.—Power rises slightly with pressure; volume decreases rapidly as pressure rises.

Centrifugal Fans.—Power increases as pressure falls, and volume increases.

Rotary Blowers.—Power increases directly with pressure, volume remaining about constant.

The 'Wing' Fan.

(F. W. Potter & Co., Phipp St., Great Eastern St., London, E.C. 2.)

The general arrangement of the blades of the Wing fan or air propeller is shown by fig. 11. t is claimed that the Wing fan, for a given amount of power, will move a greater volume of air han any other pattern, owing to the shape, angle, and curvature of the blades, and the method f securing them to the central boss. It has been found that an angle of 27½° to 30° is the best ll-round angle for combined output and efficiency.

A distinctive and useful feature of the fan is the adjustability of the angle of the blades, the atter being readily set to any angle. If desired, the direction of the air current may be reversed, his reversal of the air current being effected without impairing the efficiency of the fan.

The blades of the Wing fan are usually made of steel, but for certain purposes they are made f copper, aluminium, or Muntz metal.

The fan wheel is mounted on a spindle running in bearings lined with best quality Babbitt netal, and the framing is constructed of cast iron or wrought iron according to circumstances.

The Wing fan is manufactured in all sizes, arranged with pulley for belt drive, or direct coupled o electric motor.

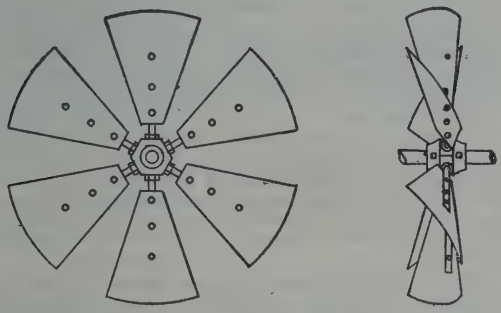


Fig. 11.

Economy of Power.—Where conditions permit of the choice between a propeller type and a entrifugal type of fan, the following rules are useful :—

(*a*) For open ventilation use propeller fans.

(*b*) Make main air duct same diameter as fan, or larger, avoiding acute or sharp angle bends.

(*c*) When small ducts and sharp bends are unavoidable use centrifugal fans.

(*d*) Use large fans at as low a speed as will overcome whatever resistance is in the way of free assage of air.

Example.—A 10 ft. Wing fan at 90 revs. per min. delivers 71,000 cu. ft. of air per min., absorbing ·2 h.p.

A 5 ft. Wing fan at 720 revs. per min. delivers 71,000 cu. ft. of air per min., absorbing 19·2 h.p. Volume for volume, therefore, the smaller fan uses 16 times the power absorbed by the larger fan.

(*e*) Use two fans of the same diameter at low speed instead of one at double the speed.

Example.—A 48 in. Wing fan at 600 revs. per min. delivers 30,200 cu. ft. of air per min., absorbing 3·6 h.p.

Two 48 in. Wing fans at 300 revs. per min. deliver 30,200 cu. ft. of air per min., absorbing ·9 h.p. ogether.

Volume for volume, therefore, one fan uses four times the power absorbed by two fans.

APPROXIMATE CAPACITIES OF 'WING' FANS (SMALLER SIZES).

Diam. of Fan Blades Ins.	Silent Speed.			For ordinary Ventilation.			For Factories and Engine Rooms.			Fast Speeds.		
	Revs. per Min.	Net H.P.	Cubic Ft. per Min.	Revs. per Min.	Net H.P.	Cubic Ft. per Min.	Revs. per Min.	Net H.P.	Cubic Ft. per Min.	Revs. per Min.	Net H.P.	Cubic Ft. per Min.
14	680	·012	850	1,090	·05	1,360	1,540	·13	1,930	2,000	·29	2,500
18	530	·02	1,410	850	·08	2,250	1,200	·22	3,170	1,600	·51	4,250
24	398	·034	2,510	640	·14	4,050	900	·40	5,680	1,200	·92	7,550
30	318	·052	3,900	510	·21	6,260	720	·63	8,850	960	1·50	11,800
36	265	·074	5,620	425	·30	9,000	600	·87	12,700	800	2·05	17,000
42	228	·10	7,680	364	·43	12,250	515	1·20	17,400	685	2·75	23,100
48	200	·14	10,100	318	·55	16,100	450	1·55	22,600	600	3·60	30,200
54	177	·17	12,700	283	·68	20,300	400	1·95	28,700	535	4·70	38,300
60	145	·19	14,300	255	·85	25,000	360	2·4	35,400	480	6·00	47,200

MOTORS FOR DRIVING VENTILATING FANS.

Too much cannot be said regarding the location of the motor. On account of the natu of the work it is frequently necessary to place the machine in an out-of-the-way place, althoug this does not necessarily mean that it must be in an inaccessible location. If it is so place that it is difficult to care for, it will probably be neglected, with the result that the service w be impaired and the maintenance charge will be high. The placing of a motor in an inco venient place because nothing else will go there, is false economy generally, and results i dissatisfaction. The question of motor efficiency in regard to fan drives is an important o and involves two factors—the efficiency of the motor when operating under normal speed, an the efficiency at other than normal speeds. Although the latter is, to some extent, influenc by inherent characteristics of the motor, the largest factor is the method of control, especial with direct-current motors. If, on account of its lower cost, a motor is selected, where adjus able speed is required, that will, when operating at normal speed, drive the fan at the maximu required speed, and it is necessary to operate for considerable periods at reduced speed, lo efficiency will result.

The cost of the power lost in the armature external resistance will usually pay a handson dividend on the additional capital required to install a motor and controller that, at norm speed, will drive the fan at the lowest speed required and beyond this point adjust the spe by field control.

The horse-power required to drive a centrifugal fan can be estimated from the followi formula:

$$HP = \frac{5{\cdot}2 \times Q \times WG}{33{,}000 \times E}$$

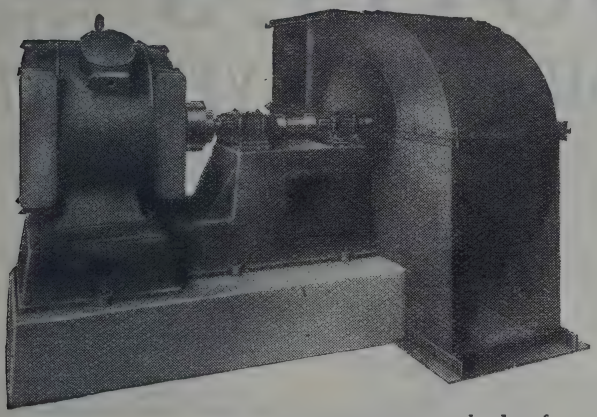
where,

HP = horse-power of motor; Q = cubic feet of air per minute; WG = pressure of a in inches by water gauge; E = efficiency of fan, which is approximately 0·5 for a steel plate fa 0·65 for Sirocco, and 0·45 for cone type.

The following mathematical relations are theoretically true for all centrifugal fans: Volun of air delivered varies as the speed; pressure of air delivered varies as the square of the spee horse-power required varies as the cube of the speed. Hence a fan, which, when operated 100 r.p.m. delivers 8,000 cub. ft. of air at ½ oz. pressure, requires 2 h.p., will, when operat at 200 r.p.m., deliver 16,000 cub. ft. of air at 2-oz. pressure and will require 16 h.p. It is ther fore necessary, in selecting a motor for driving a fan, to figure the horse-power requirements the maximum speed of the fan.

Reduction of the area of the inlet or discharge of a centrifugal fan will reduce the pow required, whereas increasing the area of either will increase the power. Disc fans produce relatively low pressure, and it is customary to figure their output on a basis of velocity. T relations between volume, speed, and horse-power for centrifugal fans hold good for disc fan However, if the outlet of a disc fan is restricted, the pressure and the power required increas and with a totally closed outlet the power needed is almost double that with an unrestricte outlet. (*'Power.'*)

Air in Harness



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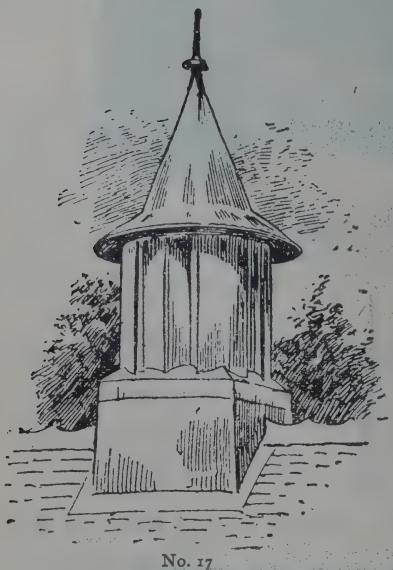
DOUBLE THE EXTRACTING POWER OF EARLIER FORMS.

OVER TWO MILLION IN USE.



No. 17

"Constructed on sound scientific principles, acts in strict accordance with the laws of nature, and cannot fail to operate."—
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REPORTS.

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"Most effective."—SIR JOHN FOWLER (Engineer of the Forth Bridge).

"Its effective action is secured by the scientific utilisation of well-known natural laws."—SIR WILLIAM CROOKES, F.R.S.

"There is no time throughout the whole year when there is not a sufficient movement in the atmosphere to secure the effective action of the 'Air-Pump' Ventilator."—PROFESSOR MACQUORN RANKIN.

"Have used it with satisfactory results."—SIR ARTHUR W. BLOMFIELD, R.A., Architect.

"A perfect method of ventilation."—SIR B. W. RICHARDSON, F.R.S. (Founder of the Royal Sanitary Institute).

"Highly efficient."—THE RIGHT HONOURABLE ACTON-SMEE AYRTON (First Commissioner of Works).

"Its complete success in securing the required continuous upward impulse is testified to by high authorities."—GOVERNMENT REPORT (*Blue Book*).

Highest Award (Two Gold Medals with Diploma), International Ventilator Tests, Paris.

ROBERT BOYLE & SON, Ventilating Engineers,

65 Holborn Viaduct, LONDON, E.C. 1.

Telephone: Central 4583.

F. 2519

Ventilators.

The Boyle 'Air-Pump' Ventilator.

In the latest patented forms of Boyle's patent 'air-pump' ventilators the wind, striking gainst and being deflected by curved vanes causes a suction effect which draws out the foul ir and effects perfect ventilation. One form of the 'air-pump' ventilator, known as the *ridge* entilator, is shown by fig. 12. The wind blows through the openings, and in passing over he curved plates causes a strong upward draught.

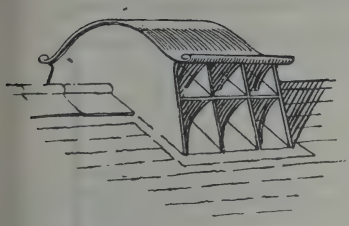


Fig. 12.

No. 175.

Fig. 13.

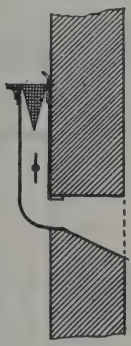


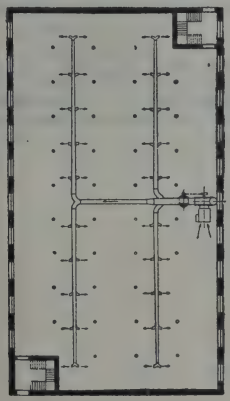
Fig. 14.

In the 'air-pump' ventilator (fig. 13) the curved vanes are set vertically.

For the necessary admission of fresh air to take the place of that extracted by the ventilator, Boyle's Air-Inlet Bracket, shown by fig. 14, may be adopted. The top of the inlet should be bout 5 ft. 9 ins. above the level of the floor, and the outside opening should be covered with n iron grating.

The Plenum System.

This system (*The Sturtevant Engineering Co. Ltd.*) is well adapted for the economical warming and ventilation of workshops, large halls, theatres, and other large buildings. The



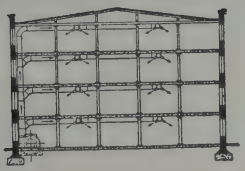


Fig. 15.

apparatus consists of a fan which draws in fresh air, delivering it through a heater where it is warmed to the required temperature, and then evenly distributed through a series of ducts to

every part of the building. The fan is usually of the steel-plate type driven by belt from line shafting, steam engine, or electric motor; the heater is built up with a nest of pipes for use with live or exhaust steam, hot water, furnace gases, etc. Ducts for distributing the air are constructed of galvanised sheet steel, masonry, wood, or other materials, and may be built in the walls or floors, or suspended from the roof or walls.

The system ensures even distribution of warmth throughout the whole building with proper ventilation. In the summer the heater can be eliminated and fresh air distributed throughout the buildings. Workshops can be quickly warmed up in the morning before work is commenced, by recirculating the air. The fan and heater can be installed at one central

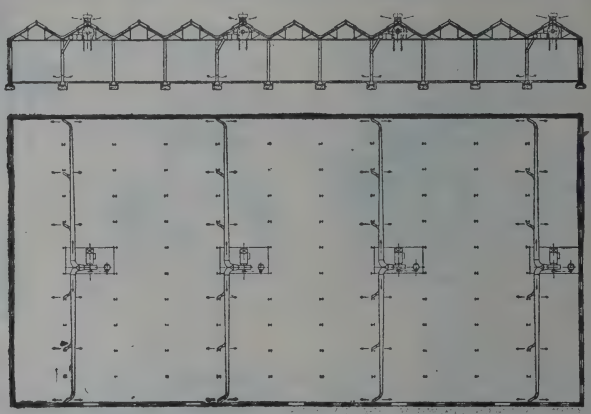


FIG. 16.

point either inside the building or outside, and they are under complete control of one man who can regulate the temperature of the air supply as required.

Two types of buildings equipped with this system are shown by figs. 15 and 16. Fig. 15 illustrates a building of several storeys, in which the apparatus is placed in the basement, one air main being carried up through the building with overhead horizontal distributing pipes on each floor.

Fig. 16 shows a large workshop of considerable height, in which the apparatus is divided into four units in order to keep down the size of the air piping. The sets of apparatus are placed out of the way in the roof, the air being distributed by overhead pipes and discharged at floor level through downtake pipes arranged alongside the column. An alternative arrangement would be to install one set of apparatus and connect it with each of the pipe mains.

SECTION XXXVIII

PART III

LIGHTING

(Revised by W. J. Jones, M.Sc., A.M.I.E.E.)

Terms in Illumination.

International Candle.—This is the unit of light intensity standardised in Great Britain, the United States of America, and France (*Bougie decimale*), and is one-tenth the intensity of the standard 10 candle Harcourt Pentane lamp burning under specific conditions of barometric pressure and humidity.

The relationship between the International Candle and other units is shown in the following table :

Unit.	Is Equivalent to :		
	International Candle.	Hefner Candle.	Carcel Unit.
One International Candle .	1·0	1·1	0·104
One Hefner Candle . .	0·9	1·0	0·09375
One Carcel Unit . .	9·6	10·66	1·0

Mean Horizontal Candle Power.—As the intensity of a light source generally varies in all directions, this term is employed to denote the mean candle power obtained by averaging the candle-power readings measured in all directions on a plane passing through the centre of the light source and perpendicular to its axis.

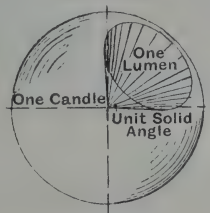


FIG. 1.

Mean Spherical Candle Power (M.S.C.P.).—This is the mean of the candle powers measured in all directions.

Lumen.—The unit denoting the quantity of light, and is the amount of light flux contained in a unit solid angle of a sphere which has a uniform light source of one candle situated at the centre. A light source of one mean spherical candle emits 4π (12·57) lumens (see fig. 1).

Foot Candle.—The unit of illumination. It corresponds to the light density on a surface. If normal to its surface, every part of an area of 1 square foot receives light of an intensity of one candle; it is said to be illuminated to a density of 1 foot candle.

If a uniform point source of light of 1 candle intensity in all directions is situated at the centre of a sphere of unit radius, every square foot of the spherical surface will be illuminated to a density of 1 foot candle. Alternatively, it may be said that if one lumen illuminates an area of 1 square foot, the average light density will be 1 foot candle.

Lux or Metre Candle.—The Continental unit of light density is analogous to our foot candle unit. When an area of 1 square metre is illuminated by one lumen, the resultant illumination is 1 lux or metre candle. It follows that 1 foot candle equals 10·76 lux.

Brightness.—The brightness of a surface is the quotient of the luminous flux intensity in a given direction divided by the area of the surface projected on a plane perpendicular to that direction.

For electric lamps and fittings this quantity is expressed in candles per square inch, while for large surfaces it is stated in candles per square foot.

Illumination.

Illumination, or the density of light received by an object, is measured in terms of foot candles, and can be shown to be directly proportional to the candle power and inversely proportional to the square of the distance from the light source, *i.e.* $I = \frac{C.P.}{D^2}$.

If a surface is oblique to the rays, $I = \frac{C.P.}{D^2} \cos \theta$, where θ is the angle subtended between the incident light and normal to the surface.

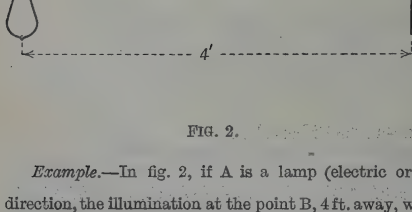


FIG. 2.

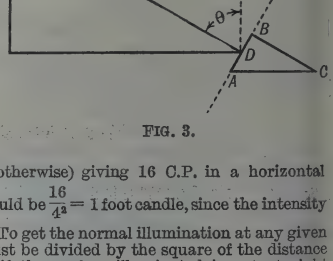


FIG. 3.

Example.—In fig. 2, if A is a lamp (electric or otherwise) giving 16 C.P. in a horizontal direction, the illumination at the point B, 4 ft. away, would be $\frac{16}{4^2} = 1$ foot candle, since the intensity of light varies inversely as the square of the distance. To get the normal illumination at any given point, the candle power in that particular direction must be divided by the square of the distance to the point illuminated. As previously explained, if the surface illuminated is not at right angles to the direction of the light, the value of the illumination obtained, as above, must be multiplied by a reduction factor, taking into account the angle at which the rays strike. A beam of light coming in the direction of OD (fig. 3) falls upon a plane AB, illuminating it with a density of 1 foot candle, then the illumination on the plane AC, which intercepts the same amount of light as AB, would be less as the light is spread over a larger surface, the reduction being in the ratio of AB to AC, which is the cosine of the angle ODF. Thus the effective illumination on any plane at a given point will be:

$$\frac{\text{C.P}}{\text{distance}^2} \times \cos \theta$$

where θ is the angle between the direction of the ray and a perpendicular to the plane considered.

BRIGHTNESS.

The brightness of an object under a given illumination depends on the amount of light reflected back by its surface, and this depends on the colour and the nature of its finish. The following table gives the approximate percentage of incident light reflected by various surfaces:

APPROXIMATE REFLECTING POWER OF SURFACES.

	Per Cent.		Per Cent.
White, rough	82	Blue paper	25
Cream	80	Wood, dirty	20
White, smooth	70	Brown paper	13
White, printed matter (grey)	60	Brown, dark	4
Wood, clean	50	Black cloth	1·5
Yellow paper (light)	40	Black velvet	0·5
Yellow, dark	30		

Photometry.

As its name implies, photometry deals with the measurement of light. By comparing the unknown light source with a known standard and using the fundamental stated above—that is, that the intensity is inversely proportional to the square of the distance—photometric readings are reduced to the measurement of lengths. In a simple photometer the standard lamp and the light source to be measured are mounted on a horizontal bench with a movable screen placed between them (see fig. 4). The screen is then moved between the lamps until both its sides appear

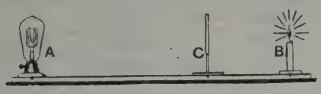


FIG. 4.

to have the same brightness. The distance AB and BC are then measured and the candle power calculated from the fact that:

$$\frac{\text{CP.A}}{\text{AC}^2} = \frac{\text{CP.B}}{\text{BC}^2} \qquad \therefore \text{CP.A} = \text{CP.B} \times \frac{\text{AC}^2}{\text{BC}^2}$$

While making such readings care must be taken that the screen is shielded from any light from other sources.

The Lummer-Brodhun photometer is a more accurate instrument in which prisms are used, so that on looking through a single eyepiece parts of both sides of the screen are seen superimposed; by this means very accurate comparisons of contrast can be made. With this instrument it is not the brightness of the surfaces that are balanced, but their contrasts, as seen in the two halves

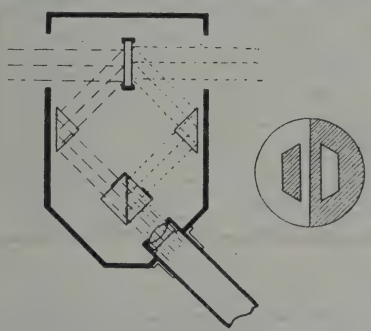


FIG. 5.

of the field. Fig. 5 shows a diagram of the Lummer-Brodhun photometer head, and also the appearance of the contrast field when viewed through the eyepiece.

The great difficulty in making candle-power measurements is the difference in the colour of various light sources, and for accurate work special means have to be adopted. One method employs colour filters, but variations in the light absorption with various lights of different complex colour composition renders this method rather unsatisfactory. Another method is to employ a flicker photometer such as the Simmance-Abady Flicker Photometer. This instrument is based on the fact that if a surface is illuminated alternately by two light sources it appears to flicker, due

both to variations in light intensity and colour. By varying the speed of the alternations it is found that the eye is more sensitive to variations of intensities than to changes of colour; so by using a critical speed of exposure the surface assumes a neutral tint only affected by flicker due to variations in intensity, and so, under these conditions, the illuminations on the screen can be balanced in the usual way.

In the actual instrument these alterations are obtained by rotating a specially shaped disc between the light sources. The rotor is provided with surfaces that slope alternately to either side, so that at any instant during the rotation the portion in front of the eyepiece is only illuminated by one lamp.

Integrating Photometer.

The sphere photometer is another form of instrument specially designed for measuring the mean spherical candle power of a light source. The apparatus consists of a large sphere with a whitened mat interior surface; the light source being placed in the centre. It can be shown that every part of the interior surface will receive the same amount of light by repeated reflections—in other words, the light is automatically averaged out; by placing a small window of diffusing glass in the side of the sphere this average intensity can be measured by the usual photometer method.

As mentioned, the effect depends on reflections in the interior, and so the window has to be carefully shielded from direct light from the source of light, also the readings must be multiplied by a constant depending on the nature of the internal surface.

Polar Curves.

Before suitable reflectors can be designed for a given source of light, or in fact before any rea idea can be formed as to the characteristics of such a source, it is necessary to know how the intensity of the lamp varies in all directions. The polar curve is a very convenient way of showing these variations, and an example is given in fig. 6. The distance scaled along any line from the

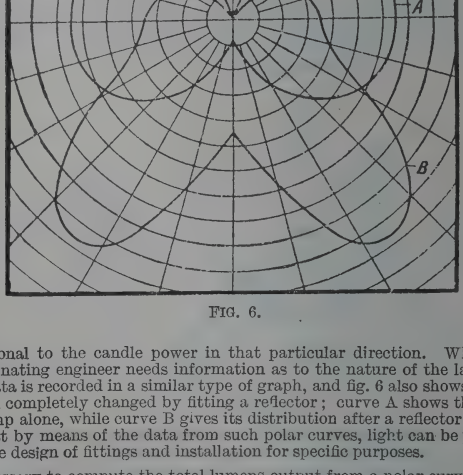


Fig. 6.

centre is proportional to the candle power in that particular direction. When handling ligh sources, the illuminating engineer needs information as to the nature of the lamp complete with reflector. This data is recorded in a similar type of graph, and fig. 6 also shows how the light dis tribution has been completely changed by fitting a reflector; curve A shows the distribution du to a particular lamp alone, while curve B gives its distribution after a reflector has been installed It will be seen that by means of the data from such polar curves, light can be properly controlled both as regards the design of fittings and installation for specific purposes.

Often it is necessary to compute the total lumens output from a polar curve, or more exactly the mean spherical candle power from which the lumens can be easily calculated. If the light source is symmetrical in its horizontal distribution and not too irregular in its vertical variations, thi can be readily performed by taking readings at what are known as the Russel Angles; the mean spherical candle power being the average of such readings. Taking the lower vertical ordinate as our zero, readings should be taken at the following angles :

Degrees.

25·8	60·0	84·3	107·5	134·4
55·6	72·5	95·7	120·0	154·2

As explained, the M.S.C.P. is the arithmetic mean of the ten readings; while if the lumen output is required this result has simply to be multiplied by 12·57.

LUMENS RATING OF GAS-FILLED LAMPS.

(B.E.S.A. Specification No. 161, 1925. (*Abstract.**))

Rated Volts.	Rated Watts.	Initial Total Watts.		Initial Efficiency.				Initial Lumens and Candles.					
				Lumens per Watt.		Watts per Mean Spherical Candle.		Lumens.			Mean Spherical Candles.		
		Max.	Min.	Max.	Min.	Max.	Min.	Nominal.	Max.	Min.	Nominal.	Max.	Min.
1	2	3	4	6	7	9	10	11	12	13	14	15	16
100 to 130	30	34	25·5	10·56	7·95	1·58	1·19	276	327	217	22	26·0	17·3
	40	46	34·5	11·42	8·55	1·47	1·10	402	470	313	32	37·4	24·9
	60	69	51	12·82	9·59	1·31	0·98	666	794	527	53	62·9	41·9
	75	83	67	13·37	10·05	1·25	0·94	880	1033	689	70	82·2	54·8
	100	110	90	14·61	10·93	1·15	0·86	1257	1438	1063	100	114·4	84·6
	150	165	135	15·32	11·42	1·10	0·82	1973	2262	1671	157	180	133
	200	220	180	15·91	11·97	1·05	0·79	2739	3142	2325	218	250	185
	300	330	270	16·53	12·44	1·01	0·76	4260	4901	3619	339	390	288
	500	550	450	18·76	13·96	0·90	0·67	8005	9199	6798	637	732	541
	1000	1100	900	19·95	14·96	0·84	0·63	17090	19670	14530	1360	1565	1156
	1500	1650	1350	19·95	14·96	0·84	0·63	25640	29490	21800	2040	2347	1735
200 to 260	40	46	34	8·85	6·65	1·89	1·42	302	364	243	24	29	19·3
	60	69	51	10·56	7·95	1·58	1·19	553	653	436	44	52	34·7
	75	83	67	11·42	8·61	1·46	1·10	754	883	589	60	70·3	46·9
	100	110	90	12·82	9·59	1·31	0·98	1106	1319	880	88	104·8	69·9
	150	165	135	13·37	9·97	1·26	0·94	1722	1973	1458	137	156·8	115·9
	200	220	180	14·61	10·93	1·15	0·86	2513	2878	2124	200	228·9	169·2
	300	330	270	15·32	11·42	1·10	0·82	3933	4511	3343	313	359·4	265·6
	500	550	450	16·53	12·44	1·01	0·76	7100	8168	6032	565	649·7	480·2
	1000	1100	900	18·76	13·96	0·90	0·67	16020	18410	13610	1275	1465	1083
	1500	1650	1350	19·33	14·44	0·87	0·65	24820	28530	21090	1975	2270	1678

* By permission of the British Engineering Standards Association.

OTHER STANDARD TYPES OF GAS-FILLED LAMPS.

Type.	Sizes.
Opal or White Sprayed	Standard sizes up to 500 watts
Bowl Sprayed	Standard sizes up to 500 watts
Internal Frost	Standard sizes up to 100 watts
Coloured Sprayed Colours :—Red, Blue, Green, Amber, Yellow, Flame and Ivory.	Standard sizes up to 200 watts
Daylight	Standard sizes up to 500 watts

Requirements of Good Illumination.

Illumination must be acceptable to the eye. We should be able to see objects clearly and with a minimum of fatigue. To accomplish this result certain conditions must be fulfilled.

(1) There must be sufficient illumination. Since objects are seen by means of the light which they reflect, more light must be thrown on dark objects than on light ones.

(2) Intensely bright lights in the field of vision should be avoided. The iris closes somewhat in order to afford a protection from such lights, and the amount of light received from illuminated objects is thereby so reduced that they cannot be seen clearly. This accounts for the well-known dazzling effects of searchlights and of many headlights. The intrinsic brilliancy or candle power per square inch of luminous area should therefore be kept as low as possible ; it should not ordinarily be higher than 4 to 6, if the source of light is in the field of vision. Clear bulbs should certainly never be used where the filaments are continuously in view. When reflectors are used it is generally desirable to ' bowl-spray ' the lamps, *i.e.* obscure only the lower portions of the bulbs.

(3) Flickering lights should be avoided. Poorly regulated circuits, such as those having varying power loads, cause disagreeable flickering. Metal filament lamps have an inherently better regulation than carbon filament lamps.

(4) The light should have a continuous spectrum, *i.e.* one containing every colour, in order that the relative colour values of objects illuminated may be the same as when seen by daylight. For matching delicate tints, as in silk and paper mills, the light should be as white as possible, while for general illuminating purposes a ' warm ' light is best ; cold glaring lights too rich in green and blue are to be avoided. Where colour matching is important special colour matching units should be employed, but for many industrial purposes absolutely correct daylight is not required and the Daylight lamps can be used.

The size of the units is a question of design. In deciding upon the proper sizes of lamps to use, one must consider the spacing of present outlets, if building is already wired, and the location of pillars, beams, etc. In general the fewest units consistent with good distribution will be the most economical, as the total cost of outlets, fixtures, and lamps, as well as the maintenance charges, will be reduced. In many cases it is preferable to entirely rewire the premises, in order to obtain correct illumination.

REPORTS OF DEPARTMENTAL (HOME OFFICE) COMMITTEE ON LIGHTING IN FACTORIES AND WORKSHOPS.

(1915–1922.)

Third Report of the Committee, H.M. Stationery Office, Cornwall House, Stamford Street, S.E. 1.

The minimum intensity of illumination desirable for the sake of general convenience and safety in parts of the workshops where work is normally carried on, and in yards, passages, and open spaces along which people are ordinarily liable to pass, is as follows:—

2. 'Over the "working areas" of workrooms the illumination measured on a horizontal plane at floor level shall be not less than 0·25 foot-candle, without prejudice to the illumination required for the work itself.'

3. 'In all parts of iron foundries in which work is carried on or over which any person is ordinarily liable to pass, the illumination measured on a horizontal plane at floor level shall be not less than 0·4 foot-candle.'

4. 'In all parts of factories and workshops (not included under recommendation 2) over which persons employed are liable to pass, the illumination measured on a horizontal plane at floor level shall be not less than 0·1 foot-candle.'

5. 'In all open places in which persons are employed during the period between one hour after sunset and one hour before sunrise, and in any dangerous parts of the regular road or way over a yard or other space forming the approach to any place of work, the illumination on a horizontal plane at ground level shall be not less than 0·25 foot-candle.'

(*a*) 'Every light source (except one of low brightness *) within a distance of 100 feet from any person employed shall be so shaded that no part of the filament, mantle, or flame is distinguishable through the shade, unless it be so placed that the angle between the line from the eye to an unshaded part of a source and a horizontal plane is not less than 20 deg., or in the case of any person employed at a distance of 6 ft. or less from the source, not less than 30 deg.'

(*b*) 'Adequate means shall be taken, either by suitable placing or screening of the light sources, or by some other effective method, to prevent direct reflection of the light from a smooth or polished surface into the eyes of the worker.'

(*c*) 'Adequate means shall be taken to prevent the formation of shadows which interfere with the safety or efficiency of any person employed.'

(*d*) 'No light sources which flicker or undergo abrupt changes of candle-power in such manner as to interfere with the safety or efficiency of any person employed shall be used for the illumination of a factory or workshop.'

Two standards 'for fine work' and 'for very fine work' are recommended. For processes grouped in Schedule A the illumination shall not fall below three foot-candles, and for processes grouped in Schedule B shall not fall below five foot-candles.

The schedules give the class of work, and cover a large number of trades.

---

* By 'low brightness' is meant an intrinsic brilliance of not more than five candles per square inch. Examples of sources of low brightness are a batswing burner, a paraffin flame, etc., and sources of about the same brightness as these are not regarded as coming within the scope of this recommendation.

'It should be remembered that the covering of a brilliant source by a very small shade (such as a silica cup covering a high-pressure gas mantle, or a small opal globe surrounding a high-power electric source) may give this shade or globe a brightness three or four times as great as the five candles per square inch, so that it may cause considerable glare and should consequently be treated as a source of light in itself.'

Illumination Calculations.

During recent years, the 'point-to-point' system referred to in the early part of this section has been abandoned in favour of the 'lumen' method of pre-determining the lighting for an installation. This is essentially due to the fact that, owing to the accumulated experience of illuminating engineers, it has been found possible to take into consideration the contributory effects due to reflection from the ceiling and the walls. The following gives the method of procedure that is adopted generally at the present time :—

Steps in the Design of a Lighting System.

1. *Intensity of Illumination.*

The foot-candle illumination according to present standards for different classes of operations are given on p. 2400–1. These values are the minimum to be adhered to if fully satisfactory lighting is to be assured. In many circumstances, particularly where dark materials are being used, or extremely fine work carried out, higher values of illumination are desirable.

2. *Type of Lighting Unit.*

The selection of the lighting unit depends, not only on the requirements of the work, but in some measure on the construction of the room and the colour of the ceiling and walls. For instance, it would be undesirable to install totally indirect lighting equipment where the ceilings are very dark. The table on p. 2402 gives information as to whether a fitting is suitable from the point of view of glare, reflected glare, efficiency, etc., and the choice of a particular fitting would depend as to which of these factors are the more important. For instance, in an office the criteria would rank as follows in importance :—

1. Direct glare must be a minimum.
2. Reflected glare must be minimum.
3. Shadows should be absent.
4. Efficiency is desirable upon the horizontal plane.
5. Maintenance is next in order of importance.
6. Vertical illumination is least important.

On the other hand, where lamps are to be hung above a crane in the foundry, the order of importance would be :—

1. Efficiency based upon the horizontal illumination.
2. Vertical illumination.
3. Maintenance.
4. Shadows.
5. Direct glare.
6. Reflected glare.

In the chart, A+ denotes the highest degree of excellence, while D, the lowest, indicates that an installation of units so rated in this particular would very likely prove unsatisfactory where this factor is of prime importance.

3. *Location of Unit.*

Table III. shows the desirable spacing of units, according to the permissible mounting height. When these spacings are used, reasonably uniform illumination will result. Consult also the diagrams at bottom of Tables III. (*a*) and III. (*b*).

4. *Size of Lamp.*

After the position of the units has been settled on the plan according to the space permissible the size of the lamp can be determined by the consideration of the following factors :—

1. *The Room Index.*—In a large room with many points the system would have a higher coefficient of utilisation than in a small room. This is due to the fact that a number of units help to contribute directly the amount of light that reaches the table or bench without loss due to reflection from the walls, etc. The room index should be obtained from p. 2469, taking into consideration the proposed mounting height of a fitting.

2. *Depreciation Factor.*—Due to the settlement of dust and dirt on fittings and the deterioration in reflectivity of the walls and ceiling, the illumination will depreciate in the course of time. It is usual to allow a factor of 1·3 for reasonably clean locations and 1·5 where cleaning is infrequent or in dirty locations.

3. *Coefficient of Utilisation.*—On pp. 2537–2540 coefficiencies of utilisation are given for a particular fitting. Having chosen the fitting and obtained the value of the room index from Table IV., p. 2536, the corresponding coefficient of utilisation, according to the nature of the

eiling and walls can be readily obtained. This figure represents the percentage of the lumen enerated by the lamp that reach the plane of work.

$$\text{Lamp Lumens required per sq. ft.} = \frac{\text{Foot-candles} \times \text{depreciation factor}}{\text{Coefficient of utilisation.}};$$

$$\text{Area in sq. ft. per unit} = \frac{\text{Total floor area in sq. ft.}}{\text{Number of units.}};$$

$$\text{Lamp Lumens required per unit} = (\text{Area in sq. ft. per unit}) \times (\text{Lamp lumens required per sq. ft.}).$$

Having thus determined the lamp lumens required per point, the wattage of the lamp to be used an be obtained by reference to the following table.

LUMEN VALUES OF VACUUM AND GASFILLED ELECTRIC LAMPS.

Vacuum Type Lamps.			Gasfilled Lamps.		
Voltage.	Wattage.	Lumen Value.	Voltage.	Wattage.	Lumen Value.
50 to 80	20	158·5	25	15	168
	30	248·38	25	30	360
	40	332·47	25	60	750
	60	520·64	25	100	1,300
			50/65	30	360
100 to 130	20	160·77	50/65	60	750
	30	251·65	50/65	100	1,300
	40	336·87	50/65	150	2,100
	60	527·56	50/65	200	2,800
			50/65	300	4,600
200 to 250	20	145·18	50/65	500	8,500
	30	225·5			
	40	324·44	100/130	40	400
	60	510·84	100/130	60	750
			100/130	100	1,300
			100/130	150	2,100
			100/130	200	2,800
			100/130	300	4,600
			100/130	500	8,500
			100/130	1,000	18,000
			100/130	1,500	28,000
			200/520	60	550
			200/250	100	1,200
			200/250	150	1,800
			200/250	200	2,500
			200/250	300	4,200
			200/250	500	7,300
			200/250	1,000	16,500
			200/250	1,500	26,000

STANDARD TYPES OF GASFILLED LAMPS.

Type.	Sizes.
Opal or white sprayed	Standard sizes up to 500 watts
Bowl sprayed	Standard sizes up to 500 watts
Coloured sprayed Colours :—Red, Blue, Green, Amber, Yellow, Flame and Ivory.	Standard sizes up to 200 watts
Daylight	Standard sizes up to 500 watts

When the lamp lumens required, fall midway between two sizes, then it is usual to choose the larger rather than the smaller, unless it is certain that the less illumination from a smaller lamp will suffice.

Illumination Design for a Departmental Store Main Floor.

The following is an example in the procedure of designing illumination for a departmental main store:—

Store is 170 ft. long and 136 ft. wide with a 16 ft. ceiling. Columns divide the area into 17 ft. × 17 ft. bays. Ceiling, walls, and pillars are painted white. Supply voltage 200. Height of counter 3 ft.

Summary of Steps in the Design.	Reference.	Required Data
1. Foot-candles recommended	Table I.	10
2. Type of fitting used	Table II.—p. 2465	Unit No. 16
3. Spacing and mounting height		
Possible mounting height above work	Depends upon ceiling height	12 ft.
Maximum spacing permissible	Table III.(*a*)—p. 2467	18 ft.
Actual spacing to suit interior	Symmetrical lay-out with respect to bays	17 ft.
Actual mounting height above work	Ceiling type unit used	11½ ft.
Height above floor	—	14½ ft.
4. Size of Lamp		
Room index	Table IV.—p. 2469	5
Coefficient of utilisation	Table V.—p. 2470	0·55
Depreciation Factor	According to dust and dirt conditions	1·3
Lamp lumens required per point	Formula—p. 2462	6820
Lamp size	Table—p. 2462	500-watt gasfilled

Table I.—Present Standards of Foot-Candle Illumination.

	Foot-candles recommended.
Shops.	
Shop windows:	
Large cities—	
Brightly lighted districts	75
Secondary business locations	50
Suburban shops	25
Medium cities—	
Brightly lighted district	50
Suburban shops	25
Small towns	25
Large shops—	
Main floors	10
Basement floor	10
Other floors	8
Commercial and Public Buildings.	
Bank—	
Lobby	6
Offices	8
Commercial and Public Buildings—*cont.*	
Carriages (public transport)—	
Luggage van	6
Ordinary carriages, dining and Pullman car	8
Mail van sorting racks	10
Corridors	3
Bus and tramcars	8
Churches—	
Church	3
Lecture room	5
Cinema—	
During interval	3
During pictures	0·1
Dentist—	
Waiting room	4
Surgery	15

TABLE I.—PRESENT STANDARDS OF FOOT-CANDLE ILLUMINATION.—*cont.*

COMMERCIAL AND PUBLIC BUILDINGS—*cont.*	Foot-candles recommended.
rawing Office	15
ymnasiums—	
Fencing, boxing, wrestling	8
Swimming bath	4
Shower bath	4
Dressing rooms	4
ospitals—	
Waiting and receiving rooms	4
Corridors	3
Wards and private rooms, with local illumination	3
Wards and private rooms, with night illumination	0·1
Operating table	75
Operating room	10
Laboratories	10
otels—	
Lounge	4
Dining room	5
Writing room	8
Kitchen	6
Bedrooms	6
Corridors	2
door recreations:	
Bowling—	
On alley, runway, and seats	5
On pins	15
Billiards—	
General	2
On table	15
Racquet, badminton, squash, and indoor tennis	15
Skating rinks	5
ibrary—	
Reading rooms	8
Book room	4
ifts (passenger and goods)	4
unch room	5
useum—	
General	5
On walls	8
ffice buildings—	
General office	8
Private office	8
Typing and book-keeping rooms	8
Filing room	4
chools—	
Blackboards	6
Class rooms, library and office	8
Corridors and stairways	3
Drawing	15
Laboratories	10
Lecture theatre	5
Manual training	10
Sewing rooms	15

COMMERCIAL AND PUBLIC BUILDINGS—*cont.*	Foot-candles recommended.
Theatres—	
Auditorium	4
Foyer	5
Lobby	8

INDUSTRIAL INTERIORS.

Works interiors:	
Offices—	
Private, general	10
Drawing office	15
Dressing rooms	4
Aisles, stairways, passageways, and corridors	3
Assembling shops—	
Rough work	5
Medium work	8
Fine work	10
Extra fine work	10–50
Store and stock rooms—	
Rough	3
Medium	6
Toilet and wash rooms	4
Cloth products:	
Light goods	10
Dark goods	20
Cutting, inspecting, sewing, pressing, cloth treating (oilcloth, etc.)—	
Light goods	8
Dark goods	12
Foundries—	
Charging floor, tumbling, cleaning, pouring * and shaking out *	5
Rough moulding and core making	6
Fine moulding and core making	10
Leather working:	
Pressing and winding—	
Light	8
Dark	10
Grading, matching, cutting, scarfing, sewing—	
Light	10
Dark	10–50
Textile mills:	
Weaving—	
Light goods	8
Dark goods	12
Knitting machines	10
Wood working—	
Rough sawing and bench work	5
Fine and bench and machine working, fine sanding and finishing	8

* Since 'pouring' and 'shaking out' are carried on in the same location as either 'rough' or 'fine' moulding, different illumination levels may be secured for these operations by cutting out some of the lighting circuits when space is used for the former.

TABLE II.—GUIDE TO THE SELECTION OF REFLECTOR EQUIPMENT.

	LIGHTING UNIT		EFFICIENCY BASED UPON ILLUMINATION ON HORIZONTAL	EFFICIENCY BASED UPON ILLUMINATION ON VERTICAL	FAVOURABLE APPEARANCE OF LIGHTED ROOM	DIRECT GLARE	REFLECTED GLARE	SHADOWS	MAINTENANCE
DIRECT LIGHTING VITREOUS ENAMEL REFLECTORS.									
1	DISPERSIVE Clear Lamp		A+	B+	C+	C	D	C+	A+
2	DISPERSIVE Bowl-Sprayed Lamp		A−	B	B	B+	B	B+	A−
3	DIFFUSER REFLECTOR		B+	B	A−	A−	B+	A−	B+
4	DEEP BOWL Clear Lamp		B+	B−	C	C+	D	C	A
5	DEEP BOWL Bowl-Sprayed Lamp		B	C+	C	B	C+	C+	B+
6	DISTRIBUTING REFLECTOR		B	B	C−	C−	D	C−	B+
7	ENAMELLED IRON SHADE Clear Lamp		B−	C	C	D	D	C−	B
DIRECT LIGHTING OPEN GLASS REFLECTORS									
8	LIGHT DENSITY OPAL Clear Lamp		B+	B	B+	C+	D	B−	B
9	LIGHT DENSITY OPAL Bowl-Sprayed Lamp		B	B−	A−	B−	B−	B+	B−
10	DENSE OPAL Clear Lamp		A+	B+	B+	B	D	C+	A−
11	DENSE OPAL Bowl-Sprayed Lamp		B+	B−	A−	B+	B−	B	B
12	MIRRORED GLASS Clear Lamp		A	B	C	C+	D	C	A−
13	MIRRORED GLASS Bowl-Sprayed Lamp		B	C+	C	B−	C	C+	B−
14	PRISMATIC INDUSTRIAL Clear Lamp		A+	A−	B+	C+	D	C+	B−

TABLE II. (*contd.*)—GUIDE TO THE SELECTION OF REFLECTOR EQUIPMENT.

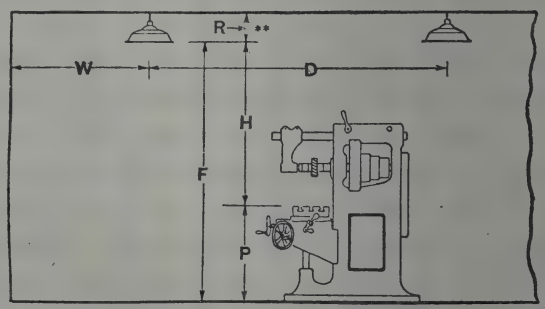
	LIGHTING UNIT		EFFICIENCY BASED UPON ILLUMINATION ON HORIZONTAL	EFFICIENCY BASED UPON ILLUMINATION ON VERTICAL	FAVOURABLE APPEARANCE OF LIGHTED ROOM	DIRECT GLARE	REFLECTED GLARE	SHADOWS	MAINTENANCE
DIRECT LIGHTING ENCLOSING AND SEMI-ENCLOSING UNITS									
15	DIFFUSING GLOBE Light Opal		B−	B−	A	B−	B	B+	B+
16	ONE-PIECE OPAL Flattened Reflecting Top		B	B	A	B	B+	A−	A−
17	PRISMATIC ENCLOSING		B+	B	A	B	B−	B+	B+
18	DEEP DIFFUSING		B−	A	A	A	B+	A−	A−
19	ONE PIECE GLASS		B	A	A	B+	B+	A−	A−
20	TWO-PIECE GLASS		C+	B−	A	B+	B+	A−	B−
21	ONE-PIECE GLASS Enamelled Ref. and Bowl		B	B	A	B+	B+	A−	A−
SEMI-INDIRECT AND INDIRECT LIGHTING UNITS									
22	LIGHT OPAL		B−	C+	A	B+	B+	A−	C
23	DENSE OPAL (or Light Opal and Bowl-Sprayed) Lamp)		C+	C	A	A+	A−	A+	C
24	ALABASTER BOWL		C+	C	A	A+	A−	A+	C
25	PRISMATIC ENCLOSED		B+	C+	A	A−	A−	A−	B
26	CLEAR TOP ENCLOSED Enamelled Glass		B−	C+	A	B+	B+	A	B
27	MIRRORED INDIRECT		C+	C	B+*	A+	A	A+	C
28	ENAMELLED METAL INDIRECT		C	C	B+	A+	A	A+	C

* For luminous bowl type, Rate A.

TABLE III. (*a*).—SPACING—MOUNTING HEIGHT.

Direct Lighting Units, including Semi-Enclosing and Totally Enclosing Units, No. 1 to No. 21.

Mounting Height of Unit.			Distance between Points and Sidewalls.	
Above Plane of Work. (H)	Above Floor.* (F)	Distance between Points. (D)	In Usual Locations where Aisles & Storage are Next to Wall. (W)	In Offices or where Work Benches are Next to Wall. (W)
4	6½	6	3	2
5	7½	7½	3½	2½
6	8½	9	4½	3
7	9½	10½	5	3½
8	10½	12	6	4
9	11½	13½	6½	4½
10	12½	15	7½	5
11	13½	16½	8	5½
12	14½	18	9	6
13	15½	19½	9½	6½
14	16½	21	10½	7
15	17½	22½	11	7½
16	18½	24	12	8
18	20½	27	13½	9
20	22½	30	15	10
22	24½	33	16½	11
24	26½	36	18	12
27	29½	40½	20	13½
30	32½	45	22½	15
35	37½	52½	26	17½
40	42½	60	30	20



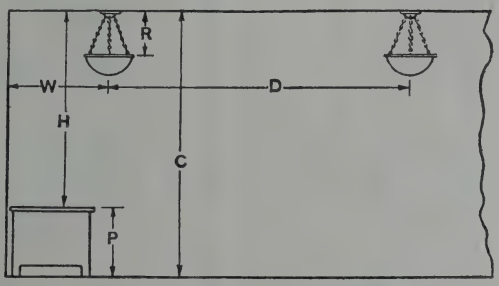
* Plane of work (P) assumed to be 2½ ft. above floor. When the plane of work is higher o lower than 2½ ft. above floor, neglect column (F) and work from column (H).

** Minimum allowance for (R) usually 1 ft.

TABLE III. (b) SPACING—MOUNTING HEIGHT.

Semi and Totally Indirect Lighting Units, No. 22 to No. 28.

Ceiling Height.		Spacing Distance Between Points.	Distance Between Points and Sidewalls.		Suspension Distance Ceiling to Top of Reflector.†
			In Usual Locations where Aisles and Storage are Next to Wall	In Offices or where Work Benches are Next to Wall	
Above Plane of Work. (H)	Above Floor.* (C)	(D)	(W)	(W)	(R)
5	7½	7½	3½	2½	1¼
6	8½	9	4½	3	1½
7	9½	10½	5	3½	1¾
8	10½	12	6	4	2
9	11½	13½	6½	4½	2¼
10	12½	15	7½	5	2½
11	13½	16½	8	5½	2¾
12	14½	18	9	6	3
13	15½	19½	9½	6½	3¼
14	16½	21	10½	7	3½
15	17½	22½	11	7½	3¾
16	18½	24	12	8	4
18	20½	27	13½	9	4½
21	23½	31½	15½	10½	5½
24	26½	36	18	12	6
27	29½	40½	20	13½	6¾
30	32½	45	22½	15	7½
35	37½	52½	26	17½	8¾
40	42½	60	30	20	10



* Plane of work (P) assumed to be 2½ feet above floor. When the plane of work is higher or lower than 2½ feet above floor, neglect column (C) and work from column (H).

† Suspension distances (R) in Table are based on best distribution of light and efficiency of utilisation for standard units. In some installations other considerations may require a different suspension distance.

Table IV.—Room Index.

Classify the room according to the proportions and the mounting height above the plane of work. Use upper column headings for direct-lighting units; for semi-indirect and totally indirect units choose column at bottom of page. Wherever the circumstances are such that the room index falls between two given figures, interpolate or use the smaller number.

Room Width.	Room Length.	Direct Lighting Units—Height Above Plane of Work. Feet												
Feet.	Feet.	4	5	6	7	8	9	10	12	14	16	20	24	30	40
8	10	1.0	0.8	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..	..	..
	12	1.25	0.8	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..	..	..
	16	1.25	1 0	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..	..	..
	24	1.5	1.25	1.0	0.8	0.6	0.6	0.6	0.6	0.6	..	..	..	..	..
	35	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	..	..	..	..
	50	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	0.6	..	..	..	..
10	10	1.25	1.0	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..	..	..
	14	1.5	1.0	1.0	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..	..
	20	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	..	..	..	..	..
	30	2.0	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	..	..	..	..
	40	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	..	..	..
	70	2.0	1.5	1.5	1.25	1.25	1.0	1.0	0.8	0.8	0.6	0.6	..	..	..
12	12	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	..	..	..	..	..	..
	18	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	0.6	..	..	..	..	..
	24	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	0.6	..	..	..	..
	35	2.0	1.5	1.5	1 25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	..	..	..
	50	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0 8	0.6	0.6	0.6	0.6	..	..
	90	2.0	2.0	1.5	1.5	1.25	1.25	1.25	1.0	0.8	0.8	0.6	0.6	..	..
14	14	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	..	..	..	..	..
	20	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	..	..	..	..
	40	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	..	..
	70	2.5	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0·6	..	..
	100	2.5	2.0	2.0	1.5	1.5	1.5	1.5	1.25	0.8	0.8	0.6	0.6	..	..
16	16	2.0	1.5	1.25	1.25	1.0	0.8	0.8	0 6	0.6	0.6	..	..	..	..
	30	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	..	..	..
	50	2.5	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.6	0.6	0.6	0.6	..
	80	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6	..
	120	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	0.8	0.8	0.6	..
18	18	2.0	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	..	..	..	..
	35	3.0	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	..	..
	50	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	..
	80	3.0	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	..
	120	3.0	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.25	1.0	0.8	0.8	0.6	..
20	20	2.5	2.0	1.5	1.5	1 25	1.0	1.0	0.8	0.6	0.6	0 6	..	..	..
	40	3.0	2.5	2.0	2.0	1.5	1 5	1 25	1.0	0.8	0.8	0.6	0.6	..	..
	60	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6	0.6
	100	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6
	140	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.6	0.6
24	24	3.0	2.5	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	..	..
	50	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0 6	0.6	..
	70	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6
	100	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1 25	1.0	0.8	0.6	0.6
	160	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.25	1.0	0.8	0.6
30	30	4.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	..
	60	4.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.25	1.0	0.8	0.6	0.6
	100	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0	0.8	0.6	0 6
	140	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.25	1.0	0.8	0.6
35	35	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	..
	70	5.0	4.0	3.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.0	0.8	0.6	0.6
	100	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	140	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	0.8	0.6
40	40	5.0	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6
	80	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	140	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8
50	50	5.0	5.0	4.0	4.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	100	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	1.5	1.25	1.0	0.8
	200	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.5	2.5	2.0	1.5	1.25	1.0
60	60	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.25	1.0	0.8
	100	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5	1.5	1.25	1.0
	200	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	2.0	1 5	1.0
70	70	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5	1.5	1.25	0.8
	140	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	1.5	1.0
	200	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	1.5	1.25
80	80	5.0	5.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	2.5	2.0	1.5	1.25	1.0
	140	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	1.25
100	100	5.0	5.0	5.0	5.0	5.0	5.0	5 0	4.0	4.0	3.0	2.5	2.0	1.5	1.25
	200	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5
120	120	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	2.5	2.0	1.5
	200	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	3.0	3.0	2.5	1.5
		6	7½	9	10½	12	13½	15	18	21	24	30	36	45	60

Feet

Semi and Indirect Lighting Units—Ceiling Height Above Plane of Work.

TABLE V.—COEFFICIENTS OF UTILISATION.
Find 'Room Index' from Table IV., p. 2536.
DIRECT LIGHTING VITREOUS ENAMEL REFLECTORS.

	COLOR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
1	DISPERSIVE (R.L.M.) Clear Lamp	0.6	.34	.29	.24	.34	.29	.24	.28	.24
		0.8	.42	.38	.34	.42	.37	.33	.37	.33
		1.0	.46	.43	.39	.45	.42	.39	.42	.39
		1.25	.50	.47	.43	.49	.46	.43	.45	.42
		1.5	.53	.50	.46	.52	.49	.46	.48	.45
		2.0	.58	.55	.51	.57	.54	.51	.53	.51
		2.5	.62	.59	.56	.61	.58	.56	.58	.56
		3.0	.64	.61	.58	.63	.60	.58	.60	.58
		4.0	.67	.65	.63	.66	.64	.62	.63	.61
		5.0	.69	.67	.65	.67	.66	.64	.65	.63
2	DISPERSIVE (R.L.M.) Bowl-Sprayed Lamp	0.6	.32	.28	.25	.32	.28	.25	.27	.25
		0.8	.40	.36	.34	.39	.35	.33	.35	.33
		1.0	.43	.39	.37	.42	.39	.37	.39	.37
		1.25	.46	.43	.41	.45	.43	.41	.43	.41
		1.5	.48	.45	.43	.47	.45	.43	.45	.43
		2.0	.52	.50	.48	.51	.49	.47	.49	.47
		2.5	.56	.54	.52	.55	.53	.51	.53	.51
		3.0	.57	.55	.53	.56	.54	.52	.54	.52
		4.0	.60	.58	.56	.59	.57	.55	.57	.55
		5.0	.61	.59	.57	.60	.58	.57	.58	.56
3	REFLECTOR DIFFUSER	0.6	.29	.25	.21	.28	.24	.21	.23	.21
		0.8	.36	.32	.29	.35	.31	.28	.31	.28
		1.0	.39	.36	.33	.38	.35	.33	.34	.32
		1.25	.42	.39	.36	.41	.38	.36	.37	.35
		1.5	.45	.42	.39	.43	.40	.38	.39	.38
		2.0	.49	.46	.43	.48	.45	.43	.44	.42
		2.5	.53	.50	.47	.51	.49	.47	.47	.46
		3.0	.54	.52	.49	.52	.50	.49	.49	.47
		4.0	.57	.55	.53	.55	.53	.51	.51	.50
		5.0	.58	.56	.54	.56	.54	.53	.52	.51
4	DEEP BOWL Clear Lamp	0.6	.31	.26	.23	.30	.26	.23	.25	.23
		0.8	.38	.34	.31	.37	.34	.31	.33	.31
		1.0	.41	.38	.35	.41	.38	.35	.37	.35
		1.25	.44	.41	.38	.44	.41	.38	.40	.38
		1.5	.47	.44	.41	.46	.43	.41	.43	.41
		2.0	.51	.48	.45	.50	.47	.45	.47	.45
		2.5	.54	.51	.49	.53	.51	.49	.51	.49
		3.0	.56	.54	.51	.55	.53	.51	.53	.51
		4.0	.58	.56	.54	.57	.55	.54	.55	.53
		5.0	.60	.58	.56	.58	.57	.55	.56	.55
5	DEEP BOWL Bowl-Sprayed Lamp	0.6	.29	.26	.23	.29	.26	.23	.25	.23
		0.8	.35	.33	.31	.35	.32	.30	.32	.30
		1.0	.38	.36	.34	.38	.36	.34	.35	.34
		1.25	.41	.39	.37	.41	.39	.37	.38	.37
		1.5	.44	.41	.39	.43	.41	.39	.40	.39
		2.0	.47	.45	.43	.46	.44	.43	.43	.43
		2.5	.50	.48	.46	.49	.47	.46	.46	.46
		3.0	.51	.49	.47	.50	.48	.47	.47	.47
		4.0	.53	.51	.50	.52	.50	.49	.49	.49
		5.0	.54	.52	.51	.53	.51	.50	.50	.49
6	DISTRIBUTING REFLECTOR	0.6	.34	.29	.25	.33	.29	.25	.28	.25
		0.8	.42	.38	.35	.41	.37	.34	.37	.34
		1.0	.45	.42	.39	.45	.42	.39	.41	.39
		1.25	.49	.45	.43	.48	.45	.43	.44	.43
		1.5	.52	.48	.46	.51	.48	.45	.47	.45
		2.0	.56	.53	.51	.56	.53	.51	.52	.51
		2.5	.61	.58	.55	.59	.57	.55	.56	.55
		3.0	.62	.60	.57	.61	.59	.57	.58	.56
		4.0	.65	.63	.61	.64	.61	.60	.61	.59
		5.0	.67	.64	.62	.65	.63	.61	.62	.61
7	ENAMELLED IRON SHADE Clear Lamp	0.6	.26	.20	.16	.26	.19	.16	.19	.16
		0.8	.32	.26	.22	.32	.26	.22	.26	.22
		1.0	.36	.30	.26	.36	.30	.26	.30	.26
		1.25	.41	.35	.30	.39	.34	.30	.33	.30
		1.5	.44	.38	.33	.42	.37	.33	.36	.33
		2.0	.50	.44	.38	.48	.43	.38	.42	.38
		2.5	.54	.48	.42	.52	.47	.42	.46	.42
		3.0	.57	.51	.46	.55	.50	.45	.49	.45
		4.0	.62	.56	.51	.60	.54	.50	.53	.50
		5.0	.65	.60	.54	.62	.56	.53	.55	.53

TABLE V.—COEFFICIENTS OF UTILISATION.
Find 'Room Index' from Table I., p. 2530.
DIRECT LIGHTING OPEN GLASS REFLECTORS.

	COLOR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
	WALLS		FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
8	LIGHT DENSITY OPAL Clear Lamp	0.6	.26	.21	.17	.24	.19	.16	.18	.15
		0.8	.32	.27	.23	.30	.25	.22	.24	.21
		1.0	.36	.31	.27	.34	.29	.26	.27	.24
		1.25	.40	.35	.31	.37	.32	.29	.30	.27
		1.5	.44	.38	.34	.40	.35	.32	.32	.30
		2.0	.49	.44	.39	.45	.40	.37	.37	.34
		2.5	.53	.48	.44	.49	.44	.41	.40	.38
		3.0	.56	.51	.47	.51	.46	.43	.42	.40
		4.0	.60	.55	.51	.55	.50	.47	.46	.44
		5.0	.62	.58	.54	.57	.53	.50	.48	.46
9	LIGHT DENSITY OPAL Bowl-Sprayed Lamp	0.6	.22	.17	.14	.20	.16	.13	.14	.12
		0.8	.27	.22	.19	.25	.21	.18	.19	.16
		1.0	.31	.26	.23	.28	.24	.21	.22	.19
		1.25	.35	.30	.26	.31	.27	.24	.24	.22
		1.5	.38	.33	.29	.34	.30	.26	.27	.24
		2.0	.43	.38	.34	.38	.34	.31	.30	.28
		2.5	.47	.42	.38	.42	.38	.34	.34	.31
		3.0	.49	.44	.40	.44	.40	.37	.36	.33
		4.0	.53	.49	.45	.48	.44	.41	.39	.37
		5.0	.56	.52	.48	.50	.46	.43	.40	.39
10	DENSE OPAL Clear Lamp	0.6	.32	.27	.23	.31	.26	.22	.25	.22
		0.8	.40	.35	.31	.38	.34	.31	.33	.30
		1.0	.44	.39	.36	.42	.38	.35	.37	.35
		1.25	.47	.43	.40	.46	.42	.39	.40	.38
		1.5	.51	.47	.43	.49	.45	.42	.43	.41
		2.0	.56	.52	.48	.54	.50	.47	.48	.46
		2.5	.60	.56	.53	.57	.54	.52	.52	.50
		3.0	.63	.59	.55	.60	.56	.54	.54	.52
		4.0	.66	.63	.60	.63	.60	.58	.57	.55
		5.0	.67	.65	.62	.65	.61	.59	.59	.57
11	DENSE OPAL Bowl-Sprayed Lamp	0.6	.29	.24	.20	.28	.23	.20	.22	.20
		0.8	.35	.31	.28	.34	.30	.27	.29	.27
		1.0	.39	.35	.32	.38	.34	.32	.33	.31
		1.25	.43	.39	.36	.41	.38	.35	.36	.34
		1.5	.46	.42	.38	.44	.40	.37	.38	.36
		2.0	.51	.47	.44	.48	.45	.42	.43	.41
		2.5	.55	.51	.48	.52	.49	.46	.47	.45
		3.0	.57	.54	.50	.54	.51	.48	.48	.46
		4.0	.60	.57	.54	.57	.54	.52	.51	.50
		5.0	.62	.59	.56	.58	.56	.54	.53	.52
12	MIRRORED GLASS Clear Lamp	0.6	.32	.27	.24	.31	.27	.24	.27	.24
		0.8	.39	.35	.32	.39	.35	.32	.35	.32
		1.0	.43	.39	.37	.42	.39	.37	.39	.37
		1.25	.46	.43	.40	.46	.43	.40	.42	.40
		1.5	.49	.46	.43	.48	.45	.43	.45	.43
		2.0	.53	.50	.48	.52	.50	.48	.49	.48
		2.5	.57	.54	.52	.56	.54	.52	.53	.52
		3.0	.58	.56	.54	.57	.55	.54	.54	.53
		4.0	.61	.59	.57	.60	.58	.56	.57	.56
		5.0	.63	.61	.58	.61	.59	.58	.58	.57
13	MIRRORED GLASS Bowl-Sprayed Lamp	0.6	.26	.22	.19	.25	.22	.19	.21	.19
		0.8	.32	.29	.26	.31	.28	.26	.28	.26
		1.0	.35	.32	.30	.34	.32	.30	.31	.30
		1.25	.38	.35	.33	.37	.35	.33	.34	.33
		1.5	.40	.37	.35	.39	.37	.35	.36	.35
		2.0	.43	.41	.39	.42	.40	.39	.40	.39
		2.5	.46	.44	.42	.45	.43	.42	.43	.42
		3.0	.47	.46	.44	.46	.45	.44	.44	.43
		4.0	.49	.48	.46	.48	.47	.46	.46	.45
		5.0	.50	.49	.47	.49	.48	.47	.47	.46
14	PRISMATIC INDUSTRIAL Clear Lamp	0.6	.33	.26	.21	.31	.25	.21	.24	.20
		0.8	.41	.35	.30	.39	.33	.29	.32	.29
		1.0	.45	.40	.35	.43	.39	.34	.37	.33
		1.25	.50	.44	.39	.47	.42	.38	.40	.37
		1.5	.52	.48	.43	.50	.45	.42	.43	.40
		2.0	.58	.54	.49	.56	.51	.47	.49	.46
		2.5	.63	.59	.54	.60	.56	.53	.54	.51
		3.0	.66	.62	.58	.63	.59	.56	.56	.54
		4.0	.71	.67	.63	.67	.63	.61	.60	.58
		5.0	.73	.69	.66	.69	.65	.63	.62	.60

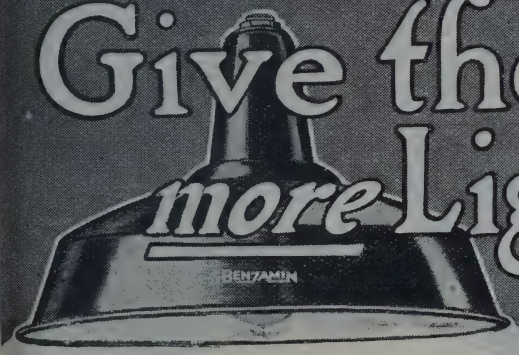
TABLE V.—COEFFICIENTS OF UTILISATION.
Find 'Room Index' from Table IV., p. 2536.
DIRECT LIGHTING ENCLOSING AND SEMI-ENCLOSING CHARTS.

	COLOR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
	WALLS		FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
15	DIFFUSING GLOBE Light Opal	0.6	.18	.13	.10	.16	.12	.10	.10	.09
		0.8	.22	.17	.14	.20	.16	.13	.14	.12
		1.0	.26	.21	.18	.23	.19	.16	.17	.14
		1.25	.29	.24	.21	.26	.22	.19	.19	.16
		1.5	.32	.27	.23	.29	.24	.21	.22	.19
		2.0	.37	.32	.28	.32	.28	.25	.25	.22
		2.5	.40	.35	.31	.35	.31	.28	.28	.25
		3.0	.43	.38	.34	.38	.33	.30	.30	.27
		4.0	.47	.42	.38	.41	.37	.34	.33	.31
		5.0	.49	.45	.41	.43	.39	.36	.34	.33
16	ONE-PIECE OPAL Flattened Reflecting Top	0.6	.22	.17	.14	.20	.16	.13	.14	.12
		0.8	.27	.22	.19	.25	.21	.18	.19	.17
		1.0	.31	.26	.23	.28	.24	.21	.22	.19
		1.25	.35	.30	.26	.31	.27	.24	.25	.22
		1.5	.38	.33	.29	.34	.30	.27	.27	.24
		2.0	.42	.38	.33	.38	.34	.31	.31	.28
		2.5	.46	.41	.37	.41	.37	.34	.34	.31
		3.0	.49	.45	.40	.43	.39	.36	.36	.33
		4.0	.53	.48	.44	.47	.43	.40	.38	.36
		5.0	.55	.51	.47	.49	.45	.42	.40	.38
17	PRISMATIC ENCLOSING	0.6	.28	.22	.18	.26	.21	.17	.19	.16
		0.8	.35	.29	.25	.33	.28	.24	.26	.23
		1.0	.38	.33	.29	.36	.32	.28	.30	.27
		1.25	.43	.37	.33	.40	.35	.31	.33	.30
		1.5	.46	.41	.36	.43	.38	.34	.35	.33
		2.0	.51	.46	.42	.47	.43	.40	.40	.38
		2.5	.55	.51	.46	.51	.47	.44	.44	.42
		3.0	.58	.54	.50	.54	.50	.47	.46	.44
		4.0	.62	.58	.55	.57	.54	.51	.50	.48
		5.0	.65	.61	.57	.60	.56	.53	.52	.50
18	DEEP DIFFUSING	0.6	.18	.13	.10	.16	.12	.10	.11	.09
		0.8	.22	.18	.15	.21	.16	.14	.15	.13
		1.0	.25	.21	.18	.23	.19	.17	.18	.15
		1.25	.29	.24	.21	.26	.22	.19	.20	.17
		1.5	.32	.27	.23	.28	.24	.21	.22	.20
		2.0	.36	.31	.27	.32	.28	.25	.25	.23
		2.5	.39	.34	.31	.35	.31	.28	.28	.25
		3.0	.41	.37	.33	.37	.33	.30	.30	.28
		4.0	.45	.41	.37	.40	.36	.34	.33	.31
		5.0	.47	.43	.40	.42	.38	.36	.34	.33
19	ONE PIECE GLASS	0.6	.22	.17	.14	.21	.16	.14	.15	.14
		0.8	.27	.23	.20	.26	.22	.19	.20	.18
		1.0	.30	.26	.23	.29	.25	.22	.23	.21
		1.25	.34	.30	.26	.32	.28	.25	.26	.24
		1.5	.37	.33	.29	.34	.30	.27	.28	.26
		2.0	.41	.37	.33	.38	.34	.31	.32	.30
		2.5	.44	.40	.36	.41	.38	.35	.35	.33
		3.0	.47	.43	.39	.43	.40	.37	.37	.35
		4.0	.51	.47	.43	.47	.44	.41	.41	.39
		5.0	.53	.49	.45	.48	.45	.42	.42	.40
20	TWO-PIECE GLASS	0.6	.20	.15	.13	.18	.14	.12	.13	.11
		0.8	.25	.20	.17	.23	.19	.16	.18	.15
		1.0	.28	.24	.21	.26	.22	.19	.20	.17
		1.25	.32	.27	.24	.28	.25	.22	.22	.20
		1.5	.34	.30	.26	.31	.27	.24	.25	.22
		2.0	.39	.34	.31	.35	.31	.28	.28	.25
		2.5	.42	.38	.34	.38	.34	.31	.31	.29
		3.0	.44	.40	.37	.40	.36	.33	.33	.30
		4.0	.48	.44	.41	.43	.39	.37	.35	.33
		5.0	.50	.46	.43	.45	.41	.39	.37	.35
21	ONE-PIECE GLASS Enamelled Reflector and Bowl	0.6	.22	.17	.14	.21	.16	.14	.15	.14
		0.8	.27	.23	.20	.26	.22	.19	.20	.18
		1.0	.30	.26	.23	.29	.25	.22	.23	.21
		1.25	.34	.30	.26	.32	.28	.25	.26	.24
		1.5	.37	.33	.29	.34	.30	.27	.28	.26
		2.0	.41	.37	.33	.38	.34	.31	.32	.30
		2.5	.44	.40	.36	.41	.38	.35	.35	.33
		3.0	.47	.43	.39	.43	.40	.37	.37	.35
		4.0	.51	.47	.43	.47	.44	.41	.41	.39
		5.0	.53	.49	.45	.48	.45	.42	.42	.40

TABLE V.—COEFFICIENTS OF UTILISATION.
Find 'Room Index' from Table IV., p. 2536.
SEMI-INDIRECT AND INDIRECT LIGHTING UNITS.

	COLOR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
	WALLS		FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
22	LIGHT OPAL	0.6	.18	.14	.11	.15	.12	.09	.09	.07
		0.8	.22	.18	15	.19	.15	.12	.12	.10
		1.0	.26	.22	.18	.22	.18	.15	.14	.12
		1.25	.30	.25	.22	.25	.21	.18	.16	.14
		1.5	.33	.28	.24	.27	.23	.20	.18	.16
		2.0	.38	.33	.29	.31	.27	.24	.21	.19
		2.5	41	.36	.32	.34	.30	.27	.24	.22
		3.0	.44	.39	.35	.36	.32	.29	.25	.23
		4.0	.49	.44	40	.40	.36	.33	.28	.26
		5.0	.51	.46	.42	.42	.38	.35	.29	.28
23	DENSE OPAL (or Light Opal and Bowl Sprayed Lamp)	0.6	.16	.13	.11	.12	.10	.08	.07	.06
		0.8	.20	.17	.15	.16	.13	.11	.09	.08
		1.0	.23	.20	.17	.18	.15	.13	.10	.09
		1.25	.27	.23	.20	.21	.18	.16	.12	.11
		1.5	.29	.26	.22	.23	.19	.17	.13	.12
		2.0	.33	.29	.26	.26	.22	.20	.15	.14
		2.5	.36	.32	.29	.28	.25	.23	.17	.16
		3.0	.39	.35	.32	.29	.27	.25	.18	.17
		4.0	.43	.39	.36	.32	.30	.28	.20	.19
		5.0	.45	.41	.38	.34	.32	.30	.22	.20
24	ALABASTER BOWL	0.6	.15	.12	.10	.11	.10	.08	.07	.06
		0.8	.18	.15	.13	.14	.12	.10	.09	.08
		1.0	.21	.18	.16	.16	.14	.12	.10	.09
		1.25	.24	.21	.18	.19	.16	.15	.11	.10
		1.5	.26	.23	.20	.20	.17	.16	.12	.11
		2.0	.29	.27	.24	.23	.20	.19	.14	.13
		2.5	.32	.29	.27	.24	.22	.22	.16	.15
		3.0	.34	.31	.29	.26	.24	.24	.17	.16
		4.0	.38	.35	.32	.28	.27	.27	.19	.18
		5.0	.39	.36	.35	.29	.28	.29	.21	.19
25	PRISMATIC ENCLOSED	0.6	.19	.15	.12	.16	.13	.10	.10	.09
		0.8	.24	.20	.17	.20	.17	.14	.14	.12
		1.0	.27	.23	.20	.23	.19	.17	.16	.14
		1.25	.31	.27	.23	.26	.22	.20	.18	.16
		1.5	.34	.29	.25	.28	.24	.22	.20	.18
		2.0	.38	.34	.30	.32	.28	.25	.22	.20
		2.5	.41	.37	.34	.34	.31	.28	.25	.23
		3.0	.44	.40	.36	.36	.33	.30	.26	.24
		4.0	.48	.44	.41	.40	.36	.34	.29	.27
		5.0	.50	.46	.43	.42	.38	.36	.30	.29
26	CLEAR TOP ENCLOSED Enamelled Glass	0.6	.16	.12	.10	.13	.10	.08	.07	.06
		0.8	.20	.16	.13	.17	.13	.11	.10	.09
		1.0	.23	.19	.16	.19	.15	.13	.12	.10
		1.25	.26	.22	.19	.21	.18	.15	.14	.12
		1.5	.29	.25	.21	.24	.20	.17	.15	.13
		2.0	.32	.28	.25	.26	.23	.20	.18	.16
		2.5	.36	.31	.28	.29	.26	.23	.20	.18
		3.0	.38	.34	.31	.31	.28	.25	.22	.20
		4.0	.42	.38	.35	.34	.31	.29	.24	.22
		5.0	.44	.40	.37	.36	.33	.31	.25	.24
27	MIRRORED INDIRECT	0.6	.15	.12	.10	.11	.09	.07	.05	.04
		0.8	.18	.15	.13	.13	.11	.09	.07	.06
		1.0	.22	.19	.16	.15	.13	.11	.08	.07
		1.25	.25	.22	.19	.18	.15	.13	.09	.08
		1.5	.27	.24	.21	.20	.17	.15	.10	.09
		2.0	.30	.27	.25	.22	.19	.17	.11	.10
		2.5	.34	.31	.28	.24	.22	.20	.13	.12
		3.0	.36	.33	.30	.26	.24	.22	.14	.13
		4.0	.40	.37	.34	.28	.26	.24	.15	.14
		5.0	.42	.39	.37	.30	.28	.26	.17	.15
28	ENAMELLED METAL INDIRECT	0.6	.14	.11	.10	.10	.08	.07	.04	.04
		0.8	.17	.14	.13	.13	.10	.09	.06	.05
		1.0	.20	.17	.15	.14	.12	.10	.07	.06
		1.25	.23	.20	.17	.17	.14	.13	.08	.07
		1.5	.25	.22	.19	.18	.15	.14	.09	.08
		2.0	.28	.25	.23	.21	.18	.16	.10	.10
		2.5	.31	.28	.26	.22	.20	.18	.12	.11
		3.0	.33	.30	.28	.24	.22	.20	.13	.12
		4.0	.37	.34	.32	.26	.24	.22	.14	.13
		5.0	.39	.36	.34	.28	.26	.24	.15	.14

Give them more Light



AT the best, artificial light, as the majority know it to-day, is a poor substitute for the real article—but that does not necessarily mean that it cannot be improved.

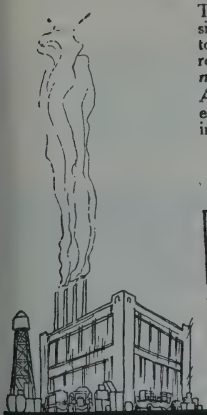
Take Industrial Lighting, for instance. How many factories attempt to get anywhere near daylight intensity in the dark hours? The majority are satisfied so long as ***some*** light is provided of sufficient brilliancy to ***appear*** adequate.

The peculiar quality of daylight is due to its perfect diffusion, and it is this diffusion combined with high intensity which should be the aim of all users of artificial light.

The attainment of this ideal is not only possible but extremely simple—merely the use of suitable lamps in reflectors designed to give adequate and complete diffusion, and providing correct reflectors are used, it is practically impossible to have too ***much*** light.

Actual experience has proved that the increase in productive effort is greatly in excess, proportionately to the extra cost of increased lighting intensity.

GIVE THEM MORE LIGHT.



BENJAMIN

R - L - M

DISPERSIVE REFLECTORS

THE BENJAMIN ELECTRIC LIMITED
BRANTWOOD WORKS - TARIFF Rd - TOTTENHAM
LONDON, N-17.

F. 2540

A Place for everything

— and everything in its place.

THE sound logic of our forefathers who perpetrated the above truism is no less applicable to-day than in their time. Thus, the attainment of increased production through Correct Industrial Lighting lies in the proper selection and installation of correctly designed equipment—reflectors specifically designed to meet individual conditions.

There are only two ways of doing things—the right and the wrong. By specifying and installing Benjamin Industrial Lighting Equipment and following the recommendations of Benjamin Engineers, correct equipment and installation are assured.

There is a Benjamin Reflector for *every* class of installation—in this case the Elliptical Angle Reflector was the only possible solution of the particular lighting problem—in other words, the right thing in its proper place.

Send for Catalogue No. 1000 to-day.

THE
BENJAMIN
ELECTRIC LIMITED

BRANTWOOD WORKS,
TARIFF ROAD,
TOTTENHAM, N.17

F. 2541

Types of Reflectors.

In the following figs. are shown some typical reflectors (made by *Benjamin Electric, Ltd.*, ottenham, London, N. 17), with their characteristic curves.

Biflector.

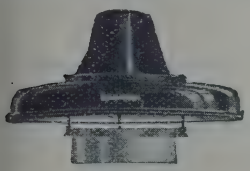


FIG. 7.

R.L.M.

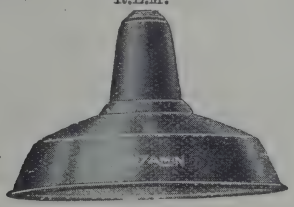


FIG. 8.

Characteristic Curves.

Biflector.

FIG. 9.

R.L.M.

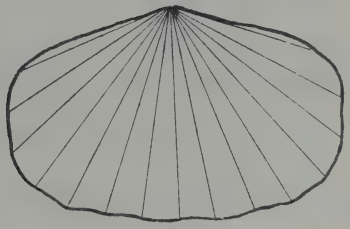


FIG. 10.

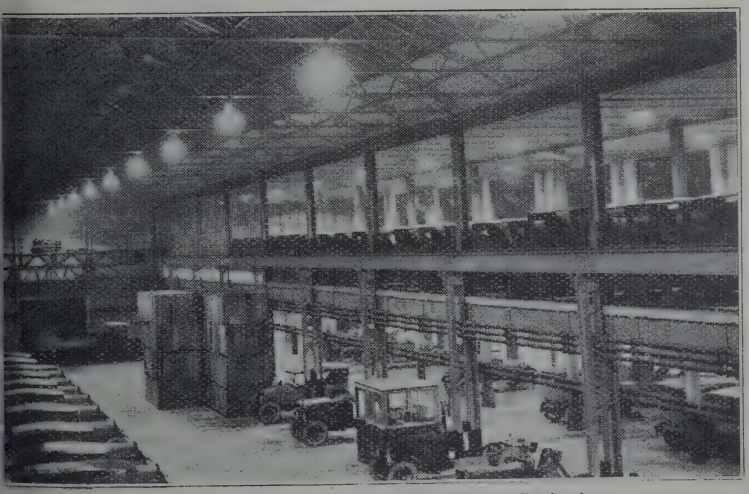


FIG. 11.—General Lighting in a large Motor Works (Benjamin R.L.M. Dispersive Reflectors).

It should be borne in mind that polar distribution curves represent the intensities correspond ing with different angles to the vertical or horizontal axis of an illuminant. The area enclose by such curves must not be associated with the total quantity of light emitted by the source.

Fig. 11 shows the excellent effect of using Benjamin R.L.M. Dispersive Reflectors in a large worl

Gas Lighting in Factories.

This may be either of high pressure (60 to 100 inches water gauge) or low pressure (4 6 inches water gauge).

The amount of gas that must be consumed to provide a given number of foot-candles illumination over the area of a workshop may be computed as follows:—

High pressure $\frac{A \times I}{200}$ = c. ft. per hour; Low pressure $\frac{A \times I}{100}$ = c. ft. per hour,

where A is the area to be lighted in square feet and I is the average illumination required foot-candles.

Thus assume a workshop having a floor area of (say) 2,000 sq. ft., and an avera illumination of 4 ft.-candles is required. According to the foregoing formula, the lighting uni as a whole would have to consume,

High pressure $\frac{2{,}000 \times 4}{200}$ = 40 c. ft. per hr. Low pressure $\frac{2{,}000 \times 4}{100}$ = 80 c. ft. per hr.

Generally it will not pay to put in high-pressure plant unless the total candle-power exceed 1,000 candles.

It remains to subdivide the installation into separate lighting units, so as to ensu as nearly as possible a uniform illumination in order that all parts of the workshop are equal available for practical use.

For instance, to develop the light from 80 cubic feet of low-pressure gas, any one of th following arrangements may be used.

No. of Lamps. . .	20	16	10	8
Cub. ft. per hour, each	4	5	8	10
Total of all Lamps .	80	80	80	80

Even larger lamps may be used, units ranging from 25 to 4,000 candle-power being avai able. The particular arrangement that may be used will depend partly upon the structur features of the building and the kind of work being done. Sometimes a uniform illuminatio must be aimed for, or in other cases it may be desirable to have certain areas extra-illuminate the intervening areas being somewhat subdued.

Generally it is not advisable to rely upon the reflecting power of walls, because in the fir place the use of reflecting shades prevents much of the light from the lamps reaching the wall and secondly, although the whitewashed surfaces have a reflection coefficient of 80 per cen when new, this rapidly deteriorates to less than half this value, due to dust created by movin machinery.

The greater the candle-power of the lighting unit used, the higher it should be placed; an in order that the illumination from the separate lamps shall overlap they should be dispose so that the distance between their centres is 1½ to 2 times their height above the level at whic work is being done.

The following points may be noted:—

If gas lamps have to be arranged amongst running shafting or belting, remote control ma be used to ensure safety in lighting and extinguishing.

If there is excessive vibration the premature fracture of mantles can be prevented by usin anti-vibrators.

Gas lamps may be arranged if required for use at various heights.

If the air round the lamps is extraordinarily dusty, the use of Keith-Blackman's 'group system will ensure their perfect working.

For large work, lamps 9 feet to 10 feet above floor level will be found convenient This ould need moderate size lamps, consuming 10 to 15 cubic feet per hour and spaced 9 to 12 feet tween centres.

For smaller work, lamps consuming 5 cubic feet per hour, set at 7 to 8 feet above floor level id 6 to 9 feet between centres, will be found suitable.

Artificial Daylight.

On many occasions it is essential that artificial lighting shall approximate in quality to that btained during the daytime. Particularly is this important in artists' studios and picture alleries, since the light obtained from an incandescent lamp has a greater proportion of red diation than daylight. This has the effect of the blue and violet colours losing their life and ie yellow and red becoming accentuated. Again in dye works and in some shops it is necessary match colours, and in order to facilitate operation under such circumstances after daylight veral expedients have been devised.

A gas-filled lamp is now available in which the filament operates in a selectively tinted blue aylight bulb, which has the effect of filtering the causes of red radiation. It is essential, however, bear in mind that when daylight lamps of this order are being used that a lamp of sufficient attage be employed. It is a good rule to bear in mind that, if under ordinary circumstances a 0-watt lamp is required, then in order to produce approximately daylight effects a 100-watt aylight lamp will be required.

A further use for these gas-filled lamps is their employment in the grading of flour or the rading of leather. It sometimes happens that even the colour which is obtained in this way s not sufficiently accurate, in which case special glass filters and reflecting materials have been esigned. In such few cases in which they must be employed it is still more important to have n ample size of electric lamp. (See 'Standard Types of Gas-filled Lamps,' p. 2529.)

SECTION XXXVIII

PART IV

FIRE EXTINCTION.

STANDARDS OF FIRE-RESISTANCE.

STANDARD TABLE FOR FIRE-RESISTING SINGLE DOORS, WITH OR WITHOUT FRAMES.

Classification.	Sub-Class.	Duration of Test at Least.	Minimum Temperature.	Thickness of Material.	Minimum Superficial Area under Test.	Minimum Time for Application of Water under Pressure.
		Min.	Deg. F.		Sq. Ft.	Min.
Temporary protective class	A	45	1500	2 in. and under	20	2
	B	60	1500	Optional	20	2
Partial protective class	A	90	1800	2½ in. and under	20	2
	B	120	1800	Optional	20	2
Full protective class	A	150	1800	½ in. and under	25	2
	B	240	1800	Optional	25	5

(*International Fire-prevention Congress.*)

Fire-Resisting Substances.

Exhaustive tests seem to show that sulphate of aluminium is one of the best fire-resisting ıbstances for wood, as it checks combustion by forming an infusible and non-conducting coat-ıg, while such substances as ammonium sulphate or ammonium phosphate when heated check ɔmbustion by emitting an incombustible gas.

The following is the formula for what is known as the United States 'Government white-ash mixture,' which also acts as a fire-retarding coating over interior wooden surfaces:—lake a half bushel of quicklime with boiling water, keeping it covered during process; strain ɔd add one peck of salt dissolved in warm water; put 3 lbs. ground rice in water and boil to a lin paste; ½ lb. of powdered Spanish whiting; 1 lb. of clean glue dissolved in hot water. Mix ell and let it stand for several days. Keep the mixture in a kettle or receptacle, and apply as ɔt as possible with a whitewash or paint brush.

(See also p. 435.)

Fire Streams.

TABLE SHOWING PRESSURE REQUIRED AT NOZZLE AND AT PUMP, WITH QUANTITY AND PRESSURE NECESSARY TO THROW GOOD EFFECTIVE STREAMS VARIOUS DISTANCES THROUGH DIFFERENT SIZE NOZZLES, USING 100 FEET OF ORDINARY 2½-INCH RUBBER-LINED HOSE AND SMOOTH NOZZLES.

Size of Nozzle, ¾ inch.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	46	57	68	80	91	102	114
Imperial gallons per minute . .	86	96	105	114	122	129	136
Distance thrown horizontal, in ft.	44	50	54	58	62	65	68
Distance thrown vertical, in ft. .	60	67	72	76	79	81	83

Size of Nozzle, ⅞ inch.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	50	63	75	88	101	113	126
Imperial gallons per minute . .	118	132	144	156	167	177	186
Distance thrown horizontal, in ft.	49	55	61	66	70	74	76
Distance thrown vertical, in ft. .	62	71	77	81	85	88	90

Size of Nozzle, 1 inch.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	58	72	87	101	115	130	144
Imperial gallons per minute . .	154	173	189	204	218	232	245
Distance thrown horizontal, in ft.	55	61	67	72	76	80	83
Distance thrown vertical, in ft. .	64	73	79	85	89	92	96

Size of Nozzle, 1⅛ inches.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	69	86	103	120	138	155	172
Imperial gallons per minute . .	197	221	241	260	279	295	312
Distance thrown horizontal, in ft.	59	66	72	77	81	85	89
Distance thrown vertical, in ft. .	65	75	83	88	92	96	99

Size of Nozzle, 1¼ inches.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	84	106	127	148	169	190	211
Imperial gallons per minute . .	246	275	301	325	348	368	388
Distance thrown horizontal, in ft.	63	70	76	81	85	90	93
Distance thrown vertical, in ft. .	67	77	85	91	95	99	101

Size of Nozzle, 1⅜ inches.

Pressure at nozzle, in lbs. per sq. in.	40	50	60	70	80	90	100
Pressure at pump, „ „ „	107	134	160	187	214	240	268
Imperial gallons per minute . .	301	337	369	398	426	452	476
Distance thrown horizontal, in ft.	66	73	79	84	88	92	96
Distance thrown vertical, in ft. .	69	79	87	92	97	100	103

N.B.—The above pressures are based on the supposition that the hose is coupled direct to the delivery of the pump and while the stream is flowing; if, however, the hose is coupled to a hydrant which is supplied direct from the pump, then the corresponding fire pump pressure must be greater than the hydrant pressure by an amount equal to friction loss and difference of head between hydrant and pump.

The pressures given in the table are *indicated* pressures, not effective pressures; effective pressures would be slightly greater.

The distances given are for *effective* fire *streams* adapted for fire purposes, and are not for mere isolated drops. (*Freeman.*)

Fire Streams and Electric Circuits.

It has always been believed to be dangerous to those handling a hose line to allow the stream come in contact with an electric circuit. Prof. F. C. Caldwell has found by experiment that ere is no danger of shocks when the distance between the nozzle and circuit is more than ft., irrespective of the voltage. (*'Power.'*)

Fire Extinguishers.

Sawdust possesses some special merits as a fire extinguisher when dealing with small outeaks of liquid combustibles, such as lacquer and petrol, which are usually difficult to extinguish ordinary means. Sand is generally looked upon as the best substance to use in such cases hen it can be applied promptly, but tests have shown sawdust to be superior.

The British Fire-Prevention Committee carried out a series of tests, the results of which nded to prove that sawdust intimately mixed with bicarbonate of soda and applied in ilk has certain advantages over sand and similar materials as an extinguishing medium for comaratively small fires occasioned by the ignition of the vapour of petroleum spirit (petrol) and her inflammable liquids. Ordinary sawdust, as obtained from saw-mills, is the most suitable r this purpose. It must be free from shavings and chips of wood, but it does not require to be ther specially dried or to contain added moisture. The addition of bicarbonate of soda, although ot essential, is advantageous. The Committee found an effective proportion of bicarbonate of oda to sawdust to be 10 lbs. to 1 bushel (or, say, 12 lbs.) of sawdust. The Committee wished to mphasise the fact that so far their investigations had been limited to small quantities of inammable liquids, not exceeding 2 gallons, and the areas over which they were spread did not xceed 6 ft. square. These conditions are met with in motor garages and hangars, for which, the opinion of the Committee, the proposed mixture is applicable and economical. The Committee added that their tests showed that the application of this or any similar mixture in small uantities from tubes or canisters does not give satisfactory results.

Some extensive tests carried out by the Standard Oil Company have proved that the foam ethod of fighting oil fires is ineffective unless the foam is applied gently at the surface of the urning oil. A 55,000-barrel tank burned right out although enough foam was dropped into it o form a blanket 6 ft. thick. When, however, the foam was applied through asbestos pipes eaching to the surface, experimental fires in the same tank were quickly put out.

British Standard Specification for Materials and Constructional Strength of Chemical Fire Extinguishers.*

(*Abstract.*) (No. 138—1922.)

Definition.

1. The term 'Chemical Fire Extinguisher' under this Specification denotes a vessel or achine manufactured as a Fire Appliance in which the pressure necessary to project the xtinguishing fluid is generated automatically either by chemical action or by the release of ompressed gas in a capsule within or affixed to the vessel itself.

Size.

2. This Specification applies only to Extinguishers having a fluid capacity of three Imperial allons and under.

Shape.

3. The shape of the vessel may be cylindrical or conical.

Method of Actuating.

4. The machine may be actuated in any of the following ways :—

(*a*) By breaking a hermetically sealed bottle containing acid and thereby allowing this acid to come into contact with an alkaline solution.

(*b*) By turning over the vessel and thereby spilling acid from a bottle into the alkaline solution.

(*c*) By opening a sealed capsule containing high-pressure gas within or affixed to the vessel.

These operations may be performed by striking a knob on the top of the machine, by a blow n the side, or by other means.

* By permission of the British Engineering Standards Association.

Material and Construction.

5. The vessel may be made either of sheet steel or copper, and the body may be jointed solid drawn.

If jointed, riveted or locked joints may be used for conical bodies, and riveted joints on for cylindrical bodies.

The ends may be attached to the bodies by riveted or lapped and edged-over joints.

All joints shall be thoroughly soldered, and longitudinal joints which are not riveted shall protected internally by means of a soldered strip or similar fitting.

Dimensions and Thickness.

6. Cylindrical jointed or solid-drawn bodies and ends after dishing shall be made in not le than the following thicknesses :—

Diameter.	Minimum Thickness.	
	Steel.	Copper.
Up to and including 4 ins. (101·6 mm.)	18 S.W.G. (1·22 mm.)	18 S.W.G. (1·22 mm.
Above 4 ins. (101·6 mm.) and up to 6 ins. (152·4 mm.)	18 ,, (1·22 mm.)	16 ,, (1·63 mm.
Above 6 ins. (152·4 mm.) and up to 7 ins. (177·8 mm.)	18 ,, (1·22 mm.)	14 ,, (2·03 mm.
Above 7 ins. (177·8 mm.) and not exceeding 8 ins. (203·2 mm.)	16 ,, (1·63 mm.)	14 ,, (2·03 mm.

Conical bodies shall be of the following thicknesses :—

Diameter at large end.	Minimum Thickness.	
	Steel.	Copper.
Up to and including 9 ins. (228·6 mm.)	18 S.W.G. (1·22 mm.)	16 S.W.G. (1·63 mm.)

The ends for both cylindrical and conical bodies shall be dished outwards to a radius no exceeding the diameter of the body at the point of attachment.

Cap and Opening.

7. The cap shall be of brass or gunmetal of ample strength.

Cap Joint.

8. The cap joint shall be made of good quality leather well greased or of acid-resisting rubbe or other approved material, and shall not exceed $\frac{1}{8}$-inch (3·18 mm.) in thickness.

Plunger.

9. The plunger or striker shall be made of brass or gunmetal. The diameter of the plunge shall be not less than 0·2 times the stroke, with a minimum of $\frac{1}{4}$-inch (6·35 mm.) diameter.

Test Pressure.

12. Every Chemical Fire Extinguisher purporting to be made in accordance with this Spec fication shall, when completed, be tested with cap screwed on and shall withstand an interna hydraulic test pressure of 300 lbs. per sq. in. (21·09 kgs. per cm.²), which shall be maintaine for at least five minutes without leakage or distortion.

Testing Connection.

13. A test connection screwed externally with a British Standard Pipe Thread shall be fitte on each machine either on the nozzle or other suitable position.

Discharge Fittings.

14. Suitable strainers shall be fitted to all discharge openings or tubes.

Expansion Outlet.

15. Suitable means shall be provided to prevent the fluid being discharged from the nozzl in the event of normal rise in temperature of the room in which the extinguisher is situated.

Interior Coating.

16. The extinguisher shall be well tinned or lead coated internally.

Clearance.

17. The clearance or air volume above the fluid level mark shall be such that the pressure the machine does not exceed 100 pounds per sq. in. (7·03 kgs. per cm.²) when discharged with ›en nozzle and with the temperature of the fluid up to 100° F. (37·7° C.).

Nozzle.

18. The nozzle shall be of brass or other corrosion-resisting metal and of stout construction. o taps shall be used.

Fire-Resisting Buildings.

The following is a reasonable standard for these :—

Walls should be of hard burnt brick or cement concrete (composed of cement and an aggregate sand, gravel, broken brick, burnt ballast, furnace slag, clinker or the like—a coke breeze aggre-.te should be avoided). The thickness of walls depends upon the duties they have to perform, it external or party walls should be at least 9 ins. thick at every point, and the latter should be rried well above the adjoining roofs and should be thicker than the external walls.

Walls built as described above and containing no openings are of great value in checking the ›read of a fire.

It should be noted that stone walls are undesirable features as they crumble on the combined ›plication of heat and water.

Roofs should be constructed as strongly as possible of incombustible material, and if glass is ›cessary, wire glazing should be used. Broken panes should be replaced immediately.

Floors require to be of incombustible material, such as concrete or ferro-concrete, but it is .ite safe to lay a wood floor flush on the concrete, *i.e.* leaving no intervening space.

All structural metal work in a floor, as also any columns or stanchions supporting the floor, ould be encased in plaster cement or concrete, as otherwise their strength is rapidly reduced on .e application of heat. Further, the piercing of floors with lifts, hoists, staircases, etc., detracts ›eatly from their value, and such lifts, etc., should be totally enclosed in brick or concrete with ›e-resisting doors to each opening into the various floors.

Windows should have wire glazing in steel frames, and partitions should be of concrete slabs hard wood. Matchlining should be avoided.

Any communications with adjoining buildings should be protected by double fire-resisting ›ors or fire-resisting compartments, especially if such adjoining buildings are of a lower standard construction.

(*The National 'Safety First' Association.*)

See also 'Accident-Prevention Pamphlet,' No. 5, December 1924, price 2*d*. The National Safety First' Association, 119, Victoria St., London, S.W. 1.

Dubbing for Preserving Leather Hose.

Melt 2½ lbs. of perfectly clean tallow, free from salt, and mix with it when hot 1 gallon or lbs. of cod oil.

The best mode of clearing tallow for this purpose is to boil it in water, which will take up the .lt and other impurities, and can be poured away when cold.

Care must be taken not to boil the oil, as this would deprive it of some of its principal ›alities.

The tallow must be first melted, and when it is warm the oil is to be poured on, and stirred ›to it until the whole mixture is perfectly cold. This will make a good stiff dubbing.

SECTION XXXIX

(Contributed and revised by Emeritus Prof. Henry Louis, M.A., D.Sc., A.R.S.M., M.Inst.C.E., F.I.C., F.G.S., etc.)

PART I

MINING (pp. 2553-2642)

PART II

MINERAL VALUATION (pp. 2643-2648)

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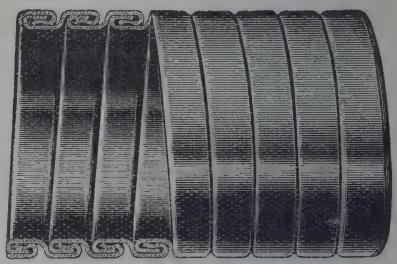

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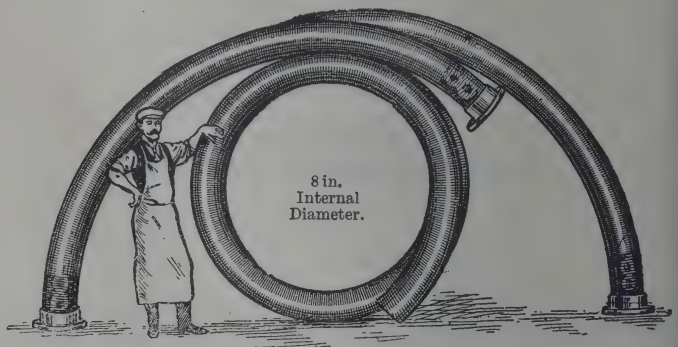

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SECTION XXXIX

PART I

MINING

Contributed and revised by Emeritus Professor Henry Louis, M.A., D.Sc., A.R.S.M., M.Inst.C.E., F.I.C., F.G.S., etc.)

EGAL—CLASSIFICATION OF MINERAL DEPOSITS—COAL—METALLIFEROUS MINERALS—BORING—DRILLING AND BLASTING—DRIFTS—SHAFTS—COAL CUTTERS—SHAFT PILLARS—MINING IN VEINS AND MASSES—HAULAGE—WINDING—WIRE ROPES—ELECTRIC CABLES—PUMPS AND PUMPING—VENTILATION—SAFETY LAMPS—RESCUE APPARATUS—DRESSING OF ORES—GOLD MILLING—ALLUVIAL MINING.

Legal.

Definitions of Minerals and Mines.

By the term 'mineral,' as used in legal documents, is meant a constituent of the earth's crust ıich possesses in its severed condition an intrinsic value by virtue of its composition, that is to y, 'any substance that can be got from within the surface of the earth which possesses a value use apart from its mere possession of bulk and weight' (Lord Fletcher Moulton, Court of ıpeal, Nov. 23, 1908). The meaning of the word 'mineral' may be affected by the context; cording to Lord Halsbury, in 'a grant of *mines* and *minerals*,' it 'is a question of fact what ese words meant in the vernacular of the mining world, the commercial world and landowners the time when they were used in the instrument' (Lord Provost of Glasgow *v.* Fairie, 13 App. ıs, 1888).

In this country a *mine* is defined as a working for mineral carried on by artificial light without :entionally disturbing the surface, whilst a *quarry* is an excavation for the extraction of mineral en to the day; the distinction is important from a legal point of view. It must be noted that quarry less than 20 feet deep is by law classed as a factory. In many other countries, notably the United States of America, the distinction between a 'mine' and a 'quarry' depends not ıon the method of working but upon the mineral wrought, any working for e.g. building stone, ıether underground or open, being classed as a quarry. In legal instruments 'mine' sometimes .s the wider meaning of the space containing the minerals, or even from which the minerals .ve been extracted.

Ownership of Minerals.

In this country the mineral occurring within any area is the property of the owner of the :ehold of the surface, with some few exceptions, the most notable of which are the Forest of ean and the Isle of Man, where the minerals are Crown property. Minerals containing precious etals—where these metals form the essential value of the mineral—are the property of the :own wherever found (except in Scotland). Minerals under copyhold land were mostly the pro- :rty of the Lord of the Manor, who could not, however, as a rule, deal with them save with the ınsent of the copyholder. Since by the Law of Property Act, 1922 (12 & 13 Geo. V. ch 16, s. 128), ›pyhold has been abolished, the minerals are as a rule enfranchised and become the property the tenant, although the latter may, if he so desire, transfer his right to the lord. This law .me into force on January 1, 1926 (Law of Property Act (Postponement) Act, 1924).

Generally speaking, in this country the minerals are leased to those exploiting them. 'A ining lease is really a sale payable by instalments' (Henn Collins, Master of the Rolls, *In re* ldam's Settled Estates, Chanc. 2, 1902). Most often the rental is based on the tonnage exploited, ıe rate per ton or *royalty* being fixed. For coal this may range from 2*d.* to 2*s.*, but is usually :tween 4*d.* and 7*d.*, the average for the United Kingdom having been pre-war probably just

about 5½*d.* per ton (Royalties Commission, 1889); it is now (1928) 5·74*d.* including wayleav per ton of saleable coal raised. Sometimes the rental is a fraction of the value of the coal, th ranging from ⅛ to $\frac{1}{50}$; sometimes the rental is a proportion of the profit made; sometimes a pri per inch thickness of coal seam per acre wrought out forms the rental. In addition to royalt wayleaves have often to be paid for; average wayleave in United Kingdom is about ¼*d.* per t (Royalties Commission, 1889).

Royalties on stratified ironstone vary from 2½*d.* to 1*s.* 6*d.* per ton, averaging about 6*d.*

In the hæmatite mines of Cumberland and Lancashire the royalties vary normally fro 1*s.* to 2*s.*, averaging about 1*s.* 4*d.* In the Forest of Dean royalties on iron ore vary from 3*d.* 5*d.* per ton.

Royalties in Cornwall on tin and copper ores range from $\frac{1}{30}$ to $\frac{1}{10}$ of the value of the mineral raise

Royalties on lead and zinc ores range from ⅛ to $\frac{1}{30}$ of the value of the ore raised.

Royalties are often on a sliding scale, the ratio increasing with the market price of the miner or of its metallic contents.

List of Principal Legislative Enactments affecting Mines and Minerals.

Land Tax Redemption Act, 1798, and subsequent Acts; 'The Mining Code,' Railway Claus Consolidation Act, 1845, Ss. 74–85; Waterworks Clauses Consolidation Act, 1847, Ss. 18–2 Public Health (Support of Sewers) Act, 1883—see, however, New Moss Colliery *v.* Manchest Corporation, 1908, and Howley Park Coal and Canal Co. *v.* L. & N.W. Railway, 1912; Copyho Act, S. 48, 1852; Coal Mines Act, 1866; Metalliferous Mines Acts, 1872, 1875; Explosives A 1875; Rating Act, 1874; Stratified Ironstone Mines (Gunpowder) Act, 1881; Conveyanci Act, S. 2, 1881; Slate Mines (Gunpowder) Act, 1882; Coal Mines Regulation Act, 1887; Quarri (Fencing) Act, 1887; Quarries Act, 1894; Coal Mines (Check Weigher) Act, 1894; Workmer Compensation Act, 1897; Coal Mines (Weighing of Minerals) Act, 1905; Workmen's Compens tion Act, 1906; Notice of Accidents Act, 1906; Coal Mines Regulation (Eight Hours) Act, 190 Small Holdings and Allotments Acts, Schedule I., 1908; Mine Accidents (Rescue and Aid) A 1910; Coal Mines Act, 1911; Coal Mines (Minimum Wage) Act, 1912; Coal Mines Act, 191 Feudal Casualties (Scotland) Act, S. 7, 1914; Price of Coal (Limitation) Act, 1915; Coal Min Control Agreement (Confirmation) Act, 1917; Coal Mines Regulation (Amendment) Act, 191 Petroleum (Production) Act, 1918; Coal Mines Act, 1919; Coal Industry Commission Act, 191 Coal Mines (Emergency) Act, 1920; Mining Industry Act, 1920; Finance (1909–10) Act, 191 Ss. 1–5, 20–24, 25–27, 33, 34; Finance Act, 1912, S. 11; Finance (No. 2) Act, 1915, S. 43; Finan Act, 1916, S. 46; Finance Act, 1917, S. 21; Income Tax Act, 1918, Schedule III.; Finance A 1919, S. 33; Finance Act, 1920, Ss. 49, 7; Mines (Working Facilities and Support) Act, 192 See Report of Mining Cases decided by the Railway and Canal Commission Court under the Min (Working Facilities and Support) Act, 1923, by P. G. Bamber. Coal Mines Act, 1926 (Amen ment of 1908 Eight Hours' Act for 5 years).

Principal Clauses in Colliery Lease.

Description of contracting parties (lessor and lessee) and of property demised.

Powers granted to lessee:—
- To break surface, make shafts, adits, etc.
- To win and work coal, bring to bank, make merchantable, dispose of.
- To work by instroke or outstroke or both.
- To make and dispose of coke and other products.
- To have necessary surface accommodation.
- To have necessary wayleaves.
- To construct roads, tramways, railways, etc.
- To erect buildings, machinery, plant, etc.
- To work quarries of lime, clay, etc. (sometimes for own use only).
- To remove coals, dead and live stock, plant, etc., after expiration of lease.
- To relinquish at stated times before termination of lease.
- To renew lease for a further period.
- To generally do all things necessary for getting coal, etc.

Reservations to lessor:—
- Of mines and minerals not demised.
- Of certain rights and wayleaves.
- Of use of ways, railways, etc.

'Habendum':—
- Lessee to have and hold property for a fixed term of years.

'Redendum':—
- Annual certain rent or deadrent, usually merging into royalty.
- Royalty per ton or otherwise.
- Rent for surface occupied.
- Rent for wayleaves, waterleaves, or other facilities.

Provisoes:—
- No royalty payable in respect of colliery consumption.
- Power to make up short workings of previous years.
- Power to carry over excess workings to subsequent years.
- For distress in case of default in payments.
- For re-entry if rents, etc., remain unpaid for certain period.

Covenants on part of lessee :—
For due payment of rents and royalties.
For due payment of taxes.
For compensating for damage done to surface or to neighbours.
For erecting (or against erecting) buildings, houses, coke-ovens, etc.
For keeping proper accounts accessible to lessor, and rendering the same.
For keeping proper mine plans, and permitting inspection of mine.
For leaving proper barriers.
For working in approved and miner-like manner.
Against sub-letting without authority.
For giving up possession in good condition at determination of lease.
For keeping mine, plant, buildings, etc., in good repair.
For properly fencing or securing shafts, adit mouths, etc.
For giving lessor power to purchase plant, etc., at a valuation on determination of lease.
Covenants on part of lessor :—
For proper title.
For quiet enjoyment.
Arbitration clause.

Leases of ironstone mines as also of metalliferous mines follow practically the same lines; regards the latter, it is usually set forth that the royalty shall be a certain part of the value the minerals, cleaned, dressed, smelted, or otherwise rendered merchantable, as the case may mand, at the expense of the lessee. There are often clauses specifying that a certain amount development work, driving, sinking, etc., shall be performed.

A tacknote or license to prospect is often granted; this differs from a lease, inasmuch as it ansfers no interest in the property. Its usual form is a license for one year to explore for all for certain specified minerals within a definite area, usually for a nominal consideration, the ensee making compensation for all damages, and paying a royalty on all minerals gotten and ld. The license is generally renewable at the option of the licensee for a term of years, usually ree, and the licensee is entitled to a lease upon conditions specified; this specification often kes the form of a schedule embodying the conditions of a draft lease.

Classification of Mineral Deposits.

A mineral deposit may be defined as a portion of the earth's crust containing mineral matter intrinsic value under favourable conditions.

The mineral substances that form the subject of mining operations may be classified as ıder :—

Group I., Fuels; II., Ores; III., Salts; IV., Gems: V., Rocks.

Group I. contains the different varieties of coal, asphalts, bitumen, and other solid hydrocarbons, mineral oils, etc., while sulphur may conveniently be included.

Group II. contains the various heavy metals either in the native state or in combination.

Group III. contains the haloids, sulphates, carbonates, silicates, phosphates, borates, etc., the alkaline earths and alkalies.

Group IV. contains those minerals that are prized as gems on account of their hardness, illiancy, and transparency, as well as the semi-gems, such as opal, turquoise, etc., which though aque are prized as precious stones on account of the beauty of their colouring and their rarity.

Group V. comprises the various rock masses, such as granite, slate, limestone, etc., the ploitation of which is more properly considered under quarrying.

With respect to their mode of occurrence, mineral deposits may be classified morphologically follows :—

- Tabular = Beds, veins.
- Irregular = Masses, lenses, pipes, etc.

A more complete classification, based on genetic as well as morphological characters, is as llows :—

Class I.—Symphytic; Syngenetic, contemporaneous or stratified
- Group *a*, clastic.
- „ *b*, formed by chemical agencies.
- „ *c*, formed by organic agencies.
- „ *d*, disseminated through beds.

Class II.—Epactic; Epigenetic, subsequent or non-stratified.
- Sub-Class A—Veins.
  - Group *a*, fissure.
  - „ *b*, bedded.
  - „ *c*, contact.
  - „ *d*, gash.
- Sub-Class B—Masses.
  - Group *a*, stockworks.
  - „ *b*, disseminated in igneous rocks.
  - „ *c*, connected with igneous rocks.
  - „ *d*, connected with soluble rocks.

Class I.—Group *a* includes auriferous alluvials, tin-bearing alluvials, ironsands, etc. Group *b* ntains deposits due to chemical precipitation, to evaporation or to metasomatic changes. ractically all the stratified ironstones belong to this group. Of group *c* the most important

representative is coal. Group *d* includes the Knottensandstein of Mechernich, the Kupfer schiefer of Mansfeld, the Banket beds of Johannesburg, and similar deposits.

Class II.—Sub-Class A. Group *a* includes most of the important vein systems of the world such as those of Cornwall, etc.

Group *b* includes veins parallel to the stratification.

Group *c* embraces certain veins following the contact of dissimilar rocks.

Group *d* contains veins carrying galena and zinc blende that characterise certain limestone districts, e.g., that of Missouri.

Sub-Class B. Group *a* consists of masses traversed by minute veinlets carrying ore, such as the tin deposits of Saxony.

Group *b* comprises such deposits as the Kimberley diamond-bearing pipes, the copper deposits of Lake Superior, etc.

Group *c* are very largely lenticular in form; the pyrite deposits of the Huelva district are a typical example.

Group *d* may be represented by the red hæmatite deposits of Cumberland and Lancashire.

Branches of Mining.

I. Prospecting, the most important part of which is 'boring.'

II. Exploiting, including the various operations of opening up mineral deposits by shafts or adits, extracting and transporting the mineral, securing, pumping and ventilating the workings and the proper care of the men employed.

III. Dressing or preparing the mineral extracted for the market.

COAL.

Classification.

Coal is generally classified under the three main heads of 'lignite' or 'brown coal,' 'bituminous coal,' and 'anthracite.' Bituminous coal is further classified according to the purposes for which it is best adapted, such terms as gas coals, house coals, furnace coals, smithy coals, steam coals, etc., being usually employed. The classification that is most widely adopted is based upon Gruner's work, and is as follows :—

Description of Coal.	Composition of Ash-free Coal.			Percentage of Fixed Residue.	Nature of Residue.	Calorific Power.
	Carbon.	Hydrogen.	Oxygen.			Cal.
Lignite	70–75	5·6	15·25	50	Non-coking	6,000
Dry coals with long flame (furnace coals)	75–80	4·5–5·5	15–19·5	55–66	Pulverulent or very slightly coking	8,000–8,500
Fat coals with long flame (gas coals)	80–85	5·0–5·8	10·0–14·2	60–68	Completely agglomerated, porous	8,500–8,800
Fat coals proper (smithy coals)	84–89	5·0–5·5	5·5–11·0	68–74	Completely agglomerated, more or less porous	8,800–9,300
Fat coals with short flame (coking coals)	89–91	4·5–5·5	5·5–6·5	74–82	Coked, compact	9,300–9,600
Anthracite	90–93	4·0–4·5	3·0–5·5	82–90	Pulverulent	9,200–9,500

Seyler's classification is based upon the percentage of hydrogen in the ash-free coal and the ratio of carbon to hydrogen :—

Genus.	H per cent.	C : H.
1. Anthracite	< 4	> 22
2. Carbonaceous	4–4·5	20·3–23·35
3. Semi-bituminous	4·5–5	16·6–20·4
4. Bituminous	5–5·8	14·6–18·2
5. Per-bituminous	> 5·8	12·9–14·7

(*Strahan & Pollard.*)

CLASSIFICATION OF THE INTERNATIONAL GEOLOGICAL CONGRESS, CANADA.

Class.	Name.	Fuel Ratio.	Composition.			Percentage of Volatile Combustible Matter.	Calorific Power B.Th.U.
			C.	H.	O & N.		
A_1	Anthracite	12 or more	93–95	2–4	3–5	3–5	14,500–15,000
A_2	Semi-Anthracite	7–12	90–93	4·4·5	3–5·5	7–12	15,000–15,500
B_1	High Carbon Bituminous	4–7	80–90	4·5–5	5·5–12	12–15	15,200–16,000
B_2	Bituminous	1·2–7	75·90	4·5–5·5	6–15	12–26	14,000–16,000
B_3	Low Carbon Bituminous	—	70–80	4·5–6	18–20	up to 35	12,000–14,000
C	Cannel	—	—	—	—	30–40	12,000–16,000
D_1	Lignitic	—	60–75	6–6·5	20–30	—	10,000–13,000
D_2	Lignite	—	45–65	6–6·8	30–45	—	7,000–11,000

Class B_2 comprises most of the coking coals; in Class D_1 moisture is 6–20 per cent., in D_2 over 0 per cent.

CLASSIFICATION OF THE IMPERIAL MINERAL RESOURCES BUREAU.

A, Brown coal or lignite; B_1, gas coal and cannel; B_2, coking coal: B_3, house coal; B_4 manufacturing or iron smelting coal; B_5, steam coal; C, anthracite.

Other classifications are also used; one much liked in America is based upon the 'fuel ratio,' that is, the figure obtained by dividing the percentage of fixed carbonaceous residue by the percentage of volatile matter.

CONSTITUTION OF COAL.

The four constituents of coal, as identified by Dr. Marie Stopes, are :—

(1) Fusain. (2) Durain. (3) Clarain. (4) Vitrain.

Vitrain appears to contain the lowest proportion of inherent ash, and it and clarain are practically the only coking constituents. These two also yield the largest proportions of gas, especially of hydrogen, on carbonisation.

CALORIFIC POWER.

The calorific power may be calculated from the ultimate analysis by the 'Deutscher Verband' formula :—

$$\text{Cal. power in calories} = 81\,C + 290\left(H - \frac{O+N}{8}\right) + 25\,S - 6\,W,$$

where C, H, O, N, S, and W are the percentages, respectively, of Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, and Moisture.

Gontal's formula is applied where only the proximate analysis (percentages of fixed carbon, volatile matter and ash) is known.

Let C be percentage of fixed carbon, V of volatile matter, A of ash; then

$$\text{Cal. power in calories} = 82\,C + a\,V,$$

where a is a coefficient depending upon the percentage of volatile matter in the ash-free coal, i.e. upon $\frac{100\,V}{100-A}$ as follows :—

$\frac{100\,V}{100-A}$	5	10	15	20	25	30	35	40
a	145	130	117	109	103	98	94	80

The ash of coals varies usually between 3 and 15 per cent.

1 lb. of ordinary coal requires theoretically 130 cub. ft. of air for complete combustion.

COKE.

Ordinary bituminous coal, containing 25 to 30 per cent. of volatile matter, coked in a modern regenerative bye-product coke-oven plant, yields approximately :—

Coke	70–75 per cent.
Tar	3·5–4·5 ,,
Ammonia as ammoniac sulphate	1–1.25 ,,
Crude benzol	1 ,,

Surplus gas, 3,000 to 5,000 cub. ft. per ton of coal.

The composition of this gas is about as follows:—Hydrogen, 48 to 55 per cent.; methane 25 to 34 per cent.; carbonic oxide, 6 to 8 per cent.; carbonic acid, 2 to 2·5 per cent.; hydrocarbons, 2 to 4 per cent.; nitrogen, etc., 5 to 12 per cent. The calorific power is about 480 to 600 B.Th.U. gross, or 425 to 550 B.Th.U. net.

Weight of Coal.

The specific gravity of coal varies from 1·1 to 1·6, most bituminous coals approximating to 1·3. The following table shows the weight of coal contained in one acre of superficial area per inch thickness of seam.

Table of the Weight of Coal under Different Circumstances.

Specific Gravity.	Weight in the Natural Bed, per Acre, per Inch Thick, in Tons.	Weight of a Cubic Foot in the Broken State, in Lbs.	
		Large Coal.	Small Coal.
1·10	111·411	42·62	37·12
1·15	116·475	44·56	38·81
1·20	121·540	46·50	40·50
1·25	126·604	48·43	42·18
1·30	131·668	50·37	43·87
1·35	136·732	52·31	45·56
1·40	141·796	54·25	47·25
1·45	146·860	56·18	48·93
1·50	151·925	58·12	50·62

Specific gravity × 101·283 = weight in tons per inch thick per acre.

To find the contents of coal of any given specific gravity per acre multiply the figure in the table by the thickness of the seam in inches; the thickness measured along a vertical line should always be taken, as the correct result will thus be obtained, whatever may be the inclination of the coal seam.

The weight of coal in its broken state, that is, as it comes to the surface, in tubs or otherwise, will depend on its largeness; the large has here, however, been computed to weigh in proportion to the solid coal as 62 to 100, and the small as 54 to 100.

The calculation now most commonly adopted in the North of England to ascertain the weight of coal in the solid state is to reckon 19 cwts. per cubic yard = 78·815 lbs. per cubic foot. On this calculation, a seam 1 foot in thickness would contain 1,532 tons 13 cwts. 1 qr. 10 lbs. per acre, and a seam 1 yard thick would contain 4,598 tons per acre.

A summary way of reckoning the quantity of available coal in a given area of a seam is to take an acre of coal 1 inch thick to produce 100 tons. This leaves a sufficient margin for faults and losses in barriers and in working.

Sizing of Coal.

In the coal trade coal is often sold by size, but there is no uniformity in practice even in the same field. Above 4 ins. to 6 ins. is usually sold as Best Coal, House, or Best House; a very general scheme of designations is:—

Cobbles	between 5 ins. to 6 ins.	and about	3½ ins. to 3 ins.
Treble nuts	3½ „ 3 „	„	1½ „
Double nuts	1½ ins.	„	1 in. to ¾ in.
Single nuts	1 in. to ¾ in.	„	⅝ in.
Duff, slack or gum below ⅝ in.			

Some collieries also make beans, say about ⅝ in. to ⅜ in. and peas, say about ⅜ in. to $\frac{3}{16}$ in. The dimensions may signify plate screens with round or with square holes, bar screens or wire gauze; in the two latter they may be measured in the clear or centre to centre. All these different methods are in use.

With reasonably closely sized coal of whatever dimensions it is found that as ordinarily heaped the coal occupies 55 per cent. of the total volume of the heap.

METALLIFEROUS MINERALS.

By *metalliferous* minerals or *metallic* minerals are meant those minerals that are technically utilisable for the extraction of the ordinary commercial heavy metals, metals of the alkalies and alkaline earths being excluded; this is almost identical with the meaning of *ores*, or with Group II, of above classification. In United States of America and Canadian statistics, a wider meaning is given to *non-metallic* minerals, which includes all minerals not actually used for the extraction of metals, e.g. ochre, although this is an oxide of iron, because it is used as a pigment and not as a source of iron.

COMPOSITION OF MORE IMPORTANT ORES.

Name.	Formula.	Percentage of Metal.
Magnetite	Fe_3O_4	Fe 72·4
Hæmatite	Fe_2O_3	,, 70
Limonite	Fe_2O_3,H_2O	,, 60
Brown hæmatite	Hydrated ferric oxide, with 10–15 per cent. H_2O	,, 45–55
Siderite	$FeCO_3$	,, 48·3
Ilmenite	$(TiFe)_2O_3$	,, 30–40
Pyrites	FeS_2	,, 46·7
Pyrrhotite	Fe_7S_8	,, 60·5
Pyrolusite	MnO_2	Mn 63·3
Manganite	$Mn_2O_3H_2O$	,, 62·5
Wad	Impure hydrated manganese oxide	,, 25–50
Chalcopyrite	$Cu_2SFe_2S_3$	Cu 34·6
Chalcocite	Cu_2S	,, 79·8
Malachite	$2(CuO)CO_2H_2O$	,, 56
Cinnabar	HgS	Hg 86·2
Galena	PbS	Pb 86·6
Cerussite	$PbCO_3$	,, 77·5
Anglesite	$PbSO_4$	,, 68·3
Blende	ZnS	Zn 67
Calamine	$ZnCO_3$	,, 52
Stibnite	Sb_2S_3	Sb 71·8
Mispickel	$FeAs_2S_2$	As 46
Cassiterite	SnO_2	Sn 78·7
Wolfram	$(FeMn)OWO_3$	W 70
Scheelite	$CaOWO_3$	,, 74·8

IRONSTONE.

Ironstone is the term applied to stratified or symphytic deposits workable for iron, iron ore to epactic deposits, veins or masses. Bessemer ore or hæmatite ore is generally understood to mean iron ore with less than 0·035 per cent. of phosphorus when the ore contains about 50 per cent. of iron. Such ores are usually quoted on a basis of 50 per cent. of iron, with a definite increase or deduction in price for each unit of iron above or below that figure, and a penalty for every unit of silica above a given percentage, often 8 per cent.

The yield of ironstone is often taken roughly at 2,000 tons per foot thick per acre.

HAEMATITES.

These weigh 3–3·5 tons per cubic metre in place, 2½ tons per cubic metre in mine cars, 2 tons per cubic metre stacked.

TABLE OF BRITISH MESOZOIC IRONSTONES.

Formations.			*Name of Ironstone.*
CRETACEOUS—Neocomian	Wealden	Lower Greensand	Seend, Wiltshire.
		Weald Clay	
		Hastings Sand	Sussex and Kent. Westbury, Wiltshire, Claxby, Lincolnshire.
JURASSIC	Upper Oolite		
	Middle Oolite	Corallian	Dover, Kent.
		Oxford Clay	Westbury, Wiltshire.
	Lower Oolite	Great Oolite	
		Estuarine Beds	
		Northampton Sands	Northamptonshire. Cleveland Dogger or Top Seam.
	Upper Lias	Upper Lias Clay	
		Toarcian	Isle of Raasay.
	Middle Lias	Middle Lias Limestone	Cleveland Main Seam. Cleveland Pecten Seam. Cleveland Avicula Seam.
		Marlstone	Blenheim, Oxfordshire. Melton Mowbray, Leicestershire. Caythorpe, Lincolnshire.
	Lower Lias		Frodingham, Lincolnshire.

COMPOSITION OF BRITISH MESOZOIC IRONSTONES, DRIED AT 100° C.

	Iron.	Silica.	Lime.	Sulphur.	Phosphorus	Loss on Ignition
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Cleveland Main Seam	30	12	5	0·3	0·5	26
Northamptonshire	38	17	3	0·15	0·7	32
Lincolnshire	25	9	21	0·2	0·35	36
Oxfordshire	28	13	11	0·15	0·3	35
Raasay	25	10	17	0·5	1·0	20

COPPER, TIN, LEAD AND ZINC ORES.

Copper, tin, lead, and zinc ores are usually sold by assay. The value is calculated on the current market price of the metal multiplied by the percentage of metal present less the percentage estimated to be lost in the operation of smelting; from the value thus found there is then deducted the 'returning charge,' being the estimated cost of smelting the ore, including the smelter's profit, etc. The following were the generally accepted (pre-war) methods :—

COPPER ORES.—Weight paid for is gross weight less moisture and less 1 per cent. draftage. Wet assay less 1 per cent. for ores assaying 3–4 per cent. (deduction varied proportionately for richer or poorer ores); for value per unit (1 per cent.) take 0·01 of price of best selected copper, less returning charge of 2*s.* 3*d.* to 2*s.* 6*d.*

Example.—Cargo of 1,000 tons ore assaying 4 per cent. copper, ¼ per cent. moisture. Net weight $= 1{,}000 - \left(\frac{1{\cdot}25}{100} \times 1{,}000\right) = 987{\cdot}5$ tons.

4 per cent. − 1 per cent. = 3 per cent. copper to be paid for.

Best selected quoted that day 82*l.* 10*s.* per ton = 16*s.* 6*d.* per unit, less 2*s.* 3*d.* returning charge = 14*s.* 3*d.* 3 units at 14*s.* 3*d.* = 42*s.* 9*d.* per ton of ore.

Value of cargo 987·5 tons at 42*s.* 9*d.* = 2,110*l.* 15*s.* 7½*d.*

LEAD ORE.—Weight paid for is net dry weight. Percentage paid for is dry assay less 4 units, on basis of soft foreign lead price in London, subtracting 40*s.* per ton for returning charge. Silver above 3 oz. per ton paid for at current rate for fine silver. Price is understood to be delivered smelter's works.

Example.—150 tons net of galena assaying 78 per cent. of lead and 5 oz. of silver per ton quotations being : lead, 20*l.* per ton; silver, 2*s.* 3*d.* per oz. Lead, 150 tons at (78 − 4) per cent. = 111 tons at 20*l.* = 2,220*l.*, less 150 tons at 40*s.* = 1,920*l.* Silver, 150 × (5 − 3) oz. = 300 oz. at 2*s.* 3*d.* = 33*l.* 15*s.* Total value of ore, 1,953*l.* 15*s.*

ZINC ORE.—Weight paid for is net dry weight. From percentage of zinc, as determined by wet assay, subtract 9 units, multiply by $\frac{18}{20}$ of price of spelter, and subtract returning charge of 3*l.*; difference is price per ton delivered smelter's works.

Example.—If ore assays 50 per cent., London quotation for spelter being 18*l.*, the ore is worth £ $\left(\left[\frac{50-9}{100} \cdot \frac{18}{20} \cdot 18\right] - 3\right) = 4l.\ 0s.\ 3d.$ per ton.

The general gangue of most ores is quartz; solid quartz averages about 165 lbs. per cub. ft. (13½ cub. ft. to the ton), broken about 100 lbs. (22½ cub. ft. to the ton), but varies considerably. the weight of veinstuff containing metalliferous minerals can be calculated from the specific gravity of the minerals.

TABLE OF SPECIFIC GRAVITIES AND WEIGHTS PER CUBIC FOOT OF MINERALS.

Mineral.	Sp. gr.	Cwts. per cub. ft.	Mineral.	Sp. gr.	Cwts. per cub. ft.
Copper pyrites	4·1–4·3	2·34	Ilmenite	4·5–5·0	2·64
Copper glance	5·5–5·8	3·15	Hæmatite	4·5–5·3	2 73
Malachite	3·7–4·0	2·20	Brown hæmatite	3·4–4·4	2·17
Cinnabar	8·9–9·0	5·00	Spathic ore	3 4–3·9	2·04
Galena	7·3–7·7	4·18	Pyrolusite	4·8–4·9	2·67
Cerussite	6·4–6·5	3·60	Cassiterite	6·4–7·1	3·76
Anglesite	6·1–6·4	3·50	Wolfram	7·1–7·6	4·12
Zinc blende	3·9–4·2	2·23	Scheelite	5·9–6·1	3·34
Calamine	4·0–4·5	2·40	Quartz	2·5–2·8	1·50
Stibnite	4·5–4·6	2·50	Calcspar	2·5–2·8	1·50
Pyrites	4·8–5·2	2·78	Dolomite	2·8–2·9	1·56
Mispickel	6·0–6·4	3·45	Fluorspar	3·0–3·2	1·73
Magnetite	4·9–5·2	2·80	Felspar	2·5–2·8	1·50

A rib of mineral 1 in. thick = 3 cub. ft. per square fathom.

Calculation of Mineral Mixtures.

The percentages of two minerals present in a mixture can easily be calculated if the sp. gr. of the mixture and of the ingredients is known. A convenient method is that proposed by R. T. Hancock.

Take a weight of x grms. of the mixture containing two ingredients of sp. gr., a and b respectively, where $\frac{1}{x} = \frac{1}{a} - \frac{1}{b}$ or $x = \frac{ab}{b-a}$; then the volume of this weight of a alone will differ from that of the same weight of b alone by 1 c.c., and for every 1 per cent. of a (the lighter substance) present in the mixture, the volume will be greater by 0·01 c.c. than the volume of b alone and for every 1 per cent. of b present, less by 0·01 c.c. than the volume of b alone. It is usually convenient to take $10x$ grms., when the differences will be 0·1 c.c.

Example.—To determine percentage of cassiterite (sp. gr. 7) and 'black sand' (sp. gr. 4·5) in a mixture of these. Since $\frac{1}{4{\cdot}5} - \frac{1}{7} = \frac{1}{12{\cdot}6}$, take 126 grms. Volume of mixture, measured by pouring the mixture into a burette partly filled with water and noting the difference in the burette readings, = 20 c.c. Volume of 126 grms. of black sand would be $\frac{126}{4{\cdot}5} = 28$ c.c. Hence percentage of cassiterite = 10 (28 − 20) = 80 per cent.

BORING.

Boreholes are put down by one or other of the following methods :—

I. Percussive:
- (*a*) Using solid rigid rods.
- (*b*) Using ropes.
- (*c*) Using hollow rods (water-flush method).
- (*d*) Using a hydraulic ram.

II. Rotary:
- A. Core drills.
  - (*a*) Using diamonds.
  - (*b*) Using steel cutting teeth.
  - (*c*) Using chilled shot.
- B. Hydraulic rotary oil drill.

Generally speaking, percussive methods are used when the primary object is to get a hole down rapidly, where information as to the nature of the ground passed through is of less importance, whilst rotary core drills, by the use of which a more or less continuous core is obtained, are employed when an accurate knowledge of the strata passed through is the first consideration. Sometimes both methods are combined; thus in some of the boreholes put down in Kent, boring through the secondary rocks was performed by percussion, whilst rotary core-boring was substituted after the coal measures had been reached. Percussion boring by the ordinary 'English' method can be used to depths of about 500 ft., costing about 10*s.* to 20*s.* per foot, and advancing 2 ft. to 6 ft. per twenty-four hours. Beyond this depth a free-falling cutter must be used, and in this way depths of 3,000 ft. or more may be reached.

Rope boring with round ropes on the American system is used almost exclusively in boring for oil, salt, etc. The plant for a hole 2,000 ft. deep would weigh about 80 tons complete and cost about 2,000*l.*; holes range from 6 ins. to 15 ins. in diameter. In Pennsylvania and Ohio such boring has been done for as little as 2*s.* per foot, and contracts are usually let at prices ranging from 4*s.* to 8*s.* The rate of boring is from 20 ft. per day upwards. In Middlesbrough, 8-in. holes have been put down to depths of about 1,000 ft. at a cost of about 8*s.* per foot with a speed of 60 ft. per day. Boring with flat ropes by the Mather and Platt system is used for very large boreholes, as for instance for waterworks; holes up to 45 ins. in diameter have been bored by this method.

The water-flush method, of which there are many varieties (Fauck, Raky, etc.), is used in hard rocks for boreholes of medium size (rarely under 8 ins. in diameter). Very fast boring can be done in this way; e.g. in the Ruhr district a borehole was put down to a depth of nearly 2,000 ft. at an average speed of 157 ft. per twenty-four hours; 30 to 50 ft. is quite a usual rate down to depths of about 2,000 ft., and over 20 ft. a day has been bored down to a depth of over 3,000 ft.

The hydraulic ram method appears to offer certain important advantages, especially for boreholes of moderately large diameter, but has hardly passed the experimental stage.

Core Boring.

Diamond boring is in use to-day for hard rocks; the main drawback is the high price of the 'diamonds' (bort, used in the softer rocks, costs 2*l.* to 3*l.** per carat, carbon costs 6*l.* to 12*l.* per carat), which tells severely against boreholes larger than 6 ins. in diameter. The cost of diamond boring in this country is about 7*s.* 6*d.* per foot down to 500 ft. and 12*s.* to 18*s.* down to 1,500 ft. for a 5-in. borehole. A 5-in. borehole put down in Scotland to 1,800 ft. cost only 6*s.* 4*d.* per foot; the rate of advance was about 6 ft. per day. In British Columbia a borehole 2,200 ft. deep cost 8*s.* 6*d.* per foot, and was bored at the rate of 10 ft. per day. In Victoria the Government does much boring to aid prospectors; the bores are mostly shallow, but in

* All costs throughout this article refer to prices before 1913.

one case a depth of 1,110 ft. was reached in about 120 days; the average cost of boring in coal measures in 1912 was 9*s.* 3*d.* and in the harder rocks 14*s.* per foot. In Nova Scotia 2 in. diamond boreholes put down by the Government in moderately hard ground to depths of 200 to 400 ft. averaged about 9*s.* per foot in 1913.

Steel cutting teeth can only be used in tolerably soft ground. The cutter should make 15–25 r.p.m. A 10-in. borehole in Kent was put down by this method by the Calyx Company to a depth of 1,400 ft., the speed at times reaching 10 ft. per hour.

The chilled shot method is very generally applicable, and is used for relatively large bore holes in hard ground. The cutter should run at 100–150 r.p.m.; about No. 5 shot is generally used. It is usually somewhat slower but cheaper than diamond boring. The consumption of shot with a cutter 4½ ins. in diameter ranges from 0·15 lb. per foot bored in shale to 1·2 lbs. in hard sandstone, but may be much higher in broken ground, where shot escapes into the fissures. In Nova Scotia 6 in. Government boreholes by this method averaged 10*s.* 6*d.* per foot in 1913.

The hydraulic rotary drill is the name given to a form now much used in boring oil-wells; it cuts out the whole of the material, leaving no core, the debris being brought to the surface by a water-flush. Over 100 ft. per day has been bored by this method.

Location of Bore-holes for Valuation of Alluvial.

When ground is systematically tested by pits or boreholes at regular intervals, three conventional views are possible:—

1. That there should be so many pits or holes per acre, or
2. That the distance between pits or holes should be so much, or
3. That no point on the ground should lie beyond a certain distance from a pit or hole.

The first two are those most generally held, but the last seems the most logical, and to attain it with the least amount of work the holes should lie at the corners of a series of equilateral triangles, the length of whose sides, or the distance of the pits apart, is equal to the maximum distance under condition (3) multiplied by $\sqrt{3}$. A line is run in any desired direction and staked at intervals equal to the distance between pits. From these stakes lines are turned off at angles of 60° or 120°, and staked at similar intervals starting from the turning-off point. The stakes are numbered to indicate their position on their own line and the number of the turning-off point, so that the pits sunk at them can be readily identified.

The advantages of this method over the more usual square lay-out are considerable. There is 6 per cent. less work involved in the lay-out of the holes, and 23 per cent. less in the sinking and sampling. The computation of values can also be more accurately done. Interpolation of values can be done on the plan, much as in contouring from spot levels, and a reliable assay plan prepared. (*R. T. Hancock.*)

The following is a list of some of the more important boreholes in the world:—

	£ *s.* *d.*
Lake Well, nr. Fairmont, Marian Co., W. Virginia .	7,579 ft.
Goff Well, nr. Clarksburg, Harrison Co., W. Virginia. .	7,386 „
Czuchow, Rybnik, Upper Silesia .	7,350 „ 2 3 4 per ft.
Gardena No.1, Dominguez, Cal. (rotary boring) . .	7319 „
Virginia, U.S.A. (1918)	7310 „
R. A. Geary, Macdonald, Penn., U.S.A.	7248 „
Paruschowitz, Silesia	6,572 ft. 0 11 6 per ft
Johannesburg, Transvaal . .	6,340 „
Dentingen, Lorraine	5,925 „
Bezuidenville, Transvaal . .	5,800 „ 2 2 0 „
Schladebach, Prussia . . .	5,737 „ 1 1 2 „
Dornkloof, Transvaal . . .	5,582 „
Wheeling, West Virginia . .	4,500 „
Balfour Main, Fifeshire . . .	4,060 „

Drilling Shot Holes.

Performed by hand, either by jumper for moderately hard rocks, by hammer and drill for hard rocks, or by the coal miner's hand machine, now used almost exclusively in coal and very largely in ironstone (W. Charlton, *Trans. Inst. Min. Eng.*, 1902, vol. xxiv., p. 526). Average rate of boring is 4 to 8 ins. in bituminous coal 2 to 4 ins. in shale, per minute.

'Mushrooming' of shank end of drill causes loss of 20 lbs. steel per man per annum. Tempered pear-shaped shank ends are being used at East Rand Proprietary Mines. (*Journ. Chem. Met. and Min. Soc. South Africa*, 1919, vol. xix. p. 168.)

Mechanical Drilling.

Also either rotary or percussive. Rotary drills mostly of the twist-drill type confined to the softer rocks; Steavenson electric drill averages 40 ins. per minute in ironstone, uses 6 h.p. Siemens and others make small electric drills, taking 1 to 2 h.p., boring 6 to 10 ins. per minute in coal. For boring in hard rock the Brandt machine has been used in the Simplon tunnel and in some German collieries; hydraulically driven under head of 1,500 lbs. per sq. in.; bores 15 ft. per hour in gneiss. The Kellow drill used in North Wales is similar; has drilled 5 ft. per minute in slates.

Percussive drills are almost exclusively worked by compressed air. The drills are of two kinds: piston drills, in which the drill bit is rigidly connected with the piston rod, and hammer drills, in which the piston rod strikes on the end of the drill bit, the latter being lighter, smaller, and running at much higher speeds.

Drills may be classified by their valve action:—

1. Valve moved by external tappets.
2. " " internal "
3. " " air with auxiliary valve moved by tappet.
4. Valve moved by air.
5. Valveless, the piston itself acting as a valve.

Most modern drills belong to Class 3, but several types belonging to Classes 2 and 4 are also in use; very many hammer drills belong to Class 4.

Piston drills are further classified by their piston diameter, ranging from 2 to 4 ins.; 2¼-in. drills are largely used for stoping, 2½ to 3½ ins. for drifting, 3 to 3½ ins. for sinking. In 1902 70 per cent. of the drills in use on the Rand were 3½ drills. Such drills use 60 to 90 cu. ft. of free air per minute at pressures between 60 and 90 lbs. per sq. in. A 3-in. drill evolves about 1¾ h.p., for which about 5 h.p. must be applied to the drill piston and 10 to 25 h.p. to the steam end of a direct-driven air compressor.

At the Rose Deep Mine, Transvaal, a trial run of 31 drills for 6 hours gave air consumption for 3¼-in. drills 81 cu. ft. compressed air, free air compressed to 70 lbs. pressure per minute; each drill required the consumption of 43 lbs. coal per hour to supply this air, 3·4 lbs. coal developing 1 h.p. hour. The average power of the compressor engine was 12·7 i.h.p. per drill; average drilling speed 4·5 ft. drill hole per drill per hour.

Relative air consumption of drills:—2½-in. drill, 0·445; 3¼-in. drill, 1·000; 3 5/16-in. drill, 1·069; 3⅝-in. drill, 1·123.

Average speed of boring, including setting up, is 10 to 25 ft. per 10-hour shift. Costs of boring in hard rock in Sweden are about 8*d.* to 10*d.* per foot bored, of which 40 per cent. is for wages and 30 per cent. for power; average boring speed is 5 ft. 6 ins. to 8 ft. per hour for downward holes and 4 ft. to 6 ft. 6 ins. for upward holes.

Hammer drills use 25 to 50 cubic feet of free air per minute; speed of boring about the same as piston drills, but holes are usually smaller. Hammer drills with a relatively rapid turning action of the bit and using bits with a chisel edge, but specially twisted steel, are used very successfully in coal.

A complete 6-piston-drill plant costs about 500*l.*

Two-stage compressors, delivering air at 100 lbs. gauge pressure, weigh on the average 27 lbs. and cost on the average 12*s.* in the U.S.A. per cubic foot piston displacement.

Sharpening Steel Bits.

A good blacksmith and striker can sharpen 30 to 40 bits per hour.

By the use of power drill-sharpeners, many of the shortcomings attendant upon the hand-sharpening process are got rid of, and drills can be kept true to gauge, with the result that where these machines are used it is possible to accomplish more drilling, whilst the cost of sharpening is considerably reduced.

According to experiment, the fastest cutting bit is the Carr (double chisel bit with central hole), the Z, + and 6 edged star in this order; cutting speed $\propto$ (drill diameter)$^{-2}$; cutting speed $\propto$ air pressure; pressure of 85 lbs. per square inch most generally satisfactory.

(*Bull. Amer. Inst. Min. Eng.*, August 1917, p. 1079.)

The Leyner compressed air operated drill sharpener, which can be handled by one man, is capable of sharpening up to 100 drill bits per hour, the number depending upon the size of the bits and steels to be handled.

In the case of small quarry plants or contract work, where drilling is done in the open, dry steam at a pressure of from 80 to 100 lbs. can be used, but will not give such good results as compressed air. Where a number of drills are used, a compressed air plant should preferably be installed, and is indispensable in underground drilling. With a properly laid pipe line of suitable size, there is very little loss in conveying compressed air from a central plant over very large distances.

Holman Pedestal Grinder.

(Holman Bros., Ltd., Camborne, Cornwall, England.)

With these grinders (fig. 1) it is possible to keep the shanks of drill steels straight and true in addition to trueing up the edges of drill bits and repointing picks when necessary. The machines can be used as general workshop grinders for all kinds of tool grinding.

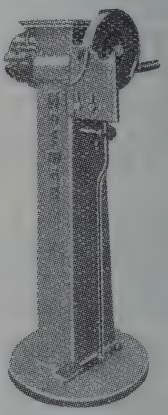


Fig. 1.

The machine does not require any foundation, but will stand wherever required, and is easily moved from place to place.

The machine provides a very economical means for cheap grinding, as it only uses power while the foot control is depressed and when released stops immediately. Full power and speed are attained immediately it is started.

The 'Holman' Drill Steel Sharpening Machine.

(Holman Bros., Ltd., Camborne, Cornwall, England.)

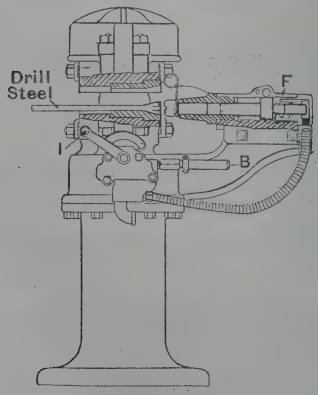


Fig. 2.

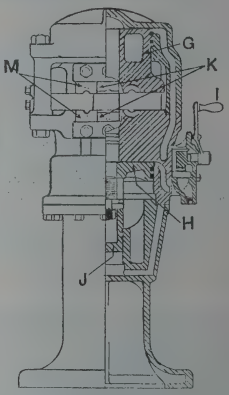
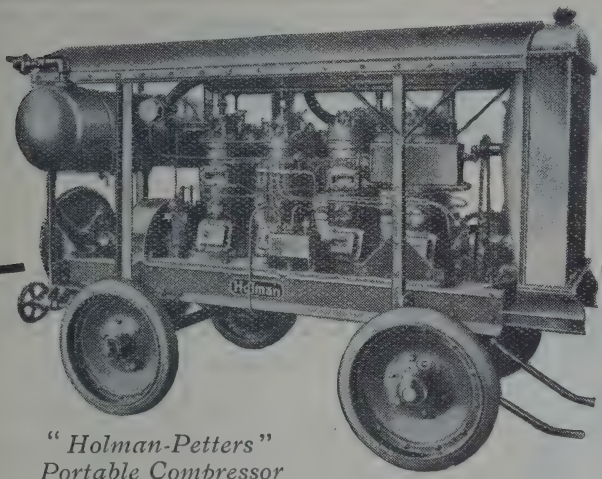


Fig. 3.

This drill sharpener is used to make various types and sizes of drilling bits for rock-drilling machines.



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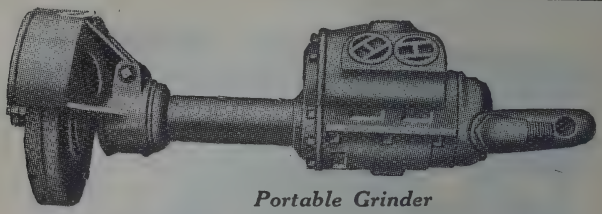
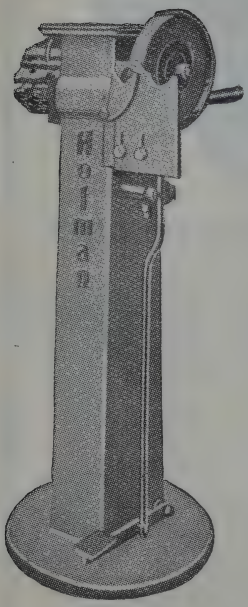


Portable Grinder

Holman Pneumatic Tools



Pedestal Grinder

Portable Grinder

Owing to its efficiency and portability, this machine is finding great favour in workshops and for all trade purposes.

The construction of the motor follows very closely that of our Air Drills. The design of the Crankshaft construction and the Roller Bearing ends has overcome overheating.

Our crankshaft runs more or less frictionless, and each machine under test has to run under full load and at free speed for four hours continuously before being passed out.

Pedestal Grinder

In rock drilling operations where hammer drills are used, it is essential that the shanks of drill steels are kept the correct size, and the ends square true with the axis of the steel, otherwise piston breakages will be common.

When these grinders are supplied as standard equipment with Drill Sharpeners, steel breakages due to improper shanking will quickly vanish, as it is possible to keep the shanks straight and true in addition to trueing up the edges of drill bits and repointing picks when necessary. The machines can be used as general workshop grinders for all kinds of tool grinding.

The machine requires no foundation.

Holman BROS. LTD.

CAMBORNE, ENGLAND

London Office: Broad St. House, E.C. 2

Gauge Pressure.	Size and Cylinder Diameter of Drill.											
	A35	A32 A86	B	C	D	D	D	E	F	F	G	H	H9
	2 ins.	2¼ ins.	2½ ins.	2⅞ ins.	3 ins.	3⅛ ins.	3 3/16 ins.	3¼ ins.	3½ ins.	3⅝ ins.	4½ ins.	5 ins.	5½ ins.
60	50	60	68	82	90	95	97	100	108	113	130	150	164
70	56	68	77	93	102	108	110	113	124	129	147	170	181
80	63	76	86	104	114	120	123	127	131	143	164	190	207
90	70	84	95	115	126	133	136	141	152	159	182	210	230
100	77	92	104	126	138	146	149	154	166	174	199	240	252

TABLE II.—MULTIPLIERS TO DETERMINE CAPACITY OF COMPRESSOR REQUIRED TO OPERATE FROM 1 TO 70 ROCK DRILLS AT ALTITUDES COMPARED WITH SEA LEVEL.

Altitude Above Sea Level.	Number of Drills.																	
	1	2	3	4	5	6	7	8	9	10	12	15	20	25	30	40	50	60	70
	Multipliers.																		
0	1·	1·8	2·7	3·4	4·1	4·8	5·4	6·0	6·5	7·1	8·1	9·5	11·7	13·7	15·8	21·4	25·5	29·4	33·2
1,000	1·03	1·85	2·78	3 5	4·22	4·94	5·56	6·18	6·69	7·3	8·34	9·78	12·05	14·1	16·3	22·0	26·26	30·3	34·2
2,000	1·07	1·92	2·89	3·64	4·39	5·14	5·78	6·42	6·95	7·60	8·67	10·17	12·52	14·66	16·9	22·9	27·28	31·46	35·52
3,000	1·10	1·98	2·97	3·74	4·51	5·28	5·94	6·6	7·15	7·81	8·91	10·45	12·87	15·07	17·38	23·54	28·05	32·34	36·52
4,000	1·14	2·05	3·08	3·88	4·67	5·47	6·15	6·84	7·41	8·09	9·23	10·83	13·34	15·62	18·01	24·4	29·07	33·52	37·8
5,000	1·17	2·10	3·16	3·98	4·8	5·62	6·32	7·02	7·61	8·31	9·48	11·12	13·69	16·03	18·49	25·04	29·84	34·4	38·84
6,000	1·20	2·16	3·24	4·08	4·9	5·76	6·48	7·2	7·8	8·52	9·72	11·4	14·04	16·44	18·96	25·68	30·6	35·4	39·84
7,000	1·23	2·21	3·32	4·18	5·04	5·9	6·64	7·38	7·99	8·73	9·96	11·68	14·39	16·85	19·43	26·32	31·36	36·16	40·84
8,000	1·26	2·27	3·40	4·28	5·17	6·05	6·8	7·56	8·19	8·95	10·21	11·97	14·74	17·26	19·9	26·96	32·13	37·04	41·83
9,000	1·29	2·32	3·48	4·39	5·29	6·19	6·96	7·74	8·38	9·16	10·45	12·26	15·09	17·67	20·38	27·6	32·9	37·92	42·83
10,000	1·32	2·38	3·56	4·49	5·41	6·34	7·13	7·92	8·58	9·37	10·69	12·54	15·44	18·08	20·86	28·25	33·66	38·8	43·82
12,000	1·37	2·47	3·7	4·66	5·62	6·57	7·4	8·22	8·9	9·73	11·1	13·02	16·03	18·77	21·64	29·32	34·94	40·28	45·48
15,000	1·43	2·57	3·86	4·86	5·86	6·86	7·72	8·58	9·3	10·15	11·58	13·58	16·73	19·59	22·59	30·6	36·46	42·04	47·47

EXAMPLE.—Required the amount of free air necessary to operate thirty 5-in. 'H' drills at 9,000 ft. altitude, using to operate these drills air at a gauge pressure of 80 pounds per sq. in.

From Table I we find, when operating the drills at 80 pounds gauge pressure at sea level, that one 5-inch 'H' drill requires 190 cubic feet of free air per minute.

From Table II we also find that the factor for 30 drills at 9,000 feet altitude is 20·38; multiplying 190 cubic feet by 20·38 gives 3,872 cubic feet air per minute, which is the displacement of a compressor for the above outfit under average conditions, to which must be added pipe line losses, such as friction and leakage.

In the first operation the heated steel is placed in the grips (fig. 2), the steel being held in one hand, the control handle in the other. This handle is pushed forward slightly, admitting air to the pistons G and H (fig. 3), which grip the steel. A further forward movement of the handle I operates the dolly hammer F and forms the rough shape of the bit. The handle is then returned to its original position, piston J lifts the grips and releases the steel, which is then transferred to the forming dies K (fig. 3). By a few quick movements of the control handle, air is admitted to one of the pistons only, to form the cruciform section. The operation is repeated until the bit is a little oversize and at an angle of 15°. The bit is then transferred to the sizing dies M and M, where a couple of blows finish it to the required diameter and give the clearance angle of 5°.

An important feature of this machine is that whilst both cylinders are used to give a powerful grip to the steel, only one is needed for ordinary swaging operations, unless a very heavy blow is required, in which case both can be used. All operations in making bits or shanks are obtained by movement of one control handle.

This is a Holman Patent (No. 5452) of 1924.

Notes on Rock Drills.

In mining practice, drills are required to be of rapid boring capacity, and at the same time of light weight, so that the work may be both rapidly advanced and the whole outfit moved in awkward places with a minimum of trouble. In driving main headings, the piston type of drill, mounted on columns, is generally used. Where space is limited, it is not uncommon to mount two drills on arms attached to one column, two runners and a helper being sufficient to handle the machines so arranged; in large tunnels the drills, from 1 to 4 in number, and of heavy pattern, are frequently mounted on drill carriages, thus enabling the equipment to be rapidly moved away from the face when the round of holes is ready for firing, without the necessity of dismantling. In stopes, raises, or small headings, the telescope-feed hammer drill, which is largely used, is a one-man drill, and is a rapid boring machine. Where the rock is of such a nature as to cause a considerable amount of dust, a condition which is to be met with in almost every metalliferous mine, drills having an automatic water feed are used. In the case of the heavy drills, the water is fed through the piston and drill bit under pressure; of this type is the Leyner-Ingersoll. Telescope-feed stope drills can also be arranged for water feed through the heads and drill bits, which have a central hole running from the shank to the cutting face for this purpose.

For hammer drill work, drill bits are furnished with single chisel, double chisel, 6 point and 'Z' cutters, the steels themselves being sometimes hollow and sometimes round, hexagonal or spiral, the section depending upon the class of rock to be bored.

Compressed Air Drilling Plants.

The Hardy-Simplex Air Hammer Rock Drill (*Patent*).

(*The Hardy Patent Pick Co. Ltd., Sheffield.*)

In this drill, fig. 4, the valve action is as follows:—When the air pressure is suddenly reduced at one end of the valve, the piston uncovers the main exhaust ports, and the full pressure acting on the opposite end causes the valve to travel to the other side of the valve box and thereby change the direction of the air pressure and reverse the piston or hammer. The action of the valve does not depend on compression set up by the piston in order to accomplish its reversal. It is not dependent on a tight piston and cylinder. It moves only $\frac{1}{64}$ in. in order to cut off the main air supply, but it has a further considerable travel before readmitting air. By the arrangement, all valve losses are practically eliminated, and the delay in readmitting air in quantity for the reversal of the piston diminishes internal resistance, so that a very powerful blow is given with a very small air consumption.

The valve will preserve its air tightness practically indefinitely, whilst at the same time it is perfectly balanced, and so light as to have great rapidity of action. The cylinder and valve box are forged together in one piece of special steel, bored, case-hardened to a glass hardness, and then accurately ground. The valve and valve bush are both manufactured from special alloy steels, both parts being hardened to suit the demands made on them. The rotation is effected by means of a rifle bar and a ratchet wheel situated at the rear of the machine in combination with a number of straight grooves cut in the piston or hammer working through a steel guide nut, situated in the chuck or drill holder. All parts of the rotation device are of hardened steel and are readily renewable.

The drills are retained by means of a cap which is provided with a strong round thread screwing over the front of the drilling machine and embracing the collar on the drill shank. The cap is slotted its full length, thereby enabling the machine to be at once disengaged from the drill steel should this for any reason become necessary.

The drills are made in three sizes, viz., the B5, B6, and B7, weighing 23 lbs., 27 lbs., and 40 lbs. respectively. The B5 pattern is for all overhead work in any class of rock; it is also used for coal boring on long wall faces and in headings, etc. The B6 pattern will bore easily

oles up to 10 ft. in depth where necessary, in rock of any hardness, the speed of boring varying rom 6 to 8 ins. per min. in hard granite to 30 ins. per min. in soft sandstone, and up to 48 ins. er min. in hard coal. Air at 60 to 80 lbs. per sq. in. The B7 pattern has been designed specially

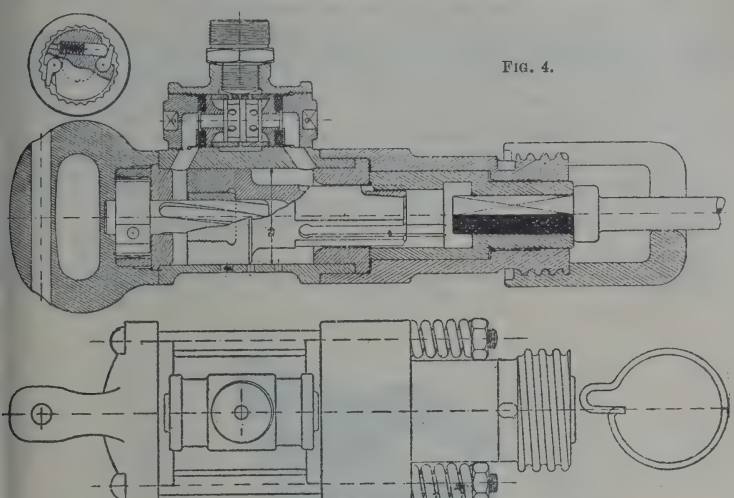


FIG. 4.

or 'down holes' in very hard ground in mine shafts and in quarries. It will easily drill holes p to 25 ft. in depth, starting at 3 ins. in diameter. Its normal boring speed in hard granite is to 10 ins. per min. with air at 80 lbs. per sq. in.

THE HARDY AIR COMPRESSOR.

(Patent.)

(*The Hardy Patent Pick Co., Ltd., Sheffield.*)

This compressor is of the vertical single-acting type, single stage. The idea has been to rovide a first-class small compressor of a simple type for driving rock drills, pneumatic ammers, etc., for use in mines, quarries, and engineering shops, and for such purposes up to 80 r 90 lbs. pressure per sq. in.

The lubrication of the whole machine is purely automatic and on the 'splash' principle.

The special feature of this compressor is the valve system. The inlet valve is situated in the iston itself, and consists of a simple ring controlling an annular inlet port in the piston head. his valve opens instantly on the down stroke, and remains open practically until the precise noment when the piston is reversed, admitting air both on its inside and outside peripheries nd thereby ensuring a very high volumetric efficiency. The great port opening combined with he absence of spring load, gives an unbreakable inlet valve with a maximum port area and a ninimum of complication.

The discharge valve is of the same ring type, made like the inlet valve of a special metal but louble-ported and spring-loaded for quick closing to prevent reflux of compressed air after lischarge. The discharge valve also uses both inside and outside peripheries, giving an ample ort area to prevent undue excess pressure at the moment of discharge. The springs are seated artly in the discharge valve guard and partly in grooves in the discharge valve. They are ery light and simple, and may be relied upon to give satisfactory service.

The water-jacketing of the cylinder walls is very thoroughly carried out and results in cool working and moderate discharge temperatures, thereby ensuring a high over-all efficiency of ompression. The cylinders are of high-grade iron, crank and connecting rod of forged steel, f full dimensions; large inspecting doors and oil reservoirs are provided. In action the ompressor is almost silent.

All machines are now fitted with automatic shut-off valve, closing the suction as soon as the lesired pressure is attained; this reopens only when the pressure falls.

The compressors are made in three sizes, giving capacities of 50, 75 and 140 cu. ft., respectively

The Holman Light Drifter.

(Type 'P.V.' 160.)

(*Holman Bros., Ltd., Camborne, Cornwall, England.*)

This drill is the latest Holman product, and is the fastest and lightest the firm has produced. Designed on standard lines, with every detail improved and several original features added, the new 'P.V.' marks a distinct advance in rock drilling practice, and may be taken as the last word in simplicity of design, reliability under practical conditions, and absence of dust in drilling.

The flap valve, although simple in construction and design, is highly sensitive, thus ensuring the greatest economy in air consumption. Two valves of the same type, but smaller, deal with the compression, enabling the piston to strike with full force and increasing the number of blows.

Among the particular advantages of the new mechanism are: the adjustable cone, and the full length cradle slide, which are important factors in drilling the maximum number of holes per shift. In ground where the 'gauge' of the bit is not seriously affected, 68 ins. in depth can be drilled with one steel. It is also useful in withdrawing the steels.

The standard type cradle can be supplied with a 42-in. feed, when required for exceptional conditions.

Another feature of this drifter is its improved water system for allaying dust. All that skilful design can do in this direction has been done, with the result that the formation of dust is absolutely impossible.

'P.V.' Drifter Valve Mechanism.

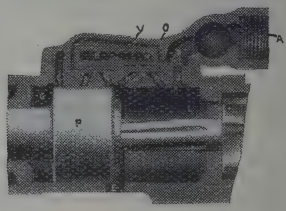


Fig. 5.

Air entering A (fig. 5) passes over the valve V to ports B and C, and moves the piston rearward. When the piston slightly opens the main exhaust E the valve lifts, and air enters port J and throws the piston forward.

Meanwhile the hollow under-face of the valve is charged with live air through ports S, which lifts it immediately the opposing pressure is reduced by the exhaust.

The air then passes under the valve, locking it in position until the exhaust slightly reduces the pressure, when the live air acting on the area of the valve projecting from the bridge and covering port J, instantly closes it, and the movement is reversed.

The compression during the above operations is dealt with by the release valves K and F which are automatically lifted by the air compressed before passing out at ports R and H.

These valves are alternately air locked by ports O and N when not in use.

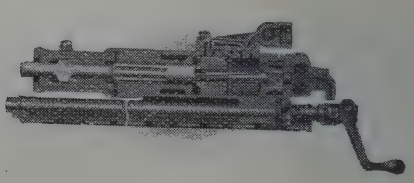


Fig. 6.—Section of Holman Light Drifter showing general arrangement of drill, also air vent at the piston point, to prevent the formation of dust. The back end shows a large oil well for lubricating the ratchet gear twist bar and nut.

For 'Holman's' Single-Stage Air Compressor, see p. 1260 ,and for 'Holman's' New Rotary ir Compressor, see p. 1261.

Metallic Tubing.

Flexible Metallic Tubing (*The United Flexible Metallic Tubing Co. Ltd.*, 112 Queen Victoria treet, London) is specially suitable for mining work. Its durability renders it economic, and it minishes 'breakdowns,' as the tubing cannot kink and is not easily crushed ; it is also unaffected y changes of atmosphere, or by vermin, white ants, etc.

Wire Clamping Tool for Compressed Air Hose.

Fig. 7 shows a tool in use in a number of the mines for winding wire around the hose to hold ie nipple in place, thereby doing away with the usual clamps and bolts.

The dimensions given are approximate for a tool used in clamping a 1-in. four-ply hose. On ie end of a piece of ¾-in. pipe 6 ins. long a standard pipe thread is cut, and on the other end a -in. bolt thread about 3 ins. long. The end with the bolt thread is inserted in the hose about ins., and the hose is ready for the wire clamping.

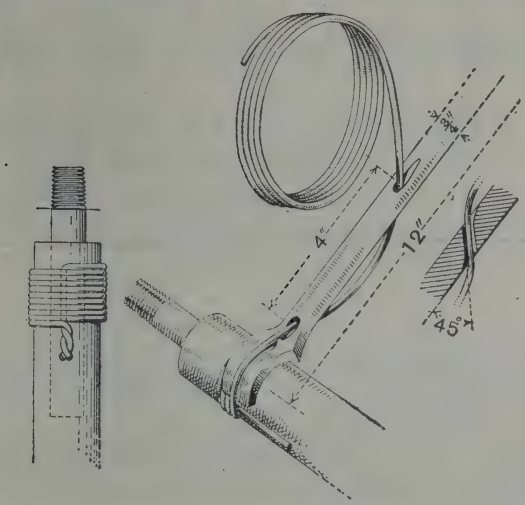


Fig. 7.

A No. 14 Stubs gauge soft steel wire is used. The wire is cut in 9-ft. lengths for winding a -in. hose, shorter lengths being used for smaller hose. The wire is first wound up on a piece f 3-in. pipe with a slot cut in it so that the wire can be hooked in it and held in place while the undle is being wound. When a hose is to be clamped, a bundle of wire is taken and started on he tool as shown in the figure. The wire is fed through the tool until about 4 ins. extends beyond he point of the tool ; this is then bent at a right angle, and is laid on the hose lengthwise. The ire is then wound around the hose layer after layer, and when the final turn is made the two ends re given two twists and the job is done. Any number of lengths of hose may be connected in his manner. The two holes through the handle are drilled at an angle of 45 deg., which gives the roper tension to the wire when winding.

(See also p. 1155.)

Air Receivers.

An air receiver is not intended so much for storage as to equalise pressure, and to allow of n even flow of air through the pipe, there being a certain amount of pulsation from the air ompressor discharge itself. In long pipe lines a smaller receiver should be placed in the pipe ine near the point of application of the compressed air, furnished with suitable drain cocks, for he purpose of drawing off the superfluous moisture which might collect, and the consequent

prevention of freezing in the line. The following table gives sizes and details of receivers which are usually considered standard practice :—

TABLE III.—AIR RECEIVERS AND PRESSURE TANKS FOR STANDARD WORKING PRESSURES. Tested to 165 lbs. Water Pressure.

Diam. in Ins.	Length in Ft.	Contents Cub. Ft. (about).	Thickness of Shell. Ins.	Thickness of Heads. Ins.	Weight Lbs. (about).	Diam. of Safety Valve. Ins.	Diam. of Inlet and Discharge Openings. Ins.	Compressor Capacity Receiver is Best Adapted for in Cub. Ft. Free Air per Minute.
18	6	10	3/16	5/16	350	1	2½	90
24	6	18	7/32	5/16	575	1¼	2½	120
30	6	29	¼	⅜	950	1½	3	150
36	6	42	¼	⅜	1,000	1½	3½	150 to 200
36	8	56	¼	⅜	1,350	1½	4	200 to 300
42	8	77	9/32	⅜	1,750	2	5	300 to 500
42	10	96	9/32	⅜	2,000	2	6	500 to 700
48	8	100	11/32	7/16	2,480	2½	6	500 to 800
48	12	150	11/32	7/16	3,000	2½	7	700 to 1,200
54	12	190	⅜	7/16	3,300	2½	8	1,200 to 2,100
60	14	275	13/32	½	5,500	2½	9	2,000 to 3,000
66	18	437	7/16	9/16	7,500	2½	10	3,000 and over
24	6	18	7/32	5/16	625	1½	4	These are only furnished horizontal style and are used as water traps in air lines.
36	6	42	¼	⅜	1,100	1½	6	
48	8	100	11/32	7/16	2,200	2½	6	

(For Air Compressors see p. 1254.)

BLASTING.

Explosives are divided into low explosives, with a slow rending action and fired by simple ignition, and high explosives, with a rapid shattering action, fired by means of a detonator. The rate of explosion of gunpowder, typical of the former, is 3 to 4 metres per second, and of blasting gelatine, typical of the latter, up to 7,000 metres per second.

For blasting in fiery coal-mines explosives known as safety explosives are employed, which have a lower temperature of detonation. No explosive can, however, be considered really safe in a fiery atmosphere. In this country only those explosives are allowed to be used that have passed the Government tests and which are scheduled in the Home Office Order in force for the time being. A shot-hole in coal should never be placed in the solid, i.e. in coal that has not previously been kirved.

If D be the depth of a properly placed shot-hole, the volume of rock blasted out averages with one free face $0{\cdot}37\ D^3$; with two free faces volume $= 0{\cdot}84\ D^3$, and with three free faces $1{\cdot}33\ D^3$. In drifting and shaft sinking the volume blasted out is approximately $0{\cdot}75\ D^3$. If L be the line of least resistance, D=about 1·75 L.

The quantity of explosive required for charging a shot-hole may be calculated by the following formula, modified from Chalon :—

Let Q be the quantity of explosive in lbs., L the line of least resistance in feet, then

$$Q = \epsilon \kappa L^2,$$

where ϵ is a coefficient depending on the explosive and κ a coefficient depending on the character of the rock.

VALUES OF ϵ.

Blasting gelatine	0·14	No. 3 dynamite (33 per cent. nitroglycerine)	0·3
No. 1 gelatine dynamite	0·20		
Tonite	0·245	Compressed powder	0·4
Roburite, bellite and similar 'safety' explosives	0·25	Ordinary blasting powder	0·6

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"The Colliery Fireman and his Duties"
"Low Freezing Explosives"
"Metal Breaking with Explosives"
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VALUES OF κ.

Very hard rocks, quartzite, hard igneous rocks, etc.	1·0
Hard igneous and metamorphic rocks, etc.	1·0 to 0·8
Schists, crystalline limestones, hard sandstones, etc.	0·8 „ 0·5
Coal measure shales, soft sandstones, etc.	0·5 „ 0·3
Chalk, soft shales, etc.	0·3 „ 0·15
Coal	0·2 „ 0·1
Gravel and other non-coherent rocks	0·1 „ 0·05

Low-tension electric fuses require a tension of about 1 volt; medium, about 4 volts; high, bout 100 volts. Low tension fuses best in series, high tension in parallel.

Liquid air is used extensively in the ironstone mines of Lorraine; a cartridge containing saw-ust, powdered cork, soot, or a similar substance impregnated with liquid air or liquid oxygen is mployed. The addition of aluminium powder to the charge greatly increases the detonating action. The uantity of liquid air used is 0·3 litre per ton of ironstone, and the cost of this explosive per ton lasted is given as 0·303 per cent. as against 0·571 per cent. with cheddite and 0·597 per cent. ith compressed black powder. Liquid oxygen is preferred to liquid air, because the latter is pt to produce fumes containing oxides of nitrogen which injuriously affect the miners, whereas ith the former no noxious gases at all are evolved.

Under Explosives Order No. 1194 of 1921, the production in the mine of an explosive by npregnating carbonaceous material with liquid air or oxygen is now permitted under licence, hus modifying Section 50 of the Explosives Act, 1875.

Detonators.

Detonators.—These are known by numbers, the charge of which varies somewhat. The ollowing is about the average practice:—

Detonator numbers	1	2	3	4	5	6	7	8
Weight of mixture in grains	4½	6	8	10	12	15	23	30

The mixture consists of 80 per cent. fulminate of mercury, 20 per cent. chlorate of potash.

Detonating Cord (Cordeau détonant) consists of a flat tube of lead, tin or aluminium usually mm. wide, 3 mm. thick, filled with nitro-methylaniline or trinitrotoluol, containing usually bout 10 grams of explosive per metre. An explosion is propagated through this at a velocity f about 7,000 metres per second. A piece of this cord is attached along a row of blasting artridges and ensures their complete and instantaneous detonation, even in wet holes. It is tated that the efficiency of the explosive is increased by 20 per cent., and that experiments at levin have shown that an explosive mixture of firedamp is not ignited by the detonation of metres of cord.

Ordinary fuse burns at the rate of 30 seconds per foot.

(See also EXPLOSIVES, p. 2783.)

ELIMINATION OF MISFIRING OF CENTRE SHOTS.

As a means towards the elimination of misfiring of centre shots in large-scale blasting in oal mines, the United States Bureau of Mines recommends that the following practices be used henever shots are to be fired in wet holes: Use waterproofed electric detonators with enamelled eg wires. When making connections with enamelled leg wires, care must be taken to scrape he ends of the wires well, otherwise the enamel will prevent good electrical contact. Fire the hots from an ungrounded power circuit that has a capacity of at least 30 kw. Use extra care hen tamping the holes in order not to damage the insulation of the leg wires. Arrange the onnections between the detonators so that they are supported clear of the earth or any other onducting medium.

Drifts.

In collieries, drifts of ordinary size, say 35 to 50 square feet in sectional area in ordinary oal measures, range in price for hand labour in 1913 from 1*s.* to 2*s.* per linear yard for each square oot, according to nature of strata and width of drift, being less the wider the drift. The cost in hale is about two-thirds of the cost in ordinary sandstone. Mean rate of advance of such drifts, bout 4 to 6 yards per week in sandstone, 6 to 8 yards per week in shale, 3 shifts per day, two niners in face with two to three labourers.

For inclined drifts rising at high angles the prices will be up to 50 per cent. higher; for drifts lipping at a high angle up to 100 per cent. In very hard sandstone the speed of driving will e about one-half, and the costs about double those given above, and in hard tough igneous ocks, such as basalts, the speed may fall to one-fourth, and the cost rise to four times these figures.

By the use of rock drills the speed may be greatly increased, especially in hard rocks, but he actual drivage costs are not much diminished, except in the harder rocks.

In making height where a top or bottom canch of stone has to be blasted, the price for a top anch of shale ranges from 1½*d.* to 2*d.* per inch for a width of 6 ft.; sandstone, 2*d.* to 3*d.* Bottom anches cost about 20 per cent. more than top canches. These prices include stowing the stone.

Driving in hard carboniferous limestone drift 30 sq. ft. in cross-section cost about 60*s.* pe yard ; three men in three shifts can drive about 4 to 5 yards per week by hand. In one case wit hand-drilling the cost was 55*s.* per yard, and rate of advance 4 yards per week, and with machine drilling the cost fell to 25*s.* and the rate of advance rose to 10 yards.

In metalliferous mines.—*By hand.*—A drift 5 ft. by 7 ft. in the clear, in rock of medium hard ness, can be driven by hand at a rate of 30 to 40 feet per month by employing two ten-hou shifts per twenty-four hours. In soft rock as much as 100 ft. per month can be penetrated. Th cost in moderate rock with labour at 12*s.* per shift will average about 2*l.* per foot, includin timber and strap rails.

By machine.—A 5-ft. by 7½-ft. drift was run in Colorado, U.S.A., at the rate of 236 feet pe month. This speed is above the average and was due to a well-trained crew (three shifts pe day) working on a bonus system. Rock was granite, gneiss, and schist, very hard to drill an breaking badly. Labour, 16*s.* per shift. Cost, 2*l.* 14*s.* per foot.

At Cripple Creek, wages 13*s.* 6*d.* per eight-hour shift, ground moderately hard, 896 ft. of 5 ft by 7 ft. drifts were run by machines, at a cost of 1*l.* 4*s.* per foot ; 1,229 ft. of 5 ft. by 7 ft crosscuts were run at a cost of 1*l.* 9*s.* per foot.

At Park City, Utah, with miners' wages at 12*s.* per eight-hour shift, a timbered drift 7 ft by 11 ft. was run in quartzite by means of 3½ inch air drill, 3 shifts per 24 hours, at rate of 4·7 ft. per day. at a cost of 2*l.* 4*s.* per foot of drift, or 7*s.* 1*d.* per ton of material broken. No hoisting

At the same mine crosscuts 7 ft. by 7 ft. in the clear are run by air drills at a rate of 8 f per day at a cost of 2*l.* 15*s.* per foot or 15*s.* per ton of material broken.

The Chipeta Adit in Colorado, U.S.A., 7½ ft. by 7½ ft. in clear, was run in hard rock a distanc of 1,712½ ft. in 152 days. The best monthly average was 342½. Two 3½ in. air drills were em ployed. The cost, including track and pipe, power, timber, labour and explosive, was 2*l.* 4 per foot. The amount of powder (40 per cent.) consumed was 14½ lbs. per foot of tunnel. Wage 16*s.* per day.

In Western Australia the drifts vary in size from 5 ft. by 7½ ft. to 6 ft. by 7 ft., and the cross cuts from 5 ft. by 7 ft. to 8 ft. by 8 ft. In eleven of the principal mines the rate of driving an crosscutting varies from 25 ft. to 90 ft. per month, averaging 60 ft. Working costs rang from 46*s.* to 103*s.* per foot, averaging 60*s.* The total costs of drives were from 3*l.* 6*s.* to 4*l.* 2 per foot and crosscuts from 3*l.* 3*s.* to 3*l.* 14*s.* At the Braden Copper Mine, Chili, all developmen work in the nature of drifts, crosscuts and upraises with average section of 4·53 square metre are run at an average cost of 14*s.* per foot driven. This cost includes all labour (native Chilian supplies, explosives, machinery, and tramming. No timber is used. The work is done unde contract and rock is moderately hard and breaks well. Machine drills are used. The rate o progress is about 130 ft. per month or 13 ft. per month per man.

Timbering Drifts.

Props 3 ins. to 5 ins. diameter and crowntrees 5 × 2½ ins. are often used in colliery drifts ; i main roads balks of much larger size may be used.

Resistance to crushing of pit props in tons per square inch of small end :

Scandinavian white wood, 1½ ; Larch, 1½ ; Scotch Fir, 1¼ ; Oak, 1 ; Beech, 1⅜.

Prof. Hudson Beare gives the following :—

Scots Pine, 1·767 ; Spruce, 1·892 ; Larch, 1·871 ; Japanese Larch, 1·379 ; Finnish Re and White Wood, 1·784 tons per square inch of mean area of prop.

In main roads ferro-concrete props are coming into use ; their crushing strength is abou 1·3 tons per sq. in. Tests by W. A. Machin (*Trans. Nat. Assoc. Col. Man.*, xv., p. 155) gav 1·58 to 1·82 tons per sq. in. on Keedon props 6 ft. long, about 4½ ins. square.

Instead of balks, steel H girders are often used. The following are some of the usual sizes :

Depth by width, in ins.	6×6	6×5	6×4	5×4	4½×4
Weight in lbs. per linear foot	31	27	24	22	18
Tons that will be carried in middle by beam 1 ft. long, supported at both ends	160	130	120	105	60

Drystone arching for roadway 6 to 7 ft. high and 3 ft. to 4 ft. 6 ins. wide in Alston distric costs about 12*s.* 6*d.* per linear yard for labour. The cost of labour for ordinary arching range from 7*s.* to 10*s.* per linear yard. Concrete arching varies from 6*s.* to 10*s.* per cubic yard of con crete put in. Arches of steel H girders supporting galvanised sheets have been used successfull in big drifts.

A coating of magnesia cement on the timbers of mines is stated to be an economical and efficient assurance against fire, especially in the arid regions where timber becomes highly inflammable and is difficult to replace. It is elastic, adheres firmly to almost any surface, and is stable and durable.

A layer of cement put on by means of a 'cement gun' (p. 496) is sometimes used for covering timbers, also the sides and roofs of drifts, etc.

In drifts in very heavy ground the Schaefer system of lining may be used ; this consists o blocks of reinforced concrete, set dry, but keyed into each other, with rows of wooden blocks t take up the squeeze ; such linings may deform under heavy pressure, but will keep the drift open (*Trans. Nat. Assoc. Coll. Managers*, vol. xxiv., 1926-7, p. 122.)

SHAFTS.

Modern shafts are generally either rectangular or circular in cross-section; the former are sed in sinking upon narrow veins or seams, where the ground is not very heavy nor the amount water excessive, or where good timber is cheap; under other conditions round shafts are pre-rred, but local custom also exercises much influence. Inclined shafts are practically always ctangular; elliptical shafts have been sunk in some places (Forest of Dean) but are now rarely sed.

Rectangular Shafts.

Rectangular shafts for large mines may be up to 25 ft. long by 15 ft. wide in the clear. xceptionally large shafts are used in Pennsylvania, e.g., No. 5 Wilkesbarre anthracite mines, ; ft. by 12 ft., Exeter Red Ash, 46 ft. 2 ins. by 13 ft. 10 ins.

Round shafts, say from 8 ft. to 24 ft. diameter in the clear; a colliery shaft to wind 000 tons per day is usually 16 to 18 ft. diameter.

Rectangular shafts are mostly wood-lined; they are either cribbed or timbered with sets olding lagging in place. In Fifeshire shafts up to 30 ft. by 12 ft. are cribbed with 'barring' 9 ins. by 3 ins. up to 6 ins. by 12 ins. The timber for a shaft 23 ft. by 8 ft., including buntons, c., would amount to about 125 cubic feet, and would cost, including nails, wedges, etc., about 3*l.* 10*s.* per fathom. The cost of sinking (the ground is usually easy) and putting in the timber about 30*l.* per fathom. In the iron-ore mines of Cumberland and Lancashire shafts about) ft. by 5 ft. are cribbed with 10 ins. × 5 ins. plank, the ends being half checked; the total ost including sinking, timbering, timber, stores, etc., is about 30*l.* per fathom, the ground being arboniferous limestone that requires blasting. Sets are made of squared timber 4 ins. × 6 ins. r a small shaft, up to 9 ins. × 15 ins. for a very large one; sets are 3 ft. to 6 ft. apart, held gether by hook bolts of 1¼-in. round iron with wing nuts.

Horned sets or bearer sets are put in about every 6 sets or so, depending on the nature of he ground; lagging is often 9 ins. × 3 ins. plank.

Round Shafts.

Round shafts are lined with brick or concrete in ordinary strata; special methods are adopted here shaft traverses water-bearing strata and the lining is required to keep back water. For afts over 18 ft. in diameter ordinary brick may be used; for smaller shafts wedge bricks should e employed. Let f be the width of the inner face of the brick, b of the outer face, l the length f the brick and R the radius of the shaft. Then $b = \frac{(R + l\,f}{R}$; if, as is often the case, $l = 2f$, is becomes $b = f + \frac{2\,f^2}{R}$. Instead of bricks, firebrick lumps 6 ins. × 8 ins. × 12 ins. to 8 ins. ×) ins. × 15 ins. may be used. They should also be made wedge shaped in accordance with the ove formula. A shaft 10 ft. in diameter lined one brick thick requires about 350 bricks laid mortar, per foot of depth. The thickness of the lining depends on the nature of the ground nd the diameter of the shaft.

Cost of Sinking.

The cost of sinking may be taken as made up of five main items: Supervision, labour, materials, ower, and interest on capital expended.

Sinking in ordinary coal measures costs 1*l.* to 2*l.* per fathom for each foot in diameter of ie shaft; to this must be added surface labour, fuel, etc., 30*l.* to 50*l.* per week. If more ater than 100 gallons per minute is met with, these costs will increase rapidly. Walling, cluding the cost of the bricks, amounts to between 15*s.* and 30*s.* per cubic yard of brickwork. 'alling a shaft 13 ft. in the clear, 15 ft. over all, cost about 15*l.* per fathom = 30*s.* per cubic ard; walling a shaft 22 ft. in the clear, 25 ft. over all, cost 24*l.* 5*s.* per fathom = 15*s.* 6*d.* er cubic yard. A walling curb costs about 10*l.* Sinking a shaft 12 ft. in the clear cost 24*l.* per thom (sinkers and waiters-on, 13*l.* 10*s.*; general labour, 7*l.* 10*s.*; explosives and stores, 3*l.*). inking a shaft 13 ft. in the clear costs 23*l.* to 30*l.* for labour in ordinary strata, and 70*l.* to 00*l.* in basalt, per fathom.

Sinking two shafts at Hylton colliery in 1897–99 cost as follows per fathom:—

	Shaft 20 ft. in the clear.						Shaft 15 ft. in the clear.					
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
Labour—Sinkers (incl. explosives)	21	0	6				17	0	0			
Wallers	7	7	2				5	11	0			
Miscellaneous	8	7	4				2	16	0			
				36	15	0				25	7	0
Materials—Bricks	9	12	0				5	2	0			
Cement, lime, sand	4	16	0				2	11	0			
Walling cribs	2	6	0				2	0	0			
Miscellaneous	0	15	0				0	10	0			
				17	9	0				10	3	0
Total per fathom				54	4	0				35	10	0

Sinking three 20 ft. shafts at Horden, each 210 fathoms deep, against a flow of 9,000 gallons water per minute, cost 350,000*l.* (*J. J. Prest.*)

The cost of sinking and tubbing a section of 22-ft. shaft at Blackhall with feeders of wate from 300 to 2,885 gallons per minute was as follows :—

	£	s.	d.	
Underground labour	70	10	10	per linear yard.
Surface „	26	13	7	
Materials, coal and stores	87	2	1	
	£184	6	6	

The cost of sinking a 22-ft. shaft through limestone and tubbing it, against feeders of wate averaging 3,000 gallons p.m., may be averaged at about 275*l.* per yard of depth.
(*J. J. Prest*, Tr. Inst. M. E. xlvii. p. 611.)

Shafts may be lined with cement, either by setting sheet iron cylinders and ramming concret round these, lifting the cylinders when the cement has set, or by walling with thin blocks or slat (about 2 ft. 6 ins. × 3 ft. 6 ins. × 5 ins.), and ramming cement behind this facing ring. Th cost of an 18-in. monolithic lining in a 22-ft. finished shaft was made up as follows :—

	s.	d.	
Mixing concrete	1	0	per cub. yd.
Cement	4	2	„
Lining shaft with concrete	2	6	„
Coal and stores	0	9	„
Steel cylinders and other plant	1	4	„
Total	9	9	per cub. yd.

There were 28 cubic yards to the fathom, hence the cost per fathom was 13*l.* 13*s.* It took seve hours to complete the concreting of one fathom.
The cost of walling a similar pit with brickwork was 24*l.* 3*s.* 3*d.*
Lining a 22 ft. shaft at Blackhall with a monolithic cement concrete (6 : 1) lining cost pe linear yard :—

	£	s.	d.
Labour in loading sand and gravel	1	18	6
Enginemen and attending mixer	0	4	1
Cement	3	13	6
Interest and depreciation on shuttering, etc.	0	19	0
Coal, stores, etc.	0	10	6
Labour in shaft	3	1	7
	£10	7	2

Lining with concrete blocks 3 ft. 6 ins. × 2 ft. 6 ins. × 5 ins. backed solid by ramming l concrete, all also 6 : 1, cost practically the same. The average cost of sinking and walling wit 18 in. concrete was 26*l.* 1*s.* 8*d.* inclusive. Suitable bricks would have cost 45*s.* per 1,000, an at this price brickwork in cement would have cost 15*l.* per running yard. (*Loc. cit.*)

In a 14 ft. pit the total costs of labour for sinking and concreting came to 15*l.* 15*s.* per fathom The cost of the concrete was about 21*s.*, and the labour of lining the shaft with it about 1*s.* 6*d* or altogether 22*s.* 6*d.* per cubic yard. There were 10½ cubic yards per fathom, so that the cos of the concrete lining amounted to 11*l.* 16*s.* per fathom; with four men at the surface and fou men in the pit, the concrete was put in at the rate of a fathom in six hours. At Karwin, Silesi an 18 ft. shaft was lined with concrete put in from above downwards at the rate of a fathom i fourteen hours at a cost of 62*l.* per fathom complete; the same shaft lined in the upper part wit brickwork had previously cost 132*l.* per fathom. Ferro-concrete has been used in place of simpl concrete. At Zweckel, near Gladbeck, a shaft was lined with ferro-concrete slabs backed wit concrete, into which the iron framework of the slabs was continued, for 23*l.* per fathom. A Rheinelbe a shaft 20 ft. in diameter was lined with Monier ferro-concrete 11 ins. thick at a cos of 2*l.* 5*s.* 6*d.* per cubic metre of lining, or 30*l.* 12*s.* per fathom of shaft: for a similar shaft at th Hansa Colliery lined 9½ ins. thick the prices were 2*l.* 3*s.* 6*d.* per cubic yard or 29*l.* 14*s.* per fathom.

Shaft Lining.

In heavily watered strata a lining has to be put in strong enough to resist the pressure of water. The thickness of such lining may be calculated as follows :—

Let R be the internal radius of the shaft, *s* the maximum admissible stress in the wall, *p* th pressure to be resisted, all to the same units, which are preferably inches and pounds, then :—

$$\text{Thickness of wall} = R\left(\sqrt{\frac{s}{s-2p}}-1\right)$$

(*Aldis*, N.E. Inst. M. E. xxxii. p. 201.)

The resistance to crushing of the various materials used in lining shafts is :—

Common brick	800 to 1,000 lbs. per square inch.
Fire brick	1,500 to 2,000 " " "
Sandstone	2,000 to 5,000 " " "
Concrete 1 : 3 : 6 to 1 : 1 : 3.	1,500 to 5,000 " " "
Average	3,000 " " "
Cast iron	90,000 to 120,000 " " "

Safe loads may be taken as $\frac{1}{10}$ of these; for best brick laid in 1 : 3 Portland cement up to 50 lbs.; for ferro-concrete up to 600 lbs. per sq. in.; for frozen sand fully saturated with water at −12° C. up to 340 lbs. per sq. in. (*Alby*, Bull. Soc. Ind. Min. 1895, p. 273.) L. Sauvestre has shown that frozen sand is highly plastic, and that its resistance to crushing increases by 8½ lbs. per sq. in. for each drop of 1° C. (*Annales des Mines*, Ser. xi., vol. ix., 1920, Pt. I, p. 5.)

The pressure to be resisted is usually taken merely as the head of water—namely, 0·434 h lbs. per sq. in., where h is the head expressed in feet. For quicksands Poetsch adopts a formula equivalent to $p = 1{\cdot}042\ h \tan^2\left(45° - \frac{\alpha}{2}\right)$, where α is the angle of repose of the sand; Poetsch gives $\alpha = 35°$ for fine quicksand, and 20° for coarse sand. These figures are used in calculating the thickness of the ice-wall required in the freezing method of sinking.

Many approximations are used for ordinary shaft linings :—

J. J. Atkinson : Thickness in inches $T = \frac{5{\cdot}2\ R\ h}{s - 0{\cdot}434\ h}$, or for cast iron $T = \frac{5{\cdot}2\ R\ h}{9{,}000 - 0{\cdot}434\ h}$.

Chaudron: for cast iron, $T = 0{\cdot}8 + \frac{0{\cdot}434\ R\ h}{600}$ where $h < 165$ ft. and $T = \frac{130}{h} + \frac{0{\cdot}434\ R\ h}{600}$ where $h > 165$ ft. (here s is taken at only 7,200).

Riemer takes $s = 11{,}400$, and writes :—

$$T = 0{\cdot}8 + \frac{0{\cdot}434\ R\ h}{950} \text{ for } h < 165,$$

$$\text{and } T = \frac{130}{h} + \frac{0{\cdot}434\ R\ h}{950} \text{ for } h > 165.$$

Cast-iron tubbing is always stiffened by ribs and flanges, and these should be taken into account (see *Morrow*, Trans. Inst. M.E. xxxiv. p. 100).

Coffering.

Coffering may be used for moderate pressures and shallow depths; costs range from 20*l.* 10*s.* per fathom (16-foot shaft) to 38*l.* per fathom (18-foot shaft), being considerably less than cost of cast-iron tubbing.

Tubbing.

Tubbing is put in either by English or German method: in the former, segments are 2 ft. to 3 ft. deep, flanges are external, not machined, and the joints are made with wood sheeting and wedges; in the latter, segments are 5 ft. to 6 ft. deep, flanges are internal, are machined, and the joints are made with lead sheeting and bolts. In both forms the tubbing is carried upon wedging curbs, followed usually by a foundation ring. In some few recent cases the wedging curb has been dispensed with, and the tubbing set direct upon a good bed.

Cost of Tubbing.

Cost of English tubbing varies with the price of pig iron, etc., from 5*l.* to 7*l.* 10*s.* per ton; cutting in the tubbing costs 2*l.* to 2*l.* 10*s.* per ton of tubbing put in, or 5*l.* to 7*l.* per fathom of shaft. The following are the detailed costs of tubbing a 15 ft. shaft with 12 segments to the ring, 2 ft. deep, ¾ in. thick, each ring weighing 2 tons 10 cwt.:—

	£	*s.*	*d.*
Three rings, 7 tons 10 cwt. at 7*l.* 10*s.*	56	5	0
Sheeting, 213 ft. at 8*s.* per 100	0	17	0
Wedges, 3,500 at 10*s.* per 1,000	1	15	0
Labour, putting in and wedging	6	0	0
Total	64	17	0
Cost per fathom, about	64	0	0

To the above must be added a due proportion of the wedging curb. The castings for the curb of a 15-ft. shaft cost 25*l.* to 35*l.*, sheeting and wedges 5*l.*, putting in and wedging 10*l.* to 15*l.* Dressing the curb seat may cost from 10*l.* to 40*l.* according to circumstances. About ten men are usually employed in the shaft in wedging tubbing, and they can wedge two to three rings per shift.

The cost of 'German' tubbing usually comes out a little less than English tubbing per fathom. The seams and joints are all machined, this costing 3*l.* 10*s.* to 4*l.* per ring; three shifts of four men can put in and bolt up four rings (20 to 24 ft.) per 24 hours.

The cost of 'German' tubbing in an 18-ft. shaft, the tubbing being 1 in. to 1¼ in. thick, 12 segments to the ring 5 ft. deep, was as follows in this country :—

	£	*s.*	*d.*	
Cast-iron tubbing, 13 tons 4 cwt. at 7*l.* 10*s.*	99	0	0	per fathom
Lead for sheeting and washers, 6 cwt.	6	0	0	
Bolts and nuts	3	5	0	
Labour	7	10	0	
Cost per fathom	115	15	0	

In the Minister Achenbach Colliery a shaft 17 ft. in diameter was tubbed with 18 rings of tubbing 8 ft. 2 ins. high, 1 in. to 1¼ in. thick, each ring composed of 10 segments. The weight of material employed were :—

Tubbing	192 tons 10 cwt.	Lead washers	1 ton 2 cwt.
Lead strips	2 „ 8 „	Bolts, nuts and washers	6 „ 3 „

Where the ground is weak and apt to run, suspended tubbing can be used to much advantage. This method was used at Astley Green (*Trans. Inst. M. E.* xxxix. p. 543), also at Hamsterley (*Trans. Inst. M. E.* xxxviii. p. 320); the latter shaft was 10 ft. in diameter and 35 ft. deep. The cost was :—

Materials, 627*l.* 2*s.* 10*d.*, labour, 141*l.* 0*s.* 3*d.*, equal to 83*l.* 16*s.* per fathom. The method is to be recommended for safety, speed and economy.

The above, which may be called ordinary methods of sinking, can only be used where a moderate influx of water has to be contended with; the greatest quantity ever dealt with by these means has been in the sinkings at Blackhall Rocks, where the Horden Colliery Company has sunk two shafts through the Magnesian Limestone in which 14,300 gallons per minute were being pumped from a depth of about 90 yards. Very much less than this is generally sufficient to cause special methods to be resorted to, 5,000 gallons per minute being generally considered prohibitive. The increase of cost due to a heavy flow of water in deep sinkings is well shown by a table of estimated costs of sinking in wet ground in Westphalia :—

COSTS OF SINKING SHAFTS 16 TO 17 FT. IN DIAMETER IN WESTPHALIA PER FATHOM.

To Depth of	Where the Average Flow of Water is	
	880 Gallons per Minute.	1,760 Gallons per Minute.
Fathoms.	£	£
27	458	548
55	566	750
82	686	960
110	804	1,170
137	914	1,316
164	1,006	1,554
219	1,188	1,920
273	1,316	2,286
328	1,554	2,652

(*L. Hoffman*, 'Glückauf,' xxxvii. p. 775.)

COST OF SHAFT SINKING IN GOLD MINES.

A shaft 4 ft. by 8 ft. in clear can be sunk in California, where wages are 14*s.* per shift, by hand drilling, at a cost of 4*l.* 10*s.* per foot. This includes labour, timbering, explosives and supplies. The hoisting done by a horse whim and no water to pump. The rate of progress is about one foot per day.

In Nevada a shaft 4 ft. by 8 ft. in clear was sunk 100 ft. in 31½ days by means of hand drilling. The cost per foot was 6*l.* 10*s.* Labour 16*s.* per shift.

Large Shafts.—In Western Australia shafts vary from 4 ft. by 10 ft. to 5½ ft. by 13½ ft. On eleven of the mines in the district the cost per foot of shaft is from 11*l.* to 16*l.*, and from 2*s.* 9*d.* to 5*s.* 6*d.* per cub. foot of material excavated. The average monthly advance was 34 ft. to 60 ft. with an average of 50 ft. Machine drills used on all above shafts.

In Utah, wages 12*s.*, a shaft 17 ft. by 65 ft. was sunk in ground of medium hardness at a ost of 12*l.* per foot driven or 1*l.* 16*s.* per ton of material broken. Machine drills used. Pumping om 300 ft. Rate of sinking 0·9 ft. per day.

On the Rand a shaft (Brakpan, Ltd.) 43 ft. by 9 ft. in the clear was sunk at a rate of 204 ft. er month. The working cost was 14*l.* 10*s.* per foot and the total cost 22*l.* 14*s.* per foot. Ground oft. Hand drilling employed.

The following are some of the Rand shafts and the cost per ton of material handled :—

Shaft.	Size.	Speed per Month.	Cost per Ton.	Method Employed.
			s. *d.*	
Rand Collieries . .	34 ft. by 9 ft.	120 ft.	10 9	Machine
Kleinfontein . .	34 ft. by 9 ft.	107 ft.	11 8	,,
Brakpan . . .	43 ft. by 9 ft.	124 ft.	8 11	Hand.
City Reef . . .	46 ft. by 9 ft.	125 ft. 6 ins.	9 2	,,
Hercules . . .	47 ft. by 9 ft.	119 ft.	8 5	,,
Wolhunter . . .	46 ft. by 9 ft.	95 ft.	10 6	,,

The Inspiration Copper Company, Miami, Arizona, sunk and completed a shaft 12 ft. 4 in. by 6 ft. 8 in., 1,400 ft. deep in 10 months.

Some exceptionally fast sinking has been done on the Rand ; thus, in one of the shafts on the rown Mines 318 ft. were sunk in August, 1925, and in one on the Randfontein Estates 386 ft. ere sunk in June 1926.

Ferro-concrete Tubbing.

(The François Cementation Co., Ltd.)

Ferro-concrete tubbing of monolithic construction is rapidly supplanting cast-iron tubbing s shaft lining. As compared with cast-iron tubbing the cost is, roughly, the same for the first 5 yds. in depth, but thereafter it becomes relatively very much cheaper. Other advantages re that it does not corrode, does not require wedging, repairing, or renewing, but increases in trength with age ; with great inertia it has great flexibility ; it is not appreciably affected by emperature variations, and it is easily adaptable to change of size while sinking. The cost of erro-concrete tubbing, to resist a static pressure of 250 lbs. to the sq. in., with a safety factor f 2 for an 18-ft. diameter shaft, is calculated at 65*l.* per lineal yard.

Winzing and Raising.

At Park City, Utah, winzes 11 ft. by 7·5 ft. in quartzite are sunk at a cost of 6*l.* per foot ink, or 1*l.* 10*s.* per ton of material broken. The advance is about 1 ft. per day. In same mine aises, 17·5 ft. by 5·5 ft., are put up at a cost of 1*l.* 14*s.* per foot or 4*s.* per ton of materia broken. he advance is at the rate of 3·3 ft. per day.

In Western Australia winzes are from 4 to 5 ft. in width and 6 to 8 ft. long. They are 50 ft. o 200 ft. deep, and the average total cost per foot in eleven of the mines is 4*l.* 15*s.*

The rises in the same district extend from 25 ft. to 120 ft. in height, and are 4 ft. to 5 ft. wide nd 6 ft. to 8 ft. long. The total cost on the average is 3*l.* 18*s.* 7*d.* per foot.

Special Methods of Sinking.

In hard, very wet ground :—

Kind-Chaudron : maximum diameter of shaft, 15 ft. ; greatest depth yet attained by it, 335 ft. ; Nos. 1 and 2 pits Marsden Colliery (the first sunk in this country by this method) ost respectively 362*l.* 8*s.* and 293*l.* per fathom ; in the North of France shafts 8 to 12 ft. iameter to depth of 100 fathoms cost 80*l.* to 240*l.* per fathom, and the rate of sinking varied om 2 to 6 fathoms per month. In Germany it is estimated that to sink 55 fathoms by this rocess at a depth of about 300 fathoms would cost about 1,400*l.* per fathom for a shaft ft. 6 ins. in diameter.

Poetsch Freezing Process.—Applicable both to fissured firm ground and to running ground he brine used is a 25 per cent. solution of magnesium chloride cooled down to —20°C., its freezing oint being about —35°C. The following table shows the pressures at which ammonia gas quefies at different temperatures :—

Temperatures.		Pressures in Lbs. per Sq. In.
—20°C.	— 4°F.	27
—10°C.	+14°F.	41
0°C.	+32°F.	62
+10°C.	+50°F.	89
+20°C.	+68°F.	125

It is estimated that to produce 100,000 negative calories per hour at —15° C., 50-60 h.p. are required at the freezing plant, and that 0·25 lb. of ammonia and 2 gallons of brine are required for each yard in length of the freezing circuit.

Saturated sand (165 parts water to 1,000 parts sand) frozen at 32° F. has a crushing strength of 242–341 lbs. per sq. in., and at — 13° F. of 2,845 lbs. per sq. in.

Shafts have been sunk to 130 fathoms by this method, the cost for shafts 13 ft. to 16 ft. in diameter ranging from about 150*l.* to 250*l.* per fathom. The cost of sinking two pits, 12 ft. and 16 ft. 6 ins. respectively in diameter, at Anzin, in 1895, to a depth of 50 fathoms, was as follows :—

	£	s.	d.	£	s.	d.
Cost of freezing plant				73	2	0
Cost of freezing operations				48	6	0
Cost of sinking and tubbing : labour	32	16	0			
Cost of tubbing	66	10	0			
				99	6	0
Total cost per fathom				220	14	0

The cost of sinking a pair of 20 ft. shafts by freezing under ordinary conditions should be :—

	£
To a depth of 50 fathoms	17,500
" " 100 "	28,000
" " 200 "	50,000

(*W. W. Wilson*, Tr. Inst. M.E. xli. 353.)

Freezing an 18-ft. shaft at Monkwearmouth cost 230*l.* per fathom to a depth of 60 fathoms.

A deep sinking was carried out by this process at Beeringen in 1920 ; a depth of 1,640 ft. of clay, quicksand, and water-bearing chalk was first sunk through in this way, and subsequently the process was applied to the more difficult task of passing through a bed of running sand 46 ft. thick, at a depth of 2,000 ft. under a pressure of 926 lbs. to the sq. in.

(*Annales des Mines*, Ser. xi., vol. ix., 1920, Pt. I. p. 5.)

At Seaham, Co. Durham, there are three freezing units, one of 300,000 negative calories and two of 150,000 negative calories each per hour (300 and 150 h.p. respectively). There are five double-acting brine pumps 10 in. diam., 10-in. stroke ; the brine is calcium chloride solution of sp. gr. 1·25. Two shafts are to be sunk 21 ft. diam. in the clear to a depth of about 490 ft.

Cement Injections.—This has been used with success in several cases, first by M. Reumaux at Lens, by M. Deffieux at the Mine de Marles (1908), and by M. François in this country ; in the former case the cost was about the same as that of freezing. The François system consists in boring 10 to 20 holes within the shaft, the bottom being first, if necessary, sealed with a plug of cement concrete ; cement slurry is forced through these holes at pressures up to 500 lbs. per sq. in., so as to fill all fissures when sinking is resumed ; another section is then cemented, and so on. Cementation in ordinary ground will cost about 50*l.* per yard for a 20-ft. shaft. See paper, Trans. Inst. M.E., liii. (1916–17), p. 22.

This system has been used in sinking a shaft 16 ft. in diameter at the Holditch Iron Mine, Chesterton, Staffs. The shaft is sunk through the water-bearing Keele strata to a depth of 632 ft., the upper bed giving off 30,000 gallons of water per hour. The total time occupied was 69 weeks, and the costs were 40*l.* 4*s.* 4*d.* for labour and 36*l.* 3*s.* 9*d.* for material per yard of finished shaft (1916–17), or together 76*l.* 8*s.* 1*d.* ; it is estimated that sinking with underhung tubbing would have cost 91*l.* 4*s.* 8*d.* The shaft was lined with reinforced concrete. Cement for injection of boreholes 350 tons 13 cwt., for the concrete walling 998 tons 6 cwt., and for the injection of the walling 50 tons 10 cwt. (*A. Hassam and T. T. Mawson*, Trans. Inst. M.E. lviii. p. 16.)

In porous sandstones M. François first injects separately solutions of silicate of soda and sulphate of alumina, and follows this up with cement. This process was used successfully at Hatfield Main, Thorne, etc. Two shafts were sunk successfully at Ollerton by this process.

In the sinking of No. 19 pit at Courrières in 1909, which was sunk by the freezing method, difficulties were encountered in the upper part of the shaft owing to running water, and these were overcome by the injection of cement to a depth of 57 ft. ; over 1,000 tons of cement were used. (*Annales des Mines*, Ser. xi., vol. ix., 1920, Pt. I. p. 38.)

In sinking through strata containing brine, *e.g.* in certain potash mines, the temperature must be reduced below —35° C. Liquid carbonic acid must be used instead of ammonia in the freezing plant and calcium chloride brine. (*Glückauf*, vol. 63, 1927, p. 293.)

In running ground :—

The Sonnenschein cementation process for sinking through quicksands consists in boring a number of holes about 5 m. deep, relatively close together, through the concrete plug in the shaft bottom. When a sufficient number of holes have been bored, water is forced down a borehole adjoining the one to be treated, thus forcing the quicksand up the latter, and leaving a conical cavity in the quicksand below the plug. Cement slurry is then forced down the borehole to be treated until the cavity previously formed is filled with cement, and the operation is repeated until a continuous body of cement, about 5 m. deep, is formed below the plug. The cement is then excavated until only enough is left to form a fresh plug, and the entire operation is repeated until the quicksand has been traversed.

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F. 2579

Sheet piling can be used for relatively shallow sinking, near the surface. At Bowburn Colliery Co., Durham, 6 fathoms of wet sand were driven through by wooden piles in 1906 at a cost of 26*l.* per fathom for timber and 34*l.* 10*s.* for labour. Interlocking steel piling (p. 607) of joists of various forms has also been used.

The dropshaft method is employed in various forms, sometimes by weighting a cutting shoe and curb, on which an iron or brickwork cylinder is built up, or more usually by building a brick or concrete pressure block against which work hydraulic rams that force down tubbing of cast iron, or in exceptionally difficult cases of cast steel. The former method (forcing down a shoe by dead-weight) was found much superior to forcing a shoe down by jacks in sinking a shaft 14 ft. by 8 ft. through 70 ft. of loose strata at Des Moines, Iowa (*Trans. Amer. Inst. Min. Eng.*, vol. lv., p. 232). The following table shows probable costs for shafts of normal size in ordinary running ground (Hoffman):—

For depth.	Cost per fathom sunk.	For depth.	Cost per fathom sunk.
	£		£
From 15 fathoms to 27 fathoms .	320	From 82 fathoms to 110 fathoms .	1,280
„ 27 „ to 55 „ .	732	„ 110 „ to 137 „ .	1,554
„ 55 „ to 82 „	1,006	„ 137 „ to 165 „ .	1,830

The *Honigmann* system has been used in a few cases down to depths of 70 fathoms on the Continent; the shaft is bored out by a dredge-borer, the walls being kept up by internal hydrostatic pressure, and the shaft is lined with tubbing composed of rings of channel iron riveted together and subsequently lined with concrete.

A sinking with a timber drop shaft lining is described in the February, 1922, *Bulletin of the Canadian Institute of Mining and Metallurgy*.

The François Cementation Process.

The origin of the use of cement grout in mine shafts is not certain. Probably the first fully authenticated use was in the injection behind shaft lining at the Rheinpreussen shaft, near Homberg, in 1864, at a pressure of 210 lbs. to the square inch. Monsieur H. Portier at Courrières in 1900 successfully injected and sealed a considerable feeder of water behind an old shaft lining of wood. Cement injection was successfully employed at a shaft sinking in Germany by R. A. Weide, at Pohlhauer, Saxe, in 1901. Early examples of its use in France were by Monsieur Remaux at Lens; and by Monsieur Deffieux at the Mine de Marles in 1908. In 1911 Mr. Albert J. François, who had previously spent some years on the Continent in experimenting with various systems of cement injection behind shaft lining and through various classes of strata, introduced his process in England, where its possibilities were at once recognised by colliery engineers, and where Mr. François was given every opportunity to improve his patents and develop his process. Over the previous crude systems his methods were as distinctive and advanced as their success was marked, and his process proved a valuable aid to the development and maintenance of coal mines in wet areas.

The process has since been introduced into France, Belgium, Germany, and South Africa, where it is extensively used. In all, forty shafts have been sunk by its means. The preliminary silicatisation of the ground, which is an essential part of the process, was first tried at Hatfield Main, in 1911, with complete success. In porous or finely fissured strata, or alluvial deposits, or generally where the injection of cement slurry proves difficult, the preliminary preparation of the ground by the injection of solutions of silicate of soda and sulphate of alumina is used, the shaft is sunk by ordinary methods until the presence of water is indicated by means of test holes. A number of holes are then bored in the shaft bottom, pipes being cemented in them, their number, position, and inclination being dependent upon the size of the shaft and the character of the strata. Through these pipes boreholes are sunk by means of a diamond drill. On the tapping of feeders by one of the holes the boring is immediately stopped and the pipe in the hole connected by means of a length of high pressure flexible hose to a column of pipes in the shaft, leading in turn to a cement pump and mixing tank on the surface. The holes are arranged in series for cementation and silicatisation, and into them cement pulp and mixtures of chemicals are pumped, the strength and proportion of the mixtures of chemicals, the percentage of cement, and the pressure employed being such as experience has shown to be best suited to the class of strata and pressure of water to be treated. The holes are cleaned out and reinjected or further deepened as necessary, the process being repeated with the various holes, boring and injecting of the different holes taking place simultaneously. The ground is treated in this manner until the desired length of ground has been rendered sufficiently watertight to allow mining and walling operations to proceed. The ground is excavated in the ordinary manner and reinforced concrete walling built up, any water not sealed off by the cementation of the boreholes being shut off by injections between the completed lining and the ground. On the walling being completed a second length of ground is excavated and walled, this procedure being continued till the water-bearing strata has been passed through. The lining employed through water-bearing or bad ground is ferro-concrete tubbing of monolithic construction. Cementation in ordinary ground will cost about 50*l.* per yard for a 20-ft. shaft (see *Transactions of Mining Engineers*, vol. liii., 1916, p. 22). For a more complete description of the process see paper by H. Standish Ball, *Proceedings of South Wales Institute of Engineers*, vol. xxxvi. No. 2, p. 111. See also p. 2578.

Mr. Eustace Mitton estimates the cost of sinking through the Bunter sandstone by cementation, including the installation of ferro-concrete tubbing to a depth of 200 yards for an 18-f shaft, at £350 per lineal yard. (*Midland Counties Institute of Engineers*, October 15, 1921.)

At two shafts recently completed at Harworth Main, where there was an indicated quantit of water of 3,000 gallons per minute, the shafts were rapidly and successfully sunk by th François process, with a total residual water in both shafts of 6 gallons per minute (see 'Harwort Sinkings,' *Colliery Guardian*, Nov. 17, 1922; see also p. 2578); while at two shafts recently com pleted at Ollerton Colliery, where the estimated amount of water was even greater than this, th shafts were sunk by the François process with an average of residual water of only two gallo per minute in each shaft. (See paper read by Mr. H. Eustace Mitton before the Institution Mining Engineers, November 4, 1925.)

The François cementation process was successfully employed in preference to sheet pili at Haugh Colliery, Kilsyth, Scotland, for sinking from the surface to some 6 fathoms in dept through running ground.

See also L. Souvestrie, *Annales des Mines*, 12th series; *Colliery Guardian*, Nov. 10, 192 an article in the *Iron and Coal Trades Review*, Sept. 8, 1922; *Kropf Industriebau*, Oct. 15, 192 'Cementation des Grès Vosgiens,' by F. Arguillère, *Rev. Ind. Min.*, Nov. 1, 1927, p. 451.

The time required to cement a 20-yd. length of shaft in various rocks is as follows:

Bunter Sandstone	16 days	Limestone	18–19 days
Pennant Sandstone	16 ,,	Chalk	12 ,,

and the quantity of cement required per yard of 20–22 ft. shaft has been found to be:—

Pennant Sandstone	15 cwt.–3 tons	Bunter Sandstone	5 tons–6 ton
Magnesian Limestone	2 tons–4 tons	Chalk	up to 4 ton
Triassic Sandstone	3 tons–6 tons		

Where silicatisation is employed, the consumption of silicate of soda is 1½ to 5 tons per line yd., and that of sulphate of alumina about half of this.
(*Vertical Shaft Sinking*, by E. O. Forster Brown, 1927, pp. 147, 148.)

Under special conditions when very rapid setting cement is required, 'cement fondu' h been used in place of ordinary Portland cement, and in intensely cold ground a mixture magnesia and magnesic chloride has been used.

List of Deep Shafts in the World (1912).

Mine and Shaft.	Locality.	Depth, Ft.	Mineral Wrought
St. John Del Rey	Brazil	6,726	Gold
Village Deep Main	Central Rand	6,263	,,
Champion Reef	Kolar, India	6,094	,,
Tamarack, No. 3	L. Superior	5,309	Copper
Calumet and Hecla, Red Jacket	,,	4,920	,,
Victoria Reef Quartz	Bendigo	4,614	Gold
Tamarack, No. 4	L. Superior	4,450	Copper
New Chum Railway	Bendigo	4,318	Gold
Flenu, Ste. Henriette	Belgium	3,809	Coal
Viviers, Gilly	,,	3,750	,,
Przibram, Maria	Bohemia	3,694	Silver, Lead
Przibram, Adalbert	,,	3,665	,,
Lazarus New Chum	Bendigo	3,682	Gold
Kimberley Main Rock Shaft	Kimberley	3,601	Diamonds
Kimberley Prospect Shaft	,,	3,520	,,
Kennedy	California	3,555	Gold
Westfalen I	Ahlen, Westphalia	3,566	Coal
Sachsen I	Heesen, ,,	3,560	,,
Zwickau, Morgenstern	Saxony	3,550	,,
Long Tunnel Walhalla (incline shaft)	Walhalla	3,450	Gold
Oelsnitz, Frisches Glück	Saxony	3,055	Coal
Dolcoath, William Shaft	Cornwall	3,000	Tin
Kaiser Wilhelm II.	Clausthal	2,960	Silver, Lead
Ashton Moss	Lancashire	2,880	Coal
Cooks Kitchen	Cornwall	2,580	Tin
De Beers Main Rock Shaft	Kimberley	2,466	Diamonds
Rosebridge	Lancashire	2,446	Coal

The Barnsley Bed was cut in the Thorne sinkings at 2,765 ft. on August 22, 1924.

In 1924 the total depth of all shafts in mines in Great Britain coming under the C.M.R. Act was 45,000 yds, and the ratio of shaft yardage to average tons of daily output was 1 : 1·183 ; in the U.S.A. the ratio of output appears to be at least 15 times as great.

(*Vertical Shaft Sinking*, by E. O. Forster Brown, 1927, p. 372.)

Coal Cutters.

In coal-getting by longwall, props with lids are set along the working face at definite distances apart, there being 1, 2, or 3 rows, as conditions may require. As far as possible, these props are drawn as the face advances, the control of the roof being a matter of prime importance. Steel props, constructed so as to yield to some extent under pressure, have been substituted with much advantage in several places. In the U.S.A. some collieries have adopted adjustable chocks, which can be advanced by screw or hydraulic jacks.

In hand kirving, the average height of a kirving is 13½ ins. in front and 1⅜ in. at back, by a depth of 3 ft., giving a volume of 1·9 cub. ft. of coal kirved out per linear foot of coal face (equal to 16 per cent. on a 4 ft. seam). In a 6-hour shift a hewer in ordinary coal will kirve a bord 5 yds. wide to a depth of 1 yd. or about 7½ sq. ft. per hour of shift. A man will kirve about 9 sq. ft. per hour's actual hewing time after the jud has been nicked in a bord ; in a wall he can kirve about three-quarters as much as in a bord, and in longwall work he can kirve one and a-half times as much as in average narrow work. Allowing for his other work a hewer in Northumberland and Durham averages about 38 sq. ft. of kirving per shift.

Machine cutting gives up to about 65 per cent. more output per man employed ; on the average about 10 per cent. more round coal is made by machine than by hand ,and a greater output of coal can be obtained from a given seam.

Coal-cutting machines for longwall work are chain-cutters, disc-cutters and bar-cutters, the former being applicable in seams where the coal is fairly hard, the cleat not too well marked, and the roof tolerably good. The disc machine makes a kirving 3⅜ ins. to 5½ ins. deep, the bar machine a kirving tapering from 7½ ins. in front to about 3½ ins. at the back. Machines may be air-driven, using compressed air at 35 to 65 lbs. per sq. in. at the machine, or electrically driven (direct, alternating, or tri-phase) at voltages of 250 to 450. The power consumption varies between wide limits, between 12 and 30 h.p. Compressed air coal-cutters cost 250*l*. to 300*l*., electrically-driven coal-cutters 350*l*. to 450*l*. ; a complete plant for a pit using 10 machines would cost about 10,000*l*. with the former and 11,000*l*. with the latter form. The area undercut per hour varies from 45 to 140 sq. ft., 90 sq. ft. being about an average, per hour of running time. An average shift's work may be taken as about 500 sq. ft. Air consumption 1,000 to 3,000 cub. ft. free air per sq. yd. undercut.

According to Mr. Mavor (*Trans. Inst. Min. Eng.*, vol. l., p. 641) a good compressor will compress 6 cub. ft. free air per minute to 60 lbs. per sq. in. per b.h.p. Tests showed coal cutters to use 143 to 1,146 cub. ft. free air per minute, or 620 to 3,642 cub. ft. per sq. yd., at mean pressure of 23 lbs. per sq. in. at machine and 68 lbs. at compressor.

Costs.

Mr. Mavor gives average costs as follows :—

	Per shift. s. d.	Per ton. d.
Interest 5 per cent. on 450*l*.	1 9	0·21
Depreciation 12½ per cent.	4 4	0·52
Labour	33 0	4·00
Air power	23 0	2·77
Picks, oil, etc.	8 4	1·00
Repairs	12 10	1·50
Total	83 3	10·00

Gate-end loaders are coming into use.

In narrow work percussive coal-cutters are mostly used, also chain-heading machines and arc wall machines. Percussive cutters supported on a fixed column are mostly in favour ; they work with compressed air at 50 to 70 lbs. per sq. in., the air consumption being 100 to 300 cu. ft. of compressed air per sq. yd. undercut ; different makes run at 300 to 600 blows per minute. A machine has undercut 30 sq. ft. per hour, but their usual performance is 80 to 100 sq. ft. per shift. Percussive cutters of the Ingersoll type on wheels are also used ; these machines weigh 5 to 7½ cwts. ; they use air at 70 to 90 lbs. pressure per sq in., with an average consumption of 100 cu. ft. of free air per min., and strike about 150 blows per min. ; they will undercut 15 to 50 sq. ft. per hour of running time, or 50 to 200 sq. ft. per shift.

Chain heading machines may be driven electrically or by compressed air, using 10 to 20 h.p. ; these machines can undercut about 50 sq. ft. per hour, but it is rare that 200 sq. ft. can be kirved per shift. See 'The Driving of Narrow Places,' by S. Walton-Brown (*Trans. Inst., M.E.*, vol. lxxiii, 1927, p. 506).

Arcwall machines will cut 10 to 15 places per shift in roads 4 to 5 ft. wide, the usual depth of undercut being about 6 ft. ; these machines weigh about 3½ tons, and their motors develop about 40 h.p.

The Stanley header cuts roads circular in cross-section through coal, using 15 to 40 i.h.p. road 5½ ft. in diameter can be driven through coal at the rate of 10 ft. per 8-hour shift, or six time as fast as handwork, the cost being sometimes rather less, sometimes rather more than han labour, namely 2*s*. 6*d*. to 4*s*. per foot of advance, everything included, as against 2*s*.8*d*. per hand.

The Jeffrey Entry driver cuts, breaks down, and loads the coal into tubs.

In the U.S.A. Longwall machines with jibs 40 ft. long cut and load 350 tons per shift. machine with a 50 ft. jib is worked by five men, and in a 6 ft. seam with a strong sandstone ro cuts and loads 200 tons per shift or 400 tons per day ; a machine with a 200 ft. jib, to cut and loa 1,000 tons per shift. is being built.

In connection with coal-cutters in thin seams face conveyors are much used for bringing th coal to the gateways. There are four main types :—(1) troughs containing scraper-chains, eithe endless or reciprocating, (2) endless belts, (3) shallow trucks or trays hauled by ropes, (4) shak conveyors. The Blackett conveyor is an example of the first type ; the chain is 6-inch pitch an rests in a trough 12 ins. wide at the bottom, 18 ins. at the top, 9 ins. deep, made in 6 ft. lengths ; will carry up to 30 tons per hour along faces 100 yds. in length. Most of the other forms hav lower capacities. and are suited to smaller outputs or shorter faces. In one case where hand-cuttin and filling cost 2*s*. 4*d*. per ton (face costs only), machine cutting and hand filling cost about 1*s*. 8 per ton (1*s*. 4*d*. face costs, plus 4*d*. for power, repairs, stores, depreciation), and machine cuttin and conveyor filling 1*s*. 3*d*. (9*d*. and 6*d*. respectively). In most cases a considerable saving shown. especially in stonework, but the amount varies considerably according to circumstances.

On the Continent shaking trough conveyors are much used, and are also coming into use in th country. (See *Glückauf*, vol. 61, 1925, pp. 89–149, and vol. 63, 1927, p. 1449).

Face loaders are coming into use in the U.S.A. Amongst the leading types are :

O'Toole loader—undercuts the coal so that it falls on to a belt conveyor.

Jeffrey loader—somewhat similar in principle ; it has been introduced into Great Britai

Wilson chain loader—has gathering arms combined with a conveyor.

Joy loader—is a combined digger and conveyor.

Goodman machine—somewhat similar in principle.

Myers Whalley—mechanical shovel loading into tubs.

Jeffrey Co. and others make scrapers combined with conveyors.

Wages and general costs may be taken as 50 per cent. higher in 1927 than all those her given.

The 'Hardiax' Coal Cutter.

(*The Hardy Patent Pick Co., Ltd., Sheffield.*)

This cutter consists essentially of a long stroke air-drill, which is fixed in position and hel up to its work by means of a solid drawn steel tube provided with powerful jack-screw an toothed head and foot. The machine is seated in a cone cup forming part of a hinged clam

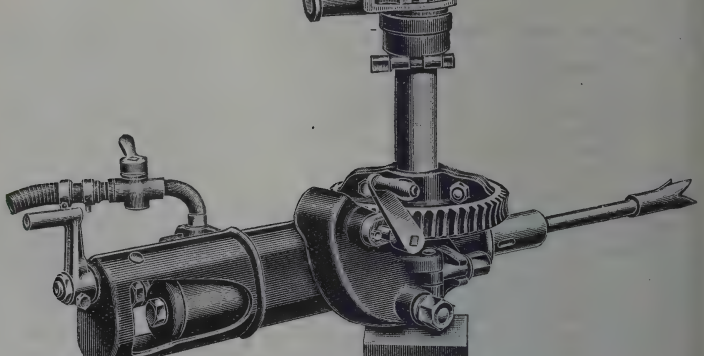


Fig. 8.—The 'Hardiax' Coal Cutter.

attached loosely to the column. This clamp carries a worm, the teeth of which mesh with those of a worm-wheel bolted rigidly on the column. By turning the worm-handle the coal cutter is caused to move around the column, whilst the forward movement into the coal is obtained by the feed screw controlled by a handle at the back of the machine. Figs. 8 and 9

give side views of the complete apparatus fixed for work at floor level. The machine may be fixed to cut at any height between floor and roof. The friction between the hinged clamp carrying the machine and the column itself is regulated to a nicety, relieving the worm of the shock of the recoil without in any way impeding the free movement of the machine right and left across the coal face.

When air is admitted to the machine the rapid and powerful blows quickly cut away the coal or other material, whilst the machine is swung right and left by the worm gear and fed forward as is necessary. An arc-shaped and continuous channel or undercut is thus speedily made, increasing in depth and width as each successive length of cutter-bar is inserted in the piston of the machine.

As soon as the desired depth is attained at the centre of the working place the operator commences to play in gradually decreasing sweeps upon the right- and left-hand sides of the arc-shaped cut, using longer cutter-bars where necessary until the undercut or channel is of uniform depth at every point, and square at the sides and corners. When pillars are taken out, or in working on a longwall face, the successive cuts break into one another, giving a continuous undercut of perfectly even depth the whole length of the coal face, whatever this may be. The cut may be any width up to, say, 20 ft. from one setting of the column. The depth of the cut is generally from 4 ft. to 6 ft. and the height 3¼ ins. to 4¼ ins. The diameter of the cutters is varied to suit different requirements.

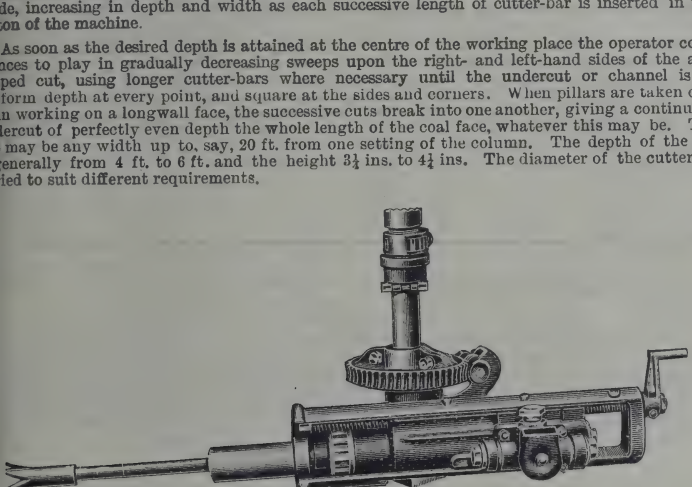


FIG. 9.—THE 'HARDIAX' COAL CUTTER.

The special constructional features of the machine are: (1) Crucible Cast Steel Cylinder. (2) Crucible Cast Steel Valve Box. (3) Crucible Cast Steel Cradle. (4) Crucible Cast Steel Gears. (5) Valve and Main Piston Hardened and Ground.

The machine is provided with a new patented piston valve action, giving great cutting power with low air consumption.

The air-pressure should, preferably, be from 40 to 60 lbs. per sq. in. or more, at which pressure the air consumption is approximately 120 cub. ft. free air per minute.

Shaft Pillars.

The 'draw' in ordinary Coal Measure strata, practically horizontal, is generally between 5° and 12° to the vertical. In Staffordshire 'draws' between 8° 45′ and 11° 10′ were observed in strata dipping 1 in 24 (W. Hay, *Trans. Inst. Min. Eng.* xxxvi. p. 47). The Final Report of the Coal Conservation Committee (Cd. 9084), 1918, p. 64, implies that the maximum angle of draw to be expected is 26° 35′.

There are reasons for assuming that the angle of draw in practically horizontal strata equals $45° - \frac{\text{angle of repose}}{2}$. For inclined strata the following formula is suggested:

$$f = b + 40 \tan (d° - 5°) \text{ and } f_1 = b - 20 \tan (d° - 5°),$$

where f is the angle of draw on the rise side of a pillar or due to workings to the dip, f_1 on the dip side of a pillar or due to workings to the rise, b the angle of draw (measured to the vertical) in horizontal strata, and d the dip of the strata measured to the horizontal. When d is $< 5°$, f and f_1 are taken as equal to b, and where d is $> 30°$, f and f_1 are taken as for 30°. For low values of b, f approximately equals b, and f_1 approximately equals 0; f_1 can never have a negative

value, but the formula is not to be relied on for values of b of less than 10° (*Trans. Inst. Min. Eng.* 1922). The following values of f and f_1 are calculated from the above formula in order to show its application :—

d.	Values of b.											
	10°				15°				20°			
	f.		f_1.		f.		f_1.		f.		f_1.	
Deg.	Deg.	Min.	Deg.	Min.	Deg.	Min.	Deg.	Min.	Deg.	Min.	Deg.	Min.
5	10	—	10	—	15	—	15	—	20	—	20	—
10	13	30	8	15	18	30	13	15	23	30	18	15
15	17	03	6	28	22	02	11	28	27	03	16	28
20	20	43	4	38	25	43	9	38	30	43	14	38
25	24	34	2	43	29	34	7	43	34	34	12	43
30	28	39	0	40	33	39	5	40	38	39	10	40

In Coal Measure strata b approximates to 10°, in Secondary strata to 20°, and in unstratified surface deposits to 30°.

In Westphalia (*Zeitsch. f. B. H. u. S. W.*, 1897) the draw in the Coal Measure has been found to be 15° on both rise and dip sides when the dip of the seam is $<$ 15° ; for dips exceeding 15°, the draw is 15° on the rise side and increases uniformly up to 35° on the dip side, reaching this value with seams dipping 35°. In the overlying clay deposits the draw is uniformly about 20°. The depth of subsidence is kT cos a, where T is the thickness of the seam and a its inclination; k is a coefficient, which is 0·8 when the goaf is not stowed at all ; with a well-stowed goaf, k is 0·4 when a is 0° to 10°, 0·3 when a is 10° to 35°, and 0·25 when a is 35°.

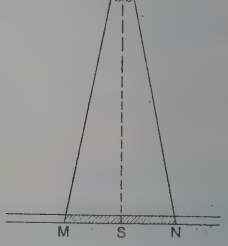


FIG. 10.

When a pillar is required to protect a colliery shaft or some structure on the surface, its dimensions can be obtained from the above formula. Thus, let it be required to determine the pillar to be left in to protect a point P (figs. 10 & 11) on the surface; let the depth of the seam be PS = D; then in a seam practically horizontal a circle, described with S as centre and radius x (SM or SN) = D tan b, will give a sufficient pillar. If the seam is inclined at an angle of d°, determine f° and f_1° as above. In fig. 11 let SB = y and SD = z, then $y = \frac{\text{D tan } f}{1 + \tan d \tan f}$, and $z = \frac{\text{D tan } f_1}{1 - \tan d \tan f_1}$.

Through P draw MN in fig. 1, with PM = PN = x as before. On the rise side of MN set out the

emi-ellipse MBN with $2x$ as the minor axis and $2y$ as the major axis, and on the dip side of MN ct out the semi-ellipse MCN with $2x$ as the major axis and $2z$ as the minor axis. This gives the lan of a pillar to protect the point P; if preferred, the rectangle circumscribing the figure formed y the two semi-ellipses may be used.

Another method, being practically that of Mr. T. A. O'Donahue, is as follows:—If D be the lepth of the seam and T its thickness, in a horizontal seam a pillar of radius R should be set out such

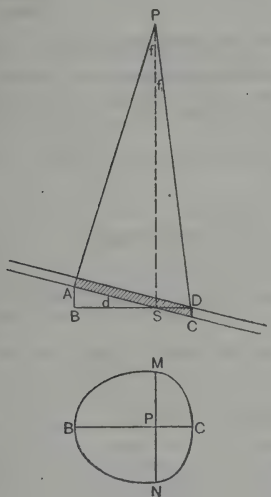


FIG. 11.

that $R = (0{\cdot}19 + 0{\cdot}01\,T)D$, all dimensions being in fact. If the seam is inclined at an angle $d°$ as above, the distance from the vertical through the point to be protected to the edge of the pillar on the rise side should be $R + \frac{2D}{3}\left(\frac{\tan d}{1 + \tan^2 d}\right)$, and on the dip side $R - \frac{D}{3}\left(\frac{\tan d}{1 + \tan^2 d}\right)$. A circular pillar should be set out with radius $R + \frac{D}{6}\left(\frac{\tan d}{1 + \tan^2 d}\right)$; the centre of the circle being at a distance $\frac{D}{2}\left(\frac{\tan d}{1 + \tan^2 d}\right)$ to the rise side of the point S. If a rectangular pillar is preferred, the square circumscribing this circle may be set out. Various other formulas have been proposed, but the two above given appear to be satisfactory.

If an area on the surface is to be protected instead of a point, a number of suitable points on the periphery of the area (e.g. the corners of a rectangle) should be selected and the protecting pillar for each be determined as above; the irregular figure thus obtained should be enclosed in any simple geometric form, re-entering angles being avoided. In a case like this, where so much uncertainty prevails as to the correct solution, an approximate result is all that can be arrived at, and a liberal margin should be allowed for safety.

Bord and Pillar working.—Pillars may be square but are mostly rectangular, sides varying from 30 to 80 yds.; 30 yds. by 40 yds. to 40 yds. by 60 yds. are usual sizes. Some engineers give areas proportional to depth; for seams 100 to 200 yds. from surface, pillars about 30 by 40 yds.; 200 yds. to 300 yds., 35 by 50 yds.; 300 to 400 yds., 40 by 60 yds.

The Coal Conservation Committee of the Ministry of Reconstruction recommends the following proportions :—

Depth from Surface.	Area of Pillar.
< 100 yds.	300 sq. yds.
100–200 ,,	500 ,,
200–300 ,,	800 ,,
300–400 ,,	1100 ,,
400–500 ,,	1400 ,,
500–600 ,,	1700 ,,

In *panel working* a rib 30 to 60 yds. wide is left between the districts, the latter being usually 20 to 50 acres in area. In American mines the width of rib is often determined by the expression T (5 + 0·01 D), where T is the thickness of the seam and D its depth below surface.

Welsh Stall working.—Single stalls are usually about 12 yds. wide with 12-yd. ribs, double stalls up to 18 yds. wide with 24-yd. ribs between them. In America the following method is sometimes used :—

Width of pillar $W = \frac{T\ D}{100}$, and width of stall $= \frac{D}{W}$, where T is the thickness of seam and D its depth, both in feet.

Subsidences.

According to O'Donahue, the working out of a coal seam 4 ft. thick will cause a subsidence of the surface of 3 ft. if the seam be not more than 200 yds. deep, and from 12 to 18 ins. if it be 800 yds. deep. It was shown that at Monkwearmouth, working two seams 6 ft. and 4 ft. thick respectively at depths of 1,725 ft. and 1,600 ft., caused surface subsidences of 6 ft. to 6 ft. 9 ins.

At Dunkirk collieries working two seams 5 ft. and 6 ft. thick, 50 yds. apart, at a depth of 445 yds., caused a subsidence of 6·8 ft. in five years and 8·92 ft. in ten years, after which it ceased.

In Staffordshire working a 5 ft. seam at a depth of 1,626 ft. caused surface subsidences varying from 1·34 to 1·47 ft.: these reached their maximum in about 29 months.

Final subsidence at the surface is equal to the thickness of the seam actually worked out (i.e. the thickness of the seam after allowing for any stowage) less the expansion due to the breaking up of the superincumbent measures. If t is the thickness of the seam and d the depth of the seam both in feet, and k the coefficient of expansion of the strata, the surface subsidence equals $t - kd$; in ordinary coal measures with seams of moderate thickness and at moderate depths k appears to be of the order of 0·2 per cent., so that if D is the depth of the superincumbent strata in hundreds of feet, then the subsidence equals $t - 0{\cdot}2$ D feet. The coefficient appears to increase with increasing thickness of the seam, which gives the strata more room to break, and it decreases as depth increases, probably because the weight of the overlying strata re-compresses to some extent the strata expanded by fracture, and this effect appears to be sufficiently well marked to prevent $t - kd$ ever coming down to zero, though it is not impossible that it might do so in the case of narrow seams at very great depth.

There are too few data available to give numerical expressions for the above general statements.

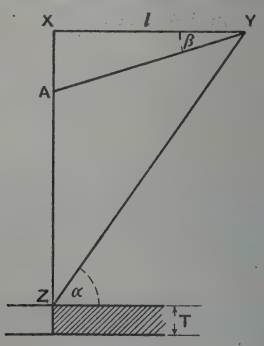


FIG. 12.

Besides the vertical subsidence over the worked-out area, a zone of draw exists over the solid coal, the breadth of which = depth of seam × tan angle of draw as given above. Let XY, fig. 12 (p. 2586), represent the zone of draw.

Let S = XA be full vertical subsidence; l = XY be length of draw (width of zone of draw); H = depth of seam; T = thickness of seam; $\alpha°$ = angle of draw measured to the horizontal, said to be about 70° in coal measures; $\beta°$ = angle of inclination of drawn surface.

There is a horizontal displacement from Y to X, and this is a maximum in the middle of the zone of draw, becoming zero at X and Y.

Tan $\beta = \frac{S}{l}$ $l = H \cot \alpha$. For seams 4ft. to 10 ft. thick, S = (0·5 to 1·0) T, when unstowed, (0·25 to 0·5) T, when hand-stowed. Maximum horizontal displacement varies from 0·05 to 0·3 T, and = $\frac{Sl}{4H} = \frac{S \cot \alpha.}{4}$

(*A. H. Goldreich, 'Die Bodenbewegungen im Kohlenrevier und deren Einfluss auf die Tagesoberflächе.'* 1926.)

In the Zwickau (Saxony) district seams differing 15°, aggregating 28 ft., worked at depths from 2,000 ft. to 3,000 ft., cause subsidence of 70 per cent. of thickness worked by goafing, 40 per cent. by hand-stowage, 10 to 5 per cent., averaging 7 per cent., by hydraulic stowage. The angle of draw by the two former methods is 80°, flatter by last-named method. In mining under densely built-over areas hydraulic stowage gives better protection against damage than leaving safety pillars. (*Goldreich, op. cit.*)

Working Costs in Getting Coal.

Working brokens is usually about 25 per cent. cheaper than working in the whole coal.

(But see 'The Driving of Narrow Places,' by S. Walter-Brown, *Trans. Inst. M.E.*, vol. lxxiii., 1923, p. 506).

Typical examples of basis yard prices in whole coal to show relative costs:

	2 yds. wide.	3 yds. wide.
Winning headways	1*s.* 6*d.*	1*s.* 2*d.* per yard
Holing walls	1*s.* 5*d.*	1*s.* 2*d.* „
Bords	1*s.* 1*d.*	0*s.* 11*d.* „

In brokens.—Jenkins, 3 yds. wide, 8*d.*; half-pillar walls, 3 yds. wide, 10*d.*; skirtings, 3 yds. wide, 6*d.* per yard.

Allowances for wet places ½*d.* to 1*d.* per ton; for band up to 2½ ins. thick, ½*d.* per ton, with ½*d.* additional for every further inch in thickness of band. For taking down ramble 3 ins. to 6 ins. thick, 1*d.* additional per ton, with 1*d.* additional for every further 3 ins.

Longwall.—Hewing price is usually about halfway between whole and broken tonnage price. An average hewing price may be taken to be 1*s.* 6*d.* per ton for a 3-ft. seam, the price rising or falling 1*d.* per ton for every 1 in. decrease or increase in thickness of seam.

All these prices are subject to local percentage increases.

PERCENTAGES OF ITEMS IN PRICE OF COAL AT PIT'S MOUTH.

Year	1913.	1901.	1866–96.	1700–50.
	Per cent.	Per cent.	Per cent.	Per cent.
Royalty	5·35	7·96	8·5	12·5
Wages	62·55	67·37	66·0	37·5
Materials	16·45	16·54	17·0	25·0
Administration	7·00			
Interest and Profit	8·65	8·13	8·5	25·0

Recent costs are given as follows:—

	Average for 1913.*	Average for Year ending March 31, 1920.*	Average for 1922.	Average for 1923.†	Average for 1924.†	Average for 1925 (10 months.)†
	s. d.	*s. d.*	*s. d.*	*s.*	*s.*	*s.*
Labour	6 4	19 7¾	12 1	11·90	13·24	13·05
Timber and stores	1 0	3 10	2 4	1·97	1·99	1·79
Other costs	0 11	1 6		2·72	2·86	3·03
Administration, etc.	—	0 1	3 2½	—	—	—
Control and contingencies	—	0 2		—	—	—
Royalties	0 5½	0 6½	0 7	0·42	0·44	0·45
Capital adjustments	—	0 4		—	—	—
Owners' profits	1 5	1 2	0 11½	0·53	0·54	—0·08 (loss)
Pithead value	10 1½	27 3¼	19 2	17·54	19·07	18·24

Hydraulic Stowage.—The best built packwall will compress down to 70 per cent. of its original height, whilst hydraulically stowed material will not compress to less than 90 per cent. Material used in Germany varies from sand to washery residues about 1¼ in. cube. Cast-iron pipes 6 to 8 ins. diameter are used, often lined with hard cast-iron or porcelain. A cast-iron tube 7½ ins. in diameter ⅜ in. thick will transport about 1,300,000 cub. yds. of stowage material before it is worn out. The average cost of tubes is 3*d.* per cub. yd. stowed. Average rate of stowage 25 to 30 cub. yds. per hour; some mines stow over 1,000 cub. yds. per day. The total cost of hydraulic stowage varies from 4*d.* to 1*s.* 6*d.* per ton of coals got—average appears to be under 1*s.* In a trial run in Scotland the working costs amounted to 9*d.* per cub. yd.

(Professor R. W. Dron, *Institute of Mining Engineers*, November 1923.)

According to P. Francke (*Glückauf*, 1926, p. 1156) hand stowage produces a settlement of 40 per cent. of the thickness of the seam, including 10 per cent. settlement before stowing, and hydraulic stowage a settlement of 5 to 15 per cent., averaging 10 per cent.

A modified form intermediate between hydraulic and hand stowage is described in *Ann. Mines Belg.* vol. 28, 1927, p. 501.

Colliery Consumption.

According to the Coal Conservation Committee of the Ministry of Reconstruction, 1918, colliery consumption in Britain varies from 5 to 9·43 per cent., averaging 6·8 per cent., of which 6·2 per cent. is produced by the direct combustion of coal under boilers, and the balance from outside sources. In 1923 colliery consumption amounted to 6·11 per cent. and miners' coal to 2·34 per cent. of the output, and in 1924 to 6·21 per cent. and 2·46 per cent. respectively.

The capital cost of a modern colliery may be taken at 20*s.* to 30*s.* per ton of coal got per annum.

Mining in Veins and Masses.

Methods employed in veins are:

Underhand stoping.
Overhand stoping.
Combined underhand and overhand stoping.
Rill stoping.
Shrinkage stoping or magazine mining.

Irregular deposits, wide veins, thick and steeply inclined seams may be worked by the following methods:—

Lost pillars.
Vertical slices.
Horizontal slices taken transversely.
Horizontal slices taken longitudinally.
Top slicing.
Caving.
Magazine mining.
Square set timbering.

Of these, overhand stoping is the most general, underhand stoping being only used in quite special cases, as when there is only a small quantity of payground to be taken below a given level. Overhand stoping can be used for veins of medium width, say up to 10 ft. on the average. Rill stoping is mainly employed in Western Australia. Magazine mining suits veins of any width, provided that they are not too flat, that the walls are fairly good, and that the whole of the veinstuff has to be extracted. Slicing and caving are used in wide veins and irregular masses when the value of the mineral is not great and where cheap methods of working are essential; it is largely used in the hæmatite mines of Cumberland and Lancashire. Square sets can only be used where the mineral is valuable and where large timber is abundant and cheap.

* *Third Report of Fuel Economy Committee. Brit. Assoc.*, 1920.
† Royal Commission on Coal Industry (1925).

The following classification has been drawn up by the Committee on Mining Methods of the *mer. Inst. Min. Met. Engs.*, vol. lxxii. 1925.

- Open cut with or without stripping
  - Benches
  - Glory holes and milling
  - Placer mining
    - Hand sluicing
    - Dredging
    - Hydraulicing
- Underground methods
  - Breast stoping (tubular flat-dipping deposits or beds)
    - Continuous horizon
    - Casual pillars
    - Room-and-pillar
  - Underhand stoping (veins and large masses)
    - Glory hole and milling
    - Open stope
      - With pillars
      - With stalls
      - With square set timbering
  - Overhand stoping (steep-dipping veins or masses)
    - Open stope
      - With pillars
      - With stalls
      - With square set timbering
    - Filled stope
      - Horizontal cut and fill (flat-back)
      - Inclined cut and fill (rill)
      - Square set timbering
      - Piercing or stripping
    - Shrinkage stope
    - Sub-level stopes
  - Top slicing (wide veins or masses)
    - Continuous horizon
    - Panel slicing
    - Block slicing
    - Inclined slicing
  - Caving (large masses)
    - Sub-level caving
    - Block caving
      - Undercut from main level
      - Undercut from sub-levels
      - Back caving into chutes
      - With branch raises
- Combined methods (large masses)
  - Alternate shrinkage stope, and pillar
  - Pillars mined by: top slicing, sub-level caving, or block caving
  - Square set timbering: pillars mined by slicing

See 'The Working of Unstratified Mineral Deposits' by G. J. Young, 1927.

The costs of stoping vary within very wide limits, and may be illustrated by typical examples.

In Western Australia, with the contract system in force, a miner breaks 7·31 tons of ore per shift. Formerly a miner on day's pay broke only 4 tons per shift.

In eleven of the West Australian mines treating from 9,000 to 22,000 tons of ore per month with veins varying from 4–20 ft. to 6–60 ft. in width the stoping costs per ton of ore ranges from 3. 4*d.* to 9*s.*, averaging 7*s.* This includes breaking ore, filling stopes, trucking, hoisting, etc. In the Rand it costs from 3*s.* 6*d.* to 5*s.* 6*d.* to stope a ton of milling ore in stopes 40 to 60 inches height. To these figures must be added cost of compressed air, rock drill maintenance, steel sharpening, and administration underground. The first three factors amount roughly to about 3*s.* per ton, while the last would not exceed 1*d.* In some Rand mines one man can break 12 tons per shift per machine, and uses one case (50 lbs.) of blasting gelatine to break 3·5 fathoms of ground. At other mines only 7 tons are broken per man and one case of explosives is used to break 2·5 fathoms.

In Nevada at the Silver Peak Mines each miner breaks 8·6 tons of rock per shift. The total stoping cost is 5*s.* per ton. Miners here receive 16*s.* per shift.

At the Braden Copper Mines native miners break 12 tons of ore per man per day with rock drills in moderately hard rock. The total cost per ton of ore broken, including superintendence and general charges, is given as 1*s.* 9*d.*

In Utah in quartzite with a stoping width of 10 ft., square set system, small air drills, the stoping cost per ton varies from 6*s.* to 8*s.*

At Douglas Island, Alaska, the ore is a mineralised igneous rock of fair hardness, the workabl portions of which vary upwards from 30 ft. in width. Wages 12*s*. Machine used 3¾ inche piston diameter. The following figures are taken over a year's working :—

COST OF BREAKING GROUND AT DOUGLAS ISLAND, ALASKA.

General Details.	Ready-Bullion.	700 Ft.	Mexican.	Treadwell.
Average number of drills used	10·12	11·586	14·917	39·13
Tons ore broken	151,460	238,696	232,875	830,551
Tons waste broken	2,756	—	10,509	1,670
Tons broken, total	154,216	238,696	243,384	832,221
Total footage drilled	241,679	269,990	362,519	803,542
Tons ground broken per machine per shift :				
Stoping	47·36	42·998	41·26	—
Developing	8·65	11·323	6·58	—
Cutting out	14·30	7·334	10·34	—
Average	23·06	30·41	24·19	28·47
Footage drilled per machine per shift :				
Stoping	29·39	33·587	33·50	—
Developing	39·14	37·78	39·71	—
Cutting out	40·11	33·954	34·79	—
Average	36·12	34·37	35·7	29·41
Tons broken per foot of hole drilled :				
Stoping	1·61	1·28	1·23	—
Developing	0·22	0·19	0·165	—
Cutting out	0·31	0·33	0·30	—
Average	0·64	0·88	0·669	0·96
Costs of breaking ground per shift per machine :	£ *s*. *d*.	£ *s*. *d*.	£ *s*. *d*.	£ *s*. *d*.
Labour	1 14 0	1 8 0	1 10 0	1 9 0
Explosives	9 8	11 4	12 2	11 4
Supplies and power	1 0 0	18 2	1 0 0	1 0 0
Total	3 3 8	2 17 6	3 2 2	3 0 4
Cost per foot of hole drilled	1 10	1 8	1 9	2 0
Cost per ton of ground broken	2 10	11	2 8	2 1
Total cost of mining, including development	4 0	4 9	4 10	4 6
Percentage of total mining cost	2 9	8	2 2	1 11

In the Granite Gold Mine, B.C., on a vein of hard quartz from 8 inches to 5 feet wide dipping 35° to 50°, the stoping costs per ton are as follows :—

	s. *d*.
Stoping by hand	14 0
„ by ¾-in. piston drills	11 6
„ by 2½-in. „ „	8 4
„ by 2-in. hammer drills	6 4

Mining costs at the Elko Prince Mine, Nevada, in 1917, stoping a 2 ft. 6 in. vertical vein of hard quartz by magazine mining, using hammer drills with 1⅛ in. cruciform steel, were as follows :—

	Per Ton of Ore $
Timbering, including ore shoots	0·5588
Blacksmith	0·0995
Stoping	0·8083
Tramming	0·2822
Hoisting	0·1956
Compressed air	0·1288
Explosives, detonators and fuse	0·4452
Repairs	0·0486
Drill steel	0·0570
Supervision, taxes, assaying, etc.	0·4987
Cost per ton	$3·1227 = 13*s*.

(*Bull. Amer. Inst. Min. Eng.*, Aug. 1918.)

Costs of stoping in 1903 in two mines on Cripple Creek, Col., in narrow veins: machinemen, ; miners, $3 for 8 hour shift; coal, $4·60 per ton; timber, $20 per mile.

	I.	II.
Machinemen and miners	$0·34	$0·369
Shovellers and trammers	0·41	0·401
Timbermen	0·23	0·215
Total labour underground	$0·98	$0·985
Compressed air, rock drills, sharpening	0·15	0·179
Tramming, trams, etc.	0·03	0·034
Explosives	0·13	0·139
Timber	0·28	0·310
Hoisting and surface transport	0·23	0·254
Miscellaneous stores	0·04	0·291
Supervision and general expenses	0·23	
	$2·07	$2·192
	= 8*s.* 7½*d.*	= 9*s.* 1½*d.*

For detailed costs of mining operations in various West Australian mines, see pages 2592–595.

Drilling.

Ordinarily two men can drill double-handed 25 to 33 ft. of 1-inch holes per day in limestone, to 8 ft. in granite. With double hammers 10 ft. of 2-inch holes can be drilled in medium rock.

On the Rand generally one white man and five Kaffirs run two air-drills; in some cases one hite man and seven Kaffirs run three drills. Eight 6-ft. holes is considered a shift's work for wo machines; these holes break on an average two fathoms of ground. The cost is as follows:—

	£	*s.*	*d.*
One white man	1	5	0
Five Kaffirs		15	0
Powder for two machines		16	0
Maintenance		4	0
Total	3	0	0 per fathom.

In Chili, with native labour, contracts are let on the basis of the number of holes drilled. The ock is moderately hard.

By hand.—1,008 man-days, by single hand work, drilled 13,855 ft. at a cost of 4·1*d.* per oot. Average amount drilled per man per day 13·8 ft.

By machine.—The actual cost of drilling for one month was as follows:—164 man-days 9 hours) with two ¾-in. air drills, drilled 5,082 ft. at a cost of 1·01*d.* per foot. Average amount rilled per man-day, 31 ft.

It is well known that drilling in siliceous rocks produces a dangerous dust, recognised as the rigin of Miners' Phthisis. The amount of dust suspended in the air is tested by the Katze onimeter; the atmosphere is considered safe if there are less than 300 dust particles per c.c. Final Report of Miners' Phthisis Prevention Committee, Pretoria, S. Africa.)

The Safety in Mines Research Board has devised a filter bag connected by a flexible tube ith the hole which is being drilled; this catches the particles of dust produced in drilling. Paper No. 23, 1926.)

HAULAGE.

Rails.

Mine rails weigh 10 to 40 lbs. per yard. The following table shows the least weight that hould be used for the given loads (weight of 1 loaded tub) and low speeds:—

Loads, in cwts.	7	10	15	20	25	30
Weight of rails per yard, lbs.	10	12	15	18	20	22
Gauge of track, in inches	15–18	15–18	16–20	18–22	20–26	20–30

For speeds above 5 miles per hour heavier rails are to be preferred.

Weight of 1 mile of single track in tons = 1·571 × weight of rail in lbs. per yard.

Sleepers 2 ft. 6 ins. to 3 ft. 6 ins., usually 3 ft. apart.

Sleepers 8 ins. to 12 ins. longer than gauge of track, 3–4 ins. deep, 6 ins. wide. A pair of shplates and 4 bolts for 18 lb. rails, weigh 4–8 lbs., usually 5 lbs.; 100 dogspikes for same weigh bout 14 lbs. Weight of fishplates, bolts and spikes is approximately 1 cwt. per ton of rails.

[*Continued on p.* 2596.

COST OF MINING OPERATIONS IN VARIOUS WEST AUSTRALIAN MINES.

General Details.	Shaft Sinking.			
	Oroya Brownhill.	Sons of Gwalia.	Lake View.	Great Fingall.
Size of machine used . . . . ins.	3¼	3¼	3⅝	—
Time taken rigging and pulling down machine	1 hour (3 men)	5 hours	4 hours	—
Time boring	8 hours	24 hours	16 hours (2 machines and 4 men)	—
Number of holes bored in face . . .	9	31	26	—
Average depth of holes . . . ins.	60	72	78	84
Feet bored in 8 hours.	45	62	42·9 (1 machine)	—
Time taken to fire out end	7·5 hours	6·5 hours	5 hours	—
Depth of cut . . . . . ft. ins.	3	5	6	5·2
Cost of compressed air per hour to run drill	1*s.* 11·5*d.*	2*s.* 1*d.*	2*s.* 6*d.*	—
Total cost of air to bore out end . .	15*s.* 5*d.*	2*l.* 10*s.*	4*l.*	—
Amount of explosives used in firing out cut (3 holes) . . . . . lbs.	—	—	—	—
Amount of nitro used in firing out cut (3 holes) . . . . . lbs.	—	—	—	—
Cost of explosives used in firing out cut .	—	—	—	—
Amount of explosives used in firing out remaining holes . . . . lbs.	—	—	—	—
Amount of nitro used in firing out remaining holes . . . . . lbs.	—	—	—	—
Cost of explosives used in firing out remaining holes	—	—	—	—
Length of fuse used in firing out end . ft.	90	216	168	—
Number of detonators used in firing out end	15	36	30	—
Cost of detonators used in firing out end	9*d.*	1*s.* 3½*d.*	1*s.* 1·2*d.*	—
Total cost of explosives, fuse, and detonators used to fire out end	1*l.* 12*s.* 10*d.*	3*l.* 19*s.* 1*d.*	4*l.* 3*s.* 4*d.*	—
Cubic contents of ground broken . .	180 cu. ft.	840 cu. ft. 5′×21′×8′	630 cu. ft. 15′×7′×6′	706 cu. ft. 17′×8′×5·2′
Amount of explosives used per foot lbs.	13·3 Gel.	17½ Gel.	12½ B.G.	24·2 Gel.
Amount of nitro used per foot . . lbs.	8·64	11·37	12·5	15·73
Amount of explosives used per ton . lbs.	2·44 Gel.	1¼ Gel.	1·42 B.G.	2·12 Gel.
Amount of nitro used per ton . . . lbs.	1·58	0·81	1·42	1·37
Amount of explosives used in firing out end . . . . . lbs.	40 Gel.	87½ Gel.	75 B.G.	125 Gel.
Amount of nitro used in firing out end lbs.	26	56·87	75	81·75
Cost of fuse used in firing out end . .	2*s* 1*d.*	4*s.* 10½*d.*	3*s.* 6*d.*	—
Cost of explosives used to fire out end .	1*l.* 10*s.*	3*l.* 12*s.* 11*d.*	3*l.* 18*s.* 9*d.*	—
Tons broken	16·36	70	52·5	58·8
Amount of explosives per hole. . . lbs.	4·45 Gel.	2·82 Gel.	2·88 B.G.	—
Amount of nitro per hole . . . lbs.	2·89	1·83	2·88	—
Tons broken per hole bored	1·81	2·26	2·02	—
Method of boring end	Stope cut	Centre cut	Centre cut	Centre cut

COST OF MINING OPERATIONS IN VARIOUS WEST AUSTRALIAN MINES—*continued*.

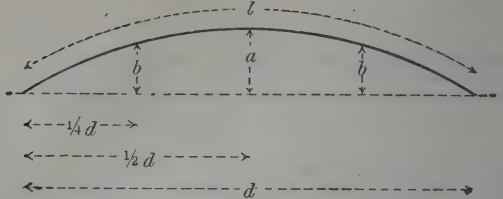
Driving.				Cross Cutting.			
Oroya ownhill.	Sons of Gwalia.	Lake View.	Great Fingall.	Oroya Brownhill.	Sons of Gwalia.	Lake View.	Great Fingall.
2½	3½	3⅝	—	2½	3½	3⅝	—
1 hour	2 hours	2 hours	—	1 hour	2 hours	2 hours	—
1 man)				(1 man)			
0 hours	20 hours	24 hours	—	17 hours	21 hours	24 hours	—
·15	15	15	—	15	15	14	
66	72	72	—	72	72	72	
32·5	36	30	—	42	34·3	28	
·5 hour	6 hours	4 hours	—	1·5 hour	7 hours	4 hours	—
5	5′ 6″	5	4·15	5′ 6″	5′ 6″	5′ 6″	4·72
1*s.* 6*d.*	2*s.* 1*d.*	2*s.* 6*d.*	—	1*s.* 6*d.*	2*s.* 1*d.*	2*s.* 6*d.*	—
1*l.* 10*s.*	2*l.* 1*s.* 8*d.*	3*l.*	—	1*l.* 5*s.* 6*d.*	2*l.* 3*s.* 9*d.*	3*l.*	—
20 Gel.	22½ B.G.	13¾ B.G.	—	20 Gel.	17½ B.G.	—	—
13	22·5	13·75	—	13	17·5	—	—
15*s.*	1*l.* 5*s.* 1½*d.*	14*s.* 5*d.*	—	15*s.*	19*s.* 6½*d.*	—	—
30 Gel.	45 Gel.	50 Gel.	—	30 Gel.	40 Gel.	—	—
19·5	29·2	32·5	—	19·5	26	—	—
2*s.* 6*d.*	1*l.* 17*s.* 6*d.*	1*l.* 17*s.* 6*d.*	—	1*l.* 2*s.* 6*d.*	1*l.* 13*s.* 4*d.*	—	—
96	96	120	—	96	100	108	—
16	18	20	—	16	20	20	—
9*d.*	7½*d.*	8¾*d.*	—	9*d.*	9*d.*	8¾*d.*	
0*s.* 4*d.*	3*l.* 5*s.* 5*d.*	2*l.* 15*s.* 1¾*d.*	—	2*l.* 0*s.* 4*d.*	2*l.* 15*s.* 11*d.*	2*l.* 5*s.* 1¾*d.*	—
0 cu. ft.	221·375	210 cu. ft.	174 cu. ft.	231 cu. ft.	211·75	231 cu. ft	198 cu. ft.
′×6′×5′	7′×5′9″×5′6 ′	7′×6 ×5′	7′×6′×4·15′	7 ×6′×5′6″	5′6″×7′×5′6″	7′×6 ×5′6 ′	7′×6′×4·72
10 Gel.	4·09 B.G.	2¾ B.G.	10·84 G.	9·1 Gel.	3 B.G.	10·23 Gel.	13·6 Gel.
	8·18 Gel.	10 Gel.			7·27 Gel.		
6·5	9·40	9·25	7·04	5·91	7·73	6·64	8·84
2·62 G.	1·11 B.G.	0·82 B.G.	3·8 Gel.	2·38 Gel.	0·99 B.G.	2·87 Gel.	—
	2·23 Gel.	3 Gel.			2·26 Gel.		
1·70	2·55	2·77	2·47	1·54	2·45	1·86	—
50 Gel.	22·5 B.G.	13¾ B.G.	55 Gel.	50 Gel.	17½ B.G.	56·25 Gel.	64 Gel.
	45 Gel.	50 Gel.			40 Gel.		
32·5	51·7	46·25	35·75	32·5	43·5	36·56	41·6
2*s.* 1*d.*	2*s.* 2*d.*	2*s.* 6*d.*	—	2*s.* 1*d.*	2*s.* 3½*d.*	2*s.* 3*d.*	—
17*s.* 6*d.*	3*l.* 2*s.* 7½*d.*	2*l.* 11*s.* 11*d.*	—	1*l.* 17*s.* 6*d.*	2*l.* 12*s.* 10½*d.*	2*l.* 2*s.* 2*d.*	—
19·09	20·11	17·5	—	21	17·64	19·25	—
·34 Gel.	1·43 B.G.	0·91 B.G.	—	3·34 Gel.	1·16 B.G.	4·01 Gel.	—
	3 Gel.	3·34 Gel.			2·67 Gel.		
2·17	3·38	3·08	—	2·17	2·89	2·60	—
1·26	1·34	1·16	—	1·4	1·16	1·37	—
ntre cut	Centre cut	Centre cut	—	Centre cut	Centre cut	Centre cut	—

COST OF MINING OPERATIONS IN VARIOUS WEST AUSTRALIAN MINES—*continued*.

General Details.	Rising.			
	Oroya Brownhill.	Sons of Gwalia.	Lake View.	Great Fingall.
Size of machine used . . . . ins.	2½	3½	3⅝	—
Time taken rigging and pulling down machine	2 hours (2 men)	2 hours	4 hours	—
Time boring	20·8 hours	17 hours	26 hours	—
Number of holes bored in face . . .	13	11	17	10
Average depth of holes . . . ins.	60	59	72	54
Feet bored in 8 hours	25	25′ 4″	31·15	—
Time taken to fire out end . . .	3 hours	4 hours	6 hours	—
Depth of cut . . . . . ft. ins.	4′ 6″	4′ 6″	5	4·28
Cost of compressed air per hour to run drill	1*s.* 6*d.*	2*s.* 1*d.*	2*s.* 6*d.*	—
Total cost of air to bore out end . .	1*l.* 11*s.* 2*d.*	1*l.* 15*s.* 5*d.*	3*l.* 5*s.*	—
Amount of explosives used in firing out cut (3 holes) . . . . . lbs	20 Gel.	18¾ B.G.	20 B.G.	—
Amount of nitro used in firing out cut (3 holes) . . . . . lbs.	13	18¾	20	—
Cost of explosives used in firing out cut .	15*s.*	1*l.* 1*s.*	1*l.*	—
Amount of explosives used in firing out remaining holes . . . . lbs.	30 Gel.	23¾ Gel.	50 Gel.	—
Amount of nitro used in firing out remaining holes . . . . . lbs.	19·5	15·4	32·5	—
Cost of explosives used in firing out remaining holes	1*l.* 2*s.* 6*d.*	19*s.* 9½*d.*	1*l.* 17*s.* 6*d.*	—
Length of fuse used in firing out end . ft.	96	90	120	—
Number of detonators used in firing out end	16	18	20	—
Cost of detonators used in firing out end .	9*d.*	7½*d.*	8¾*d.*	—
Total cost of explosives, fuse, and detonators used to fire out end	2*l.* 0*s.* 4*d.*	2*l.* 3*s.* 5*d.*	3*l.* 0*s.* 8¾*d.*	—
Cubic contents of ground broken . .	180 cu. ft.	189 cu. ft. 4′6″×6′×7′	175 cu. ft. 7′×5′×5′	116 cu. ft. 4′6′ × 6′×4·28′
Amount of explosives used per foot lbs.	11·1 Gel.	4·15 B.G. 5·3 Gel.	4 B.G. 10 Gel.	9·3 Gel.
Amount of nitro used per foot . . lbs.	7·21	7·57	10·5	6·04
Amount of explosives used per ton . lbs.	3·05 Gel.	1·12 B.G. 1·5 Gel.	1·37 B.G. 3·42 Gel.	—
Amount of nitro used per ton . . . lbs.	1·98	2·09	3·59	—
Amount of explosives used in firing out end . . . . . lbs.	50 Gel.	18·75 B.G. 23·75 Gel.	20 B.G. 50 Gel.	40 Gel.
Amount of nitro used in firing out end lbs.	32·5	34·15	52·5	26
Cost of fuse used in firing out end . .	2*s.* 1*d.*	2*s.*	2*s.* 6*d.*	—
Cost of explosives used to fire out end .	1*l.* 17*s.* 6*d.*	2*l.* 0*s.* 9½*d.*	2*l.* 17*s.* 6*d.*	—
Tons broken	16·36	15·75	14·58	—
Amount of explosives per hole . . lbs.	3·84 Gel.	1·7 B.G. 2·16 Gel.	1·37 B.G. 3·43 Gel.	—
Amount of nitro per hole . . . lbs.	2·49	3·1	3·59	—
Tons broken per hole bored . . .	1·25	1·42	0·84	—
Method of boring end	Centre cut	Centre cut	Centre cut	—

COST OF MINING OPERATIONS IN VARIOUS WEST AUSTRALIAN MINES—*continued*.

Winzing.				Stoping.			
Oroya. Brownhill.	Sons of Gwalia.	Lake View.	Great Fingall.	Oroya Brownhill.	Sons of Gwalia.	Lake View.	Great Fingall.
					(Average for 3 faces)	(Stope 14′×12′)	
2½	3¼	3⅝	—	2½	2½	2½, 3¼, 3⅝	—
1 hour	3 hours	6 hours	—	2 hours	6 hours (3 times)	4 hours	—
2 men) 2 hours	29 hours	26 hours	—	8 hours	56 hours	28 hours	—
9	14	17	16	5	24	16	8
60	62	72	60	72	62	96	60·72
30	24	31·15	—	30	17′ 8″	36′ 6″	—
Winch Windlass	4 hours	48 hours	—	4 hours	6 hours (3 faces)	24 hours	—
3	4′ 9″	5	5·10	6	4′ 6″	9	—
1*s.* 6*d.*	2*s.* 1*d.*	2*s.* 6*d.*	—	1*s.* 1·37*d.*	1*s.* 3*d.*	1*s.* 10*d.*	—
18*s.*	3*l.* 2*s.* 6*d.*	3*l.* 5*s.*	—	1*l.* 13*s.* 3*d.*	3*l.* 10*s.* (3 faces)	2*l.* 11*s.* 5½*d.*	—
15 Gel.	17½ B.G.	20 B.G.	—	—	—	—	—
9·75	11·37	20	—	—	—	—	—
11*s.* 3*d.*	14*s.* 7*d.*	1*l.*	—	—	—	—	—
15 Gel.	30 Gel.	50 Gel.	—	—	—	—	—
9·75	19·5	32·5	—	—	—	—	—
11*s.* 3*d.*	1*l.* 5*s.*	1*l.* 17*s.* 6*d.*	—	—	—	—	—
72	85	120	—	72	140	120	—
12	17	20	—	12	28	20	—
7*d.*	7½*d.*	8¾*d.*	—	—	1*s.*	8¾*d.*	—
1*l.* 4*s.* 8*d.*	2*l.* 2*s.* 1½*d.*	3*l.* 0*s.* 8¾*d.*	—	2*l.* 5*s.* 6*d.*	3*l.* 6*s.* 8*d.* (3 faces)	2*l.* 0*s.* 8¾*d.*	—
20 cu. ft.	182·87 cu. ft. 4′9″×5′6″×7′	175 cu. ft. 5′×7′×5′	275 cu. ft. 9′×6′×5·10	720 cu. ft.	1262·25 cu. ft. 13′6″×11′×8′6″	1,512 cu. ft. 14′×12′×9′	—
10 Gel.	10 Gel.	4 B.G. 10 Gel.	11·9 Gel.	—	—	—	—
6·5	6·5	10·5	7·73	—	—	—	—
1·75 Gel.	3·12 Gel.	1·37 B.G. 3·42 Gel	—	0·9 Gel.	0·714 Gel.	0·39 Gel.	—
1·77	2·02	3·59	—	0·58	0·464	0·25	—
30 Gel.	47·5 Gel.	20 B.G. 50 Gel.	61 Gel.	58 Gel.	75 Gel.	50 Gel.	—
19·5	30·87	52·5	39·65	37·70	48·7	32·5	—
1*s.* 7*d.*	1*s.* 11*d.*	2*s.* 6*d.*	—	1*s.* 7*d.*	3*s.* 2*d.*	2*s.* 6*d.*	—
1*l.* 2*s.* 6*d.*	1*l.* 19*s.* 7*d.*	2*l.* 17*s.* 6*d.*	—	2*l.* 3*s.* 4*d.*	3*l.* 2*s.* 6*d.* (3 faces)	1*l.* 17*s.* 6*d.*	—
10·9	15 24	14·58	—	65	—	126	—
3·34 Gel.	3·4 Gel.	1·37 B.G. 3·43 Gel.	—	4·8 Gel.	3·125 Gel.	3·12 Gel.	—
2·17	2·21	3·59	—	3·12	2·03	2·02	—
1·21	1·08	0·84	—	5·4	4·37	7·87	—
tope cut	Centre cut	Centre cut	—	—	—	—	—



To bend rails to ar
curve, let l be length of ra
r radius of curve, both
feet, a the middle ordina
in the centre of the curv
b the quarter ordinate, mi
way between a and t
end of the rail (both a ar
l in inches) :—

Then

$$a = 1{\cdot}56\,\frac{l^2}{r}, \qquad b = 1{\cdot}17\,\frac{l^2}{r}.$$

Width of track ½ in. to ¾ in. greater than gauge of wheels.

Additional width round curves :—

Gauge of track	15	18	24	30 ins.
Additional width	¼	½	⅝	¾ in.

In going round a curve with locomotive traction or on self-acting inclines, the outer r must be elevated ; with rope haulage the inner rail may have to be elevated.

Let

e = super-elevation in feet; s = gauge of track in feet; v = velocity in feet per secon
r = radius of curve in feet;
then,

$$\text{for outer rail, } e = \frac{v^2 s}{32{\cdot}2\,r}.$$

For inner rail, the elevation depends upon whether the centrifugal force due to the veloci of running is greater or less than the inward pull on the drawbar ; it will be greater at high speed say, exceeding 20 miles per hour, and less at low speeds ; under ordinary conditions at 15 mil per hour the elevation of the inner rail should be about 2 ins.

Colliery Tubs.

Colliery tubs carry from 7 to 40 cwts. of coals.

In North country average dimensions of tub body are about 3 ft. 9 ins. × 3 ft. × 2 ft. ; whe 11 ins. diameter, axles 1¾ in. diameter.

Such a tub if made of wood will carry about 7½ cwts. of coals, if of iron about 9 cwts. ; wood tubs weigh about 55 per cent. of the load, iron tubs about 50 per cent. Tubs cost approximate 15*s.* to 17*s.* per cwt., and their upkeep is about 10*s.* per annum. Upkeep is often reckoned 1*d.* per ton of coal. In South Wales much larger tubs, holding up to 2 tons, are used ; the gener tendency in other parts of the country is towards increasing the size of tubs.

Using ordinary tubs carrying about 10 cwt. of coals, it is usually reckoned that a collie requires for its equipment about one tub per ton of coals raised per day.

In U.S.A. colliery tubs carrying 1 to 4 tons are in use ; average 3-ton tub, 9 ft. 6 ins. lon 4 ft. 3 ins. wide, 1 ft. 3 ins. high.

Coefficient of friction of tubs on well-kept mine road (level), 1 per cent. to 3 per cent., avera say 1·5 per cent. ; with tubs badly greased on roads in bad repair may be two to three tim as much. Coefficient of sliding friction (wheel spragged) is from 12 to 20 per cent. ; if m coefficient of rolling friction, m' of sliding friction, the coefficient of friction with :—

1 wheel spragged $= \dfrac{3m + m'}{4}$; 2 wheels spragged $= \dfrac{m + m'}{2}$; 3 wheels spragged $= \dfrac{m + 3m'}{4}$.

Additional friction in going round curve of radius r, where the gauge of the track $= s$ (bo in feet), is $\dfrac{s}{2r}\,m'$.

Tractive effort with 18-in. wheels on good level track, 40-in. gauge, at 5 to 6 m.p.h. = 24·3 lbs. p ton with plain bearings, 12·8 lbs. with roller bearings. (*Trans. Amer. Inst. Min. Eng.*, vol. lv. p. 2

A wooden tub with plain bearings at speed of 1·75 m.p.h. showed coefficients of friction :—

$\frac{1}{30}$ with poor, $\frac{1}{54}$ with average, $\frac{1}{65}$ with good lubrication.

Coefficient on starting from rest with average lubrication $\frac{1}{30}$; tests with plain bearings collieries gave $\frac{1}{20}$, $\frac{1}{33}$, and $\frac{1}{35}$ respectively. A steel tub with plain bearings gave $\frac{1}{58}$, wi Climax bearings $\frac{1}{60}$, with Skefko ball bearings $\frac{1}{158}$; tub with Rowbotham wheels $\frac{1}{55}$.

A 9-ft. radius curve trebles, a 12-ft. radius curve doubles, the coefficient of friction with fix wheels ; loose wheels give ⅔ of increase of fixed wheels.

Starting effort to get up to a speed of 1·75 m.p.h. = 2 to 3 times the effort required to mai tain that speed with plain bearings, 1½ to 2 times with Rowbotham wheels, and 1 to 1½ times wi Skefko ball bearings. (J. Wilson, *Trans. Inst. Min. Eng.*, lxiii., p. 294.)

With 'wheel' greasers the consumption of grease averages about ¼ lb. per tub per diem f ordinary collieries.

On the average a putter can put 10 tons of coal over a distance of 200 yards (level) in a 8-hour shift.

A horse does its best work when travelling at a speed in feet per second $= \frac{1}{4}h$, where h is the eight of the horse in hands, and exerting a pull in lbs. of $\frac{60\,c^2}{h}$, where c is the circumference of the orse's chest in feet (*Baron*). Average pull is about 1¼ cwt.

Maximum gradient for hand putting, 17 per cent.
Maximum gradient for horse haulage, 12 per cent.

Gradient at which resistance of full tub downhill equals that of empty tub uphill:—Let W e the weight of a loaded tub, w that of an empty one, θ the inclination of the road, μ the co-fficient of friction :—$\tan\theta = \frac{\mu\,(W - w)}{W + w}$ (usually $\tan\theta = 0{\cdot}005$ about).

Work done in hauling a tub of weight W up or down an incline of length $l = l\,(\mu\,W\cos\theta \pm W\sin\theta)$.

Self-acting Incline.

Self-acting Incline.—Let the sets consist of n tubs each of weight w lbs., and capable of carrying V lbs. of mineral. Let the slope of the incline, assumed uniform, be $\alpha°$. Let l be the length of he rope (= length of incline) in feet, c its weight in lbs. per foot.

Let the rope be supported on rollers, the weight of which per foot of rope (= weight of one oller divided by the distance in feet between the centres of successive rollers) is r lbs. Let D e the diameter of the rollers, d of the spindle. Let μ be the coefficient of friction of the tub n rails (usually say about 0·015) and μ_1 the coefficient of friction of lubricated bearings (say ·005 to 0·008). Let F be the frictional resistance of the drum at the head of the incline, including hat of the rope coiled upon it—a figure that is always relatively small and may often be neglected. Then at any distance x feet from the starting point the full set is just able to move down the ncline when :—

$$\tan\alpha = \frac{\mu n\,(W + 2w) + \mu_1\,l(c + r)\,\frac{d}{D} + F}{nW - c(l - 2x)}$$

By putting $x = 0$ the above expression gives the angle at which the set will just start from the op of the incline.

The time occupied in descending a distance x will be:—

$$t \text{ seconds} = \sqrt{\frac{2x\,[n\,(W + 2w) + (c + r)\,l + M]}{g\left[\sin\alpha\,(nw - cl) - \cos\alpha\left(l\,(c + r)\,\frac{d}{D}\,\mu_1 + n\,(W + 2w)\,\mu\right) - F\right]}}.$$

nd the velocity in feet per second v attained after travelling a distance of x feet will be :—

$$v = \sqrt{\frac{2gx\left[\sin\alpha\,(nw - cl) - \cos\alpha\left(l\,(c + r)\,\frac{d}{D}\,\mu_1 + n\,(W + 2w)\,\mu\right) - F\right]}{n\,(W + 2w) + (c + r)\,l + M}},$$

where M is the weight of the drum and its fittings and g the acceleration due to gravity.

All the above expressions are approximations, but are accurate enough for practical purposes.

When the slope is not uniform, the calculations become more complicated. If H be the total ertical fall of the incline and L its horizontal length, it is usually sufficient, with the low radients prevailing in collieries, to use the above formulas, putting $\alpha = \tan^{-1}\frac{H}{L}$. As the enominator of the expression given above for $\tan\alpha$ increases with x, it is obvious that the ncline should, whenever possible, flatten going downwards, or be concave, though not so much o as to cause the rope to rise too high above the rails. The exact shape of the curve is not very mportant; it may with advantage be a parabola, which may be set out by making the height at any point distant y ft. horizontally from the foot of the incline $= \frac{y^2H}{L^2}$. The rope will then ollow the curve whenever the relations are such that $H = \frac{cl^2}{4T}$, where T is the tension of the ope.

Main-and-Tail Rope Haulage.

Main-and-Tail Rope Haulage.—Loaded tubs in sets up to 40 are hauled outbye by motors (steam-ngines, compressed-air engines or electro-motors) at speeds up to 20 miles per hour, whilst the mpty tubs are hauled inbye by means of the tail rope. The size of the engine depends upon the ull to be exercised when one set (nearly always the full set) is in its least favourable position. Let T be the tension in the rope in such position, made up of the weight of the set plus rope × ine of angle of inclination of the roadway, the friction of the set and of both ropes on the rollers and the pull required to accelerate the moving parts. Let C be the diameter of the steam cylinder

in inches, one of which is alone assumed to be effective at the start, let K C be the stroke of the engine in feet (K is usually $\frac{1}{2}$ to $\frac{3}{4}$), S the steam pressure in lbs. per sq. in., z the ratio of the number of teeth in the spur wheel on the drum shaft to the number of teeth in the pinion on the crankshaft, D the diameter of the drum in feet, then

$$C = \sqrt[3]{\frac{4DT}{\pi SKz}}$$

For any portion of the trip except the start (i.e. with set already in motion), both cylinders are effective, and the value as found above must be divided by $\sqrt{2}$.

These engines are usually small and run at a piston speed of 500 to 800 ft. per min.

Endless Chain and Endless Rope.

Endless Chain and Endless Rope.—Endless chain is now rarely used except on steep gradients and for short distances; it is less reliable than endless rope on long roads, requires more power and is rather more expensive to work, but admits of rather higher speeds: it may work up to 6 miles per hour; endless rope rarely exceeds 4 miles.

The following calculations apply to both methods unless otherwise stated:—

If Q be the quantity of mineral in tons to be transported per hour, W the weight in lbs. carried by one tub, V the speed of haulage in miles per hour, f the distance apart of the tub in feet, then

$$= 2{\cdot}36 \frac{V \cdot W}{Q}.$$

Endless chain is always over-tub haulage, endless rope may be over-tub or under-tub. In over-tub haulage the tubs must be so near together that the rope does not touch the ground between them. Let T be the least tension in the hauling rope or chain (i.e. between the two tubs nearest the driving pulley on the empty side), let c be the weight of the rope or chain per foot, h the height of the tub, then the distance f_1 of the tubs apart is given by

$$f_1 = \sqrt{\frac{8hT}{c}}.$$

If f is greater than f_1 empty tubs must be run on the full side.

The pull to be exerted by the engine driving the haulage is

$$\mu\left[n\ (2w + W) + 2c \cdot l\right] \cos a \pm W \sin a,$$

using the same notation as above, n being the number of tubs on any one side of the rope at any time, so that $n = \frac{l}{f}$; the lower sign is used when the gradient is with the full tubs, the upper one when against it. If this expression has the − sign, the arrangement is self-acting.

The return wheel of an endless rope haulage is often used as a tightening pulley being capable of sliding and pulled by a weight W.

Let the radius of the pulley, fig. 13, be R and of its spindle r.

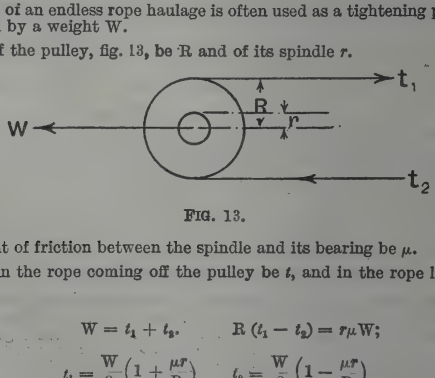


FIG. 13.

Let the coefficient of friction between the spindle and its bearing be μ.

Let the tension in the rope coming off the pulley be t_1, and in the rope leading to the pulley be t_2,

then,

$$W = t_1 + t_2. \qquad R(t_1 - t_2) = r\mu W;$$

whence

$$t_1 = \frac{W}{2}\left(1 + \frac{\mu r}{R}\right) \qquad t_2 = \frac{W}{2}\left(1 - \frac{\mu r}{R}\right).$$

See also table, p. 987.

Cost of Haulage.

Cost of Underground Haulage.

System of Haulage.	Average Gradient for Full Tubs.	Cost in Pence per Ton per Mile.							
		Ropes or Chains.	Tubs.	Grease and Oil.	Coals.	Repairs to Engines and Boilers.	Maintenance of Way.	Labour.	Total.
Tail Rope	Rise 1 in 213	·276	·114	·186	·558	·096	·064	·583	1·879
Endless Chain	„ 1 „ 59	·083	·173	·155	·256	·072	·068	·572	1·379
Endless Rope	„ 1 „ 36	·252	·309	·138	·323	·196	·083	1·692	2·993

Cost of Secondary Haulage in North of England Collieries.

	Average Distance.	Tons per Animal.	Cost per Ton in Pence.			
			Wages.	Maintenance.	Interest & Deprecn.	Total.
Pony putting	180 yds.	27·0	1·584	0·500	0·068	2·152
Horse driving	423 „	30·0	0·531	0·615	0·087	1·233
Putting and driving.	603 „	14·1	2·115	1·115	0·155	3·385

(*Trans. Inst. Min. Eng.* xv. 1897, p. 136.)

Cost of underground locomotive haulage in Westphalia in 1912, including redemption of capital :—

Petrol	2·51 pence per ton-mile.
Continuous current (with conductors)	2·16 „ „
Alternating „ „ „	1·58 „ „
Continuous „ (with accumulators)	2·65 „ „
Compressed air	2·12 „ „

So-called fireless locomotives using superheated water, and oil or coke-fired steam locomotives are also used.

Steam Mine Locomotives.

Mine locomotives (*steam*) usually have cylinders 5 ins. to 8 ins. diameter, stroke 1½ diameters, driving wheels 20 ins. to 30 ins. diameter, wheel base 3 ft. to 6 ft., weight complete 4 to 15 tons, drawbar pull ⅓ to ¼ weight. Boiler pressure 120 to 150 lbs. Speed with full load in miles per hour ⅓ diameter of driving wheel in inches.

When D is piston diameter, *l* length of stroke, *d* diameter of driving wheel, all in inches, and P the gauge pressure of the boiler in lbs. per sq. in. then drawbar pull = approximately, $\frac{0{\cdot}85\ P\ l\ D^2}{d}$.

Compressed Air Locomotives.

Compressed air locomotives are worked at 600 to 1,000 lbs. per sq. in. gauge pressure, charged from underground receivers, in which air is compressed to 50 to 100 lbs. higher. Pressure is reduced to about 150 lbs. per sq. in. before the air enters the cylinders. The formula above given for drawbar pull may be used, P being the pressure of air as supplied to the cylinders, omitting 0·95 instead of 0·85.

Electric Locomotives.

With trolley wires, electric locomotives may use either continuous or alternating current. Weight complete is usually 7 to 15 tons, and drawbar pull 0 to ⅛, usually 0 of weight; coefficient of adhesion, 25 to 30 per cent. 75 per cent. to 80 per cent. of electric input is converted into effective effort, 1 per cent. to 2 per cent. of which will move the locomotive on the level, the remainder being available for hauling load. Speed on the level usually 6 to 8 miles per hour.

With accumulators, small locomotives are used in places for secondary haulage. The B.E.V. locomotive has a battery capacity of 193 amps. at 65 volts, and can pull or push 3-ton trucks on the level. Its use is on the increase in this country.

WINDING.

In sinking pits, the excavated material is usually hoisted in steel buckets or hoppits, usuall unguided, and usually single. The load is thus wholly unbalanced, geared engines are ofte used, and the winding speed is slow. Such buckets have capacities of 25 to 50 cubic feet, sa 30 to 60 cwts., the weight of the bucket being from $\frac{1}{2}$ to $\frac{3}{4}$ of its load. For ordinary colliery wor cages carrying two to twelve tubs are used, always in pairs running on wooden, rail or ro guides; in the Pennsylvania anthracite mines large skips are sometimes used instead of cage

Skips are largely used instead of cages in metalliferous mines; when the mineral has to b crushed the fact that the skip breaks the mineral up more than does the cage is no drawbac Self-dumping skips are used on large mines, whilst underground bins and loading stations at th shaft enable the skips to be filled very quickly. Skips usually hold from 20 to 100 cubic fee say up to about 5 tons of rock; they are made of $\frac{1}{4}$ in. to $\frac{3}{8}$ in. steel plate.

In some Illinois collieries, where the coal is to be crushed afterwards, skips about 6 ft. 6 ft. × 12 ft. 6 ins., holding about 12 tons of coal, are used; the speed of winding is up to 1,600 f per min.; the average power consumption is 0·485 kw. hour per ton of coal; up to 1,000 to of coal has been hoisted per hour from a depth of 200 yards.

On the Continent the total load lifted is about: cage 30 per cent., tubs 20 per cent., coa 50 per cent. German practice is: Let W be the weight of coals, T weight of the tubs, and Q th total weight of coals, tubs, and cage (including chains, hook, etc.); then

$$\frac{W}{T} = \frac{1}{0{\cdot}38} \text{ to } \frac{1}{0{\cdot}78}, \text{ averaging } \frac{1}{0{\cdot}56} \text{ and } \frac{W}{Q} = \frac{0{\cdot}27}{1} \text{ to } \frac{0{\cdot}44}{1}, \text{ averaging } \frac{0{\cdot}36}{1}.$$

In skip hoisting the ratio of the weight of the skip to that of the load of mineral is 0·6 : 1 to 0·9 to in hoisting in cages, the weight of cage and tubs: weight of coal: : 1·5 : 1 to 1·9 : 1 (*Zsch. B.H. u.S.W.*, 1915, p. 285). In Great Britain the cage usually weighs 35 to 45 per cent. of the tot load, or approximately as much as the useful load of coals lifted. It is carried by bridle chai usually six in number. Their factor of safety should be at least 10, and the size of the chai may be calculated thus:

Let d be the diameter of the chain in eights of an inch, and W the safe working load in to then $d = \sqrt{10W}$.

Slack adds greatly to strain on rope; according to numerous experiments, if the pull requir to lift a given cage with rope taut be taken as 1, it requires a pull equal 1·5 to 1·7 with 3 i of slack, to 2–2·25 with 6 ins., 2·25 to 2·5 with 9 ins., and up to a pull of 3 with 12 ins.

The velocity of winding varies from 15 to 75 ft. per second; a rule given by O'Donahue i allow a speed of 20 ft. per second for shafts up to 200 yards in depth, and add 5 ft. per seco for every additional 100 yards.

Wooden guides are usually 3 ins. × 4 ins. to 4 ins. × 6 ins.; rail guides 50 to 70 lbs. p yard. Rope guides made of single strand of 7 to 15 wires each $\frac{1}{2}$ to $\frac{1}{4}$ in. diameter, stretch by weight of $1\frac{1}{2}$ to 5 tons; weight is often calculated at 1 ton for every 250 yards depth of sha The friction on the guides is but small; it usually amounts to about 0·025 of the total load the rope with wooden or rail guides and 0·02 of the load with wire rope guides.

Size of Winding Engine.

To calculate the size of the winding engine the conditions of the wind must be known assumed. The diameter of the cylinders must be such that (*a*) one cylinder is capable of starti the unbalanced load and (*b*) that the two cylinders taking steam on the full stroke shall be capa of accelerating the total load to be set in motion.

If w be the weight of a cage and fittings with the empty tubs, W the weight of minerals lift per wind, h the depth of the shaft in feet, c the weight of the rope in lbs. per foot, v the veloci in feet per second up to which the load is to be accelerated during a lift of f feet; let P be t steam pressure in lbs. per sq. in., d the diameter of the piston in ins., S the length of the stro in feet, D the diameter of the drum in feet, M the weight of drum, pulleys, etc., and allowi 20 per cent. to cover the friction in the shaft, of the pulleys, drum, and engine, etc., then fulfil condition (*a*)

$$d = \sqrt{\frac{D\,(W + ch)}{0{\cdot}471\ P.S.}}. \qquad (a)$$

To fulfil condition (*b*)

$$d = \sqrt{\frac{4\,D\left[\left\{W + c(h - f)\right\} f + (W + 2w + 1{\cdot}5\,ch + 0{\cdot}5\,M)\,\frac{v^2}{2}\right]}{3\ .\ P.f.S.}} \qquad (b)$$

The larger value of d as found by (*a*) or (*b*) should be adopted.

This formula only applies to the ordinary form of winding engine with the drum carried dire on the crankshaft and the two cranks at right angles.

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Specialities :—

WINDING ENGINES,

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Daglish's Patent Automatic Cut-off and Throw-out Gears applied to Existing Engines

SAVE 25% TO 60% OF STEAM.

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Steel Conical Winding Drums.

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CHEMICAL & DYE WORKS PLANT

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On the average the total load, namely, coal, tubs, and cage, equals 2·66W; assuming a factor f safety of 10 and a rope of 100 tons steel, $c = \frac{26 \cdot 6W}{16{,}000 - 10h}$.

The diameter of a rope in inches equals approximately $0 \cdot 45 \sqrt{c}$; taking the diameter of ie drum as 120 times the diameter of the rope, $D = 4 \cdot 5 \sqrt{c}$.

On these assumptions, formula (*a*) becomes

$$d = 3 \cdot 856 \sqrt{\frac{\sqrt{c}\,(W + ch)}{P}}.$$

Assuming that $S = \frac{d}{6}$, and that the diameter of the drum is 120 times the diameter of the rope, lis expression takes the following form :—

$$d = 4 \cdot 59 \sqrt[3]{\frac{(W + ch)\sqrt{c}}{P}}.$$

An empirical formula which gives reasonably good results is :

$$d = 3 \sqrt{\frac{WD}{P}};$$

Usually $S = \frac{d}{6}$ and the length of the connecting rod is $2\frac{1}{2} - 3$ S. Average piston speed 500 ft. er min., varying from 300 to 800 ft.

If the load is partially or wholly balanced, the formula must be correspondingly modified.

Once the load has been accelerated to its full speed, the steam admission is reduced by means f valve gears with variable cut-offs, and during the last part of the wind work must be absorbed) as to retard the load and bring it to rest gradually ; powerful brakes are employed or the engine iay be reversed as well as the brakes applied.

The weight of the rope may be balanced by :—

1. Chain counterbalance, suitable for slow winding only, and adding enormously to the veight to be accelerated.

2. Balance rope beneath the cages ; this adds to the weight to be accelerated, but the chief bjection is the additional strain put upon the cappings of the winding ropes. Some engineers se a balance rope heavier than the winding rope, so as to overbalance the latter, to help the ngine to accelerate the load at start and to aid in retardation at the finish of the wind.

3. The conical or scroll drum. The ascending load is attached to the end of the rope which at the small end of the drum, and the descending load to the end at the large end. Using the ame notation as before, but calling r the mean radius of the drum, r_a the smaller radius, r_d the irger, Q_a the resistance due to the ascending load and Q_d the force derived from the descending oad and n the total number of revolutions of the drum during the wind :—

$$r = \frac{r_a + r_d}{2} = \frac{h}{2\pi n}$$

$$r_a = r\left(1 - \frac{hc}{Q_a + Q_d + hc}\right); \qquad r_d = r\left(1 + \frac{hc}{Q_a + Q_d + hc}\right);$$

$$\frac{r_a}{r_d} = \frac{Q_a + Q_d}{Q_a + Q_d + 2hc}$$

If δ be the diameter of the rope, the width of the drum will be approximately $1 \cdot 5\, n\, \delta$. Cylindro-conical drums, giving partial counterbalance (where most needed), are often used.

Flat ropes wound on a reel are equivalent to a spiral drum ; they will counterbalance in the hree main positions where

$$r_d - r_a = nt \text{ and } r = \sqrt{\frac{Q_a + Q_d + hc}{4\pi c}}\, t,$$

'here t is the thickness of the flat rope.

The time of banking varies considerably ; it may be averaged at about 10 to 15 seconds for ne deck and 25 to 45 seconds for double decks. Up to 3,000 tons may be wound in 10 hours, ut 2,000 tons is not often exceeded.

The consumption of coal in winding engines varies from 0·5 to 1·5 per cent. of the weight of oals wound. Steam consumption 50 to 100 lbs. per shaft h.p. hour.

The cost of a winding engine and boilers erected varies from about 3,500*l.* to about 10,000*l.*

The cost of winding, exclusive of interest and depreciation on the winding plant, varies from bout 3*s.* to 10*s.* 6*d.* per 100 tons wound.

Electric Winding Plants.

Electric winding plants are coming increasingly into favour; according to Mr. Mounta (*Trans. Inst. M.E.* xxxi., p. 329) the first cost of electric winders is considerably in excess of stea winders, so that interest and depreciation of the plant form serious items in the working cost Some of the large geared electric winders in use on the Rand raise a 3-ton load from a depth 2,500 ft., taking 2,000 e.h.p. An electric winder at a Durham pit raises 63 cwts. of coal p wind from 1,350 ft., uses 3-phase induction motor, 700 h.p., 2,900 volts; motor runs at 230 r.p.m geared 5·45 to 1; cylindro-conical drum 10·20 ft. diam., weighing 45¾ tons; overall efficienc 51 per cent.

A winder in a South Wales pit uses 2,000 volts alternating, lifts 55 cwts. from 600 ft., us 174 kw. per wind; drum cylindro-conical, 8 ft. to 13 ft.; overall efficiency, 48·25 per cent.

ELECTRIC WINDERS ON WITWATERSRAND.

Name.	Depth in ft.	Tons (2,000 lbs.) per hour.	Weight of Mineral.	Weight of Skip.	Maximum Rope Speed.	Drum Diameter.	Winding Rope Diameter.	Tail Rope Diameter.	H.P.	System.
			lbs.	lbs.	ft. per min.	ft	in.	in.		
City Deep . .	3,210	157·5	9,000	8,000	3,500	11	$1\frac{9}{16}$	$1\frac{9}{16}$	1,600	A.C.
Village Deep .	4,200	152·0	10,600	7,000	3,500	11	$1\frac{5}{16}$	$1\frac{3}{8}$	1,600	A.C.
Brakpan . . .	3,800	180·0	10,000	6,000	3,500	11	$1\frac{1}{2}$	$1\frac{1}{2}$	1,450	Ward Leonard
Village Deep, Turf Shaft	4,093	150·0	10,000	7,000	3,500	12	$1\frac{1}{2}$	—	1,600	A.C.

The last-named winder (Whiting hoist) shows an overall efficiency of 77 per cent.
(J. F. Perry, *Trans. Nat. Assoc. Col. Man.*, xv. p. 299.)

An electric winder is used at Orient No. 2 mine at West Frankfort, Ill. (Chicago, Wilmingto & Franklin Coal Co.). Coal skips normally weigh 10 tons, maximum weight, 11·5 tons; co dumped at shaft bottom from mine cars by tipplers; depth of shaft, 202 yds.; normal outpu 1500 tons per hour; maximum, 2,000 tons per hour; time of wind, 16 secs.; maximum windi speed, 4,000 ft. per minute; peak load during acceleration, 8,000 h.p.; two motors, each 2,000 h.p one placed at each end of drum shaft; motor generator set, 40 tons; fly wheel, 12 ft. diamete equipped with two 1,800 k.w., 600 volt, 600 r.p.m., d.c. generators, driven by a 2,200 h.p. inductio motor 220 volts, 3-phase, 60 cycles, 600 r.p.m.

The largest electric winder in Gt. Britain is at the Carlton Main Colliery, Grimethorpe; raises 300 tons per hour from a depth of 2,610 ft., and can develop 7,500 h.p. at 49·6 r.p.m.; has a 23-ton flywheel Ilgner set.

For full information on electric winders see "Electric Winders" by H. H. Broughton, 1927.

Headgears.

Headgears.—Steel-framed headgears usually range from ⅝ to 1 ton per foot of height, and cos erected 12*l.* to 18*l.* per ton; headgears composed of angles and joists only, not lattice girder weigh ⅜ to ⅝ per foot of height. Wooden headgears weigh about ¼ ton per foot of height an cost 10*l.* to 12*l.* per ton. The size of the main legs of timber headgears is given approximatel by the expression $A = 0{\cdot}03\ H^2\sqrt{W}$, where W is the total working load on the winding ropes i tons, H the height in feet of the headgear from the ground to the pulley centres, and A th area of the cross-section of the main leg; the area of the backstay = 0·64 A.
(R. Boyle, *Scott. Inst. Min. Stud.* 1908.)

Ferro-concrete headgears have been erected in several places and have proved quite satisfac tory.

Pulleys.

Pulleys.—Usually 10 to 20 ft. in diameter, mostly of the same diameter as the drum. Pillo blocks may be carried on strong springs to diminish shock at starting.

If W be the weight of a pulley in cwts. and d its diameter in ft., $W = 9{\cdot}2\,(d-8)$ approximatel for large colliery headgear pulleys. $W = \frac{d^2}{4}$ is a useful approximation, but is too low for pulley under 6 ft. in diameter.

The angle of lead from the drum to the head gear pulleys should not exceed 2° on either side f the centre line; the horizontal distance between the drum and pulley centres should not exceed 50 ft., otherwise the rope is apt to surge.

The first Koepe winder, supported directly over the shaft, thus dispensing with the usual eadgear and pulleys, to be erected in this country, is in operation at Plenmeller Colliery, orthumberland. The Koepe driving pulley is 11 ft. 6 ins. in diameter, driven through single eduction gearing at 200 r.p.m. by a 240 h.p., d.c. motor, fitted with Ward-Leonard control. urrent is supplied by a 200 kw., 350 volt generator direct coupled to a 3-phase 50 cycle 600 volt nduction motor running at 730 r.p.m. The depth of the shaft is 815 ft., and single deck cages aking 3 tubs holding altogether 48 cwts. of coal are used. The whole of the hoisting machinery contained in a two-storied steel-framed house with corrugated iron sides and roof mounted on a ull lattice-girder framework. An overall efficiency of 60 per cent. is attained.

(*Trans. Inst. Min. Eng.*, lv. p. 170.)

Another has been erected at Murton Colliery, Co. Durham. The motor here is 400 h.p. on a ,000 volt, 40 period current; it draws 4 tons of coals per wind from a depth of 1431 ft. in 80 secs., he coefficient of friction between rope and driving pulley has been found to be 0·407. The verall efficiency is 61 per cent. (G. Raw, *Trans. Inst. M.E.*, vol. lxxiii., 1927, p. 380.)

On the Rand, hoisting with skips costs 8*d.* to 1*s.* per ton from depth of about 1,000 ft.

ROPES FOR HAULING AND WINDING.

Weight in lbs. of rope of circumference C inches per yard :—

Of ordinary hauling or winding ropes with hemp cores about	0·55 C^2.
„ wire ropes with wire cores . . . . „	0·6 C^2.
„ flattened strand rope	0·57 C^2.
„ locked coil rope	0·75 C^2.
„ all-steel guide ropes	0·65 C^2.
„ hemp ropes	0·2 C^2.
„ coir „	0·12 C^2.
„ aloes „	0·1 C^2.

The number of wires of diameter d in a wire rope of diameter D is approximately $0·75 \frac{D^2}{d^2}$.

The breaking strength in tons of ropes of circumference C inches is approximately :

Ordinary hemp rope	0·3 C^2.	Aloes fibre rope .	0·4 C^2.	Mild steel . .	1·75 C^2.
Best „	0·6 C^2.	Charcoal iron .	1·5 C^2.		

For ordinary ropes (with hemp cores) of	80–90 T wire . . .	3·3 C^2.
„ „ „	90–100 „ . . .	3·7 C^2.
„ „ „	100–110 „ . . .	4·0 C^2.
„ „ „	110–120 „ . . .	4·4 C^2.
„ „ „	>120 „ . . .	4·6 C^2.

The weight of rope in lbs. per yard which shall have a breaking strength of W tons = kW, where k has values :

For 80–90 T wire .	0·167	For 100–110 T wire .	0·138	For >120 T wire .	0·120
„ 90–100 „ .	0·148	„ 110–120 „ .	0·125		

If S is the breaking strength of the wire in tons, the strength of the rope is approximately

$$0·04\ C^2\ S.$$

If a rope n yards in length is required to carry a load of W tons with a factor of safety of f, using wire having a breaking strength of S tons per sq. in., weight of rope in lbs. per yd. is

$$\frac{2{,}240\ f\ W}{160\ S - f n}, \quad \text{or} \quad \frac{2{,}240\ k\ f\ W}{2{,}240 - k\ f\ n}.$$

If 160 S is $< f n$, a stronger wire must be selected.

The British Association of Wire Rope Manufacturers has adopted the following distinctive nomenclature for the steel wire ordinarily used in rope manufacture :—

Description.	*Breaking Strain.*
Best patent steel wire	80 to 90 tons per sq. in.
Special improved patent steel wire	90 to 100 „ „
Best plough steel wire	100 to 110 „ „
Special improved plough steel wire	110 to 120 „ „
Extra special improved plough steel wire . . .	above 120 „ „

Mild steel used for special purposes has breaking strength of 26 to 80 tons per sq. in.

For wire ropes of	6	strands of	7	wires	deduct	5%	off sum of strength of wires.				
„	6	„	12	„	„	10%	„		„	„	„
„	6	„	30	„	„	15%	„		„	„	„
For locked coil ropes deduct . . .						5%	„		„	„	„

Wire rope should never be bent round a drum or pulley whose diameter is less than 100 I or 1,000 d; 150 D, or 1,500 d, are preferable, and the respective coefficients 120 and 1,200 a quite frequently employed. In Belgium, diameters of pulleys greater than 750 d for flat rope or greater than 1,000 d for round ropes, are allowed. In the Pas de Calais the following propo tions of drum diameter have been adopted: for Lang's lay, greater than 68 D, for flattene strand greater than 72 d, and for lock coil, greater than 80 d.

(J. F. Perry, '*Mining Engineer*,' vol. iv., No. 34, p. 24.)

The maximum bending stress in pounds per square inch produced by bending a rope roun a pulley of diameter $\triangle$ is theoretically $E\frac{d}{\triangle}$, where E is the modulus of elasticity of the wi used; it ranges from 10,000,000 to 30,000,000 lbs. Owing to the strain not acting directly right angles to the cross section of the whole rope, it is found in practice that the mean stre is more correctly represented by the expression $\frac{3}{8}E\frac{d}{\triangle}$. According to R. W. Chapman (*Pro Austr. Inst. Min. Eng.*, vol. iii., No. 3, April 1908), if a is the angle of pitch of the wires in strand and b of the strands in a rope, the bending stress is $E\frac{d}{\triangle}\cos^2 a \cos^2 b$.

If s be the mean bending stress as above, T the breaking strength in lbs. per sq. in., m th factor of safety (ratio of total breaking load to total working load), W the total load to be carrie and A the total cross-section of steel in the rope, $A = \frac{mW}{T - s}$.

For ordinary winding ropes $A = 0{\cdot}6\ D^2$ approximately.

Factor of safety for haulages for 5 to 6, for winding ropes 8 to 10.

Coefficients of friction of wire rope :—

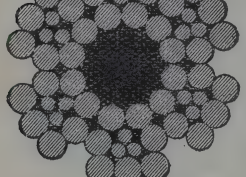
Dry rope on a grooved iron drum . .	0·120	Greased rope on a wood filled sheave	0·14
Wet „ „ „ „ . .	0·070	Dry rope on rubber or leather filling	0·49
Greased „ „ „ . .	0·70	Wet „ „ „ „ .	0·40
Dry rope on a wood filled sheave . .	0·235	Greased „ „ „ .	0·20
Wet „ „ „ „ . .	0·170		

According to G. Raw (*Trans. Inst. Min. Eng.*, iv., p. 180) the coefficient of friction of slightly oiled flattened strand rope upon an elm-filled sheave, fibres on end, is between 0·3 an 0·35.

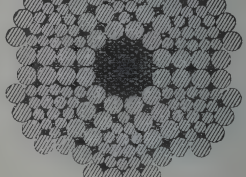
The resistance to bending of a rope under tension T lbs. round a pulley of radius r ft. $= 1{\cdot}26 - 0{\cdot}002276\frac{T}{r}$ (*Weisbach*). The maximum admissible stress in a medium wire rope may be taken a averaging 5,000 times the weight of 1 foot of the rope.

Flattened Strand Ropes.

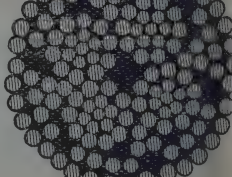
Flattened strand ropes are constructed of strands each of which has a flattened surfac exposed for wear throughout its entire length, so that the wear due to friction in working ove pulleys is distributed over a larger number of wires than is the case with ordinary round strande



No 48 K.
Haulage Rope.



No. 49 K.
Winding Rope.



No. 163.
Flexible Crane Rope
(Non-rotating).

ropes. In the latter the wear is very severe on the crown wires of each strand, which are, consequently, considerably reduced in sectional area before any appreciable wear has taken place in the adjoining wires. The smooth surface of flattened strand ropes materially reduces wear and tear on drums and pulleys; owing to the wear being so light on the ropes, it is not necessary to have so large a margin between the working load and the breaking strain as in ropes of ordinary make. Being more compact, they contain a larger metallic area than ordinary ropes, and therefore a flattened strand rope is of smaller size than an ordinary rope of equal breaking

strain, and is not so liable to be forced out of shape by the crushing stress it has to sustain. When required, flattened strand ropes are made non-spinning for winding and sinking purposes. They are very suitable as balance ropes, as, being absolutely dead, they can be used with or without pulleys in the sump.

Flattened strand haulage ropes splice more effectively than ordinary ropes, as the core is slightly smaller than the strands, and there is consequently less risk of the splice drawing. This construction is of special utility in ropes used for power transmission purposes, aerial ropeways, etc., where an efficient splice is essential. The greater surface of flattened strand ropes increases the holding power of grips or clips used in haulage work. For use on cranes and lifts, these smaller ropes possess special advantages, as the construction gives greater strength than the ordinary make without increase in size or loss of flexibility. Non-rotating ropes of special formation are in great demand for crane work, particularly for cranes used in the erection of large buildings, and on quays and shipping wharves, as any tendency of the rope to spin is entirely obviated.

Circum.		Diameter.			Approximate Weight.		Approximate Breaking Strains.				
					Per fthm.	Per metre.	Best Patent Steel.	Special Improved Patent Steel.	Best Plough Steel.	Special Improved Plough Steel.	Extra Special Improved Plough Steel.
Ins.	mm.	Ins.	Ins.	mm	Lbs.	Kilos.	Tons.	Tons.	Tons.	Tons.	Tons.
1	25	$\frac{5}{16}$	0·318	8	1·14	0·29	3·53	3·92	4·36	4·55	4·99
1¼	31	$\frac{3}{8}$	0·397	10	1·71	0·42	5·51	6·23	6·9	7·2	7·92
1½	38	$\frac{15}{32}$	0·477	12	2·51	0·63	8·1	9·04	10·01	10·49	11·53
1¾	44	$\frac{9}{16}$	0·557	14	3·43	0·85	11·09	12·38	13·69	14·34	15·77
2	50	$\frac{5}{8}$	0·636	16	4·57	1·14	14·54	16·21	17·95	18·79	20·66
2¼	57	$\frac{23}{32}$	0·716	18	5·71	1·42	18·43	20·59	22·8	23·87	26·24
2⅜	60	$\frac{3}{4}$	0·756	19	6·4	1·6	20·36	22·73	25·18	26·38	29·0
2½	63	$\frac{13}{16}$	0·795	20	7·09	1·76	22·31	24·95	27·58	28·8	31·68
2¾	69	$\frac{7}{8}$	0·875	22	8·57	2·17	27·13	30·31	33·53	35·14	38·64
3	76	$\frac{15}{16}$	0·954	24	10·29	2·55	32·39	36·2	40·04	41·92	46·1
3¼	79	1	0·994	25	10·86	2·7	34·92	39·05	43·15	45·19	49·7
3¼	82	$1\frac{1}{32}$	1·03	26	12·0	2·97	36·12	40·38	44·7	46·8	51·48
3½	88	$1\frac{1}{8}$	1·11	28	13·94	3·43	43·62	48·77	53·82	56·48	62·12
3¾	94	$1\frac{3}{16}$	1·19	30	16·0	4·0	51·02	57·02	63·0	66·02	72·62
4	101	$1\frac{1}{4}$	1·27	32	18·29	4·57	56·71	63·23	69·84	73·12	80·42
4¼	107	$1\frac{13}{32}$	1·35	34	20·57	5·14	70·04	78·25	86·68	90·68	98·92
4½	114	$1\frac{7}{16}$	1·43	36	22·86	5·71	78·0	87·28	96·47	101·10	110·25
5	127	$1\frac{5}{8}$	1·59	40	28·57	7·08	97·32	108·63	120·13	125·75	137·18
5¼	133	$1\frac{11}{16}$	1·67	42	31·43	7·8	104·75	117·13	129·44	135·56	147·88
5½	139	$1\frac{3}{4}$	1·75	44	34·51	8·56	118·84	132·44	146·33	153·34	167·28
5¾	146	$1\frac{13}{16}$	1·83	46	37·6	9·33	128·52	143·78	159·06	166·57	181·70
6	152	$1\frac{7}{8}$	1·91	48	41·14	10·2	139·62	156·17	172·42	180·68	197·10
6¼	158	2	1·99	50	44·57	11·0	152·97	171·02	189·01	198·03	216·0

NOTE.—The figures given above are calculated on flattened strand ropes, having six strands with hemp main core, see No. 49K, p. 2604.

(*Wrights Ropes Ltd., Birmingham.*)

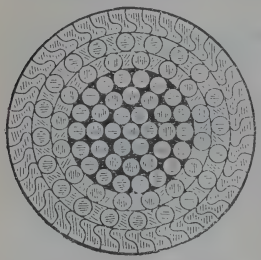
Locked Coil Ropes.

Locked coil ropes are in many cases advantageous where heavy loads have to be raised from great depths. Strength for strength, they are of less diameter than ordinary ropes, and consequently admit of corresponding reduction in width of drum, thus minimising lateral friction on drums and pulleys. They are absolutely free from any tendency to rotate, and are therefore of special utility in sinking operations and for winding in shafts where there is not much clearance, as the possibility of collision between the cages is obviated. Frictional wear on guides is also very much reduced by the use of locked coil ropes in winding. They are of longer duration than any other form of rope, as owing to their smooth surface the external wear is evenly distributed over the periphery of the rope, and internal friction, which is so marked a feature of ordinary ropes, is reduced to a minimum. In the event of any wire being broken in use, it is held in position and does not, as in an ordinary rope, unravel and lay across the adjacent wires, causing other fractures in working over drums and pulleys. The tendency to internal corrosion is less in locked coil ropes than in any other type of rope, as during the process of manufacture the successive annular layers of wires of which the ropes are composed are coated with a special

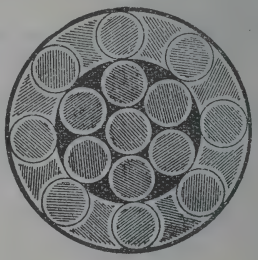
rust and acid-proof lubricant, which cannot be worn off during work owing to the protection afforded by the interlocking wires of the outer cover. In consequence of the wear on these ropes being so light, they may be worked with a lower margin of safety than is the case with ordinary ropes, as with the latter, in estimating factor of safety required, provision has to be made for the rapid wear which takes place.

As guide ropes, the advantages of the locked coil construction may be readily understood when it is borne in mind that, in the event of a rod breaking in the ordinary twisted guide rope, it would strand out from the rope, and be caught by the cage gland with disastrous results; in a locked coil rope the broken rod would be securely held in position.

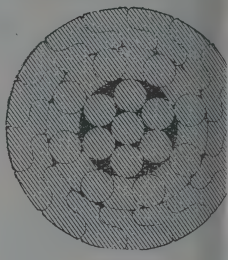
Locked coil ropes are eminently desirable as standing ropes for aerial ropeways, as their smooth surface affords very easy running for the wheels of the carrier; consequently less haulage power is required and wear and tear considerably reduced.



No. 63.
Winding Rope.



No. 64.
Guide Rope.



No. 66A.
Aerial Rope.

Locked Coil Steel Wire Ropes for Winding, Sinking, etc.

Circum.		Diameter.			Approximate Weight.		Approximate Breaking Strain.		Minimum Diameter of Drum and Pulley.
					Per fthm.	Per metre.	Special Improved Patent Steel.	Special Improved Plough Steel.	
Ins.	mm.	Ins.	Ins.	mm.	Lbs.	Kilos.	Tons.	Tons.	Feet.
$3\frac{1}{8}$	79	1	·994	25	$15\frac{1}{2}$	3·86	49	60	$9\frac{1}{2}$
$3\frac{1}{4}$	82	$1\frac{1}{32}$	1·03	26	$16\frac{1}{2}$	4·1	54	70	$9\frac{3}{4}$
$3\frac{1}{2}$	88	$1\frac{1}{16}$	1·11	28	18	4·5	65	80	$10\frac{1}{2}$
$3\frac{3}{4}$	94	$1\frac{3}{16}$	1·19	30	21	5·21	75	87	$11\frac{1}{4}$
4	101	$1\frac{1}{4}$	1·27	32	24	5·95	86	100	12
$4\frac{1}{4}$	107	$1\frac{11}{32}$	1·35	34	$26\frac{1}{2}$	6·45	95	111	$12\frac{3}{4}$
$4\frac{1}{2}$	114	$1\frac{7}{16}$	1·43	36	30	7·44	107	123	$13\frac{1}{2}$
$4\frac{3}{4}$	120	$1\frac{1}{2}$	1·51	38	34	8·43	118	140	$14\frac{1}{4}$
5	127	$1\frac{5}{16}$	1·59	40	38	9·43	132	154	15
$5\frac{1}{4}$	133	$1\frac{11}{16}$	1·67	42	41	10·25	144	170	$15\frac{3}{4}$
$5\frac{1}{2}$	139	$1\frac{3}{4}$	1·75	44	45	11·16	157	185	$16\frac{1}{2}$
$5\frac{3}{4}$	146	$1\frac{13}{16}$	1·83	46	49	12·23	173	203	$17\frac{1}{4}$
6	152	$1\frac{7}{8}$	1·91	48	53	13·14	190	222	18
$6\frac{1}{4}$	158	2	1·98	50	59	14·71	203	243	$18\frac{3}{4}$
$6\frac{1}{2}$	165	$2\frac{1}{16}$	2·06	52	62	15·5	215	260	$19\frac{1}{2}$
$6\frac{3}{4}$	171	$2\frac{1}{32}$	2·14	54	65	16·24	235	281	$20\frac{1}{4}$
7	177	$2\frac{3}{16}$	2·22	56	74	18·44	253	303	21

Guides, Rubber Ropes, Standing Ropes for Aerial Ropeways, etc.

Approximate Breaking Strain.		
Special Mild Steel.	Best Patent Steel.	Special Improved Patent Steel.
Tons.	Tons.	Tons.
23	30	46
25	34	50
31	41	62
36	48	72
41	55	82
45	60	90
51	68	102
57	76	114
63	84	126
68	91	136
74	99	148
82	109	164
90	120	180

(*Wrights Ropes Ltd., Birmingham.*)

Size and Weight in Lbs. per Yard, and Safe Working Load in Cwts., of Round Wire Ropes.

Iron Ropes.

Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.
Best Charcoal Iron.											
1	$\frac{1}{4}$	4	$2\frac{3}{8}$	$2\frac{1}{4}$	20	$3\frac{3}{8}$	$4\frac{1}{2}$	36	$4\frac{1}{8}$	9	72
$1\frac{1}{8}$	$\frac{5}{16}$	6	$2\frac{1}{2}$	$2\frac{3}{8}$	22	$3\frac{1}{2}$	5	40	$4\frac{3}{8}$	$9\frac{1}{2}$	76
$1\frac{1}{4}$	$\frac{3}{8}$	8	$2\frac{3}{8}$	3	24	$3\frac{3}{8}$	$5\frac{1}{2}$	44	$4\frac{3}{8}$	10	80
$1\frac{3}{8}$	$\frac{7}{16}$	10	$2\frac{3}{8}$	$3\frac{1}{4}$	26	$3\frac{3}{8}$	6	48	5	11	88
$1\frac{1}{2}$	$\frac{1}{2}$	12	$2\frac{3}{8}$	$3\frac{1}{4}$	28	$3\frac{3}{8}$	$6\frac{1}{2}$	52	$5\frac{1}{4}$	$11\frac{3}{4}$	94
2	$\frac{5}{8}$	14	3	$3\frac{3}{4}$	30	4	7	56	$5\frac{1}{4}$	$12\frac{1}{2}$	100
$2\frac{1}{8}$	$\frac{3}{4}$	16	$3\frac{1}{4}$	4	32	$4\frac{1}{8}$	$7\frac{1}{2}$	60	6	15	120
$2\frac{1}{4}$	$\frac{7}{8}$	18	$3\frac{1}{4}$	$4\frac{1}{4}$	34	$4\frac{3}{8}$	8	64	$6\frac{1}{4}$	$16\frac{1}{2}$	132

Steel Ropes.

Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Circumference in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.
Best Crucible Steel.											
1	$\frac{1}{4}$	6	$2\frac{1}{4}$	$2\frac{1}{4}$	30	$3\frac{1}{4}$	4	56	$4\frac{1}{4}$	$7\frac{1}{2}$	100
$1\frac{1}{4}$	$\frac{5}{16}$	8	$2\frac{3}{8}$	$2\frac{3}{8}$	32	$3\frac{3}{8}$	$4\frac{1}{2}$	60	$4\frac{3}{8}$	9	120
$1\frac{3}{8}$	$\frac{3}{8}$	10	$2\frac{1}{2}$	$2\frac{1}{2}$	36	$3\frac{1}{2}$	5	64	$4\frac{1}{2}$	10	132
$1\frac{1}{2}$	$\frac{7}{16}$	12	$2\frac{3}{8}$	3	40	$3\frac{3}{8}$	$5\frac{1}{2}$	72	5	11	154
$1\frac{5}{8}$	$\frac{1}{2}$	16	$2\frac{3}{4}$	$3\frac{1}{4}$	44	$3\frac{3}{4}$	6	76	$5\frac{1}{4}$	$12\frac{1}{2}$	175
$1\frac{7}{8}$	$\frac{5}{8}$	20	$2\frac{7}{8}$	$3\frac{1}{4}$	48	$3\frac{7}{8}$	$6\frac{1}{2}$	80	$5\frac{1}{4}$	$13\frac{1}{2}$	189
2	$\frac{3}{4}$	22	3	$3\frac{3}{4}$	52	4	7	94	6	15	210
$2\frac{1}{8}$	2	26									
Plough Steel.											
1	$\frac{1}{4}$	10	$2\frac{1}{8}$	2	36	3	$3\frac{3}{4}$	72	$3\frac{7}{8}$	$6\frac{1}{2}$	120
$1\frac{1}{4}$	$\frac{5}{16}$	12	$2\frac{1}{4}$	$2\frac{1}{4}$	44	$3\frac{1}{2}$	4	76	4	7	132
$1\frac{3}{8}$	$\frac{3}{8}$	16	$2\frac{3}{8}$	$2\frac{1}{4}$	48	$3\frac{1}{4}$	$4\frac{1}{4}$	80	$4\frac{3}{8}$	8	154
$1\frac{1}{2}$	$\frac{7}{16}$	22	$2\frac{1}{2}$	$2\frac{3}{8}$	52	$3\frac{3}{8}$	$4\frac{1}{2}$	88	$4\frac{1}{2}$	9	175
$1\frac{5}{8}$	$\frac{1}{2}$	26	$2\frac{3}{8}$	3	56	$3\frac{3}{8}$	$5\frac{1}{2}$	94	5	11	189
2	$\frac{3}{4}$	32	$2\frac{3}{4}$	$3\frac{1}{4}$	64	$3\frac{3}{4}$	6	100			

Messrs. Latch & Batchelor are putting on the market an anti-corrosive steel wire rope, which ppears to be giving good results.

Flat Ropes.

W = width, in inches. t = thickness, in inches. k = 35 for charcoal iron, 55 for crucible, 0 for plough steel.

Safe working load = Wtk cwts.

Size and Weight in Lbs. per Yard, and Safe Working Load in Cwts., of Flat Wire Ropes.

Dimensions in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Dimensions in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Dimensions in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.	Dimensions in Inches.	Weight in Lbs. per Yard.	Working Load in Cwts.
Best Charcoal Iron.											
$2\frac{1}{4} \times \frac{1}{2}$	5	40	3 × $\frac{5}{8}$	8	64	4 × $\frac{11}{16}$	11	88	$4\frac{5}{8} \times \frac{3}{4}$	$15\frac{1}{2}$	124
$2\frac{1}{4} \times \frac{1}{2}$	6	48	$3\frac{1}{4} \times \frac{5}{8}$	9	72	$4\frac{1}{4} \times \frac{11}{16}$	$12\frac{1}{2}$	100	$4\frac{5}{8} \times \frac{7}{8}$	17	136
$2\frac{1}{4} \times \frac{1}{2}$	7	56	$3\frac{3}{4} \times \frac{5}{8}$	10	80	$4\frac{1}{2} \times \frac{11}{16}$	14	112	$4\frac{5}{8} \times 1$	18	144
Best Crucible Steel.											
$2\frac{1}{4} \times \frac{1}{2}$	5	64	$2\frac{3}{4} \times \frac{5}{8}$	7	80	$3\frac{1}{4} \times \frac{5}{8}$	9	124	$3\frac{3}{4} \times 1\frac{1}{16}$	11	144
$2\frac{1}{4} \times \frac{1}{2}$	6	72	3 × $\frac{5}{8}$	8	100	$3\frac{1}{2} \times \frac{5}{8}$	10	136	$4\frac{1}{2} \times \frac{3}{4}$	$15\frac{1}{2}$	180
Plough Steel.											
$2\frac{1}{4} \times \frac{1}{2}$	5	80	$2\frac{3}{4} \times \frac{5}{8}$	7	124	3 × $\frac{5}{8}$	8	144	$3\frac{1}{2} \times \frac{5}{8}$	10	180
$2\frac{1}{2} \times \frac{1}{2}$	6	100									

(See also pages 286, 925.)

Steel Wire Ropes for Oil-well Drilling.

Wire ropes are largely employed in drilling oil-wells, particularly where the American syst of drilling is in use, which is known as the Californian Cable Rig. This system uses a drilli line for manipulating the tools, a casing line for manipulating the casing, and a sand line cleaning out the wells. The two former are generally 6 × 19 construction, and the latter 6 ×

The Russian or Galician system employs jointed rods in place of drilling lines, but wire ro are used for cleaning out the wells and for manipulating the casing and the string of tools. T sand, pump, or bailing lines are usually 6 × 7 construction, and the other ropes, which run to $1\frac{1}{2}$ ins. diameter, are 6 × 19, 6 × 24, or 6 × 30.

Oil-well drilling, being exceptionally severe, calls for ropes of high quality.

Galvanized ropes are sometimes advisable on account of the corrosive action of the wa in the wells.

It is a matter of general practice to have the drilling ropes left-hand lay.

Electrical Cables for Collieries.

See Mines and Quarries Form No. 11, Mines Dept. (*April* 1921).*

Pumps and Pumping.

Cornish pumps from 4 ft. to 12 ft. stroke, 6 ins. to 30 ins. diameter, 12 to 16 strokes per mi piston speeds vary from 60 to 120 ft. per min. A rule sometimes adopted is that speed in feet second $= \sqrt{l}$, where l is the length of stroke in feet. Ram pumps work at speeds of 100 to 200 per minute.

If n be number of complete strokes (i.e. up and down strokes) per min., and d the diame of the ram or bucket, the theoretical discharge G in gallons per min. is given by $G = 0{\cdot}034d^2$ The actual discharge is less than this by the slip, which ranges from 3 per cent. to 30 per ce

* Printed and published by H.M. Stationery Office. Price 1s. net; 1s. 2d. post free.

n extreme cases. In practice it is usually between 10 per cent. and 15 per cent. It must ıe deducted from the theoretical discharge to get the actual discharge. Maximum velocity ıf water in rising main 200 to 300 ft. per min., rarely exceeds 100 ft. in small pumps; maximum velocity in windbore, 40 ft. per min.

Pressure at bottom of rising main = pressure due to static head + pressure required to overcome resistance of pipe.

If v be the velocity of discharge in feet per second, H the vertical head in feet, L the length n feet of the pipe, D its diameter in inches, and P the total pressure at bottom of rising main, :hen,

$$P = 0{\cdot}341\ D^2\left(H + 0{\cdot}024\left(\frac{L}{12D}\right)^4\frac{v^2}{2g}\right).$$

The pressure in the steam cylinder must be capable of overcoming this pressure, allowing for the mechanical efficiency of the engine (say 0·66).

The content of a pipe in gallons of water = $0{\cdot}034\ D^2L$.

The thickness of a pipe can be calculated thus:—

Thickness in inches = 0·000125 P.D. + 0·5.

Thickness of pump-barrel = $0{\cdot}5 + \frac{\text{P.D.}}{2{,}000}$, where P is pressure in lbs. per sq. in.

Weight of pipe in lbs. = $2{\cdot}5\ L\ (D^2 - d^2)$, where D and d are external and internal diameters. The flange = weight of 1 ft. of pipe.

Horse-power in the water lifted = $\frac{g\ H}{3{,}300}$, where g is the actual delivery in gallons per min.

The 'duty' of a Cornish pumping engine is the number of millions of pounds of water lifted one foot high by the consumption of 112 lbs. of coal (before 1856 of one bushel = 94 lbs., and in America of 100 lbs. of coal) under the boilers. To convert duty into lbs. of coal burnt per h.p. in the water, divide 222 by the duty. It is always theoretical discharge that is taken in calculating duty. Cornish engines have worked with as little as 1·5 lb. coal per h.p.; 2·5 to 3 lbs. is a usual figure.

For double-acting pumps the formula for discharge previously given becomes

$$G = 0{\cdot}068\ d^2\ n.l.$$

If A be the area of the piston, n number of strokes per minute, S length of stroke, b the height of the water barometer, l the length of the windbore, a its area, h the vertical height of the suction lift, g the acceleration of gravity,

$$a > 0{\cdot}0055\ \frac{An^2\,Sl}{g(b-h)}$$ for single-acting pumps, and $> 0{\cdot}00275\ \frac{An^2\,Sl}{g(b-h)}$ for double-acting pumps,

or the piston will rise faster than the water can follow it, and hammering will result.

The air-vessel should have a volume = 4 times that of barrel for single-acting, and 1·6 times for double-acting pumps. (*Weisbach.*)

Centrifugal Pumps.

Let u be peripheral velocity of impeller in ft. per sec.

- r radius of the impeller in feet.
- n number of revolutions per second.
- d depth of openings in impeller in feet.
- i number of impellers in series.
- h height of total lift in feet.

then

$u = 2\,n\,\pi\,r$. Velocity of radial water discharge from impeller = K u, where K is a coefficient between 0·1 and 0·3, averaging 0·2. Quantity of water discharged per second = $K\,u\,2\,\pi\,r\,d = 4\,K\,n\,\pi^2\,r^2\,d$ cub. ft. $h = c\,i\,\frac{u^2}{2g}$, where c is a coefficient that varies considerably, but is mostly between 0·75 and 1.

Mechanical efficiency (m) is between 0·5 and 0·8, usually about 0·7.

Hence h.p. required $= \frac{8\ K\ c\ \pi^4\ n^3\ r^4\ i\ d}{8{\cdot}8\ m\ g}$, or, taking average values, h.p. = about $\frac{2}{3}\ n^3\ r^4\ i\ d$.

Direct coupled motor-driven centrifugal pumps to pump 1,500 gallons p.m. to a height o 1,000 ft. have been found to have an overall efficiency of 71·6 per cent.; electrically driven ran pumps would have a similar efficiency of 80 per cent. *(Prest & Leggat.)*

(See also PUMPS, p. 1330).

VENTILATION.

MINE GASES AND VENTILATION.

Normal air contains 79 vols. nitrogen, 21 vols. oxygen, carbonic acid 0·06 to 0·11 per cent With 17·0 vols. of oxygen a candle is extinguished, but breathing is still possible; with 15·2 vols of oxygen breathing becomes more difficult; with 10 vols. of oxygen, very difficult; and with 5 or 6 vols. practically impossible. Prussian rule for volume of air in mines is 70 cubic fee per min. per man underground, reckoning each horse as four men; it must never amount t less than 53 cubic feet per ton of daily output.

Approximately in Great Britain 5·8 tons of air pass through coal mines per ton of coal raised The blood in a man's body is capable of absorbing about one pint (about 20 per cent. of it volume) of either oxygen or carbonic oxide when saturated. If it be half saturated with carboni oxide, unconsciousness sets in, and with higher proportions death follows. In air containin 0·1 per cent. of carbonic oxide the blood would become half saturated in about an hour in the cas of a man at rest, and in about half an hour in the case of a man taking exercise. Anything abov 0·15 per cent. of carbonic oxide must be considered dangerous; 0·16 per cent. will cause sligh distress to mice in an hour, 0·2 per cent. distress in 8 minutes, 0·3 per cent. distress in 4 minutes 0·45 per cent. distress in 2 minutes and collapse in 4 minutes, 0·57 per cent. distress in 1 minut collapse in 6½ minutes, and death in 12½ minutes. With canaries 0·09 per cent. causes distres in one hour, 0·15 per cent. distress in 3 minutes, fall from perch in 18 minutes, 0·2 per cent. distres in 1½ minutes. fall from perch in 5 minutes, and 0·3 per cent. fall from perch in 2½ minutes.

Fire-damp.—Fire-damp consists essentially (up to 95 per cent. or more) of marsh gas o methane, CH_4, the remainder consisting of nitrogen and carbonic acid; hydrogen and som of the higher hydrocarbons have also been found in some samples. Haller and Moureu hav found helium with traces of neon (0·003–0·05 per cent.), and argon with traces of krypton an xenon (0·003–0·04 per cent.) in fire-damp. A mixture of air and marsh gas will explode if th mixture contains between 5 and 15 per cent. of marsh gas by volume. The maximum of explosiv violence is attained with 9 to 10 per cent. of marsh gas. The igniting point is between 650° and 750° C., and there is always a perceptible 'lag' or delay in the ignition, the amount o which depends upon the temperature. According to Taffanel and Le Floch, mixture containing only 3 per cent. of marsh gas will ignite at 680° C. and as much as 30 per cent. a 875°. In a mixture of 6·5 per cent. of marsh gas with air, the quantity of gas burnt per second varies from 0·00075 per cent. at 535° C. to 0·05 per cent. at 640° C. According to H. Le Chatelie the igniting point of acetylene is 450° C., hydrogen 550° C., methane and carbonic oxide 650° C The velocity of propagation of ignition of methane ranges from 0·03 m. per sec. with 6 per cent of methane to a maximum of 0·61 m. per sec. with 12 per cent., and falls again to 0·1 m. per sec with 16 per cent. of methane in air. The velocity of the explosive wave in a mixture of methane with pure oxygen is 2,500 m. per sec. Marsh gas has been given off in quantities up to 4,500 cubic feet per ton of coal wrought, and has been shown to exist in coal under pressures up to 40 atmospheres. It is on record that in one mine as much as four million cubic feet of fire-damp has been given off in 24 hours.

Experiments on the ignition of mixtures of methane and air by electric sparks have been recorded by Dr. Thornton (*Trans. Inst. Min. Eng.*, xliv. p. 145, and xlvi. p. 112); the most inflammable mixture is one containing about 7 per cent. of methane. With sparks between copper poles the least continuous current capable of igniting a 9 per cent. mixture was found to be:—

50	100	240	480 volts.
4·0	0·9	0·175	0·05 amps.

With iron poles slightly greater currents are required. With alternating currents of low periodicity, the current required is far greater, ranging from 3 times at 50 volts to 12½ times at 500 volts. The higher the frequency, the larger the current required for ignition.

PRINCIPLES OF VENTILATION.

The difference of pressure producing ventilating currents in mines is measured by the water-gauge; a column of 1 in. of water corresponds to about 66 ft. of air at 60° F and 30 ins. of barometric pressure. The theoretical velocity of air due to such pressure is given by the expression

$=66\sqrt{h}$, where v is the velocity in feet per second and h the water-gauge in inches. If the ction in the airways of a mine is taken into account, according to Murgue—

$$h = K\frac{l\,p\,v^2}{a} \text{ or } h = K\frac{l\,p\,Q^2}{a^3}$$

here l is the length of the air passage, p its perimeter, a its area, all in feet, and Q the quantity air in cubic feet per second. Values of coefficient K: for drifts, bricked and arched, =0·000,0012; in ordinary rock, untimbered, K=0·000,0034: timbered in the usual way, mensions taken inside timbers, K = 0·000,0057. If the quantities and velocities be given in ousands of feet per minute, these coefficients become 0·00033, 0·00094 and 0·00156 respectively; me engineers use Mr. Fairley's coefficient, which is 0·002. The critical velocity of air flowing

circular pipes $= \frac{18}{D}$ feet per min., where D is the diameter of the pipe in feet.

The work required to move a quantity Q of air under a water-gauge of h inches=5·2 hQ foot-ounds.

Mr. J. T. Storrow has found that the quantity of air flowing through material under 0·25 in. size at a slow rate varies directly with the pressure and not with the square root.
(*Trans. Inst. Min. Eng.*, lv. 313.)

The loss by scaling through packwalls, etc., would therefore be greater than in an open airway r the same difference in pressure.

Measurement of flow of air. — In a pipe circular in section a velocity equal to the mean flow at 0·15 of radius from the wall of the pipe. In a mine drift the mean of two measurements lfway between roof and floor and one-sixth of the width of the airway from either side will pproximate to the mean velocity of the air in the drift. The mean velocity is between 0·7 and 85 of the maximum velocity at the centre of the drift, averaging 0·78.

With the ordinary plain Pitot tube, if v be the velocity of airflow in feet per second and h the ater-gauge in inches, $v=66\sqrt{h}$; with the double Pitot tube (one branch facing the other pointing the direction of the flow) $v = 56{\cdot}5\sqrt{h}$.

If the pressure of air on either side of a regulator or other diaphragm with an aperture of a quare feet be determined by water-gauge, and the difference of gauge pressure be d inches, the uantity of air flowing is $40\,a\sqrt{d}$ cubic feet.

Natural Ventilation and Furnace Ventilation.

Natural Ventilation and Furnace Ventilation.—If there be two shafts, the mean temperature f the air in each of which is respectively T and t (in degrees Fahrenheit), the water-gauge due o this difference of temperature will be $\frac{H}{66}\left(\frac{T-t}{459+T}\right)$, where H is the depth of the pit, assuming that the temperature of the atmosphere is 60° and the pressure 30 ins., under which conditions cubic foot of air weighs 0·0765 lb.; under any barometric pressure of β inches and temperature Fahrenheit, the weight of a cubic foot of air is $\frac{1{\cdot}326\ \beta}{459+t}$, by means of which formula the necesary correction can be applied. The number of heat units required to produce the above water auge will be $\frac{1{\cdot}326\ Q\ \beta\ (T-t)}{459+t} \times 0{\cdot}2375 = \frac{0{\cdot}315\ Q\ \beta\ (T-t)}{459+t}$ heat units per second.

The grate area is often taken $= \frac{34}{\sqrt{H}} \times \frac{5{\cdot}2\ hQ}{550}$ sq. ft.

In practice, to pass 300,000 cubic feet of air per min. with a 2-in. water-gauge about one ton f coal is burnt per hour.

Fan Ventilation.

Fan ventilation.—If u be the peripheral velocity of the fan blades in feet per second, the heoretical water-gauge produced $= \frac{u^2}{68g} = \frac{u^2}{2180}$.

The manometrical efficiency of a fan ranges from about 0·45 for an open-running fan up to about 0·9 for a good modern enclosed fan.

The volumetric efficiency under given conditions is the volume of air actually passed by the fan divided by the volume of the fan × number of revolutions.

The mechanical efficiency is the horse-power required to drive the fan (or the fan and fan engine, as the case may be) divided by the horse-power in the quantity of air moved = $\frac{5{\cdot}2\ h\mathrm{Q}}{550}$. It varies from about 45 to about 75 per cent. in different types of fans.

The equivalent orifice of a mine $o = 0{\cdot}4\ \frac{q}{\sqrt{h}}$, where q represents the quantity of air in thousands of feet per minute, and o the area in sq. ft. The equivalent orifice of British mines is usually between 20 and 30 sq. ft.

If H be the initial water-gauge of a given fan (maximum water-gauge, produced on exhausting out of a closed vessel), the equivalent orifice of a fan, working on a mine with equivalent orifice o, should be $= o\sqrt{\frac{h}{\mathrm{H}-h}}$. The inlet area of a fan should be about 20 per cent. greater than its equivalent orifice. The equivalent orifice of a fan should be about three times that of the mine on which it works. The velocity at which air enters the fan orifice should be between 1,000 and 1,500 ft. per min. If k be the manometric efficiency of any fan, according to Murgue—

$$u = \sqrt{\frac{g\ 68\ h}{k}}.$$

To find the horse-power of a motor or engine required to drive a fan under average mine conditions, multiply the number of cubic feet of air by the water-gauge and divide this product by 4,500. Example: If a fan is delivering 100,000 cub. ft. of air at 2-in. water-gauge, what should be the horse-power of the motor or engine required to drive it?

$$\text{H.P.} = \frac{100{,}000 \times 2}{4{,}500} = 44{\cdot}4.$$ (*Machinery.*)

The average consumption of brattice cloth in U.S.A. is 1,697 sq. yds. per 100 tons of coal raised. (*Report on Brattice Cloth, U.S.A. Bureau of Mines.*)

REGULATORS.

Regulators.—If A be the area in sq. ft. of a regulator which is required to produce as much resistance to the flow of air as a roadway of length l, perimeter p, both in feet, a area in sq. ft., K = Murgue's coefficient of friction as above when the quantity of air is expressed in thousands of cubic feet per minute and the pressure in inches of water-gauge, then $\mathrm{A} = 0{\cdot}4\sqrt{\frac{a^3}{\mathrm{K}\,p\,l}}$. The regulator should be placed behind the last man in the split.

Safety Lamps.

The gauze should contain not less than 784 meshes per square inch.

TABLE SHOWING AVERAGE CANDLE-POWER OF VARIOUS LAMPS (*a*) AT BEGINNING, AND (*b*) AT END OF TEN HOURS' BURNING WITH FIVE DIFFERENT OILS.

Lamp.	No. 1 Oil.		No. 2 Oil.		No. 3 Oil.		No. 4 Oil.		No. 5 Oil.	
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
Marsaut	0·73	0·63	0·75	0·64	0·74	0·63	0·72	0·64	0·72	0·64
Donald	0·50	0·37	0·49	0·43	0·48	0·43	0·48	0·44	0·48	0·42
Mueseler	0·54	0·42	0·49	0·40	0·46	0·41	0·49	0·40	0·49	0·38
Davy	0·51	0·44	0·83	0·69	0·78	0·70	0·82	0·75	0·81	0·72
'Geordie'	0·46	0·36	—	—	—	—	—	—	—	—
Clanny	0·78	0·72	—	—	—	—	—	—	—	—
Scotch Davy	0·59	0·48	—	—	—	—	—	—	—	—
Deflector	0·96	0·90	—	—	—	—	—	—	—	—

TABLE SHOWING COST IN PENCE PER 1,000 LAMPS OF ONE AVERAGE CANDLE-POWER HOUR, WITH DIFFERENT OILS.

Oil.	Marsaut.	Donald.	Mueseler.	Davy.	'Geordie.'	Clanny.	Scotch Davy.	Deflector.
No. 1	11½	22	14½	18	16	11½	17½	11½
No. 2	19½	33¾	32	19	—	—	—	—
No. 3	25½	43	43½	26½	—	—	—	—
No. 4	35	56	59½	42½	—	—	—	—
No. 5	45½	73	75¾	43¾	—	—	—	—

The oils used were as follows :—

Oil.	Specific Gravity.	Composition, per Cent.		Cost per Gallon.
		Mineral.	Vegetable.	s. d.
No. 1	0·820	100	0	0 9
No. 2	0·841	70	30	1 6
No. 3	0·844	50	50	1 9
No. 4	0·865	30	70	2 3
No. 5	0·889	0	100	2 9

Lamps burning benzine of sp. gr. 0·765, costing 1*s.* per gallon, gave the following results :—

	Candle-power.		Cost in pence per 1,000 lamps of one average c.p. hour.
	At Beginning.	At End.	
Wolf	0·99	0·94	16½
Protector . . .	0·72	0·66	25½

Gas Caps.

Gas caps are shown in an ordinary safety lamp with the flame turned down so as just not to show any white light, when introduced into an atmosphere containing small amounts of marsh gas or methane, approximately as follows :—

2 % of marsh gas. Cap ¼ in., just visible except at extreme tip.
3 % " " " ½ in., fully formed.
4 % " " " ¾ in., well defined.
4½% of marsh gas. Cap 1½ in., well defined.
5 % " " " 2½ ins. " "
5½% " " " 4 ins. " "
6 % " " " fills the safety lamp.

Gas-testing lamps burning alcohol will show clearly as little as 0·2 per cent. of marsh gas.

Coal Dust.

Coal-dust.—Three ounces of coal-dust per cubic yard of gallery space is sufficient to produce an explosive mixture; excess of coal-dust prevents neither the initiation nor the propagation of an explosion. Coal-dust giving less than 12 per cent. of volatile matter is practically incapable of initiating an explosion. At least 50 per cent. of inert stone-dust is required to prevent the initiation of an explosion. If less than 75 per cent. of the dust passes the 200 sieve it is difficult to initiate an explosion. (*Abstracted from the Lievin experiments.*)

The temperature of ignition of coal-dust is about 1,000°C. Mixed with air and introduced into a heated vessel the temperature may be as low as 590°; there is very little lag. (*Taffanel and Le Floch.*)

The General Regulations provide that in all coal mines except anthracite mines and except mines of which the floor, roof, and sides of the road are naturally wet throughout, every road or part of a road shall be treated with incombustible dust in such a manner as to ensure that the dust on the floor, roof, and sides throughout shall never contain more than 50 per cent. of combustible matter, or else they shall be treated with water in such a manner that the dust is always combined with 30 per cent. (by weight) of water. It is provided that the percentage of incombustible dust required by this regulation may be reduced by an amount equivalent to the percentage of water present. The incombustible dust shall contain not less than 50 per cent. of material capable when dry of passing through a sieve with 200 meshes per linear inch. If more than 50 per cent. of dust is used, the percentage of fine material in such dust may be reduced proportionately, but shall not fall below 25 per cent. Representative tests must be made by the management at intervals of not less than one month, and the results posted at the pit head. The method in which the tests are to be made is fully prescribed by the Statutory Orders.

Rescue Apparatus.

There are three main types of rescue apparatus :—

(1) The supply of oxygen is maintained by means of compressed oxygen carried in steel cylinders.

(2) The supply of oxygen is obtained from liquid air.

(3) Oxygen is chemically generated from peroxides, usually sodium-potassium peroxide.

In (1) and (2) the expired carbonic acid is absorbed, usually by caustic soda, in (3) the reagent that evolves the oxygen also absorbs the carbonic acid.

Particulars of some forms are as follows :—

Apparatus.	Weight.	Oxygen Capacity.
	Lbs.	Cubic Feet.
Pneumatogen (Type II.)	14¼	5·8
Draeger	36–39	8·9
Shamrock	36	9·7
Fleuss	31	8·0
Weg	About 30	5·3
Proto	37	8·5
Meco	39½	8·5
Salvus	16	3·0
Aerolith	22	?
Aerophor	30	?

It is estimated that 120 cubic inches of oxygen per min. is ample for the severest exercise; a man at rest requires about 15 cubic inches, and climbing hills 90 cubic inches per min. The Aerolith uses liquid air containing about two parts of oxygen to one of nitrogen; it is stated that one gallon is sufficient for three hours' work.

The Aerophor holds 10 lbs. of liquid air, equal to about 125 cubic feet.

The following has been found to be a man's average consumption of oxygen per minute, gas dry, at N.T.P.

Rate of doing Work.	Breathing.			
	Air.		Oxygen.	
	Litres.	Cub. in.	Litres.	Cub. in.
At rest	0·36	22	0·32	19·5
3,000 ft.-lbs. per min.	1·12	68·3	0·97	59·2
6,000 " "	1·74	106·2	1·54	95
9,000 " "	2·33	142·2	2·16	131·8

The most economical rate of walking when travelling a flat road and wearing a rescue apparatus—*i.e.* the rate at which a maximum distance can be covered for a given supply of oxygen—is about 2½ miles per hour.

('*Second Report of the Mine Rescue Research Committee of the Department of Scientific and Industrial Research.*')

When the wet-bulb temperature is much above 80°F., a man cannot remain long at work; he can stand a wet-bulb temperature of 120°F. for about five minutes. (*J. S. Haldane.*)

To Detect Carbon Monoxide in the Air.—A Technical Paper (No. 11) of the United States Bureau of Mines suggests the following simple test capable of detecting as little as 0·03 per cent. of carbon monoxide in the air. One or two drops of blood from a pricked finger are diluted with water until this assumes a buff-yellow colour. Some of this discoloured water is placed in two 100 cubic centimetre test tubes, and one of the tubes is to be taken into the mine, where one-half is to be poured away at the place where the air is to be tested, the mine air taking the place of the water poured away. The tube is then to be corked, taken to the surface, and to be shaken for about ten minutes. If the air in the test tube contains CO, the pink colour of the liquid will indicate the presence of hæmoglobin on comparing the tube with the other test tube filled with the normal fluid. Mr. Ivor Graham has shown that carbon monoxide is a normal constituent of the air of coal mines over 1,500 ft. deep, being produced by the slow oxidation of carbonaceous material at the coal face, in the roads and in the goaf; it is usually under 0·005 per cent., but in a few cases 0·012 per cent. has been found.

('*Trans. Inst. Min. Eng.*,' Sept. 1920.)

Spontaneous Combustion.

Work in the Doncaster Coal Owners' Laboratory has shown that the liability of a coal to spontaneous combustion in the goaf depends, other things being equal, upon its capacity for absorbing oxygen. It appears that a coal, 100 grammes of which, ground to 200 mesh, absorbs less than 200 c.c. in 96 hours at 30°C., is only liable to gob fires when the working conditions especially favour the latter. Coals liable to fire absorb over 300 c.c. in the same time. Presence of pyrites, especially when finely divided, increases the liability to spontaneous combustion.

Fire Extinction.

Investigations have been made recently into the scientific side of mud-jet working for fire extinction in colliery workings, and it has been decided that the material of the mud, some of which should be of a lime and some of a clay character, should consist of sifted earth of 5 mm.

esh, boiler ash, dust from the cleaning of blast-furnace gas, and even combustible material, such s the refuse of coal washing, can be added to make up bulk without any risk should nothing ore suitable be at hand. In the majority of instances the mud tank can be so placed as to operate y gravity, but steam or compressed air pressure can be used. It has been found that if a tank placed at a height of, say, 15 yards, it will force the mud a horizontal distance of 150 yards, ven allowing for fairly sharp bends in the conducting pipes.

Electric Signalling in Coal Mines.

A circular issued by the Home Office points out that while there is no difficulty in constructing ells and relays that will comply with the requirements laid down—i.e. which will not 'spark'—ost of those in ordinary use in coal mines do not comply with the provision of General Regu-tion 132; and it states that in mines to which this regulation applies steps must be taken ithout delay to bring into compliance with the regulation any existing installations which o not already comply, while no new apparatus must be installed except such as does strictly omply. The fact is emphasised in the report that with the usual type of bell and magnitude f battery at present employed, nearly every break-flash that occurs when the bare signal wires re separated would ignite a mixture of firedamp and air containing between 7·5 and 9·5 per cent. f methane, were such a mixture to surround the wires at the time.

Relays, although not requiring for their action so great a battery power as bells, have wing to their higher inductance a lower 'igniting-current' at which the break-flash on the ignal wires becomes dangerous. At the present time, with few exceptions, the battery power sed on relays is in excess of that sufficient to give a dangerous break-flash at the signal wires. he commonest kinds of relays are dangerous when used with a battery of more than four wet eclanché cells, or with any current in excess of the current given by such a battery.

The report shows in detail how the bare wire system of electrical signalling as commonly mployed can be rendered quite secure from any danger of the ignition of inflammable gases y the break-flash at the signal wires or at the contacts of the signalling instruments.

In order to secure a safe bare-wire signalling system it is necessary in the first place that he battery power employed on any one circuit should be limited, and, in the second place, that he signalling instrument, whether bell or relay, should comply with certain requirements set ut in the report.

The maximum pressure allowed by the General Regulation (No. 134 (a)) for a signalling ircuit is 25 volts, and from the point of view of safety a pressure of 25 volts is not excessive, rovided that, as is usual, wet Leclanché cells (quart size) are employed.

Systems in which the battery used consists of dry primary cells or secondary cells, or in which continuous or alternating current generators are employed, can be rendered safe if, in ddition to the use of anti-sparking devices, sufficient non-inductive resistances are permanently nstalled in the circuit.

Both bells and relays should have flame-tight covers (preferably locked), and should be so onstructed and maintained that when included in a circuit with a battery at 25 volts the break-lash produced, when bare signal wires are separated after giving a signal, is incapable of gniting an 8 per cent. methane air mixture.

ORE DRESSING AND COAL WASHING.

(For details see 'The Dressing of Minerals,' by Henry Louis, from which the following is mainly bstracted.)

The operations included under the head of dressing comprise all the operations between the xtraction of the crude mineral from the mine and rendering it merchantable, thus forming a link etween the operations of the miner and the metallurgist. By common consent, gold milling is enerally looked upon as a dressing operation, though it is doubtful whether cyanidation should lso be included.

The various operations consist of :—

Hand picking or sorting.

Comminution (coarse breaking or crushing and fine breaking or grinding).

Sizing (preliminary or rough sizing and final or fine sizing).

Classifying.

Separation by differences of specific gravity, magnetism, electric conductivity, or surface ension.

Usually a more or less complicated series of operations is required, especially in the case of omplex ores, and these are usually indicated by means of flow sheets.

Let the weight of feed in any concentration process be A and its assay a per cent., the weight nd assay of concentrates be B and b and of tails C and c respectively, then the

$$\text{Enrichment ratio} = \frac{b}{a} = \frac{\%\ \text{Recovery}}{\%\ \text{Concentration}}.$$

$$\% \text{ Concentration} = \frac{100B}{A} = \frac{100(a-c)}{b-c}.$$

$$\% \text{ Recovery} = \frac{100b(a-c)}{a(b-c)} = \frac{B100b}{Aa}. \quad A = \frac{B(b-c)}{a-c}.$$

$$\% \text{ Efficiency of concentration} = 100\frac{B}{A}\left(\frac{b}{a} - \frac{100-b}{100-a}\right) = 100\frac{a-c}{b-c}\left(\frac{b}{a} - \frac{100-b}{100-a}\right) =$$

$$100\ \frac{\% \text{ Recovery} - \% \text{ Concentration}}{\% \text{ Waste in feed}}.$$

(*R. T. Hancock.*)

Sorting is performed either on floors or on picking belts or tables. An ordinary pickin belt may be of iron plates 4 ft. wide, 50 to 100 ft. long, travelling at 40 to 65 ft. per minute Pickers stand on both sides, 7 ft. to 15 ft. apart; each picker can treat 1–3 tons of coals pe hour.

Power required to drive, 2½ to 5 h.p. Upkeep, about 50*l.* per annum.

Rubber-covered canvas belts about 32 ins. wide are also used, and will carry 25 to 50 ton per hour at speeds of 30 to 60 ft. per minute.

Circular tables are 3 to 4 ft. wide, 10 ft. to 18 ft. in diameter, revolving with a peripheral spee of 40 to 60 ft. per minute, and can deal with 30 to 70 tons of mineral per hour.

Comminution.—Rough breaking is done by jaw breakers, either reciprocating like thos of the Blake, Dodge, etc., type, or gyrating like the Gates type. The former have been built t take pieces up to 5 ft. by 7 ft., requiring 300 h.p. to drive, and breaking 300 tons per hour. Smalle breakers usually break 1 ton per hour for a consumption of 2–3 h.p. The gyrating crusher i better suited to very large outputs, but cannot take such large pieces, and appears to be rathe more economical of power.

Fine Crushing.—Rolls are used for medium and fine crushing. Let r be the radius o the particle to be broken and d the radius of the particles in the crushed product (both con sidered as spheres); the minimum radius of the roll should be $> 25\ (r - d)$.

For fine crushing to about ⅛-in. mesh the following table shows the general practice :—

Rolls.		Revs. per minute.	Horse-power required.	Cwts. crushed per hour.
Diam.	Face.			
10½ ins.	10½ ins.	130	3	25
12½ ,,	10½ ,,	110	4½	45
16 ,,	10½ ,,	90	6½	65
21 ,,	10½ ,,	75	9½	100
27 ,,	11 ,,	45	12½	145
37 ,,	12 ,,	45	16	200

The peripheral speed should be greater the finer the product required; for grinding t 40 mesh the speed should be 1,000 ft. per minute.

In large plants three or four sets of rolls are placed in series so as gradually to reduce the or to the desired size. At Mount Morgan, such a plant consisted of eight sets of rolls in two serie of four, thus :—

26 ins. diam., 15 ins. face, set $\frac{3}{32}$ in. apart, 112 revs. per min.
26 ,, 15 ,, ,, $\frac{1}{16}$,, ,, ,,
30 ,, 16 ,, ,, $\frac{1}{16}$,, ,, ,,
30 ,, 16 ,, ,, in contact ,,

The total power consumption was 100 h.p. and the crushing capacity 125 tons per 24 hour crushed to 20 mesh (0·025 in.); the wear on the steel roll-shells was 0·108 lb. of steel per to of ore crushed.

Stamps.—The ordinary gravitation stamp is used more largely for gold milling than fo other purposes, but also for crushing tinstone, etc. The complete stamp consists of the head shoe, stem and tappet, the weight of which may be up to 1,500 lbs. The relative weights ar about 30, 17, 40, 13. It is lifted by a cam forming the involute of a circle; if h be the lift o the stamp, r the radius of the pitch circle of the involute, and a the angular motion of the cam during the lift, $h = \frac{\pi r a}{180}$. The speed is usually about 90 drops per minute.

If n be the number of drops per minute, h the drop in inches, s the number of stamps, and w the weight of a stamp in pounds, the power required is approximately $\frac{nhsw}{300{,}000}$. (For a more

exact formula see 'A Handbook of Gold Milling,' by H. Louis.) The average crushing capacity s 2–8 tons per 24 hours for a 1,000 lb. stamp. The Husband atmospheric stamp with two heads requires 35 h.p. to work it, and can crush 40 tons of hard tinstone per 24 hours down to 0·048 in.

Steam stamps are used mainly for crushing the copper-bearing rocks of the Lake Superior Mines, down to about ¼-in. mesh. One such stamp will crush 10 tons per hour, the efficiency being about 1·75 tons per i.h.p. per 24 hours.

Ball mills have been made both for dry and wet crushing. The Krupp mill is a dry-crushing mill; the No. 5 size, which is largely used, is 86 ins. diameter by 46 ins. length, makes 20–25 r.p.m., weighs 182 cwts., and a set of balls weighs 18 cwts. At Mount Morgan these mills require 13 h.p. and crush 22·7 tons per 24 hours to 20 mesh (0·025 in.). The balls wear at the rate of 0·725 lb. and the hunch plates at the rate of 0·681 lb. per ton of ore crushed.

Wet crushing ball mills are 60 ins. to 80 ins. in diameter and about 40 ins. long. A charge of balls for such a mill weighs about 2 tons; it is run at 25 to 30 r.p.m., takes from 25 to 35 h.p. to drive it, and will crush 25 to 100 tons down to 0·02 mesh per 24 hours; the water consumption is about 65 gallons per minute.

The tube mill is also used wet or dry, and is in effect an elongated ball mill, 3 ft. to 5 ft. in diameter and 13 ft. to 26 ft. long. A tube mill 4 ft. in diameter, 16 ft. 6 ins. long, crushed in Western Australia 38 tons of sand per 24 hours, 95 per cent. of the product being finer than 100 mesh, requiring 30 h.p. to drive it. Such mills are lined with silex, chilled iron, or hard steel bars, and are usually charged with flints. According to Mr. Davidson, the best number of r.p.m. $= 200 \div \sqrt{d}$, where d is the internal diameter in inches; the weight of flints in pounds should be $N \div 44$, where N is the internal capacity of the mill in cubic feet. Western Australian practice corresponds nearly to $N \div 60$.

The Marathon mill uses rods in place of balls; a mill 3 ft. diam., 7 ft. long, charged with 7,000 lbs. of rods ½ in. to 2 in. diam., running at 30 r.p.m., crushed 18 tons per hour with a consumption of 12·5 h.p., using 42 U.S.A. gallons of water per minute. The feed was below ½-in. mesh and the product was ground to $\frac{1}{1\cdot3}$-in. mesh, 14 per cent. being below $\frac{1}{400}$-in. mesh. The wear of the line plates was 0·14 lb. and of the rods 0·4 lb. per ton of feed.
(*Trans. Amer. Inst. Min. Eng.*, lv., p. 678; lvii., p. 355.)

The Hardinge tube mill has the form of two cones base to base. An 8 ft. Hardinge mill requires 50 h.p. to drive it, and requires about 10 h.p. hours per ton crushed to about 48 mesh.

An 8 ft. × 22 ft. mill crushed 200–250 tons per 24 hrs. using about 56 h.p., with a charge of 5 tons of Danish pebbles wearing at the rate of 2·16 lbs. per ton of feed; with steel balls instead of pebbles 360–400 tons were crushed per 24 hours.
(*Trans. Amer. Inst. Min. Eng.*, lv., p. 678.)

The Marcy mill is a short mill (5–6 ft.) with perforated diaphragm at the discharge end, from 2 ins. to 48 mesh. An 8 ft. by 6 ft. mill driven by a 225 h.p. motor crushes 550 tons per 24 hours at 24 r.p.m., carrying 30,000 lbs. chrome steel balls.
(*C. T. Van Winkle, Trans. Amer. Inst. Min. Eng.*, vol. lix. (1918), p. 227.)

The Huntingdon mill is made in three sizes, 3 ft. 6 ins., 5 ft. and 6 ft. diam.; No. 2 is most used; it weighs about 5 tons; consumes 12 h.p.; makes 60–70 r.p.m., and will crush about 10 tons per 24 hours to about 15 mesh.

The Arrastra is 10 to 20 ft. in diameter, has usually four dragstones, 6–8 cwts. in weight. At 6 to 12 r.p.m. a charge of 1 to 3 tons is ground in 2–3 hours.

The Chilian mill has 2–3 rollers, 4 to 6 ft. in diameter, takes up to 75 h.p., and crushes up to 150 tons per 24 hours.

Sizing.—For coarse screening fixed grizzlies or 'jigging' screens are used. For medium and fine screening mostly trommels, 8 ft. to 2 ft. in diameter by 12 ft. to 3 ft. long; the peripheral velocity is usually 50 to 200 ft. per minute. The slopes may vary from 5° to 14°, averaging about 7°. A set of seven trommels, 3 ft. diam., 5 ft. long, will size about 7 tons of ordinary crushed material per hour, and require up to 5 h.p. to drive it.

Classification.—This term applies to the separation into groups of equal falling particles The terminal velocity of a particle falling freely in water is approximately $V = 2{\cdot}6\sqrt{D(S-1)}$ where V is the velocity in metres per second, D the diameter in metres of the screen mesh through which the particle just passes, and S the density of the mineral. This velocity will be attained

after the particle has fallen a distance equal to $V^2 \div 4$ metres approximately. When V is less than 0·5 to 1, according to the substance, the law on which these formulas are based (friction ∝ velocity and viscosity negligible) no longer holds good. The particles fall more slowly, obey a different physical law, and are known as slimes, which are incapable of classification.

The minimum radius of a particle that obeys the above law of terminal velocity is

$$\sqrt{\frac{9\,\mu^2}{2\,g\,(s-1)}}\ \text{cm.};$$

where μ is the viscosity (0·0115) and g the acceleration of gravity (981), both in C.G.S. units, and s is the specific gravity of the particle.

Hence log radius in cm. $= \bar{3}\cdot92764 - \frac{1}{2}\log(s-1)$.

The following table is calculated from the above formula :—

Sp. gr.	Radius in mm.	Sp. gr.	Radius in mm.	Sp. gr.	Radius in mm.	Sp. gr.	Radius in mm.	Sp. gr.	Radius in mm.	Sp. gr.	Radius in mm.
1·2	0·1528	1·6	0·1004	2·0	0·08465	2·4	0·07567	3·5	0·06237	5·5	0·05128
1·3	0·1265	1·7	0·09534	2·1	0·08201	2·5	0·07395	4·0	0·05870	6·0	0·04950
1·4	0·1149	1·8	0·09118	2·2	0·07966	2·6	0·07238	4·5	0·05575		
1·5	0·1071	1·9	0·08768	2·3	0·07757	3·0	0·06719	5·0	0·05333		

Spitzkasten ; the first box should be 2 ft. wide for 10 cub. ft. pulp per minute, or 1–2 cwts. of solid matter ; boxes may increase in geometrical progression with factor of 1·5 ; length of first box about 6 ft., increasing by 3 ft. for each successive box.

Trough classifiers 10 to 20 ft. long, 1 ft. wide at narrow end, will treat 100 tons per 24 hours, with 100 cub. ft. of water per ton of crushed material.

Jigs.—The following represents the general modern practice :—

Diam. of particle .	0·25	0·50	0·75	1·00	1·25	1·50	1·75	2·00 ins.
Length of stroke .	0·4	1·2	1·55	1·8	2·0	2·15	2·3	2·4 "
No. of strokes per min.	200	160	145	130	125	125	125	125

CONTINENTAL JIGGING PRACTICE ON ORDINARY LEAD-ZINC ORES.

Three to five compartment jigs; screen surface 20" × 31·5".

Size of Particles.	Length of Stroke.	Strokes per Min.	Water per Cwt. treated.	Capacity per Sq. Ft. of Screen Area per Hour.
Inch.	Inch.		Gallons.	Cwt.
0·04	0·2	280	90	0·6
0·046 to 0·06	0·25	280	73	0·9
0·06 to 0·08	0·35	260	60	1·2
0·08 to 0·11	0·50	240	55	1·6
0·11 to 0·16	0·60	220	52	1·8
0·16 to 0·22	0·80	200	50	1·9
0·22 to 0·32	1·00	180	46	2·0
0·32 to 0·43	1·20	160	45	2·1
0·43 to 0·63	1·25	140	54	2·2
0·63 to 0·87	1·60	140	58	3·7
0·87 to 1·25	2·00	140	61	4·3

Jig screens of steel wire are liable to rapid corrosion when pyritic ores are being treated ; wire drawn from Ambrac (Cu75Ni20Zn5) has been recommended in such cases.

Round buddle; diam. 18 ft. to 25 ft. ; makes 5–10 r.p.m.. Capacity 1½–3 cub. ft. per min., carrying 28 to 56 lbs. material ; time of filling 3–10 hours.

Slime table; diam. 15 ft. to 25 ft. ; ¼–1 r.p.m. Pulp 1½–3 cub. ft. per min., carrying 4 to 7 lbs. per cub. ft. Clear water 1½–3 cub. ft. per min. Power required ½–1½ h.

Frue vanner; belt surface 4 ft. by 12 ft. ; fall 3 ins. to 6 ins. ; travel 6 ft. per min. ; strokes 200 per min. Capacity 0·25 to 0·5 cub. ft. pulp per min. ; 5 to 8 tons material 24 hours. Clear water ¼ of pulp. Power required ¼ h.p.

Lühring vanner; belt surface 3 ft. 6 ins. by 12 ft.; travel 8–12 ft. per min.; 160–180 strokes per min. Capacity 2½–7½ tons per 24 hours; clear water 1–2 cub. ft. per min. Power required ¾–1½ h.p.

Wilfley table; 16 ft. long, 6 ft. wide, tapering to 3 ft. Will take particles up to ¼ in. 240 strokes per min., ¾ in. long. Capacity 25 to 50 tons per 24 hours. Clear water 1 to 2 cub. ft. per min. Power required 1 h.p.

Coal Washing.*

Coal as it comes from the mine is first screened, usually over a 2 ins. to 2½ ins. screen; the oversize drops on to picking belts, where shale, dirty coal, etc., are picked out. The undersize is taken to a washery, especially when it is required for coke-making. A jigging screen with ¾-in. holes will screen about 1 ton per hour for each 0·75 sq. ft. of screening surface.

Coal is sometimes dry-cleaned in the Purdee spiral separator, in which it is allowed to slide down a spiral track, the clean coal falling over the outer edge, whilst the shale, etc., remains on the track.

When the separation of the clean coal from the accompanying shaly matter is easy, or when the products are not required in the highest possible state of purity, a simple form of washer may be used. Such is, e.g., the Elliott trough washer, capable of treating 5 to 10 tons of small coal per hour with a water consumption of 1,750 gallons per ton of coal washed. The Blackett washer is similar in principle, but the fixed trough with the moving dam-plates is replaced by a revolving drum within which is a spiral baffle-plate; it will treat 10 tons of small coal per hour, requiring 3,000 gallons of water in circulation per ton of coal washed. The Robinson washer works on the principle of a spitzkasten, with upward flow of water and a revolving stirrer; it can treat 15 to 20 tons of small coal per hour.

The purity of the washed coal is usually determined by floating it in solutions of known specific gravity; coal that floats in solutions of sp. gr. 1·35 to 1·45 is generally considered clean coal. The washing characteristics of a coal are best determined by constructing a washability curve or Henry curve. (See *Colliery Engineering*, 1925, p. 341.) The washability of coals is generally determined by plotting the proportions of the whole which float in solutions of definite specific gravities and the ash contents of these fractions as a curve, from the shape of which much valuable information as to the washing properties of the coal may be obtained. Most plants for such complete washing make use of jigs (bashes or boxes), and the coarser refuse is sometimes crushed and re-washed See flow-sheet No. I., p. 2623.

The Coppée Washery is typical of the more usual form of plant. The unwashed coal, say under 2 ins. to 3 ins., is sized before washing. The washing is carried out in two types of boxes, viz.: (*a*) Small coal feldspar boxes, which treat all the coal below ½ in.; (*b*) nut coal type of box, which treats the various sizes below 3 ins. and above ½ in. These sizes vary according to local conditions and the requirements of the market. The nut washers are 8 ft. deep, and the sieves are 5 ft. long and 3 ft. to 5 ft. wide, each washer treating 2·5 to 3·5 tons per hour per foot of width of screen. The more important data affecting the operations of nut washers are shown in the following table:—

Size of Nuts.	Depth of Layer of Shale on Sieve.	Length of Stroke.	No. of Strokes per Minute.	Mesh of Sieve.
½ in. to ¼ in.	2½ ins.	2½ ins.	80	$\frac{1}{10}$ in.
¼ " " 1 "	3 "	3 "	75	$\frac{2}{10}$ "
1 " " 2 ins.	3½ "	3½ "	70	¼ "
2 ins. " 3½ "	4½ "	4¾ "	65	$\frac{3}{10}$ "
3½ " " 5 "	5½ "	6¼ "	60	$\frac{5}{10}$ "

The Feldspar Washer is built in two compartments, each 4 ft. long, making a total length of 8 ft. by 2 ft. 6 ins. wide, the box being 5 ft. deep; such a washer can wash 7 to 10 tons of small coal per hour up to ½ in. in size. The following are the leading data:—

	1st Compartment.	2nd Compartment.
Thickness of layer of feldspar	2½ ins.	2½ ins.
" " " shale	$\frac{2}{10}$ in.	$\frac{2}{10}$ in.
Size of pieces of feldspar	$\frac{8}{10}$ in. to 1 in.	$\frac{8}{10}$ in. to $\frac{8}{10}$ in.
Length of stroke	0·55 in.	0·47 in.
No. of strokes per minute	165	165
Mesh of screen	0·55 in.	0·47 in.

* See 'The Preparation of Coal for the Market,' by H. Louis.

A plant to wash 100 tons per hour, 50 per cent. on nut washers and 50 per cent. on feldspa washers, would require four of the former, 4 ft. wide, and six of the latter. Such a plant woul require in circulation about 135,000 gallons of water, and make-up water amounting to betwee 2,800 and 3,500 gallons per hour.

When the refuse from the nut washers contains sufficient intergrown coal to be worth treating it is crushed, generally in a disintegrator, and the crushed material is re-washed on feldspa washers.

A coal washery may require from 1·5 to 3·5 h.p. for each ton of unwashed coal treated pe hour, varying with (*a*) the total output of the washery (a large washery requiring a relatively smaller h.p. per ton); (*b*) the quantity of interstratified coal, and whether the larger size i crushed and washed together with the smaller size, or whether the smaller size only is re-washed (*c*) the type and capacity of draining and storage bunkers, and whether apparatus is installe for mixing the various products.

Messrs. Simon-Carves, Limited, build washeries on the so-called Baum principle, in whic washing precedes classification. The slack below about 2 ins. is delivered to a bash having a area of about 0·8 sq. ft. per ton per hour; the washed coal then passes to a screen of abou $\frac{3}{8}$-in. mesh; the over-size is clean coal, and the under-size goes to a second bash having an are of about 1 sq. ft. per ton of coal per hour, the product being clean coal and refuse. The dir produced in the first washing can be further crushed and washed over again if necessary. A plant to treat 100 tons of slack per hour would, therefore, require a first bash with an area o 80 sq. ft., and a second bash with an area of $\frac{1}{4}$100 sq. ft.; the water in circulation would be abou 130,000 gallons per hour, and the make-up water required about 2,500 gallons.

The rhéolaveur consists of a series of troughs of steel, cement or wood, sometimes lined wit tiles, fitted with a series of pockets with adjustable discharges and, for the coarser sizes of coal, wit upward water flows. These are arranged so as to discharge clean coal, refuse or middlings for re washing as may be required. The plant is relatively cheap, compact and efficient and can treat a sizes from 4 in. to slurry. No general figures can be given as the plant has to be specially designed for each case. It is largely used in Belgium, and altogether about 60 million tons c coal a year are treated by it.

At Grassmoor Colliery a rhéolaveur plant treats 100 tons per hour 0-1 in. in two sizes, 40 ton 0-$\frac{3}{8}$ in., 60 tons $\frac{3}{8}$-1 in., absorbs 105 h.p., uses 140,000 gals. water in circulation.

(*A. Audry, Proc. So. Wales Inst. Eng.*, vol. xli., p. 567.)

In the United States small coal is being largely washed on shaking tables of the Wilfley type such a table will treat 5 to 8 tons per hour of coal under $\frac{3}{8}$-in. mesh, requiring about 1 h.p.

The flotation process has been applied to washing fine coal. (See *Trans. Inst. Min. Eng.* lxvii. p. 374.) It is being extensively used in Spanish collieries.

The Chance process employs a separating cone worked with a sludge consisting of sand an water; it is said to give excellent results on Anthracite, and is used in the U.S.A. (See *Tran Amer. Inst. Min. Met. Eng.*, vol. lxx. p. 740.)

The American Coal Cleaning Corporation's machine consists of a shaking table with riffle and a porous deck through which a current of air ascends on the principle of the Sutton-Steel table; this cleans dry coal and the finished product contains under 2 per cent. of extrinsic ash Over 10,000,000 tons of coal were cleaned in this way this year in the U.S.A. (See *Trans. Amer Inst. Min. Met. Eng.*, vol. lxx. p. 758.)

The largest American plant is the McComas plant at Crane Creek Mines, W. Virginia, treatin 225 tons per hour.

This table, known in England as the Birtley S.J. table, is used in a dry-cleaning plan erected at Wardley Colliery, Co. Durham. It treats coal under 2½ ins. and consists of six S.J tables with dust aspirators and bag house. Its capacity is 125 tons per hour, and it clean efficiently to within 2 per cent. of the intrinsic ash, there being under 1 per cent. of free coal i the refuse. A new type of dry-cleaning table, known as the Y table, having double the capacit of the S.J. table, and requiring less close sizing, has recently been introduced. Dust ma advantageously be removed from coal before the latter is washed, and treated separately b dry-cleaning in combination with a washery.

Dry-cleaning plants have been erected at Altham (Lancs) and Snowdon (Kent) and others ar being completed at Horden (Durham) and Thorne (Yorks); the last named is to treat 250-30 tons per hour.

The dry-cleaning system is fully described by K. C. Appleyard, *Trans. Inst. M.E.*, vol. lxxiii 1927, p. 404.

Dust is now often removed from coal that is not naturally too wet before it is cleaned by washin or dry-cleaning; it may be screened off by fine vibrating screens or may be taken out by an a current either on the screens or on the dry cleaning tables or else in a dust extractor; the dust collected by cyclones and bag-houses and is often used for dust-firing. Wedge wire is often used fo the fine screens.

Vibrating screens have a tightly stretched screening surface kept in rapid vibration and set at tolerably steep angle; the Hummer, Hayle, Overstrom, etc., screens differ mainly in the mechanism by which the vibration is produced.

For a good comparison of different methods of coal-cleaning see paper by Wheeler and Chapma in report of the Coal-Cleaning Conference at Edinburgh, July, 1927, pub. by Soc. Chem. Ind.

Mr. Norman Kemp has applied X-ray analysis to the products of the coal washery.

(*Trans. Inst. Min. Eng.*, vol. lxvii. p. 59.)

Magnetic Separation.

Maxima of magnetic susceptibility of minerals by volume in C.G.S.

Soft iron		400
Magnetite (pure crystallised)	Piedmont	3·12
Magnetite	Hey Tor, Devonshire	1·44
Magnetite	Altenfjord, Norway	0·27
Magnetite	Lake Champlain, U.S.A.	0·234
Magnetite (altered carbonate, impure)	Bettwys Garmon, Carnarvonshire	0·06
Red Hæmatite	?	0·00073
Red Hæmatite (crystallised)	Cumberland	0·00017
Specular Hæmatite	Nova Scotia	0·00106
" "	?	0·0005
Brown Hæmatite	?	0·00042
Brown Hæmatite (pure crystallised)	Nova Scotia	0·00011
Franklinite	New Jersey	0·0037
"	"	0·00253
Ferrous Sulphide	Artificial	0·064
Spathic Ore	?	0·000559
Clayband	?	0·00069
Impure Carbonate Ore	Northamptonshire	0·00056
Ilmenite	India	0·00147
Monazite	Travancore	0·000069
Zircon	Ceylon	0·00000055
Pleonaste	?	0·000102
Gahnite	?	0·000054

Common non-ferrous minerals, e.g. mica, quartz, felspar, calcite, have susceptibilities < ·000001. 'Strongly' magnetic minerals have susceptibilities > 0·001. 'Feebly' magnetic minerals between 0·001 and 0·0001. (*After Prof. Ernest Wilson.*)

Magnetic separators: (1) For minerals of high magnetic susceptibility:—

Dry working, e.g. Wenström: drum 30 ins. diam., 24 ins. face. Capacity 5–7 tons per hour; will take lumps up to 7 lbs.; 30 r.p.m. Current 15 amperes at 120 volts.

Wet working, e.g. Gröndal: 24 ins. wide, 24 ins. diam., 100 r.p.m. Capacity up to 5 tons per hour. Current 10 amperes at 110 volts.

(2) For minerals of low magnetic susceptibility:—

Dry working, e.g. Rowand-Wetherill. Belt 18 ins. wide, three electro-magnets taking respectively 5, 15, and 30 amperes at 110 volts. Capacity, 0·25 to 1 ton per hour.

Wet working, e.g. Ulrich.

The Rapid Magnetting Machine Co., Ltd., Magnetic Separators.

(*The Rapid Magnetting Machine Co., Ltd., Birmingham.*)

When choosing a magnetic separator the greatest possible care should be exercised. The best method, which is, without exception, adopted by mineral mining concerns, is to send a reasonable size *normal* sample of the material to be treated, accompanied by information likely to be useful, as, for instance, the quantity to be treated per hour, voltage of current (D.C.) available, whether to be self-contained with feed attachment, space available, etc., etc., and inquirers should insist on the magnetic products being returned for examination for cleanliness.

Specification should be compared with specification, even after material has been tested, as a machine efficient as regards the actual extraction may be of such unsuitable design as to cause a constant loss of material being treated; and, where iron is to be removed as an impurity, guarantees of *efficient* output should also be obtained.

For feebly magnetic minerals the magnetic separators have to be of a special type. For such minerals the 'Rapid' (Thompson-Davies) Patent Ore Separator (dry-working) machine has been designed; this machine is 4 pole, 3 disc, 15-in. belt; the maximum current on each pole is 2½ amps. at 110 volts capacity. The machine will deal with about 3 tons of wolfram-tin per day, monazite sands 5 tons per day, but the capacity varies according to the characteristics of the ore.

Flotation Processes.

These may be classified as follows:—

I. *Film Flotation*, utilising differences of surface tension on particles at an air-water interface—e.g. De Bavay, Macquisten processes.

II. *Oil Flotation*, utilising differences of surface tension in an oil-water medium where the particles are buoyed up by oil—e.g. First Elmore process.

III. *Adhesive Processes*, utilising differences of surface tension between particles and oil or grease, causing differential adhesion to oiled or greased surfaces—e.g. Murex, Cattermole, greased-plate processes.

IV. *Froth Flotation*, utilising differences of surface tension at gas-water interfaces, wher the particles are buoyed up by bubbles of gas :—

(*a*) Where the bubbles are produced by chemical action—e.g. Potter, Delprat processes.
(*b*) Where the bubbles are produced by releasing the air dissolved in water—e.g. Elmor vacuum process.
(*c*) Where the bubbles are produced by mechanical means—e.g. Minerals Separation, Callow Janey, K. & K. (Kraut & Kolberg), Rork processes.

(See also 'Froth Flotation : its Commercial Application and its Influence on Modern Con centration and Smelting Practice,' Walter Broadbridge, *Bull. Inst. M. M.*, January 1920.)

COSTS OF FLOTATION MACHINES.

Tons capacity for 24 hours.	First Cost per ton of daily capacity.		Operating Costs per ton daily capacity.	
	Mechanical Agitation.	Pneumatic Agitation.	Mechanical Agitation.	Pneumatic Agitation.
25	$30–50	$25–40	$0·20–0·75	—
50	25–45	12–20	—	$0·20–0·75
100	20–40	8–12	0·35	0·35
250	15–35	6– 8	0·28	—
1,000	12–25	4– 6	0·17	0·17

Reagents used :— (*Ralston.*)

Gangue modifying :—Acids, alkalies, silicates, carbonates, and other salts.
Froth producing :—Soluble oils, essential oils, cresylic acid, amyl alcohol, etc.
Froth stabilising :—Insoluble oils, petroleum, etc.

Surface Tension of Liquids against Air.

	Dynes per sq. cm.			Dynes per sq. cm.
Water (at 0° C.)	75·8	Water with 0·14 per cent. cresol	(at 23° C.)	71·5
Water (,, 20° C.)	75·1			
Phenol (,, 41° C.)	37·0	Water with 0·14 per cent. amyl alcohol	(,, 23° C.)	68·4
Cresol	34·8			
Olive oil	32·0	Water with 0·134 per cent. saponine	(,, 23° C.)	48·7
Petroleum	27·7			
Turpentine	25·6	Water with eucalyptus 'solute'	(,, 20° C.)	44·6

Dilute sulphuric acid reduces the contact angle and hysteresis range of that angle far mo for quartz, silicates, and oxides than it does for metallic sulphides; oiling the latter greatl increases the contact angle and the hysteresis range.

(*H. L. Sulman*, 'A Contribution to the Study of Flotation,' *Bull. Inst. Min. Met.*, November 1919.)

The Inspiration Consolidated Copper Company's plant at Miami, Arizona, treats 15,000 tons i 24 hours. The ore contains 1¾ per cent. of copper, mainly in finely disseminated sulphide Flotation reagents used, 1¾ lbs. per ton of ore. Recovery, 85 per cent. of total copper, 90 per cen of copper present as sulphide ; concentrates contain 20 per cent. of copper.

(*Trans. Amer. Inst. Min. Eng.*, lv., 1916, p. 576.)

Selective flotation is very largely employed for the treatment of lead-zinc ores in th Western States and in Mexico.

Finely-ground coal may be froth-floated from shale, using 1 lb. of cresol and ½ lb. of paraffi per ton of coaly shale ; the latter contains about 65 per cent. of ash, the clean coal about 8 per cen

ELECTROSTATIC SEPARATION is used in some special cases—e.g. for concentrating ros blende, molybdenite, and graphite (Blake-Marsden and Huff processes).

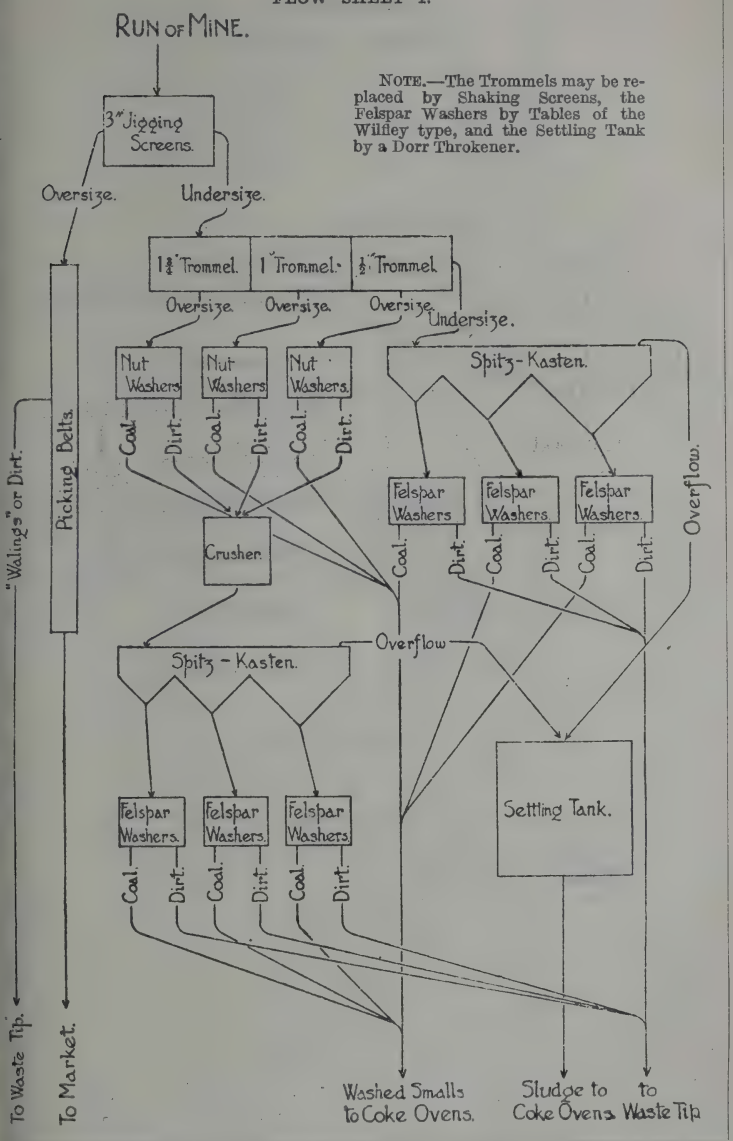
DRY SEPARATORS, using currents of air instead of water, are used under exceptional condition

FLOW SHEETS.

The diagrams given on pp. 2623–2631 are specimen flow sheets, illustrating the sequenc of operations in certain typical cases :—

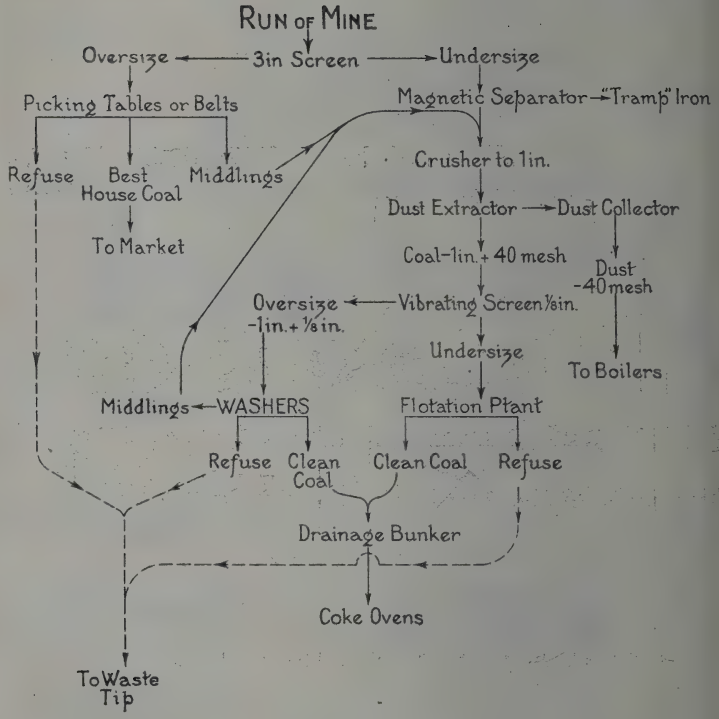
I and II. Coking coal. III. Dry cleaning of coal. IV. Low grade magnetic iron or V. Quartz carrying cupriferous pyrites. VI. Lake Superior copper ore. VII. Lead ore VIII. Tinstone containing wolfram. IX. Copper ore by Froth Flotation.

FLOW SHEET I.

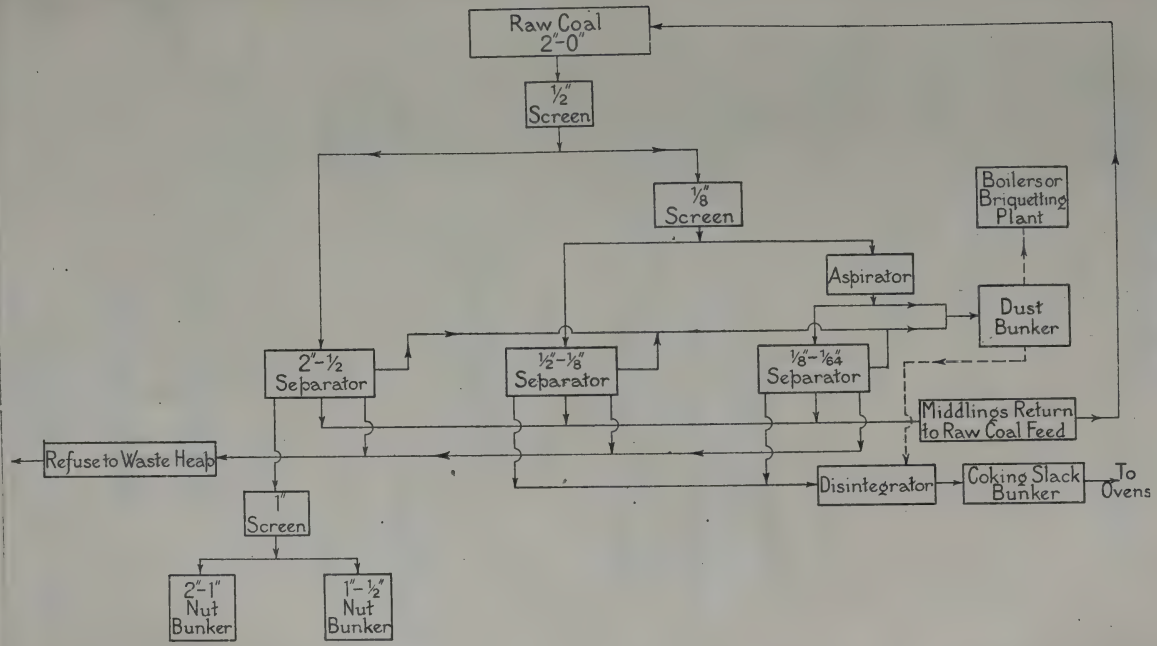

RUN OF MINE.
3" Jigging Screens.
Oversize.
Undersize.
NOTE.—The Trommels may be replaced by Shaking Screens, the Felspar Washers by Tables of the Wilfley type, and the Settling Tank by a Dorr Throkener.
1½" Trommel.
1" Trommel.
½" Trommel.
Oversize.
Oversize.
Oversize.
Undersize.
Nut Washers
Nut Washers
Nut Washers
Spitz-Kasten.
Coal.
Dirt.
Coal.
Dirt.
Coal.
Dirt.
"Walings" or Dirt.
Picking Belts.
Felspar Washers
Felspar Washers
Felspar Washers
Overflow.
Crusher.
Coal.
Dirt.
Coal.
Dirt.
Coal.
Dirt.
Overflow
Spitz-Kasten.
Settling Tank.
Felspar Washers.
Felspar Washers.
Felspar Washers.
Coal.
Dirt.
Coal.
Dirt.
Coal.
Dirt.
To Waste Tip.
To Market.
Washed Smalls to Coke Ovens.
Sludge to Coke Ovens
to Waste Tip

FLOW SHEET II.

(ALTERNATIVE TO SHEET I.)



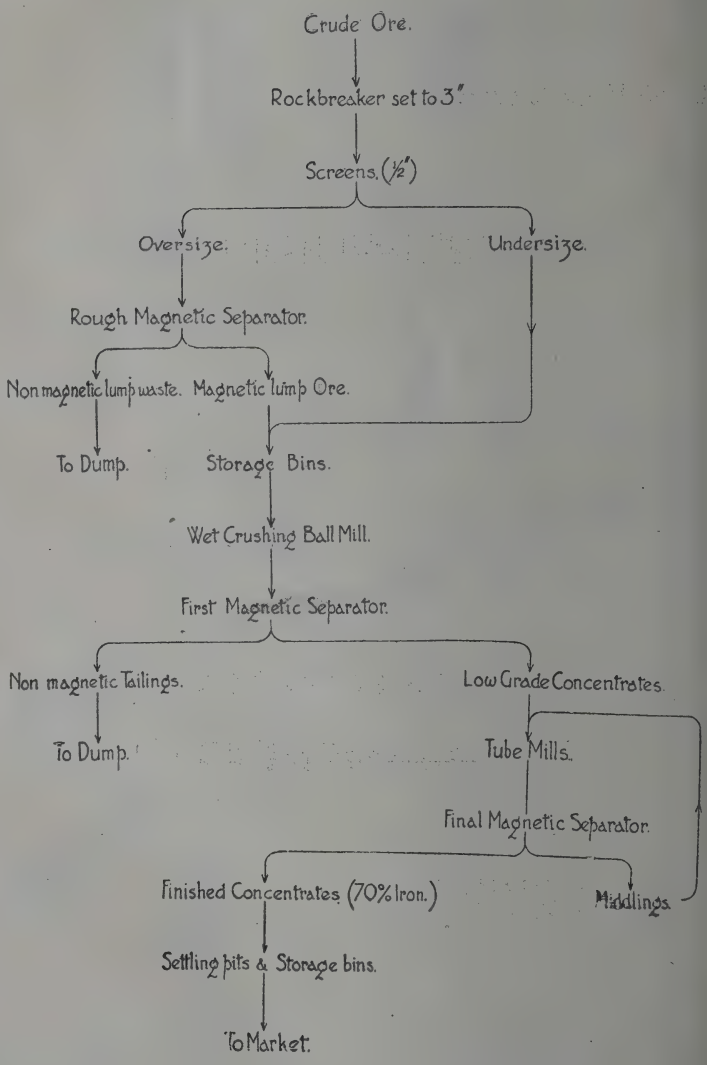
DRY CLEANING OF COAL.



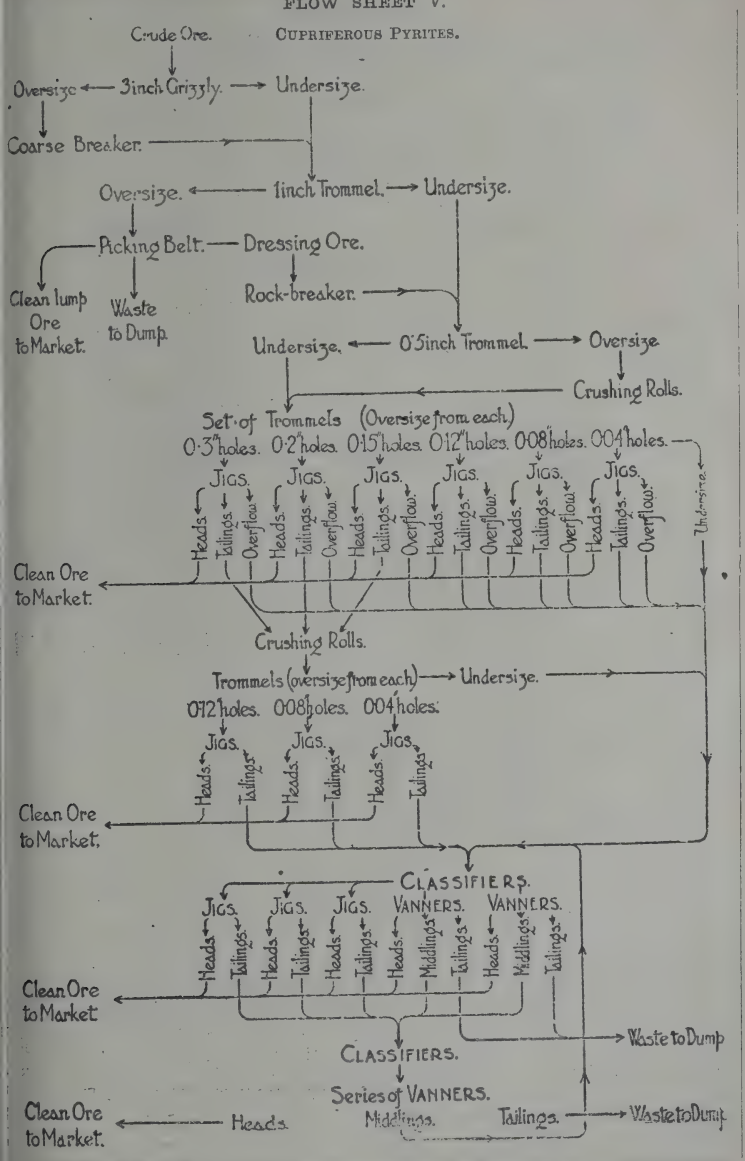
FLOW SHEET III.

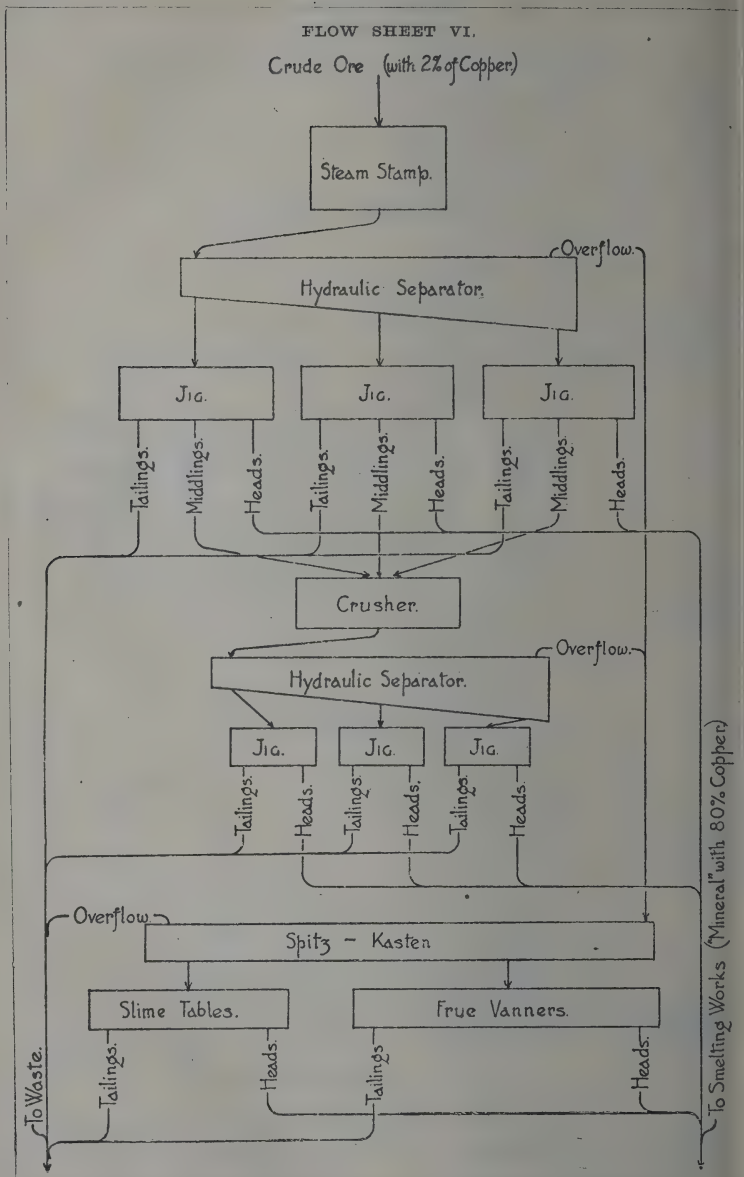
FLOW SHEET IV.

LOW GRADE MAGNETIC IRON ORE. (with about 25% IRON)



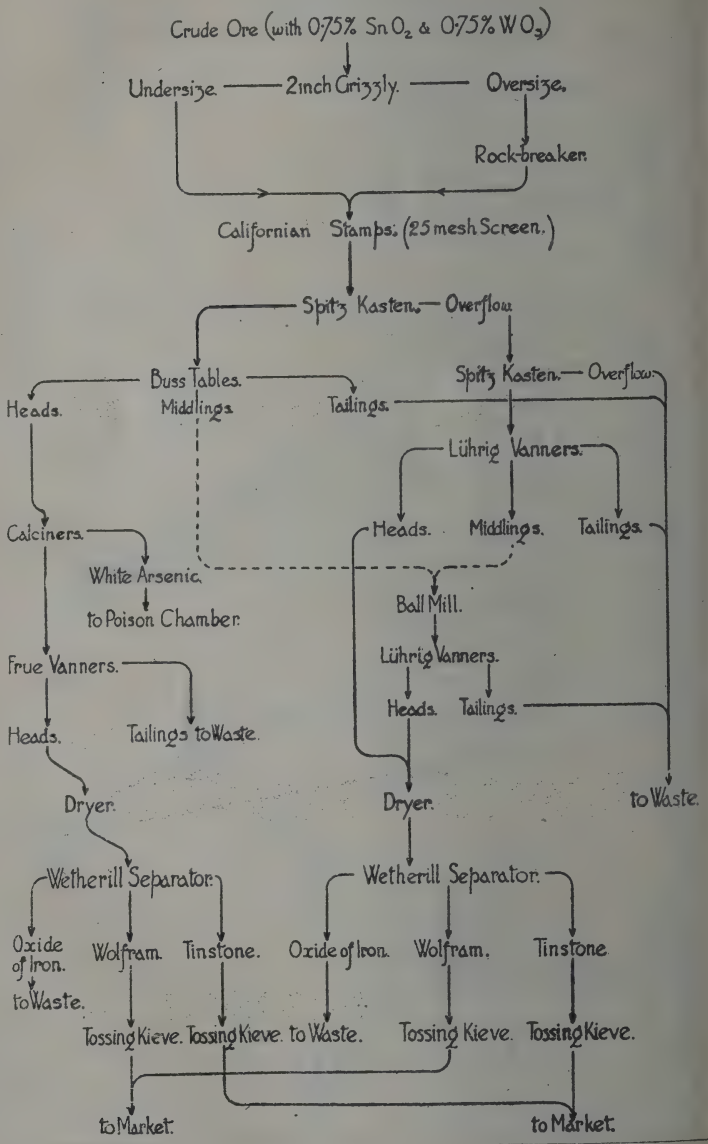
FLOW SHEET V.


Crude Ore.
Cupriferous Pyrites.
Oversize
3 inch Grizzly.
Undersize.
Coarse Breaker.
Oversize.
1 inch Trommel.
Undersize.
Picking Belt.
Dressing Ore.
Clean lump Ore to Market.
Waste to Dump.
Rock-breaker.
Undersize.
0·5 inch Trommel.
Oversize
Crushing Rolls.
Set of Trommels (Oversize from each)
0·3" holes.
0·2" holes.
0·15" holes.
0·12" holes.
0·08" holes.
0·04" holes.
Jigs.
Heads
Tailings
Overflow
Undersize
Clean Ore to Market.
Crushing Rolls.
Trommels (oversize from each)
Undersize.
0·12" holes.
0·08" holes.
0·04" holes.
Clean Ore to Market.
Classifiers.
Vanners.
Middlings
Clean Ore to Market
Waste to Dump
Classifiers.
Series of Vanners.
Clean Ore to Market.
Heads
Middlings.
Tailings.
Waste to Dump


FLOW SHEET VI.
Crude Ore (with 2% of Copper)
Steam Stamp.
Overflow.
Hydraulic Separator.
Jig.
Jig.
Jig.
Tailings.
Middlings.
Heads.
Tailings.
Middlings.
Heads.
Tailings.
Middlings.
Heads.
Crusher.
Overflow.
Hydraulic Separator.
Jig.
Jig.
Jig.
Tailings.
Heads.
Tailings.
Heads.
Tailings.
Heads.
Overflow
Spitz - Kasten
Slime Tables.
Frue Vanners.
Tailings.
Heads.
Tailings.
Heads.
To Waste.
To Smelting Works ("Mineral" with 80% Copper)

FLOW SHEET VII.

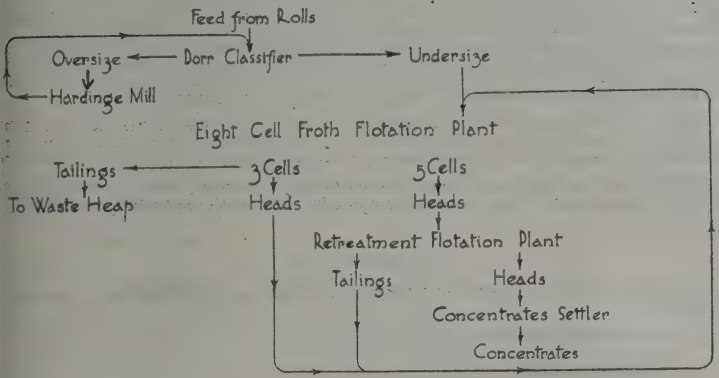
FLOW SHEET VIII.



TREATMENT OF COPPER ORE BY FROTH FLOTATION.

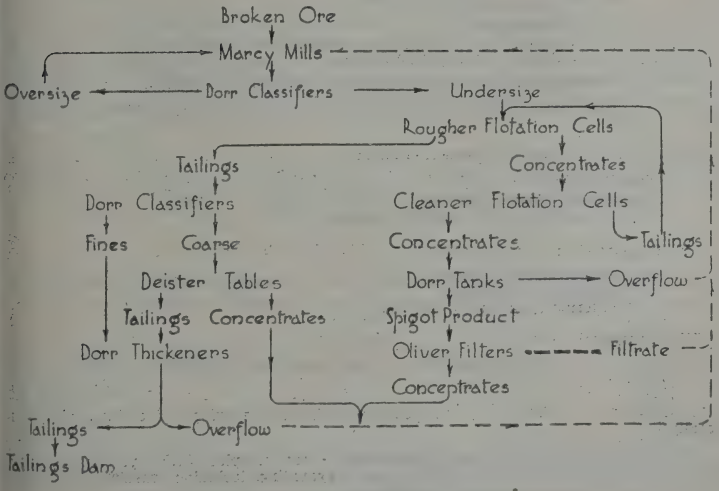
FLOW SHEET IX.

Where the Frothing Agent is added in the Flotation Boxes.



FLOW SHEET VIII.

Where the Frothing Agent is added during Grinding.



GOLD MILLING.

With the improvements in the cyanide practice and also with the exhaustion of the rich free milling surface ores of various camps, which rendered such improvements necessary, have come changes in the process of treating gold ores. Instead of the simple Californian practice of crushing by 900 lb. stamps to about 40 mesh, amalgamating either in or outside the battery, concentrating the sulphides on vanners or shaking tables, chlorinating the concentrates, and sometimes treating the tailings by cyanidation, the 'all-sliming' process has come into force.

As practised on the Rand, the ore is screened through grizzlies with bars 2¾ ins. apart, the oversize going to a sorting belt, thence to a crusher. The ore passes into a feeder, thence to stamps weighing 2,000 lbs. per head, where it is crushed to pass a 10-mesh discharge screen. The pulp is classified in cones and the coarse product delivered to tube mills where it is slimed. The product of the tube mills, together with the overflow from the classifying cones, is delivered to the amalgamating tables. From the tables it is again classified, the sands being cyanided direct and the slimes treated by air agitation, then filter-pressed or vacuum-filtered.

The most vital changes from the old practice to the new have been: the use of the heavy gravity stamp merely as a preliminary coarse crusher for the tube mills; the adoption of the tube mills for fine grinding and the employment of the tall, air-agitation tanks and of filters.

The practice is modified in each district, the modification depending largely upon the nature of the ore. In some camps silver ores are being successfully treated by fine crushing and cyaniding

CYANIDE PROCESS.

This process may be conducted in a number of different methods, which may be classified as follows:—

I. Coarse crushing and direct cyanidation (exceptional).

II. Fine crushing with:—

A. Simultaneous cyanidation.

B. Subsequent cyanidation without classification.

C. Subsequent cyanidation, preceded by classification into (*a*) sand, (*b*) slime.

(*a*) Sand cyanidation, generally by percolation.

(*b*) Slime cyanidation, performed by

1. Decantation.
2. Agitation (mechanical or pneumatic) and filtration.
3. Direct cyanidation in filters.

D. All sliming methods with simultaneous or subsequent filtration.

(*H. Louis*, '*Handbook of Metallurgy*,' i. p. 1031, 3rd edn., Schnabel and Louis.)

Filtration methods may be classified as under:—

I. Suction filters, divided into:—

(*a*) Filters forming a thin cake, continuous acting.
(*b*) Filters forming a thick cake, intermittent.

II. Pressure filters, divided into:—

(*c*) Ordinary filter presses.
(*d*) Sluicing filter presses.
(*e*) Filtering chambers or cylinders.

III. Centrifugal filters.

(*S. J. Young*, '*Trans. Amer. Inst. M.E.*,' xlii., 1911, p. 752.)

Precipitation is performed by zinc shavings, zinc-lead shavings, zinc dust, aluminium electrolysis.

An average cyanide may be roughly estimated to cost complete $1,000 per ton treated per day in the Western States. An average cost of cyaniding, including crushing is thus about $1.50 per ton, but varies within very wide limits.

Stamps.

The duty of stamps depends upon the nature of the ore, the weight of the stamp, its speed and drop, the size of the aperture of discharge screen, and the height of the discharge, The following table gives the duty per stamp in various districts :—

DUTY OF STAMPS.

Mine or District.	Weight of Stamp.	Drop in Inches	Number of drops per Min.	Screen Aperture.	Discharge in Inches.	Tons Crushed per head per 24 Hrs.	Remarks.
California . .	900 lbs.	7	90	900 per sq. in.	4	3	Gold Quartz
Melones, Cal. .	1,000 ,,	7	104	20 mesh	—	4·41	
Tonopah Mill, U.S.A.	1,050 ,,	6½	104	slot ·04 in. wide	2½	5·09	Gold and Silver
Montana-Tonopah, U.S.A.	1,050	7	100	20 mesh	3	3·3	Gold and Silver
Tonopah Belmont, U.S.A.	1,050 ,,	6	104	24 mesh	—	3·7	,,
Goldfield, U.S.A..	1,050 ,,	7	108	12 mesh	—	6	,,
Komata Reefs Mine	1,030 ,,	6½	100	4½ holes per in.	4	5	Gold
Luipaards Vlei Rand	1,629 ,,	8½	98·6	200 holes per sq. in.	4	9·6	,,
Simmer & Jack East	1,550 ,,	8	96	200 holes per sq. in.	3½	8·3	,,
Waihi Grand Junction	1,110 ,,	7	105	5 to 10 mesh	1½	7·6	,,
Oroya Brownhill.	1,100 ,,	7¾	108	10 mesh	2	6·48	,,
Ivanhoe . .	1,192 ,,	7½	104	225 mesh	2	5½	,,
Gt. Fingall . .	1,150 ,,	8	106	12 mesh	3	7	,,
Mysore Gold Mine, Mysore, India	1,150 ,,	7·5	96	1,200, 625 and 400 per sq. in.	3	3·63	,,

It is claimed that the new 2,000 lb. stamps of the Goldfield (S.A.) are capable of crushing 6 tons of ore per stamp per 24 hours by introducing an elimination screen to 'bypass' the fine material from the rock bins direct to the tube mill and using screens with aperture of ·284 inch.

Amount of water varies on the Rand, from 5 to 10 tons of battery water to one of ore, depending upon the duty. In Western Australia the amount of water required is 4 to 8 gallons of water per stamp per minute.

Power per stamp.—The 2,000 lb. stamp requires 5 h.p. per stamp. In Nevada, for 1,250 lb. stamp 3·5 h.p. per stamp is used. At the Goldfield Con. in Nevada with 140 stamps, fine grinding and cyaniding, 1,500 h.p. is supplied to the mill or 1·73 h.p. per ton of ore milled.

COST OF EQUIPMENT OF GOLD MILLS.

The following is the comparative cost of gold mills, including all machinery and buildings :—

Mill.	Number of Stamps.	Cost of Machinery and Plant.	Cost per Stamp.
Rand Mill	200	£334,000	£1,670
New Kleinfontein	200	420,480	2,102
Wit Deep	200	346,210	1,731
Robinson Central Deep . .	100 and Tube Mill	234,013	2,340
Great Fingall	,,	193,745	1,937
El Oro	,,	160,000	1,600

In Nevada, the cost of complete plants doing fine grinding and slimes filtering is 1,400*l.* a stamp.

Tube Mills

are used as secondary crushers following the stamps. On the Rand they are most efficient when fed with ore that has been crushed through a screen the apertures of which are ·27 in. or say ¼ in. They are here 25 ft. in length by 5½ ft. in diameter, and one tube mill crushes the product of 10 stamps. Each tube mill requires 100 h.p. to drive it. In New Zealand tube mills are 16 ft. by 4 ft. revolving at 29 r.p.m., and driven by 25 h.p. motor. The feed is 1½ parts of water by weight to 1 part of ore. In 22 months a tube mill ground 28,500 tons of hard quartz, 50 per cent. of which passed through a 200-mesh screen.

At Pachuca 90 h.p. is used for a 5 ft. 6 ins. by 22 ft. tube mill. Output 140 tons per day through a 60-mesh screen.

At Waihi Grand Junction tube mills 19 ft. 3 ins. long by 4 ft. 8 ins. diameter require 42 h.p. Those 16 ft. 3 ins. long by 4 ft. 3 ins. diameter require 25 h.p. They consume 2·89 lbs. of flint pebbles per ton of ore crushed at stamps. They are run at 27 r.p.m.

Chilian Mills.

Chilian mills are employed either for crushing preliminary to amalgamation, in which case the gold is partly amalgamated in the mill itself, or they are used in lieu of the tube mill as fine grinders following the stamps.

For crushing ores for direct amalgamation the so-called slow speed Chilian mills are well adapted. Machines of this type are extensively employed in Russia and Siberia. They are expensive in first cost, but the power, labour, and repair costs are very low. Furthermore they are notable for their simplicity, requiring little close or skilled attention.

A slow speed Chilian mill was employed in California on hard close quartzose gold ore. It ran at 8 to 10 r.p.m. It had four runners each weighing 1,200 lbs. travelling on a steel die 3 ins. thick with 5 ins. face and 7 ft. outside diameter, 4½ tons of rock in a tank above and sustained by the axles giving additional crushing weight. Twenty tons of ore per 24 hours were crushed with a 4 in. discharge, and 88·1 per cent. extraction obtained 0·85 per cent. of the ore passed through a 100-mesh screen. One man per shift handled the mill. Cost of ore crushed 6*s.* per ton. Gasoline power was used consuming under heaviest load 2·17 gallons of distillate per hour. (*A. McLaren.*)

The standard type of Chilian mills used in Russia is 7 ft. to 10½ ft. in diameter with 2 runners 5½ to 6½ ft. in diameter, and from 7 to 12 ins. in width. The speed is 11 r.p.m. The discharge is 8 to 10 ins. Feed is about 1 in. and discharge screen slotted. The water is 6·5 to 10·1 times the ore in weight and duty is 16 to 24 tons per 24 hours. The power required is 7 to 12 h.p.

Rapid-running Chilian mills were used as fine grinders after the stamps in the Goldfield Consolidated mill in Nevada on fairly soft ore. There 140 stamps were in operation and six 6-ft. Chilian mills crushing from 4-mesh to 16-mesh were installed. These were operated at 32 r.p.m. Their capacity was 75 tons per 24 hours and the power required 35 h.p. each. The cost of crushing by these mills is given at 5*d.* per ton of ore milled. (*J. W. Hutchinson.*)

At Cripple Creek a 6-ft. Chilian mill running at 33 r.p.m. reduces 4 tons of ore per hour, 60 per cent. of which will pass a 150-mesh screen. The feed passed a ⅜-in. aperture.

Rolls.

Where a relatively small tonnage is to be crushed coarse, as for example when coarse concentration is employed or where the ore is porous and is cyanided coarse, it is the practice to use rolls. They are cheaper than gravity-stamps in first cost, repairs, labour, and power, and are not complicated by screens.

In South Dakota the ore, a hard, close-grained Cambrian quartzite, carrying from 5 dwts. to 7 dwts. per ton, is crushed by rolls. The ore is fed to two 16- by 36-in. rolls used as cracking rolls and two others of the same size are used as finishing rolls. The final product goes through a ⅛-in. mesh direct to the cyaniding vats. The rolls require 100 h.p. The milling and cyaniding cost is 2*s.* 2*d.* per ton and 14,800 tons of ore are treated monthly.

Ball Mills.

Krupp ball mills are used extensively in Kalgoorlie where 44 are at work. Size No. 5 will crush up to 45 tons of ore per day consuming 25 h.p. No. 8 will crush 90 tons per day requiring 50 to 60 h.p. About 45 per cent. of the product from a 25-mesh screen will pass 150-mesh. It is charged with 1 or 2 tons of steel balls and revolves from 21 to 25 times per minute. They work well on either wet or dry ores. The wear and tear of liners, hunch and scoop plates cost 4·64*d.* per ton milled.

Milling Costs.

The following are the milling costs of different stamp mills :—

Mill.	Stamps.	Tons Crushed Monthly.	Cost of Milling per ton.	Rate of Wages per day.	Remarks.
Tonopah, U.S.A.	100	15,000	12*s.*	13*s.*	Silver Gold ore
Goldfield Con., U.S.A.	140	29,500	9*s.*	13*s.*	
Ivanhoe	100	16,600	8*s.* 9*d.*	12*s.* to 14*s.*	Bromo-cyanide treatment of slimes
Oroya Brownhill	50	8,950	17*s.*	12*s.* to 14*s.*	
Gt. Boulder	—	14,800	12*s.* 4*d.*	12*s.* to 14*s.*	Dry crushing with Griffin mills. Roasting.
Melones, Cal.	100	12,000	1*s.* 1½*d.*	10*s.*	Cheap power, labour and supplies
New Unified (Rand)	—	10,000	1*s.* 4*d.*	—	Milling only
Simmer East	—	—	2*s.* 6*d.*	—	

On the Rand, cost of milling of those companies using tube mills varies from 4*s.* 10*d.* to 8*s.* 8*d.* per ton of ore.

In California, with free milling ores and cheap water power, milling costs average from 2*s.* to 4*s.* per ton. In Alaska, with large tonnages of soft, free milling ore treated daily and no cyaniding or fine grinding the costs are about 1*s.* per ton of ore.

Horse-Power per Ton of Ore Treated per Day.

Type of Mill.	Mesh.	Horse-power.
Stamps and vanners	20 to 40	0·75 to 1·0
Coarse concentration	10 to 20	0·5 to 0·8
Combination-stamp	16 to 30	1·5 to 1·75
Chloridising stamp (dry)	to 16	2·0 to 2·5
Chloridising stamp (wet)	to 40	4·0 to 4·5
Magnetic separator	—	0·25 to 0·5
Cyanidation (dry) roll-crushing	20 to 30	0·5 to 0·8
Cyanidation (wet), stamp crushing and sliming	to 80	0·75 to 1·5

(*J. A. Barr*, 'Testing for Metallurgical Processes.')

Standards Adopted by the Institution of Mining and Metallurgy.

1 oz. of fine gold = value 85*s.*
1 ton = 2,000 lbs. (avoirdupois).
1 miner's inch = a flow 1½ cubic ft. of water per minute
1 sluice head = „ 60 „ „
1 gallon of water = 10 lbs. at 34°.

Temperatures are to be expressed in centigrade.

Screen apertures and diameters of wire are equal, giving 25 per cent. screening area.

GOLD AND SILVER TABLES.

It is the practice of Continental and South American engineers to report the values of ore in grammes per metric ton. English engineers generally employ the method of quoting values in grs. and dwts., in some cases per long ton of 2,240 lbs., in others per short ton of 2,000 lbs.

TABLE for Conversion of Grammes per Metric Ton into Grains, etc., per Long and Short Ton.

Grammes per Metric Ton.	Per Short Ton.		Per Statute Ton.		Grammes per Metric Ton.	Per Short Ton.		Per Statute Ton.	
	Dwts.	Grs.	Dwts.	Grs.		Dwts.	Grs.	Dwts.	Grs.
1	0	14	0	15·7	6	3	12	3	22
2	1	4	1	7	7	4	2	4	14
3	1	18	1	23	8	4	16	5	5
4	2	8	2	15	9	5	6	5	21
5	2	22	3	6	10	5	10	6	13

TABLE for Conversion of Dwts. per Ton into Grammes per Metric Ton; the equivalent of Dwts. per Short Ton is given in the first column, per Statute Ton in the second.

Dwts.	Grammes per Metric Ton.				Dwts.	Grammes per Metric Ton.			
	Dwts.	Grs.	Dwts.	Grs.		Dwts.	Grs.	Dwts.	Grs.
1	1	71	1	53	6	10	29	9	18
2	3	43	3	06	7	12	00	10	71
3	5	14	4	59	8	13	71	12	24
4	6	86	6	12	9	15	43	13	28
5	8	57	7	65	10	17	14	15	31

Alluvial or Placer Mining.

Deposits of auriferous or tin-bearing alluvial gravels are termed placers, alluvial drifts, or more simply alluvials. They are classified as shallow or superficial and deep-lying, sometimes called deep leads. Deep leads are accumulations of gravel from extinct or ancient rivers. They are mostly capped by igneous flows, as in California and Victoria, though sometimes they may be buried under recent gravels or drift, as at Lightning Creek, B.C., and the Lena Goldfields in Siberia.

The methods of mining used to exploit deposits of this character resemble pillar and stall in some cases and long wall in others. In California the gravel beds can be attacked by means of adits which also serve as drains for the large amount of water present. When the topography of the ground permits adits being used, the cost of mining is low, as at the Hidden Treasure, California, where the costs average 4*s*. 6*d*. per cub. yd. of gravel washed. In the Deep Leads of Victoria, where the pumping charges were unusually large (eleven million gallons per day being raised from one mine), the total cost per cub. yd. was 12*s*. to 15*s*. At the Lena Goldfields the total cost is from 20*s*. to 30*s*. per cub. yd. of gravel washed.

Superficial Deposits.—All gravel under 60 feet in thickness may be termed shallow or superficial gravels. Surface gravels are worked by the following methods:—

Panning.—A miner can pan ½ cub. yard to 1 cub. yd. of gravel per 10-hour shift, depending on character of ground and nearness to water; 100 pans per day is a good day's work. Gravel in place is usually estimated at 3,000 lbs. per cub. yd., and the standard sheet iron pan 16 ins. diam. at top and 10¾ ins. diam. at bottom will hold 20 lbs.; 150 pans full will make a cub. yd. of dirt.

Rocker.—A man can rock ordinarily from 2 to 3 cubic yards of gravel per day, and save, in practical mining, 90 per cent. of the gold. In alluvial examinations the rocker plays a most important role, and is used in conjunction with the pan for determining the gold contents of any parcel of gravel. When used for this purpose, the design of the rocker differs slightly from that of the ordinary miner's rocker. A well-designed rocker, carefully employed, should save practically all the gold. The plans of most rockers, as published from time to time, are those of the ordinary mining rocker, which is too short, and set on too great a grade for use in saving fine gold. If much fine gold is present in the gravel, it will be advisable to use a strip of common Brussels carpet, laid along the floor of the rocker. This carpet is held in place by cleats and so can be easily removed in cleaning up.

Long Tom or short sluice can handle 3 to 10 cub. yds. of dirt per day, depending on the amount of water available and the character of the dirt.

Hand Sluicing.—Capacity of a sluice box depends upon the amount of water, grade of sluice, deposition of tailings, and character of gravel. No capacity can be given. Grade of sluice varies from 2 ins. to 21 ins. per box (12 ft.). An ordinary sluice box is made from 2-in. planks, and is 12 ins. wide by 12 ft. long.

Grade and Duty of Sluices.

Grade and Duty of Sluices.—The relation of actual width to the best ratio of quantity to width may not be very significant, but there is a notable increase in efficiency in passing from the smallest widths to the larger, and boxes less than 1 ft. wide are to be avoided, especially if the gravel is coarse. Treating 30- to 40-mesh sand on a 1 per cent. grade (say 1¼ in. per 12 ft. box), one sluice head of water requires a channel 2 ft. wide to enable it to attain maximum duty. On a 2 per cent. grade, half a sluice head requires 2 ft. of width, the quantity of water required for maximum duty with a fixed width diminishing with increasing grade, but at what rate there are insufficient data to determine. Apparently the best width required for constant quantity of water varies directly as the grade. Coarser material requires a greater depth of water, and for 4 to 6 mesh gravel on a 2 per cent. grade, 1 ft. of width per sluice head is indicated. Variations up to 50 per cent. in the water make little difference to its duty, consequently the actual position of the optimum is not easily determined. Naturally the capacity of the sluice itself is correspondingly varied, and the mode of transportation and the saving are doubtless affected in any case.

The rate at which duty varies with slope is the resultant of so many variables that no law can be stated for all cases. In the neighbourhood of the best conditions the Utah experiments support the approximate rule that duty (water, width, and material being constant) varies as the 1·75th power of the grade. A single experiment with natural gravel on low grades by the U.S. Geol. Survey gave the 1·84th power. (*R. T. Hancock.*)

Good modern practice provides about 1 ft. of sluice-box width for every 2 cub. yds. of average material treated per hour, and 3,000 gallons of water per cub. yd. treated on a grade of 6 ins. to 12 ft.

Besides the ordinary feeding of sluice box by means of hand shovelling, many modified methods of feeding and disposing of tailings are employed. In Russia and Siberia the favourite method in use is to transport the gravel to and from the sluice box (here greatly modified from the plain open sluice box) by the employment of horses and small carts. This is a most expensive system and the yardage treated is small. Other variations are: the use of wheel barrows, tramming by cars, handling gravel by means of derricks, digging gravels by means of steam shovels, and loading into cars or direct into sluice, feeding sluice by means of scrapers operated by horses or steam power (drag-line scrapers).

The methods of preventing accumulation of tailings are to deposit them in running water or to remove them by means of drags, belt or link elevators, or hydraulic elevators.

HYDRAULIC MINING.

Hydraulicing proper is the method of mining by which jets of water under high pressure are thrown against a gravel bank, thereby undermining the gravel which falls, and is carried by the current into the sluice. The necessary pressure is obtained either by natural means, *i.e.* by conveying the water from some source having a greater elevation than the working face, or by pumping directly into the supply pipe by powerful pumps. In the former case water is conveyed to the working by means of pipes, flumes or ditches. Ditches are generally most convenient and economical for conveying water for long distances, but sometimes the nature of the ground is such (either too porous or too rocky and difficult to excavate) that a flume becomes cheaper. When lumber is abundant wooden flumes are built, but in many cases, especially in the tropics, where wood rots rapidly, sheet steel flumes are preferable. Steel flume per foot, including rivets, angle iron, etc., ready for transport, costs from 4*s.* to 1*l.*; the sizes vary from a cross-section of 1·28 sq. ft. to 20·48 sq. ft. From the ditch or flume the water is fed through a strainer into a pressure box. From here, a pipe leads to the Y's, which in turn lead to the monitors or giants.

Monitors or Giants.

Monitors or Giants.—These are appliances consisting of a base for attachment to the pipe line and a long conical reducing piece, arranged with one or more joints so that it can be rotated in any direction horizontally and through a very wide angle vertically. The smaller or conical end is fitted with a nozzle butt to which different sizes of nozzles may be attached as circumstances may require. Modern giants are fitted with deflectors, attachments on the butts whereby the giant is turned or deflected by means of the force of the water itself. The high-pressure giants also have ball-bearing joints.

Nozzles from 2 ins. up to 10 ins. are used, working under heads or pressure from 100 up to 600 ft. or more.

The amount of gravel which can be washed down will depend upon its nature, upon the volume and pressure of the stream of water issuing from the nozzle, and is also dependent in no small degree upon the skill of the operator who handles the giant.

The following gives the approximate amount of gravel washed under various heads :—

Effective Head in Feet.	Size of Nozzle.	Flow in Cub. Ft. per Minute.	Approximate amount of Gravel in 24 hours in Cub. Yds.	Weight of Giant. Lbs.	Price of Double Jointed Ball Bearing Giant.
					£
100	2 ins.	104·88	160	120	28
200		148·32	230		
300		181·61	280		
400		209·82	320		
100	4 ins.	420·06	650	225	55
200		594·00	930		
300		727·56	1,130		
400		840·12	1,300		
100	6 ins.	944·58	1,460	335	66
200		1335·72	2,000		
300		1634·02	2,540		
400		1889·16	2,920		
100	8 ins.	1679·82	2,600	600	97
200		2375·46	3,600		
300		2909·58	4,500		
400		3239·70	5,300		
100	10 ins.	2624	4,080	690	107
200		3711	5,760		
300		4545	7,050		
400		5248	8,140		

(*Hendry.*)

Hydraulic Monitors and Pelton Wheel Jets.

J. J. Garrard (*Trans. I.M.M.* 1917) gives a table of discharges in cubic feet per minute for different sizes of nozzles and various heads derived from the formula : Delivery in cub. ft. per min. $= 3{\cdot}75\, d^2\sqrt[3]{P}$, where d = diameter of nozzle opening in ins. and P = gauge pressure in lbs. per sq. in., or effective head $\times 0{\cdot}4326$. An equivalent formula given by him is $2{\cdot}468\, d^2\sqrt[3]{h}$, where h = effective head in ft. The factor 2·468 allows for a nozzle contraction coefficient of 0·94, whereas Hendry's figures in the above table are based on the theoretical value 2·624, and make no such allowance.

Costs.

The costs per cub. yd. were at North Bloomfield 2·05*d.* per cub. yd. and at La Grange 3*d.*

In British Columbia one and a half million cub. yds. were mined and washed at a working cost of 0·97*d.*

In Northern California placer ground containing only 1·26*d.* per cub. yd. has been profitably worked. The amount of gravel washed was 1,251,399 cub. yds., yielding 6,330*l.* The profit obtained was 821*l.*

Hydraulic and other Elevators.

When a hydraulic mine possesses an insufficient slope of bed rock for moving material (the lightest grade permissible being 220 ft. to the mile) other methods of disposing of the gravel 'piped' must be employed. Where water under pressure is cheap and abundant the hydraulic elevators are employed. They are of the pipe type—either Hendry, Evans or Campbell and the Giant Elevator.

The pipe elevator operates on the principle of an injector. Water under pressure is discharged through a nozzle set within a steel jacket, creating a vacuum, and causing water and sand and gravel fed into intake to rise to a height corresponding to 10 per cent. of the head under which the water is applied.

Three sizes are made: 10-inch throat 3½–4½ inch nozzle, using 300 to 500 ins. of water; 12-inch throat 4½–5 inch nozzle, 500 to 750 ins. of water; 15-inch throat, 750 to 1,000 ins. They weigh about a ton and cost 250*l.*

In South Oregon, U.S.A., at the Weimer placer mine, two hydraulic elevators are employed to handle the gravels. One of them has a lift of 39 ft., and operating with a head of 330 ft., uses 11 cub. ft. of water per sec., besides taking all water from two No. 2 Giants. The second elevator has a lift of 9 ft., a head of 125, and uses 18 cub. ft. of water per sec. besides all the water from the first elevator. This makes a final discharge of 40 cub. ft. per sec.

Giant Elevators.

Besides undermining and cutting the gravel it has been discovered that gravel can be effectively 'driven' up a slope or incline to a raised line of sluices by means of the power of water under pressure. An elevator based on this principle is termed a 'stacker.'

In California a stacker was operated as follows: A chute was built sloping upwards at 30°. This was 4 ft. wide by 24 ft. long and constructed of 1½-inch planks. Riffles 2 ins. apart and with a drop of 2½ ins. between were laid across the bottom. These were covered by an iron grizzly. At the foot of this chute a 3-foot sump was dug in which was set up a hydraulic elevator with a 12-inch throat and worked by a 5-inch giant. This elevator, working under a 90-foot head, elevated to 16 ft. vertically the seepage, fine and water from two field-giants.

Twenty feet in front of the stacker was installed the 3-inch drive giant. Two 4-inch field-giants wash the gravel to the chute and the drive giant forces it up the stack, the fine material falling through the grizzly and down the riffles to the elevator, which raises it to the sluice-boxes.

The field-giants handled 600 cub. yds. per 24 hours, and the gravel could easily be raised to 25 ft. vertically by means of the drive giant. The cost of handling material exclusive of equipment was under 2½*d.* per cub. yd. (*S. S. Smith.*)

Ruble Elevator.

The Ruble elevator is constructed on the above principle, but it is more portable and does away with the hydraulic elevator. It is also self-contained, as the sluice-box is part of the machine.

In Idaho, U.S.A., this elevator has been tried with excellent results (*see* Porter, T.A.I.M.E., 1909, for a detailed description of this elevator). The following points are claimed to its merit: 1. It handles larger rocks with less water than other types of elevators. Handles boulders up to 1 ton in weight. 2. It dispenses with the boulder crew, either at the mine, ground, sluice-box or dump. 3. It saves the gold and the gold-saving department may be protected by lock and key. 4. The gravel is picked up in close proximity to the giants, the gold immediately extracted, and the boulders and other waste material dropped back on bedrock previously worked off, instead of being transported a long distance to the dump. It makes its own dump.

Mechanical Elevator.

In regions where water is neither cheap nor abundant, in handling gravel or tailings, resort must be made to some form of mechanical elevators. A mechanical elevator was erected some years ago on Bonanza Creek, Alaska. This was made of a frame of steel, 49 ft. high, mounted on wheels. The gravel was elevated by a bucket line of the close-connected type, 76 buckets in all, each with a capacity of 3 cub. ft. each. These discharged at a rate of 26 per min. directly into a sluice-box. The pit was drained by means of a 12-inch centrifugal pump, assisted by a hydraulic jet. The power was 200 h.p. in all, 35 for the bucket line and 165–175 for the pumps. The actual capacity per day was 1,500 yds. (*T. A. Rickard*). The first cost of this machine was high, and in actual running it proved costly in operation and repairs. Another machine of the same type, but employing a heavy dredge bucket, is being erected in Eastern Canada. No results of actual working are yet to hand.

Centrifugal Pumps.

Centrifugal Pumps as a means of elevating gravel and tailings have been extensively employed in Australia. It is claimed that with wood fuel at 7*s.* per ton of 50 cub. ft. and European rate of wages paid, to elevate tailings with pumps should not cost more than 2½*d.* per cub. yd. of solid. Thompson & Co., of Victoria, are the makers of gravel pumps suitable for this class of work. Their pumps vary in size from 3½ ins. to 16 ins. The capacity of solids per hour from 7 to 150 cub. yds. The indicated horse-power from 2½ to 583. The combined suction and delivery head from 10 feet to 100. An installation of this kind possesses the advantage of being cheaper to erect and easier to move than the belt or bucket type of elevators mentioned. However, where there is an undue amount of large stones present in the gravel, the latter type is preferable.

Pipe Lining.

Three rubber-lined pipes, each of 9 in. internal diameter and length of about 20 ft., have been in continuous operation on the discharge line from an 8-in. gravel pump at the Sungei Bari Mine, Malaya, for a period ranging from 18 months from the date of installation of the first pipe. These pipes have been subjected to a continuous flow of gravel, amounting to about 17,000 cub. yds. of solids per month, and a working pressure of about 17 lb. per sq. in. The three pipes, although differing somewhat in design, are all alike regarding the successful results of the rubber applied to them, there being little or no evidence of wear or abrasion on the rubber after this lengthy period of operation. The lining is of crepe rubber about ½ in. thick. The life of a lap-welded mild steel pipe ⅝ in. thick on the same line, with frequent turning to ensure even wear, does not amount to an average of seven months. ('*Mechanical World*,' Jan. 21, 1927.)

Dredging for Alluvial Minerals.

(Contributed by Harold E. Fletcher, A.I.N.A., M.I.Mar.E.).

The most important form of alluvial mining is dredging, for the recovery of gold, platinum, and tin. The greater part of the platinum recovered in Siberia and Russia is by dredging, and that of the tin in the Malay States. When all conditions requisite for successful working are present, when the ground has been properly proved* and a well-designed and effective dredge installed, then this type of mining is the safest and surest of all forms of mining investment.

Careful systematic boring is necessary to get true values. Dredging properties call for certain conditions, and unless these exist the success of the enterprise suffers. The conditions are :

(1) The presence of the mineral, which should be evenly distributed throughout the pay dirt.
(2) Sufficient ground to warrant the installation of at least one dredge.
(3) Soft bedrock, free from pinnacles.
(4) Absence of large boulders.
(5) Absence of permanently frozen ground.
(6) Absence of great amount of clay.
(7) Absence of heavy floods.
(8) Surface of an even contour, not too rough and broken.
(9) The ground should retain sufficient water to float dredge (50 miner's ins.), or available water supply from a river.
(10) The economic conditions, *i.e.* labour, transport, climate, vary inversely with amount of mineral in ground.

Broad flood plains or ancient lake gravels form more suitable dredging ground than does deposit situated in narrow rocky gulches. Frozen ground cannot be dredged without preliminary thawing. Dredging of gravels lying in rapid rivers is risky, as there is always danger of losing the dredge by sudden floods. Gravels from 10 to 80 ft. below water and 20 ft. above have been successfully dredged.

The modern dredge consists of a hull or pontoon of wood or steel, upon which is mounted the digging device, a bucket ladder capable of being raised and lowered, the washing plant comprising screen, tables or launders, the pump, of the centrifugal type for water supply to screen and tables, the stacker or elevator to dispose of the tailings well astern of the dredge, and the power plant. The buckets raise the ground and discharge into the revolving perforated screen, the fines pass through the perforations on to the tables, and the stones and large material pass through the screen to the tail chute and on to the tailings stacker. The dredge can cut its own passage. The cutting depth and manœuvring lines are worked by special multi-barrelled winches, controlled by one man, the winchman.

'Suction' dredges are used at times; they are only successful in light and free ground with level bedrock. The power required has been found to exceed that of the bucket dredge of equal output. With the suction dredge it has been found difficult to control the surges of water that sweep the tables when the spoil will not draw easily. This type of dredge has not given good results on tin in the Straits of Malay.

'Bucket' dredges are classified in two types, the New Zealand and the American; the latter has been evolved from the former to suit conditions existing in California and other parts. The principle is the same, but the American type is associated with heavier construction, larger buckets of the close-connected type instead of open, spuds (adjustable piles) instead of a headline, the raised pilot (or central control house), and other modifications. Both types have their advocates and both their utility.

The New Zealand type was associated with open-connected buckets, moderate power, simple engine for driving all units and light construction, but to-day this type is built of fairly large capacity and heavier construction. In its smaller sizes for lighter ground its first cost is in its favour, also for prospecting work or proving a dredging property; also where difficulties of transport prevent the use of the heavier type of dredge.

Transport.—Dredges are generally shipped in pieces for re-erection, the steel pontoons being riveted and launched at site. The heaviest parts to transport are the main engine castings, the boiler shell, the tumbler castings (mostly steel), crown wheel castings, winch barrels, screen ends, etc. The 'Tumblers' weigh from 15 cwts. in the small to 15 tons in the large sizes; boilers stripped, from 3 to 10 tons; watertube boilers, the heaviest part being the steam drum, from 7 to 60 cwts.

Hulls.—These have to be strongly designed to stand the stresses. Wood pontoons are not entirely satisfactory and generally have to be replaced during the life of the machinery; they suffer damage by ice in cold countries, and are difficult to build to stand stresses, and much heavier than steel.

Power.—Where wood and coal are plentiful, steam is cheapest. In Malay the Rawang coal (8,000 B.Th.U.) is used in water-tube boilers with chain grate stokers; steam pressure 160 lbs., and 100° superheat. Where oil is available at reasonable cost, it can be burnt under boiler or used in Diesel or semi-Diesel engines, and these have proved more economical than steam.

A gold dredge with 9 cu. ft. close-connected buckets is running in South America with semi-Diesel engines, also smaller dredges in Burma, etc. Full Diesel engines require the services of

* See *Alluvial Prospecting*, by C. Raeburn and H. B. Milner. 1927.

a specially skilled engineer. Producer gas plant and engines are used in Burma, Malay, Africa, etc., running on charcoal, driving direct or driving generators to supply current to the several motors. Where electric current is available and power can be transmitted to the dredge by cable at reasonable cost, and transformed on the dredge to the required voltage, it is in favour of low running costs, but it is generally accepted that it does not pay to build a special generating plant unless the ground will carry four or more dredges. Waterfall power to generate current is also being used.

The horse-power installed on gold and platinum dredges varies according to the capacity of bucket, dredging depth, etc. The distribution of power is generally as follows:

Bucket chain . .	33% of total power.	Screen . . .	10% of total power.
Water-pump . .	30% ,, ,,	Elevator . . .	12% ,, ,,
Winch . . .	15% ,, ,,		

On tin dredges, where larger water supply is necessary and higher water pressure, the pump power proportion is larger. On large dredges a separate winch is often fitted to deal with the bucket ladder.

Gold Dredges.

Larger types of American design are used in America, Siberia, etc., in addition to the open-connected type. Gold is saved on tables covered with cocoanut matting and expanded metal; the gold by reason of its heavy specific gravity settles in the mats, the dirt being washed down the tables overboard, the mats being taken up at periods and washed. With properly designed tables and adjustable water supply, quite fine gold can be saved. Platinum is easier to save owing to its heavier specific gravity.

Tin Dredges.

Of recent years these have increased in size considerably. The difficulty is not in raising the ground, but in treating it efficiently; the tables require to be of large area and the water supply larger than for gold dredging. Tables or 'launders' are generally from 3 to 4 ft. wide and up to 80 and 100 ft. long, wood riffles are fitted, and the wash agitated gently by hand-raking or mechanical means to allow the tin to sink through the wash and settle on the bottom of the launders. Owing to the large area of the tables the pontoons are of larger dimensions than for gold dredges; tables up to 7,000 to 8,000 sq. ft. area in two tiers are in use. Owing to the difficulty of carrying such tables, some of the latest dredges have been designed with jigs and classifiers, or a combination of riffles, launders, jigs, and classifiers, which will allow of better treatment and the saving of finer tin. The use of jigs allows of better saving adjustment. With skilled attention, up to 92 per cent. of the boring values have been obtained. Clay in the ground in both gold and tin dredging presents great difficulty to the dredge designer, and to break it up and release the values it contains call for special arrangements, such as puddlers, high water pressure, etc.

The design for tin dredges is tending towards the American type in regard to the design of the driving gear, buckets, tumblers, winches, etc. The latest dredges have close-connected buckets of cast manganese steel and nickel-chrome steel pins, cast manganese tumblers, etc.

There has been a vast amount of capital put into tin dredging in the Malay States and Siam, the number of dredging plants reaching towards 300. Some of these companies have paid 5 per cent. dividend for a number of years.

The largest English-built dredges have close-connected buckets of 12 cu. ft. capacity, a large proportion 8 and 9 cu. ft. The open-connected dredges range from 6 to 15 cu. ft. buckets.

Dredging depth ranges from 30 to 80 ft., and dredges are being built to dig 100 ft.

Output varies according to bucket capacity and the rate at which the ground can be efficiently treated. The open-connected bucket is run from 14 per minute for the smaller to 12 per minute in the larger sizes. The close-connected bucket from 28 to 18 per minute.

Maximum output is calculated:

$B \times S \times 60 \div 27 =$ cu. yds. max. per hour. $S =$ number of buckets delivering per minute.
$B =$ capacity of buckets in cu. ft. $27 =$ number of feet per cubic yard.

Roughly, 1 cu. yd. is calculated 1½ tons.

To obtain the estimated output, one-third is deducted from the maximum, but this is not always reached; buried timber and large boulders tend to decrease output. The removal of barren overburden (to reach pay dirt) and difficulties of cleaning up bedrock lessen the profitable dredging time. A further factor is time lost in cleaning up the tables or launders to recover the gold or tin. Working time varies; many dredges have averaged over 600 hours per month.

Working costs vary with difficulties of ground, cost of fuel, and labour.

Comprised in above are European and native labour, fuel, stores, spares, camp upkeep, passage money and leave pay, management expenses, depreciation of plant, insurance.

The aggregate cost of running a small dredge does not vary greatly from running a larger one, and ground that is too low in value to give a return on a small dredge could be made to pay with a dredge of large output. With favourable conditions, dredges on easy ground have been run for as low as 1·5*d.* per cu. yd. treated. Large tin dredges in Malay 3·13*d.* to 4·0*d.* per cu. yd. treated.

TIN DREDGES.

Bucket Cap.	Type.	Monthly Output in cu. yds.	Working Hours per Month.	Dredging Depth.	Pontoon.	Steam. H.P.	Net Weight.
				Ft.	Ft. Ft.		Tons.
10	Open-con.	57,350	592	50	150 × 34	250	500
11	,,	89,000	550	50	150 × 40	320	700
12	,,	85,000	560	60	165 × 42	375	750
13	,,	78,000	—	60	165 × 45	380	820
15	,,	99,000	600	35	140 × 46	*400	—
5½	Close-con.	89,000	651	45	150 × 45	320	900
6	,,	Est. 90,000	600	50	155 × 45	375	—
8	,,	,, 120,000	,,	60	160 × 46	400	1,200
9	,,	,, 130,000	,,	60	170 × 52	450	1,300
12	,,	,, 150,000	,,	60	180 × 52	500	1,600

* Gas engines.

The difference in output is due to difficulties in working the ground.

MALAY TIN BASIS.

1 Kati = 1⅓ lbs. 100 Katis = 1 Picul = 133⅓ lbs.
16·8 Piculs = 1 ton. Straits Dollar = 2*s.* 4*d.*
Value of tin in ground varies from 0·33 to 2·0 Katis.
Native labour costs 1*s.* 9*d.* to 2*s.* 3*d.* per day. Engineers, 4*s.* 6*d.* to 5*s.* per day.
Native coal, 24*s.* per ton. Wood, 25*s.*
Fuel oil, 90*s.* per ton. In bulk, about 82*s.*

NEW ZEALAND TYPE DREDGERS (GOLD).

Size of Buckets.	Estimated Capacity. In cu. yds.	Digging Depth below Water-Line	Weight including Hull.	Price, f.o.b. London.	Horse Power.
Cu. Ft.		Ft.	Tons.	£	
3	30,000	20	100	5,000	35
4	40,000	20	180	9,000	—
5	50,000	26	220	13,000	56
6	60,000	40	280	16,000	—
7	74,000	32	350	20,000	180

The Californian or American dredge is costly, very heavily built, with close-connected buckets, digs with spuds, and till lately built with wooden hulls.

For properties where the transport is high, as in parts of Siberia, and where heavy repairs are difficult, a well-built New Zealand type of dredge, with ample stock of spares, is preferable. Indeed, its choice is imperative in some cases, for the high transport costs to some properties exclude the use of the ponderous American type of dredge. On the other hand, cheap transport, access to machine shops, and with heavy or stiff semi-cemented gravel, or large deep deposit of fair digging gravel (the latter permitting the handling of enormous daily yardages) are conditions favourable to the use of the American dredge.

CALIFORNIAN TYPE DREDGERS (GOLD).

Size of Buckets.	Estimated Capacity per month. In cu. yds.	Digging Depth below Water-Line.	Weight exclusive of Hull.	Price Erected.	Horse Power.
Cu. Ft.		Ft.	Tons.	£	
3	45,000– 60,000	36	350	22,000	180
5	90,000–110,000	36	520	30,000	220
7	110,000–150,000	35	576	34,000	300
8½	150,000–185,000	48	1,000	65,000	560*
13	250,000–280,000	40	1,100	90,000	415

* This includes 100 h.p. for pump for two monitors or giants.

SECTION XXXIX

PART II

MINERAL VALUATION.

(By Professor Henry Louis, M.A., D.Sc., A.R.S.M., M.Inst.C.E., etc.)

General Principles.

Under the head of Mineral Valuation are included two somewhat different valuations, namely, that of a mineral property, whether worked or not, and that of a mine as a going concern ; the difference arises from the fact that the proprietor of the minerals does not as a rule work them himself, but disposes of them, usually for a royalty, to the mine-owner who works them. In cases where the mine-owner is also the proprietor of the minerals, it is generally more convenient to value the mine, the royalty derivable from the ownership of the minerals being included as a part of the profit derivable from the mining operations.

In either case it is necessary to determine the present value of a number of annuities, the latter being the annual revenue derived from the royalties or the profits, as the case may be.

The amount of the royalty per ton is generally known or can be closely approximated, being the price paid or to be paid for the mineral in its unsevered condition as it lies in the deposit.

The profit per ton must be estimated from the probable cost of working and the probable value of the mineral in its marketable condition.

The tonnage to be wrought annually must be estimated, having due regard to all the conditions of the deposit, and should be taken to be the amount that can be extracted, so as to produce the maximum total profit over the period under consideration. It is obvious that a deposit worked out with excessive rapidity will yield no profit when the interest on the capital outlay required to so work it exceeds the profit derivable from working ; on the other hand, if worked excessively slowly, the standing charges may exceed such profit. Between these extremes lies the rate of economic working ; it will generally be found that there is a considerable range of working rate, within which the economic results are practically uniform, and the best rate within that range is usually determined by market conditions or other purely commercial considerations.

The probable total quantity of mineral that can be economically produced from the property must next be calculated, meaning thereby the amount which is as likely to be exceeded as to be fallen short of ; it is obvious that the quantity that can actually be produced from any property can never be known until the property has been exhausted, when the information is naturally valueless. Hence the question becomes one of probabilities, never one of actually ascertained figures, and must always be considered as subject to the laws of probability in the mathematical sense. The quantity thus estimated divided by the estimated or proposed annual output determines the probable life of the property ; if the latter is held under mineral lease, the period of which is less than the probable life, the length of the lease is substituted for the probable life in the calculations.

Sometimes not only the tonnage but also the assay value of the mineral deposit enters into the calculation, and in either case it is never a certainly known figure, but always the most probable figure, that has to be employed. Thus, where the value of a mineral deposit depends upon its thickness and its assay value, let the ascertained most probable thickness be T units and the ascertained most probable value be V units ; as neither are known with certainty, these figures should be written $T \pm t$ and $V \pm v$ respectively, where t and v are the respective probable errors ; then since the probable error of the product VT is $\sqrt{T^2v^2 + V^2t^2}$, the value of the deposit will be a function of $VT \pm \sqrt{T^2v^2 + V^2t^2}$. (See *Mineral Valuation*, by H. Louis, p. 128.)

In the following formulas, the annual income = annual tonnage × royalty per ton, or annual tonnage × profit per ton, as the case may be, will be designated by a.

The number of years of life of the property or of the lease will be designated by n.

The problem then becomes that of determining in the first instance the present value (P) of a series of annuities of £a for a term of n years.

Generally the ordinary compound interest formulas apply, which show that X pounds invested at a rate of interest i per unit will amount in n years to $X(1+i)^n$, and conversely the present value of Y pounds payable at the end of n years, allowing interest at rate i, is

$$\frac{Y}{(1+i)^n}.$$

(See page 3, Section I.)

The main difficulty in all mineral valuations lies in determining the proper rate of interest to allow. The rate of interest in operations in which there is practically no risk, that is to say where the probability of the payment of capital and interest in full is practically unity, may be taken to be the rate obtainable by investment in such securities as Trustee Stocks. In all mining operations the risk is always greater, or in other words the probability of payment is less, hence a higher rate of interest is demanded to cover the risk. If i be the safe rate of interest the risk rate may be expressed by ri, where r is a number greater than unity, depending upon the conditions of the case, and which may conveniently be described as the risk factor; it may also be defined as the reciprocal of the fraction representing the probability of success, and is therefore greater the more hazardous the nature of the enterprise. In practice the risk factor ranges from 2 to 5, being lowest in well-proved bedded deposits, the uniformity of which has been determined by experience, and highest in veins or masses in which values are known to be very irregularly distributed. **It is less where money is invested merely in the purchase of a mineral property than when it is invested in a mining enterprise, because royalties form a first charge on revenue and are almost invariably secured on the assets of the mining enterprise, whereas the latter can take only remainder profits, which are totally unsecured.**

The determination of a proper risk factor is the principal problem that the mining engineer has to solve in valuations.

Present Value.

Let $ri=s$, so that s is the rate of interest *per unit* that is required in any given case.

Some writers call i the 'accumulative' and s the 'remunerative' rate of interest; the term 'risk rate' will be adhered to here in order to emphasise that the high rate is required in compensation for the risk that the investor runs. Of course i is governed by the money market, and is the rate of interest paid on investments in Government stocks and similar first-class securities; it will be noted that s varies directly with i.

The value of the mineral property or mine *at the moment of commencing profitable operations* is therefore P, the present value of n annuities of £a. This should obviously be equal to the present value of sums of £a payable at the end of each of the first, second, third, etc., years up to the end of the nth year, and this sum

$$=\frac{a}{s}\left(1-\frac{1}{(1+s)^n}\right).$$

It is sometimes useful to remember that, if A is the present value of £a due at the end of n years,

$$P=\frac{a-A}{s}.$$

The expression for present value given above is often spoken of as Inwood's formula. Calculations are easily made by this formula; the table on page 6, which gives the present value of an annuity payable at the end of each year for a varying number of years and at various rates of interest, obviates this calculation, as it is only necessary to multiply the present value taken from the table by the amount of the annuity. The table gives the values of

$$\frac{(1+s)^n-1}{s(1+s)^n}$$

for different values of n and s; in the headings of the table the rates of interest are given per cent. and not per unit. Again, the sum of n annuities of £a payable at the end of each year up to the end of the nth year is

$$\frac{a}{s}\left((1+s)^n-1\right),$$

and the present value of this sum is

$$\frac{a}{s}\cdot\frac{(1+s)^n-1}{(1+s)^n}$$

as before. Again, the annuity may be looked upon as part interest on the present value, the remainder being applied annually to the reduction of the capital, interest being paid each year on the unredeemed portion of the capital. If calculated on this basis the same result is obtained.

There is yet another method of looking at the problem. The annuity exceeds the simple interest on the present value by an amount equal to $a-Ps$ in each year; if this difference be allowed to accumulate at rate s for n years it will amount to

$$\frac{a}{s}\cdot\frac{(1+s)^n-1}{(1+s)^n}=P,$$

hat is to say, to the original capital, as it obviously should do, because the purchaser of n annuity, spending each year only the interest on the capital invested, should get back his apital at the end of the period, because this operation would be equivalent to investing the apital at the given rate of interest during the given term of years.

This last method of looking at annuities has given rise to another method of calculating hem, known from its originator as Hoskold's method. He considers that the risk rate of nterest s should be allowed upon the capital, but that the difference between the annuity and he interest $(a-Ps)$ should be looked upon as accumulating at a safe rate i because it is not ecessarily invested in the risky mining operation. This view gives rise to the formula

$$P = \frac{a}{\frac{i}{(1+i)^n-1}+s}.$$

This value may be taken out from any ordinary tables as follows :—

$$\frac{(1+i)^n-1}{i}$$

s the amount of £1 at interest i for n years, and the reciprocal

$$\frac{i}{(1+i)^n-1}$$

s the sinking fund for the repayment of £1, *i.e.* the sum to be set aside annually and allowed to ccumulate at interest i in order to amount to £1 in n years. These values are obtained from ables (see pp. 3 and 9). The denominator of the fraction in Hoskold's formula can be taken nt by adding the risk rate to the sinking fund for £1 at interest i for n years.

This method is often used, but is not one that fairly answers all the tests of a true annuity ormula. Nevertheless, it is used by valuers on the grounds that the difference between the nnuity and the simple interest cannot, in fact, be invested at the risk rate s, but must be invested it the safe rate i, and that this method, therefore, more correctly represents what would obtain n actual practice.

Hoskold's method depends upon considering only one out of the various methods in which he true annuity formula may be looked at; obviously the two can be made to give the same esult by selecting suitable risk factors in each case. Thus if r is the risk factor in Inwood's ormula, and r' in Hoskold's method, the present values will be the same whichever formula be ised, when

$$r' = \frac{r(1+ri)^n}{(1+ri)^n-1} - \frac{1}{(1+i)^n-1}.$$

It follows that r' must be greater than r; in other words Hoskold's method allows a rate of nterest higher than the stipulated risk rate, and hence puts a lower present value on a given nnuity. It need hardly be said that both his method and the ordinary method provide equally or the replacement of the original capital, if suitable sums are set aside in each case out of the nnuities received.

Hoskold's is the generally accepted method of dealing with mineral valuation; it is, however, bvious that year by year a portion of the original purchase price (or present value) is withdrawn rom the speculative investment and set aside to form the sinking fund for its repayment, whilst he risk rate of interest is still being paid upon the whole of the original purchase price. It night, however, fairly be stipulated that this risk rate is only to be paid upon such portion of the riginal capital as has not yet been redeemed by the sinking fund, which accumulates as before it the rate i per unit, whilst the portion of the capital thus withdrawn from the risky investment, hough not yet really returned to the inventor is credited with interest at the rate j per unit of course i and j may in some cases be the same). On the basis of these stipulations, the following ormula results :—

$$P = a\,\frac{(1+s-j)^n-(1+i)^n}{s-(j+i)+s\,[(1+s-j)^n-(1+i)^n]}$$

(*H. Louis*, '*Trans. Inst. Min. Eng*,' lxx., 1925, p. 368.)

Since an investor in mines usually stipulates that he shall receive the risk rate of interest on his investment throughout the whole life of the mine, the Hoskold formula, though possibly less equitable, is generally applicable.

Increasing and Decreasing Values

The above methods of valuing mineral properties tacitly assume that the mine will forthwith commence to produce at its full rate of output and will continue to do so until the mineral is worked out; this is, of course, not the case in practice, a mine only reaching its full output after several years, and this gradually declining again as the deposit approaches exhaustion. There would be no difficulty in allowing for this in the valuation, but as a rule it is neglected; as has already been pointed out, the figures on which the valuation is based are only probable, not actual figures, so that there is no use in endeavouring to attain minute accuracy in these computations.

There is obviously no difficulty in introducing these refinements if it is considered desirable; the computation is made as above for the estimated period of full production deferred during the period of production at a lower rate than the full output; the income expected in each year of output less than full output is calculated and its present value is determined, and all these present values are added together to obtain the total present value of the property.

The author has recently pointed out that this formula demands a risk rate also on the portion of the capital no longer at risk, and suggests the following :—

$$P = a\,\frac{(1+s-i)^n-(1+i)^n}{s-2i+s[(1+s-i)^n-(1+i)^n]}$$

(See *Trans. Inst. M.E.*)

If preferred, calculations can also be made directly, whether the annuity increase or decrease in arithmetical or in geometrical ratio. Let c be the income in the first year and let it increase or decrease by b each year, so that the income for the second year is $c \pm b$, for the third year $c \pm 2b$, etc., during n years. Then the present value of this annuity on the Inwood method is :—

$$c\left(\frac{(1+s)^n-1}{(1+s)^n s}\right) \pm \frac{b}{s}\left(\frac{(1+s)^{n-1}-1}{(1+s)^{n-1}s}\right) \mp \left(\frac{(n-1)b}{s}\cdot\frac{1}{(1+s)^n}\right).$$

These values can be taken out from the tables: the first expression is, as before, the present value of £c for n years at rate s; the second is the present value of £$\frac{b}{s}$ for $(n-1)$ years at rate s and the third is the principal which will amount to £$\frac{(n-1)b}{s}$ in n years at rate s. (See Present Value Table, p. 11.)

If Hoskold's method be used, the present value is :—

$$\frac{c+\frac{b}{i}}{\frac{i}{(1+i)^n-1}+s} \mp \frac{nb}{i-s+s(1+i)^n}$$

The first part of this expression is the present value of an annuity of £$\left(c+\frac{b}{i}\right)$ calculated for n years by Hoskold's method; in the second expression $s(1+i)^n$ is the amount of £s at interest i for n years (see table, p. 3).

Again, let c be the income for the first year and let it increase geometrically by a ratio k, so that the income for the second year is ck, for the third ck^2 . . . etc., during n years. Then the present value of the annuity on Inwood's method is

$$\frac{c}{(1+i)^n}\cdot\frac{k^n-(1+i)}{k-(1+i)}, \text{ or, if } \frac{k}{1+i}=f, \text{ it is } \frac{c}{1+i}\cdot\frac{f^n-1}{f-1}.$$

On Hoskold's method the present value becomes :

$$c\cdot\frac{(1+i)^n-k}{1+i-k}\cdot\frac{i}{i+s[(1+i)^n-1]}.$$

All the above calculations are based upon the hypothesis that the annuity is paid at the end of each year; in practice royalties are mostly paid quarterly, and mining dividends at least half-yearly. To meet this point, for n substitute $2n$, and for s substitute $\frac{s}{2}$ when payments are made half-yearly, these becoming $4n$ and $\frac{s}{4}$ respectively when payments are made quarterly.

Dead-rent.

In computing the present value of mineral royalties 'certain rent' or 'dead-rent' has sometimes to be taken into account. Mineral leases usually stipulate for a definite dead-rent, which may be in addition to the variable royalty, or may be a merging dead-rent, that is to say that the amount of royalty to be paid is determined by the tonnage which is in excess of that which corresponds to the dead-rent at the agreed royalty rate. As the dead-rent is payable in full, whatever the results of the mining operations, its present value must be calculated not on the mining risk rate of interest, but on a rate obtained by multiplying the standard safe rate by a factor depending only on the financial stability of the lessee. This consideration may be neglected when the dead-rent is very small compared with the expected annual royalty, but must be taken into account when it is considerable, the present value of the whole royalty, in the case of an additive dead-rent, or of the excess of royalty, in the case of a merging dead-rent, being computed as above and added to the present value of the dead-rent.

Relinquishment.

When, as is often the case, the lessee has power to relinquish the lease after a given number of years or at stated intervals, there is a risk that the lease may be cancelled because the mine proves unprofitable or because the deposit is exhausted, and the rate of interest applicable to the dead-rent during the definitely fixed period is estimated as above, but it must be multiplied by a risk factor representing the probability of such relinquishment in computing the present value of the dead-rent during the successive periods. Here, again, the difficulty of the problem consists entirely in determining the proper probability factor.

Deferment.

In opening a mine there is always a period of development during which no mineral is produced, or at any rate none is produced profitably, whilst the main capital expenditure in the way of shafts, adits, plant, machinery, etc., is incurred. The present value at the commencement of the profit-producing period as found above must therefore be looked upon as deferred for the requisite number of years and the actual value determined. If V be the actual value at the commencement of mining operations and d the number of years occupied in development,

$$V = \frac{P}{(1+s)^d}.$$

The risk rate of interest must be taken, because the capital is being spent and is subject to the full risks of the mining operation.

The annuity formula and deferred value formula may be combined, thus :—

$$V = \frac{a}{s} \cdot \frac{(1+s)^n - 1}{(1+s)^{(n+d)}}.$$

It is, however, better as a rule to make the computation in the two stages, as above.

The table on page 11 facilitates calculation of actual values; it gives the present value of £1 due at the end of a varying number of years at varying rates of interest; the present value taken from the table and multiplied by P gives the value of V. This table gives the values of

$$\frac{1}{(1+s)^d}$$

for different values of d and s, rates of interest being expressed in the headings as percentage rates.

Mr. O'Donahue has proposed a method of calculating deferments that has some analogy with Hoskold's method of computing the present values of annuities, being also a two-rate method. He considers that simple interest at the risk rate s should be allowed on the actual value V, whilst the interest assumed to fall due accumulates at the safe rate i, whence

$$V = \frac{P}{1 + \frac{s}{i}\left[(1+i)^d - 1\right]}.$$

Since interest is never in fact paid nor payable on the actual value, this method cannot be recommended. This formula and the ordinary deferment formula may be connected as follows :— Let r be the risk factor in the ordinary method and rf the risk factor when O'Donahue's method of deferment is employed; then

$$rf = \frac{(1+ir)^d - 1}{(1+i)^d - 1} \text{ and } r = \frac{\sqrt[d]{1 + r'[(1+i)^d - 1]} - 1}{i}.$$

In some cases, however, where two different rates are involved, another method must be adopted. In the most general case, it is required to determine the present value, V, of a mine that will take d years to develop, during which time no profits are earned, and which will then yield a profit of £a per annum during n years, it being a condition that the original capital shall bear interest at the risk rate s, but that all accumulations can only be invested at the ordinary investment rate i. At the end of the n years the investor is entitled to receive back his capital plus the accumulations of interest (Vs per annum) at the rate i or

$$V + Vs\,\frac{(1+i)^{n+d} - 1}{i}.$$

This must be equal to the amount of an annuity of a per annum for n years, or

$$\frac{a}{i}\left[(1+i)^n - 1\right].$$

Equating :—

$$V = \frac{a\left[(1+i)^n - 1\right]}{i + s\left[(1+i)^{n+} \quad -1\right]}$$

This is the same result as follows from the method of calculating deferred annuities, published by Mr. George King in his 'Theory of Finance.' Further, if $d = 0$, the above formula becomes the ordinary Hoskold formula given above.

Capital Expenditure.

From the present value, V, as determined by any of the above methods, the capital necessary to bring the mine into full work must be deducted in order to obtain the value of the mineral property; if the capital expenditure is spread over several years, the present value of this deferred expenditure must be computed at the ordinary investment rate i, and the sum thus found deducted from V.

Deferred Development.

It occasionally happens that the valuation is required of a mineral property which it is not intended to commence to develop for a number of years; in this case the present value must be calculated as the present value of a sum V, the payment of which is deferred for the given period at a rate of interest i per unit. The risk rate of interest must not be taken into account because there is no mining and therefore no mining risk. If the value of V has been properly determined, making all due allowance for mining risks, the problem resolves itself into determining what capital sum must be invested in safe securities in order to produce the sum V at the time when mining operations are to be commenced. Special attention is drawn to this point, because mistakes are often made in confusing the rate of interest required during the development period and the rate required during the period preceding development, the latter depending on ordinary acutarial considerations and not on the risks incidental to mining.

Investment Value.

Finally, in comparing investments in mines or in mineral properties with other investments of capital, the effect of Income Tax as well as of Mineral Rights and Increment Value Duties must be taken into account. Mines and minerals both constitute wasting assets, but income tax is charged upon the gross revenue derived therefrom, hence not only on the true revenue, but also on that portion of the gross revenue that ought to be looked upon as forming a sinking fund set aside to replace the original capital at the end of operations; mineral rights duties specifically affect only mineral properties and thus constitute an additional charge upon these. In both these respects, therefore, these investments are at a disadvantage compared with ordinary investments, a fact that requires due consideration in computing mineral valuations as a basis for the investment of capital.

SECTION XL

PART I

METALLURGY (pp. 2651–2745)

By Professor Owen W. Ellis, M.Sc. (B'ham.), A.M.Inst.C.E.

(With contributions by A. H. Allen, M.I.E.E., Ernest W. Birch, A.M.I.A.E., F. J. Cook, L. C. Harvey, Colin Livingston, Professor Dempster Smith, M.B.E., M.Sc., M.I.Mech.E. and others.)

PART II

WELDING AND CUTTING (pp. 2747–2779)

By D. Richardson, Wh.Exh., A.M.I.M.E., Capt. R.A.F.

SECTION XL

PART I.

METALLURGY

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FURNACES.

CLASSIFICATION OF FURNACES.

Furnaces in which the Charge and the Fuel are Intermingled.

1. Hearth Furnaces.

(*a*) With blast. Forge for smithing. Grate for zinc-white manufacture.

(*b*) Without blast. Heap and stall for coking and roasting. Trough for liquation and crossing.

2. Shaft Furnaces.

(*a*) With forced draught. Blast furnaces for smelting ores of iron, copper, lead, etc. (see p. 2752). Cupolas for iron-foundry practice (see p. 2655).

(*b*) With induced draught. Only rarely employed.

(*c*) With natural draught. Furnaces for smelting readily fusible ores. Kilns for calcining, roasting, etc.

Furnaces in which the Charge and the Fuel are Separate.

1. Reverberatory Furnaces (Radiation).

(*a*) With forced draught. Furnaces for the refining of metals and the smelting of ores.

(*b*) With natural draught. Furnaces for the roasting of ores. Furnaces for the manufacture of wrought iron, etc.

2. Crucible, Retort, Muffle, etc., Furnaces (Conduction).

(*a*) With solid, liquid or gaseous fuel (see p. 2658)

(*b*) With electricity (see p. 2661).

Furnaces in which the Charge Supplies its own Fuel.

(*a*) Preheated furnaces with solid charge. Kilns for ore-roasting. Beehive coke ovens.

(*b*) Preheated furnaces with liquid charge. Converters for refining, etc.

(*c*) Non-preheated furnaces with solid fuel. Blast-roasting furnaces with up and down draught.

Electric Furnaces Heated by Resistance Effects

(*a*) The charge is included in the electric circuit. Héroult aluminium furnace. Kjellin induction furnace (see p. 2661).

(*b*) The charge is heated by means of an electrically-heated conductor (see p. 2661).

Electric Furnaces Heated by Arc Effects.

(*a*) Direct heating. The charge forms one or both poles of an electric arc (see p. 2661).

(*b*) Indirect heating. The charge is enclosed in a space heated by an electric arc (see p. 2661).

Electric Furnaces Heated by Combined Resistance and Arc Effects.

Girod, Greaves-Etchells, Héroult, etc., steel furnaces (see p. 2661).

SHAFT FURNACES.

BLAST FURNACES.

(*Contributed by Colin Livingston.*)

A blast furnace should be designed to suit the materials used in smelting; successful designs can best be accomplished by keeping in view the best practice with particular materials. No general formula for the design of all blast furnaces, for a given output, is possible. The following points are common to all successful blast furnace plants, and should be kept in view, in new construction:—

The aim of all blast-furnace work is the production of a good marketable iron at the lowest cost. Low costs rest chiefly on low fuel consumption; low fuel consumption is governed by the quantity of fuel, dryness and temperature of blast, with correct furnace lines for the ores smelted.

Blast temperature is entirely one of stove capacity; it is essential that stove capacity should be on the generous side.

Output will depend on capacity of furnace, diameter of hearth, and will vary according to materials used, quantity and pressure of blast, dry or wet blast, temperature of blast; blast pressure should be able easily to penetrate to centre of furnace.

Bosh line angles are found to vary very little; short steep bosh lines are a decided advantage with most materials. Leading American blast-furnacemen attribute some of their remarkable results, in part, to low steep boshes and large hearths.

Furnaces with hearths 20′ 9″ in diameter are in successful operation.

In general practice, furnace shafts should have a batter of at least 0·625 in. in 12 ins.; where fine ores are smelted this could be considerably increased with advantage. Diameter of bell should be 4 ft. to 4 ft. 6 ins. smaller than diameter of throat.

The furnace should be entirely enclosed in a strong steel shell, from the hearth level up.

All parts of furnace top work should be securely fixed to main shell structure.

In designing blast-furnace details the main considerations should be (1) efficiency, (2) strength, (3) simplicity.

The number of gas offtakes should be such that the gas leaves furnace as slowly as possible, so as to avoid carrying dust over to flues.

The height of furnace varies from 80 to 100 feet; with the materials used, each district has come to fix the height found most suitable for its particular conditions.

Sufficient relief area, by bleeders or explosion doors, should be provided on top of furnace to prevent injury from slips; the relief should, if possible, be directly upwards.

For hearth well and boshing nothing but the best quality of fire-brick should be used. The ricks should not be too large, so that they may be thoroughly burned.

For the upper lining a fire-brick with more wear resisting qualities can be used.

Care should be taken that all bricks when laid are properly bedded and tight built, with fire-ay joints as thin as possible.

In relining a furnace, the bear in old hearth need not be removed, but simply levelled to start uilding well on.

This will save much hard work and expense—experience will prove that nothing better for hearth can be put in.

Some means should be taken to preserve the upper lines of furnace from wear where stock om bell strikes brickwork; a satisfactory way of doing this is to insert with brickwork alternate ayers of cast iron or steel plates. In normal working, the stock level should be kept just high nough to allow bell to swing freely when full open.

The number of tuyeres is not so important (if sufficient area for output is provided) as equal istribution and penetrative power of blast.

There should always be a reserve of blowing power available after providing for normal naximum requirements.

Where blast-furnace gas is fully utilised and gas economy a necessity, the blowing should e done by gas engines. Where there is a surplus of gas the turbo-blower can be installed with dvantage, and will prove an ideal blowing engine. Reciprocating steam-blowing engines are ill being installed, but only in cases where conditions make it unsuitable or inconvenient to iscard existing plant.

Cooling.—Apart from tuyeres, jumbos, and hearthcooling, any cooling appliances provided or the bosh or upper lining should be carefully considered; external or spray-cooling has the reat advantage that leakage of water into the furnace is prevented, or rather more easily de-ected. The trouble caused by water leakage from blocks inserted in the building is considerable, nd can never be fully known; it is often when the damage is done the leak is located. The atest practice is to spray-cool the bosh and sometimes the entire outside shell; by this means much thinner brickwork can be used, the furnace preserves its original lines longer, and the ning has a longer life.

Stoves.—Should be as simple in design and equipment as possible, with ample facilities for leaning and inspection, and have a good chimney draught.

Using unwashed gas, chequers should not have less than 9-in. by 9-in. openings; with washed as smaller chequer openings can be used, giving greatly increased heating surface for same size of hell, and higher blast temperatures and lower chimney temperatures for same gas consumption. Openings 3½ ins. × 3½ ins. with 2-in. thick walls have proved satisfactory in practice.

In latest practice for heating stoves the gas and air is forced by special fan into combustion hamber, the stove burns more gas, which gives higher and more regular temperatures, with a aving up to 25 per cent. in stove construction for a given production.

Preheating the blast before entering the stove proper is in successful operation with increased verage temperatures.

It is decided economy to clean blast-furnace gas, as better results are obtained.

It is no advantage to go beyond 1,550° F. in stove heats, any fuel economy being more than ff-set by stove repairs.

Better results with certain ores will sometimes be obtained by running on lower blast heats; his may seem to conflict with theory, but in blast-furnace work it is often the case that sound heory follows successful practice.

Uniform ore mixtures and quality of fuel and flux should be kept in view, rather than frequent hanges of ore mixture, with varying qualities of fuel and flux. It is an advantage to break hard lense ores, especially magnetites.

The approximate saving in lbs. of coke per ton of iron by increase in blast temperature is s follows:—

1,000° to 1,100° F.,	50 lbs.
1,100° „ 1,200° „	40 „
1,200° „ 1,300° „	30 „
1,300° „ 1,400° „	20 „

Dry Blast.—Average results with dry blast give a saving of 10 per cent. in fuel consumption vith 10 per cent. increase in output, more regular grade of metal, and more regular working onditions.

A blast furnace in its working and results responds readily to improper treatment; proper egulation of flux has much to do with this, and the formation of a correct slag is all important.

The slag should not be too basic or limey ; this causes the furnace to become stocky and go up. If the slag is too acid the furnace will drive harder, but trouble is sure to result with grad and quality of pig.

When the lime content of slag is high it will prove profitable to make such slag into cement the slag form from furnaces making Bessemer iron will generally be found suitable for this purpos Most blast-furnace slags can be easily made into first-class building bricks.

The slightest indication of irregular furnace working should be promptly attended to an put right ; irregular conditions will probably show first in change of slag or irregular settlin of stock. The appearance and degree of fluidity of the slag is the furnaceman's best indicatio of working conditions.

Irregular working at tuyeres is generally caused by water leakage from jumbos and tuyer blocks. It is quite possible for tuyeres to be shut by water leakage, in spite of very carefu watching.

No tuyere in a regular working furnace will close while the blast is on except by water leakage.

Irregular working at tuyeres is sometimes caused by an alteration in burden ; in this cas every tuyere will give trouble, which will continue till the trouble has been put right.

The best way to open tuyeres that may have been hard closed by slips, irregular working or water leakage, is by the application of oxygen ; the apparatus used is simple and cheap : th worst stuck tuyere can be opened in a few minutes.

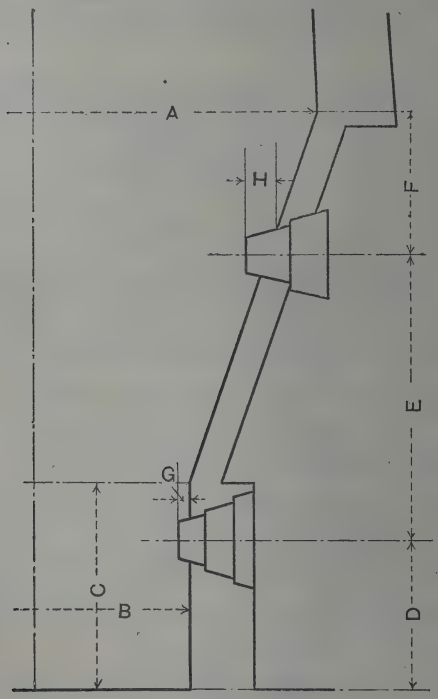

FIG. 1.—Bosh Tuyere.

Bosh tuyeres, it is claimed, increase the output of a furnace 20 per cent. with a slight increase in fuel consumption and more regular working. Fig. 1 and the 'Table of Bosh Tuyeres' give sizes and position of bosh tuyeres from actual practice.

TABLE OF BOSH TUYERES.

(*See Fig.* 1.)

Furnace.	A	B	C	D	E	F	G	H	Tuyeres. Bosh No.	Tuyeres. Bosh Dia.	Tuyeres. Main No.	Tuyeres. Main Dia.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	in.	in.		in.		in.
1	20 0	12 6	8 0	5 6	9 0	6 0	6	4	5	4	8	5
1 (*a*)	18 6	11 6	7 6	5 3	5 5	9 4	6	4	6	4	8	5
2	21 0	13 0	—	6 6	10 7	2 6	9	—	6	3	12	5–
3	19 10	11 6	—	5 6	6 6	12 9	9 to	5	5	4 to 3½	9	66
3 (*a*)	19 10	11 0	—	5 6	7 6	11 9	3	5			9	6
4	20 0	12 6	—	7 10	10 7½	0 10½	9	6	4	6	8	5
5	19 0	11 0	—	5 3	9 5	3 10	6	4	5	4	8	5½
5 (*a*)	21 9	12 6	—	7 0	10 9½	3 11½	6	4	5	4	10	6
6	19 8	11 0	7 3	5 3	9 4	5 10	6	2½	4	2½	8	5
6 (*a*)	19 8	11 0	7 3	5 3	11 0	4 2	6	3	4	4	8	5

(*J. S. Hollings.*)

FLUE DUST.

The treatment of flue dust has developed into a distinct branch of blast furnace work ; he true solution of the problem is to keep the dust in the furnace, thereby increasing roduction and reducing costs. Flue dust is caused chiefly by (1) fine ores ; (2) soft fuel ; 3) hard driving ; briquetting or sintering gets over the first, but furnace design will need to e adapted to surmount the second and third.

For a comprehensive schedule of blast-furnace data see ENGINEER'S YEAR-BOOK, 1927, p. 2580–2591.

CUPOLAS.

BLAST-QUANTITY AND PRESSURE IN CUPOLA WORKING.

An average of 120—in terms of quantity of air in pounds, multiplied by $\sqrt{}$ pressure in ounces— required to melt one ton of ordinary phosphoric iron.

The maximum output of metal melted per hour is more nearly comparative to diameters of upolas than areas of same.

The maximum output of a cupola will be obtained when the pressure and quantity of the last in ounces and pounds per minute respectively are so adjusted that $\frac{W \sqrt{P}}{D} = 330$, D being he diameter of the melting zone in feet. Any further increase in the product $W \sqrt{P}$ results in xcessive oxidation of the metal in the cupola.

Iron melted in a cupola is affected in hardness directly as the pressure of blast used, so that he total area of the tuyeres employed should be regulated according to the class of iron being nelted, small areas being used when greater hardness is required.

The height of the cupola from the top tuyeres to the charging-door sill should *not be less* than wo and a half to three times the diameter across the melting zone.

The coke consumption in a well-designed cupola need not be more than 0·075 lb. to 0·09 lb. per pound of ordinary phosphoric iron melted, when the coke contains from 90 to 92 per cent. of carbon. (*F. J. Cook.*)

CENTRIFUGAL FANS FOR CUPOLAS AND SMITH'S FIRES.

To give the high pressure required to supply air to Cupolas and Smith's Fires the fans must be of the 'centrifugal' type and suitably designed. They usually have smaller inlets and outlets than those used for ventilating, as pressure, not volume, is the essential feature.

Care is required in the choice of a suitable fan, as the efficiency varies within wide limits with the design.

CENTRIFUGAL FANS FOR CUPOLAS, SMITH'S FIRES, ETC.

No. of Fan.	For Cupolas.				For Smith's Fires.		
	Dia. of Cupola.	Tons per Hour.	Speed r.p.m.	Power B.H.P.	No. of Tuyeres.	Speed r.p.m.	Power B.H.P.
1	—	—	—	—	3	3,825	¾
2	18	1	4,100	2¾	6	3,050	1½
3	18	1½	3,150	4	10	2,440	2½
4	24	2½	2,950	7	15	2,280	4½
5	36	3½	2,600	10	20	2,030	6½
6	42	4½	2,230	14	28	1,810	10
7	48	6	2,050	20	37	1,510	13
8	54	8	1,800	26	50	1,400	18
9	60	10	1,600	35	60	1,250	24
10	66	13	1,450	42	80	1,080	32

The duct to the cupola or fires should be made at least as large as the fan outlet; in lon lengths it should be made larger, so as to reduce friction, which increases the power to no purpos If the ducts are below ground cast iron is the best material; sheet-steel ducts ⅛ in. thick, wit flanged joints, are also very suitable, especially if carried above ground. If earthenware pip are used great care must be taken to lay them straight, with good, sound, and permanent joints.

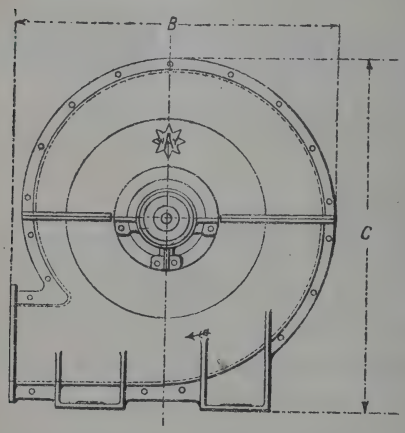

FIG. 2.

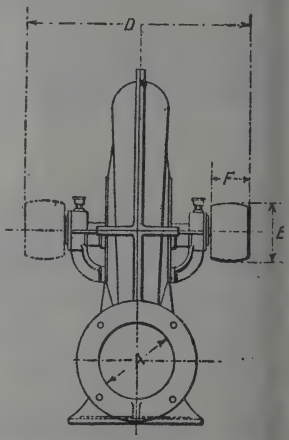

FIG. 3.

APPROXIMATE DIMENSIONS IN INCHES.

No.	A.	B.	C.	D.	E.	F.
1	4	17	19	14	3	2½
2	5	21	24	17	3½	3
3	6	26	29	20	4½	3½
4	7	30	33	22	5	4
5	8	34	37	24	6	4
6	9	39	43	27	7	4½
7	10	44	49	30	8	5
8	12	50	55	34	9	5
9	14	58	63	38	10	5½
10	16	67	73	44	12	6

(*Oswald Stott.*)

VELOCITIES AND VOLUMES OF AIR AT VARIOUS PRESSURES

Pressure. ns. Water Gauge.	Ozs. per sq. in.	Velocity of outflow. Corresponding ft. per sec.	Volume through 1¼ in. tuyere = 1·2 sq. in. cu. ft. per min.	Volume through 10 sq. ins. of Orifice cu. ft. per min.	Air h.p. with 10 sq. ins. Orifice.
½	0·3	46·4	23·2	193	0·015
¾	0·45	56·9	28·4	237	0·028
1	0·6	65·6	32·8	273	0·043
1½	0·9	80·4	40·2	335	0·079
2	1·2	92·8	46·5	387	0·122
3	1·8	113·4	57	473	0·223
4	2·4	130·8	65·5	545	0·343
5	3	145·8	73	608	0·478
6	3·5	160	80	667	0·630
8	4·7	183·9	92	766	0·965
10	5·9	205·2	103	855	1·35
12	7	224·5	112	935	1·77
14	8·2	241·6	121	1,007	2·22
16	9·4	258·2	129	1,075	2·71
20	11·8	287·0	143	1,195	3·77
24	14	313·0	157	1,304	4·93
28	16·5	336·8	169	1,404	6·18
32	19	357·9	180	1,492	7·51

DETAILS OF DISCHARGE NOZZLES, ETC.

Size No.	Diam. Discharge Nozzle.	Overall Sizes. Length.	Breadth.	Height.	Melting Capacity Tons per hour.	Cupola Diam.	Speed of Fan.	Pressure inches Water.	B.H.P.
	Ins.	Ins.	Ins.	Ins.		Ins.			
0	¼	17½	14	18	½– ¾	15	4,800	10	1½
1	4⅞	20	16½	21	¾– 1½	16	4,700	12	2½
2	5½	23	18	24	1½– 1¾	18	4,100	12	3¾
3	6¼	27	21	28	1¾– 2½	20	3,700	14	5¼
4	7⅛	31½	26	33	2½– 3½	26	3,200	14	7½
5	8⅞	37½	29½	39½	3½– 4¾	29	2,900	16	12
6	10½	43	34	45½	4½– 6	35	2,750	16	15
7	12	50½	41	52	7 – 9½	41	2,300	18	27
8	13⅞	58	46	59	10 –14	53	2,100	18	40
9	16	67	51½	69½	13 –17	70	1,800	20	50
10	18½	76½	61	80½	17 –23	80	1,600	20	66

(*Sturtevant.*)

Forge Air Pressure.

The air pressure for a forge commonly varies from 2 to 4 ozs. per square inch, with an averag of about 3 ozs. A pressure of 4 ozs. at the blower has been recommended when the averag number of fires does not exceed ten, and a pressure of 5 ozs. when the number is more than twelve Small forges with the blower close to them are adequately supplied with 1½ ozs. pressure. I the blower is some distance away and a long discharge pipe with many bends leads to the forge even though the latter be small, it may be necessary to carry 3 ozs. pressure or more, to overcom the friction in the air ducts. The volume of free air required by the average forge fire is abou 140 cubic feet per minute. The exhaust fan for a blacksmith shop should have a capacity approxi mately four times that of the forge blower, and should operate under a pressure of about ¾ oz.

REVERBERATORY FURNACES.

In a reverberatory furnace the material to be heated is contained in a long horizontal o slightly sloping hearth, the heat being supplied by flames and hot gases which travel over it. A considerable amount of heat is radiated on to the hearth from the arched roof of the furnace The proportions of the various parts of the furnace are important, as if the roof is too high the gases will not 'lick' the hearth, but will travel close to the roof. Care must be taken to have a sufficient volume of gases in the furnace, as otherwise the upper part of the hearth will be too cool There is a strong tendency to open the exit damper too wide. When in constant use, a reverbera tory furnace heated by producer gas is more economical than one heated by solid fuel.

KILNS.

A kiln is a furnace which is filled almost completely with the articles to be heated. Usually the flames and hot gases from the fuel circulate among the goods and raise them to the required temperature by conduction. When contact with the kiln gases would spoil the goods, they may be enclosed in fireclay cases or a *muffle furnace* may be used.

MUFFLE FURNACES.

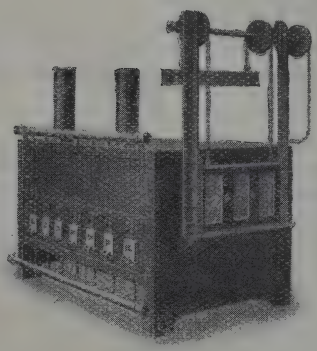

Fig. 4.

A muffle furnace is one in which the articles or materials to be heated are protected from direct contact with flames and hot gases from the fuel, but the term is sometimes used loosely for any kind of furnace heated by town's gas instead of solid fuel. The latter kind of furnace is extensively used for annealing, normalising, case-hardening, tempering, forging, and other heat treatments of iron, steel, and the non-ferrous metals.

Fig. 4 shows an oven furnace heated by the 'Lopress' system, in which gas at ordinary main pressure is used in conjunction with air at approximately 4-in to 6-in. water gauge. No compressor is necessary, the requisite air supply at this pressure being derived from a fan. Very rapid heating and much higher temperatures can be obtained compared with natural-draught heated furnaces. The 'greasy' flame so essential to annealing work on a large scale can be produced to perfection, while economy is ensured by regeneration of the air supply to the burners.

The following are figures from actual practice :—

Operation.	Load.	Duration.	Cub. ft. ton.
Annealing H.S. steel	3½ tons	8 hrs.	3,000
,, steel	3½ tons	15½ hrs.	6,000
,, C.I. parts packed in filings in boxes	2,000 lbs.	3 hrs.	3,360

High-speed Tool Steel.*

In no heat treatment of metal is uniformity of furnace mperature more important than in the treatment of igh-speed steel. Tool makers nearly always state the ract temperature required for various processes.

The furnace shown in fig. 5 enables any temperature be quickly reached and regularly maintained down to ie very narrow limits frequently required by particular eels. Whatever the composition of the steel. this rnace enables the operator to produce good tools, ving the maximum of service, and avoiding the waste expensive material and time due to under, over, or regular heating, etc.

The upper chamber is heated by waste heat from the wer, and serves to preheat the tools, etc., before they re put into the lower chamber, thus raising them to a edium temperature preparatory to the final rapid eating necessary to bring them to the hardening mperature

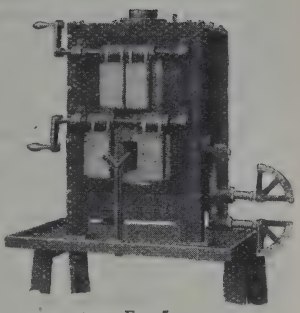

FIG. 5.

CRUCIBLE MELTING FURNACES.

(L. C. Harvey.)

'Lift-out Crucible' or Pit Type Furnaces.—These are supplied where requirements of molten metal are small, or in cases where it is preferable to melt in relatively small apacity crucibles. *Natural Draught Coke Furnaces* can be either connected up to one main flue nd chimney or can be provided with smaller collecting flues, each flue having a chimney to erve a small number of fires, or again, each fire can have its own small stack.

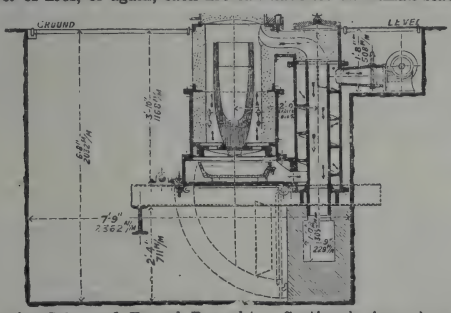

FIG. 6.—Furnace for Coke and Forced Draught. Sectional view, showing ground level.

Forced Draught Coke Furnaces (fig. 6) can be similarly arranged as regards provision for hausting the waste gases, and as they are not dependent upon chimney pull the heights of acks are considerably less than those required for natural draught furnaces.

It is usual to supply air from a blower or fan of sufficient capacity to feed any number to the whole of the plant. Forced draught offers the advantages of (*a*) independence of mospheric conditions, and, therefore, absence of variation in chimney pull; (*b*) quicker ating qualities of furnaces; (*c*) a greater degree of heat intensity than is possible under all nditions in natural draught furnaces.

Oil-fired Furnaces.—These can be fitted with burners to work with compressed r at 20-30 lbs. per square inch, depending to a large extent upon the temperature desired, ie higher pressure effecting a more perfect atomisation of heavy grades of fuel, or with low ressure burners which run with a pressure of only $\frac{3}{4}$ lb. per square inch for all temperatures to that necessary for melting mild steel and nickel.

The former require an air compressor, which is a relatively expensive machine, and may velop 5 to 10 h.p. per burner, whereas the latter needs only the ordinary open high-speed n, and the burners will take $1\frac{1}{2}$ to $2\frac{1}{2}$ h.p. according to size of the furnace, etc. Almost any ade of commercial fuel oil can be used with either type of burner, and this is fed to the rners by gravity.

* See also p. 1136

Producer Gas can be applied to lift-out crucible furnaces if these are made in the multip form, viz. several crucibles in one common melting chamber, or several crucibles in separa chambers, but exhausting into one air or gas heating regenerator.

For ordinary low-power producer gas, 135 to 175 B. Th.U. per cubic foot, is essential to prehe the air or gas supply to about 300° C. for efficient melting of copper alloys; for iron and high temperature melting, both the gas and air should be supplied at about this temperature.

When using high-power gas, such as water gas of roughly 280 B.Th.U. value per cubic foot, n preheating is required for melting temperature up to about 1,400° C.

Tilting Furnaces *for Coke Fuel* are always of the forced draught pattern, for one their chief features, quick heating, would be greatly impaired if worked on natural draught. Th type of furnace is more efficient than the pit type, and it has the important advantage of meltin in greater bulk than can be handled in a lift-out crucible—up to ½ ton of metal at one charge- and the further advantage of making it possible to mechanically tilt the furnace on a fixed fro trunnion, so that the metal can be poured direct into ladles or moulds. In the portable patter the body portion holding the crucible can be transported by means of an overhead crane to th point at which the molten metal is wanted.

Furnaces for Oil Fuel.—The remarks made above in connection with pit furnaces appl also to the tilting pattern. The economy in oil when melting, say, ½ ton of metal in one crucib with one burner, will be very marked, compared with, say, five burners for five 200-lb. size p furnaces, and the consequent saving in power for air blowers in equal proportion.

Producer Gas can be applied to tilting furnaces as for pit furnaces, but tilting furnaces bein of greater capacity than the latter it becomes possible to run single furnaces with producer ga the heat in the waste gas being utilised to warm the incoming air or gas supply. For copp alloys it is usual only to preheat the air.

The 'Radiation' Gas-heated Furnaces.

Natural-draught Oven and Muffle Furnaces for Hardening, Case-hardening, Annealing, etc.

These furnaces are of the 'under-fired' type, and are heated by means of gas supplied a normal town's pressure, the burners being so proportioned and located under the furnace heart as to ensure even heat at the required temperature throughout the whole working chambe Each burner has separate gas taps and air adjustments. Depending on the class of work, thi apparatus can be constructed as either a muffle or oven furnace. The furnaces are frequentl constructed with two heating chambers, an arrangement which gives, without lowering tempera ture in the bottom chamber or increasing the gas consumption, a pre-heating top chambe maintained at a temperature of about 300° C. less than the lower one. Where temperature of 1,000° C. and over are required, the furnaces are used in conjunction with air-blast burners as natural-draught furnaces are not recommended above 950° to 1,000° C. The furnaces ar also capable of modification to use oil fuel as a heating medium.

Low-pressure Gas and Air Furnaces for Annealing, Case-hardening, Reheating, Hardening, and Forging, etc., etc.

This furnace is 'over-fired,' i.e. the gas supply at normal town's pressure is led through port at one or both sides, where it comes into contact with the air supplied (at approximately 2 in. w.g. obtained from a small fan, which air has been previously well pre-heated by being taken throug the opposite side of the furnace in fine clay tubes, and then passed along the bottom of furnac in close proximity to waste products. Combustion takes place inside working chamber, th flames produced keep well up and sweep round the arch. The products of combustion then pas to the opposite side of furnace, are carried under the floor and up the other side away to the flue

Patent Twin-chambered Furnaces for Hardening High-speed Steel.

This twin-chambered furnace is specially designed for the hardening of high-speed stee tools, and combines durability with economy of working. The furnace linings are of exceptiona thickness, and the doors are constructed to conserve the heat and protect the operator. The fuel in this case may be either oil or gas, and special attention has been paid in order to secure a reducing atmosphere, in consequence of which the tools can be raised to the necessary high temperature without scaling or blistering. The upper chamber is heated by the waste heat from the lower one, and is used for the preheating of tools before finally raising them to the high temperature required for hardening.

Patent Salt Bath Furnace for Hardening and Heat-treatment of Cast and Special Steels and Reheating of Mild Steel after Carburising.

This furnace is designed for very accurate control, and consists of a metal pot containing fusible salt (pyromelt), which fuses at 670° C. Suspended above this pot is a rising and falling tray, which holds the work and also acts as a stirrer when in the molten liquid. Special provision is made for a pyrometer to be inserted in the liquid, and for protecting it against damage. This apparatus is suitable for heating up to 900° C., but at this high temperature the life of the pots is uncertain. Up to this point, however, heating is under complete control, and any required treatment may be repeated with mechanical precision. The furnace may be heated by coal gas, producer gas, or oil, in conjunction with air under pressure.

Tilting Crucible Furnaces for Melting Copper, Gunmetal, Brass, Aluminium, etc.

This type of furnace is designed for use where a large quantity of metal is to be heated at ne time, and where it is important that the heat be maintained while the metal is being poured. he furnace body is constructed in wrought steel, strongly stiffened and lined with fire-brick. is mounted on trunnions and tilted by means of a hand wheel, operating bevel, and worm gears. hese latter are covered in to protect them from damage by sand, etc., and for safety. The rnace is fitted with a loose bottom plate with slag holes, and this can be removed to facilitate ie renewal of the base brick. Below the bottom plate is a loose pan, so that should a crucible reak, the molten metal runs through the slag holes and is collected, thus preventing damage burners beneath.

ELECTRIC FURNACES.

(*A. H. Allen, M.I.E.E., and Professor Owen W. Ellis, M.Sc.*)

The classification of electric furnaces has already been dealt with (pp. **2651–2652**). It mains to treat in detail of these furnaces and their application industrially.

Electric Furnaces Heated by Resistance Effects.

Those furnaces of this type in which the charge is included in the electric circuit (fig. 7) e of indirect interest only to the engineer. They are employed largely in the manufacture of minium, carborundum, calcium carbide, etc.

Those furnaces of this type in which the charge is heated by means of an electrically-heated nductor find extensive employment in laboratories, and are coming into more general use for ie annealing and thermal treatment of steel and the melting and heat treatment of non-rrous alloys.

The smaller furnaces, such as are used in laboratories, are often made after the style of gas-ated muffle furnaces, but in place of gas jets, wire of platinum or incorrodible alloy, heated by ie passage of an electric current, is wound round the body of the chamber. Another type nsists of a tube of carbon, cut into a spiral or helix, through which the current flows.

Discussing furnaces of the larger type, T. F. Baily states that a 150-kw. annealing furnace ating 1,000 lbs. of steel to 900° C. in one hour consumes 300 kw.-hours per ton. With regard melting in a shop working 24 hours per day, the following costs were recorded :—

	s.	*d.*
Electricity, 400 kw.-hours per ton at $\frac{1}{2}d.$	16	8
Metal loss, 1 per cent. zinc at 5*d.* per lb.	8	4
Labour, 1 man per 600 lbs. per hour at $\frac{3}{8}d.$ per hour .	5	0
Renewals and repairs	4	2
Total per ton of brass melted	£1 14	2

These furnaces are provided with separate heating elements of carbonaceous material, which not come into contact with the charge, but are made incandescent by the current passing rough them, and thus heat the interior of the furnace chamber.

Induction furnaces (figs. 8 and 9), which may be classed under this head, find employment the manufacture of steel. They are able to hold their own against other types of steel-melting rnaces on account of their steady current consumption and low power consumption in the melting cold stock, but suffer from certain disadvantages of a well-defined character. The heat being nerated in the metal and only conducted to the slag renders it impossible to work a fluid basic ag, with the result that desulphurisation of the charge is not so efficiently carried out as in the se of furnaces of the resistance or arc-resistance type. Nor can dephosphorisation be so rfectly attained, since the design of these furnaces militates against ready and complete removal the oxidising slag needed for the removal of phosphorus. A further disadvantage arises as result of the continuous circulation of the molten metal in the bath which leads to the erosion the lining. This, in addition to the corrosive effect of the slag, leads to high figures for lining pairs.

Were the induction furnace of more flexible character and efficient design, it should nd wide application in the melting of brass containing as high as 50 per cent. zinc. At present is type of furnace is being experimented with in the direction of non-ferrous alloy melting.

Electric Furnaces heated by Arc Effects.

Only furnaces in which indirect heating of the charge (fig. **10**) is carried out are of interest this connection. The Stassano furnace is the most striking example of this type. The power nsumption of arc furnaces is high, and fluctuations in the value of this factor are, when the rnace is being employed in the fusion of cold stock, of high magnitude.

In the melting of copper alloys the indirect arc furnace may be employed economically in rge units. For melting brass containing not more than 10 per cent. zinc it has also been used.

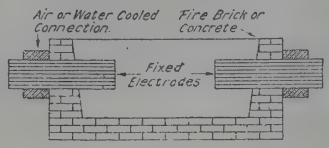

FIG. 7.

Cross Section of Resistance Furnace. Current passes from one electrode through the charge to the other electrode.

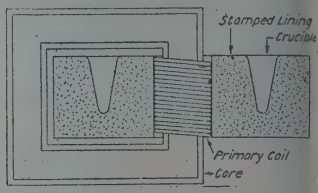

FIG. 8.

Cross Section of Single Ring Induction Furnace.

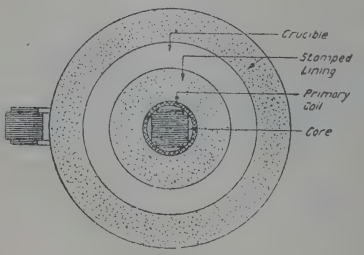

FIG. 9.

Cross Section in Horizontal Plane of Single Ring Induction Furnace.

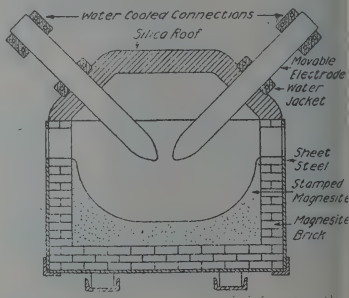

FIG. 10

Cross Section Indirect Heating Arc Furnace. Current arcs from one electrode to the other above charge.

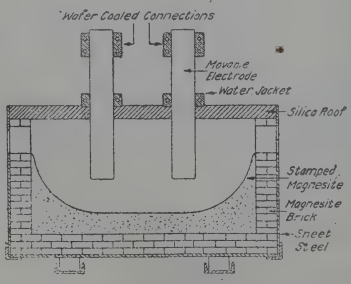

FIG. 11.

Cross Section Direct Heating Arc Furnace. Current arcs from one electrode to charge and from charge to other electrode.

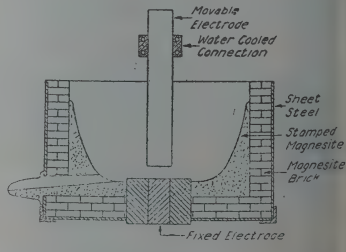

FIG. 12.

Cross Section of Smothered Arc Furnace. Current arcs from the electrode to the charge in which the electrode is plunged and the current passes through the charge to the lower fixed electrode.

Electric Furnaces heated by Combined Resistance and Arc Effects.

By far the largest number of electric furnaces in use industrially are of this type. In this lass of furnace an arc is struck between the extremities of vertical electrodes and the liquid or olid furnace charge (fig. 11). In many furnaces of this type negative electrodes are built into he furnace bottom or sides so that current is forced to flow through the bath (fig. 12). In oth cases the bath is heated by (i) the heat of the arc and (ii) the heat produced by the esistance of the steel and slag to the passage of electric current.

The electrodes, which are of graphite or amorphous carbon, are capable of movement in a irection parallel to their axis and are controlled, either by hand or by electrical device, so as to etain the arc at as constant a length as may be desired either for melting, refining, heating, tc., of the metal. In certain cases the practice of completely immersing the electrode in he molten charge—thus utilising the resistance effect of the electric current only—is in vogue.

For making steel the arc resistance type of furnace is that chiefly used, the charge generally onsisting of scrap steel. The composition of electric steel can be very accurately controlled, nd the proportions of sulphur and phosphorus in the final product can be reduced to mere traces. n improvement in quality is, therefore, to be expected. The most widely used arc-resistance urnace is the Héroult, of which, according to the Society for Electrical Development, 181 were n operation on January 1, 1917, 84 of these being in the United States and Canada. These nd similar furnaces are largely used for making small castings in steel, malleable iron, and ast iron, their capacities ranging from 1 to 20 tons ; 6-ton furnaces are very common. Other ell-known furnaces of this class are the Girod, Nathusius, Keller, Gronwall, Electro-metals, nd Greaves-Erchells. Each of these furnaces is possessed of special characteristics which ppeal to individual users. While steel melting and refining, and the production of steel and ron castings, occupy the vast majority of electric furnaces, all the foregoing types can be, and ave been, used for melting brass, copper, etc., though it is questionable whether their use for uch purposes can be considered as expedient.

Arc-resistance furnaces for steel melting are most frequently lined with basic refractory naterials. Acid-lined furnaces are, however, employed, chiefly to melt down high-grade raw naterials. The necessity for utilising such materials, for which high prices must be paid, renders he mere melting process a costly one. Further, as the treatment of molten steel on an acid earth leads to an appreciable gain in those elements, sulphur and phosphorus, most to be voided, the process is still further limited in its application.

The process employed for the production of steel in basic-lined arc-resistance furnaces is letermined by (*i*) the stock on hand and (*ii*) the product desired.

Should the stock on hand be of fair quality, i.e. containing contents of sulphur and phos-horus not above 0·06 per cent., the process may consist of (*i*) the application to the charge of basic oxidising slag and (*ii*) the conversion of this slag, by means of suitable additions of coal lust and lime, into a reducing slag, which is allowed to remain in contact with the molten steel luring the operations of teeming from the furnace and of casting from the ladle. Such additions f ferro-alloys as are required to bring the steel up to the standard required are made when the lag is as completely reducing in character as is possible under the conditions imposed by practice.

If the stock on hand is of poor quality, i.e. should it consist of scrap containing high (from ·06 to 0·20 per cent.) sulphur and phosphorus, or if it is desired to specially refine stock of fair uality, the first slag—the basic oxidising slag—is removed from the surface of the steel in the urnace. The removal of this slag implies the removal of the major portion of the phosphorus rom the steel, and unless the removal be very complete a return of phosphorus to the steel may e expected, the content of phosphorus returning to the steel under these conditions being oughly proportional to the amount of slag allowed to remain upon the charge. Occasionally it may be necessary to apply a further oxidising slag to the metal in the bath ; generally, however, one slag only is made. The first slag having been removed, deoxidation and desulphurisation are effected by the medium of a slag composed largely of calcium silicate. The 'physic' required to provide for carbon, manganese, etc., in the finished steel may be added immediately after the first slag has been removed. Generally speaking, the additions are made at a later stage in the process. The complete deoxidation of the metal is made evident by the appearance of the slag, which, the above conditions prevailing, decrepitates spontaneously and is practically white when cool.

Melting and refining carried out on a basic hearth results in a practically complete loss of carbon, silicon and manganese, and a very appreciable loss of sulphur, phosphorus and such elements as chromium, molybdenum, etc.

The possible uses of the electric furnace in the steel foundry have been tabulated by J. H. Hall:—

Melt scrap	Impure: eliminate phosphorus and sulphur. Pure: get hot and cast. Alloy steels.
Melt pig and more or less scrap. Eliminate C, Si, Mn.	Impure: eliminate phosphorus and sulphur. Pure: get hot and cast.
Treat hot metal	From cupola: eliminate C, Si, Mn, S and P. From acid Bessemer or open hearth: eliminate S and P. From basic open hearth: eliminate S and P.
Melt pig and scrap and treat cupola metal	Eliminate C, P and S without loss of Mn and Si. (Greene's process.)

The arc-resistance furnace proved to be of value during the war in the preparation of high grade pig iron to replace the Swedish pig iron so much sought after for the preparation of high grade steels.

According to E. K. Scott, a 10-cwt. steel-melting furnace running 9 charges a day will do as much as 36 crucible-steel furnace holes, each accommodating two 56-lb. pots, and can be operated by one man and an ammeter boy, whereas the crucible furnaces require 15 men, most of them skilled. The electric furnace, with its transformer and switch-gear, occupies one quarter as much space as the crucible plant, and costs half as much to instal. It can deal with a charge consisting entirely of turnings, millings, etc., whilst in the crucible-steel process only a very limited quantity of turnings can be used. The renewal of the furnace linings costs less than that of crucibles for the same output. Consequently the electric-steel furnace has been largely adopted in Sheffield in place of crucible furnaces.

The chief **losses** in electric furnaces are due to radiation from the walls and conduction through the electrodes. Since the radiation losses increase as the square and the capacity as the cube of the linear dimensions of furnaces, it is obvious that large installations are more economical than small ones. Conduction losses can be reduced to a minimum by suitably designing the electrodes.

Although, with coal at 14*s.* per ton and electrical energy at ½*d.* per kw.-hour, the latter costs twenty-eight times as much as the former per British thermal unit purchased, the efficiency with which the electrical energy is applied is so much higher that the difference is largely neutralised, and in the case of crucible steel is completely wiped out. In addition, the labour cost is greatly reduced with electric furnaces and there is a considerable economy of space and buildings, while the steel produced is of higher quality and uniformity than by any other method.

A useful method of calculating heat flow through the furnace walls, etc., has been developed by Carl Hering on the lines of Ohm's law. If—

W = heat flow in watts; T = drop in temperature in degrees C.; R = thermal resistance in 'thermal ohms,'

then,

$$W = T/R.$$

A thermal ohm is that thermal resistance which requires a drop of temperature of 1° C. to produce one watt of heat flow and = 4·2 gramme-calorie units; 1 gramme-calorie unit of thermal resistance = 0·24 thermal ohm.

Assuming that the electrodes are of uniform section, and that no lateral loss of heat takes place—conditions which are only approximately fulfilled in practice—Hering finds that the total loss of heat through the cold end of the electrode equals the sum of the loss by heat conduction alone (i.e. when no current is flowing) and half the T^2R loss. This combined loss is least when the loss by heat conduction alone equals half the T^2R loss; the total loss then equals the T^2R loss, and no heat will be conducted out of the furnace by the electrodes. This minimum loss is dependent only on the material of the electrodes, the current, and the temperature, but not on the absolute dimensions; it fixes the ratio of cross-section of electrode to length. In the case of a furnace working at 1,400° C., the cool end of the electrode being at 100° C., the length of the electrode 20 ins., and the current 10,000 amperes, the following dimensions were given by Hering's method of calculation:—

Carbon, 12·5 ins. diameter, loss of power in electrode 23·4 kw.; Graphite, 7·1 ins. diameter, loss of power 15·1 kw.; Iron, 4·8 ins. diameter, loss of power 4·6 kw. (*Stansfield.*)

F. T. Snyder states that in the case of a furnace melting 1,000 tons of steel a month, the cost of renewing the electrodes, plus the cost of the heat conducted out of the furnace by them, represents an expenditure of some 1,200*l.* a year per electrode. Hence the type of furnace having

.e fewest electrodes has an advantage in this respect. By using the metal bath as one terminal the arc, a furnace can be operated with one carbon electrode per arc. The furnace lining :omes conducting at very high temperatures, and this fact limits the voltage between two ectrodes passing through the same roof to a maximum of 110 volts to avoid serious leakage of irrent. The bulk of the cost of renewing refractory linings is due to roof wear round the ectrodes, and for the size of furnace above mentioned can be kept down to 800*l.* per annum per ectrode. The higher the power input the quicker is the heating and the greater the efficiency the furnace. With three electrodes the limit of power is soon reached, owing to lack of room space the electrodes sufficiently far apart to prevent current leakage through the roof lining, it with a single electrode there is no such limit to the power input.

The power, etc., provided in connection with Héroult furnaces used by the United States eel Corporation are given in the following table, which applies to cold charges; if the charge put into the furnace in a molten condition about half this power suffices :—

POWER REQUIRED FOR ELECTRIC FURNACES.

Size of Furnace, tons.	Transformer capacity, kva.	Amperes, per phase.	Square inches Copper, per phase.
1	375	2,250	3
2	600	3,600	5
3	750	4,500	6
4	900	5,400	7
6	1,200	7,200	9
10	2,000	12,000	16
15	3,000	18,000	24

The voltage used in arc furnaces depends upon the current and the length of the arc. In ree-phase furnaces it ranges between 75 and 100 volts, and in single-phase furnaces between 0 and 200 volts. In resistance furnaces the voltage at starting, with a cold charge, may be 0 volts, decreasing as the charge heats up to 35–60 volts. The consumption of the electrodes ries widely according to the conditions obtaining, from 3½ to 20 lbs. per ton of steel produced. ie furnace bottoms last from 1 to 3 years, the walls from 100 to 300 heats, and the roof from to 200 heats. To make ordinary carbon steel of crucible quality with a 6-ton furnace requires)m 550 to 750 kw.-hours per ton, starting cold. In smaller furnaces the input per ton is eater. The following figures for a Rennerfelt furnace are due to C. H. Vom Baur.

ENERGY REQUIRED IN TREATING VARIOUS METALS.

	Kw.-hours
Melting red brass	168
„ pure copper	197
„ white iron	280
„ gray iron	325
„ 80 per cent. ferro-manganese	441
„ and refining steel scrap on a basic bottom	700

The power factor of the arc resistance furnace varies from 85 per cent. to more than 90 per it.; that of the resistance type from 90 to 97 per cent.; that of the induction furnace varies)m 50 to 60 per cent. only.

The efficiency of a Héroult furnace was tested with a charge consisting of 5,733 lbs. steel ap, 430 lbs. iron ore, 346 lbs. lime. The input was 215 kws. for the first hour, at 110 volts, and erwards 342 kws. The total time taken to melt the charge was 5⅓ hours, and the total ergy input for melting was 1,680 kw.-hours. The ratio of heat utilised to heat supplied (the iciency) was 76·5 per cent. The time required for the purification and carburisation of the el was 3 hours, and the result was 5,161 lbs. of tool steel. The total consumption of energy s 2,580 kw.-hours, or 0·171 e.h.p.-year per ton of steel.

The leads from transformers to electric furnaces should be as short and direct as possible, and se together, as the voltage drop due to their self-inductance and the very large currents is con-erable, resulting in a low power factor. The conductors should be wide thin bars, or tubes, to vent loss of energy due to the tendency of alternating current to flow in the skin of the nductor.

ELECTRICAL RESISTIVITY OF MATERIALS, OHMS PER INCH CUBE.

Material.	Cold.	Hot.	Temperature ° C.
Graphite	0·00034	0·00031	100–2000
Carbon	0·0018	0·0014	100–2000
Silicate slag	∞	1 to 2	Molten
Fire bricks (various)	∞	8 to 24	850
		24 to 300	815

(*Stansfield.*)

FURNACE CONSTRUCTION.

The following are points requiring special attention in the construction of furnaces :—

1. Sections of furnaces such as are exposed to differing physical and chemical actions shoul be united in such a manner as to allow of free and independent movement and as to be subjec to independent condition.

2. Such sections as are exposed to high temperatures should be made thin and should, whe possible, be water-cooled; such sections as are exposed to low temperatures should be mad of such a thickness as will reduce thermal losses due to radiation and conduction to a minimun

3. The interiors of furnaces should be constructed so as to resist mechanical, physical an chemical wear. With this end in view choice must be made of suitable materials of constructio and of efficient design. In this connection note should be made of the following factors :—

(*a*) The action of heat.
(*b*) The erosive and corrosive actions of flame, slag, etc.
(*c*) The mechanical wear due to abrasion by the solid charge, etc.

4. The exteriors of furnaces should be supported and strengthened in such a way as to allo of the free expansion and contraction of the body. The foundations of all furnaces must be of strong and rigid character.

MELTING POINTS OF REFRACTORY MATERIALS.

	° C.
Alumina (pure)	2010†
Bauxite	1820†
Bauxite brick	1565 to 1785†
Bauxite clay	1795†
Chromite	2180†
Chromite brick	2050†
Fireclay brick—Highest grade	1843*
General grade	1650 (average)*
Ditto	1649 (average of 41 samples)†
Ganister	1700 to 1800
Kaolin	1735 to 1740†
Magnesia brick	2165
Silica—Pure	1750†
Pure	1830*
Pure, with 14·5 per cent. alumina	1690*
Pure, with 63·0 per cent. alumina	1890*
Brick	1700 to 1750†

The melting points have been considered to be those temperatures at which the material i question was first seen to flow easily.

* Boudouard.
† Kanolt—'Iron and Coal Trades Review,' vol. lxxxv. p. 309.

FURNACE EFFICIENCY.

The thermal efficiency of furnaces may be stated either absolutely or relatively :—

$$\text{Absolute furnace efficiency} = \frac{\text{Net thermal effect produced}}{\text{Calorific power of the fuel}}.$$

$$\text{Relative thermal efficiency} = \frac{\text{Net thermal effect produced}}{\text{Actual calories realised}}.$$

Owing to the large variation in the actual number of calories realised in individual furnaces it is general to employ the former of the above ratios. In order that a determination of the absolute efficiency of a given furnace may be made, a knowledge of the heat-absorbing and the heat-producing factors that are likely to be encountered in practice, of which a number are tabulated below, is required.

(*A*) Heat-absorbing Factors.

1. Heat absorbed by fume, gases, etc.
2. Heat removed by such solids and liquids as are periodically or continuously removed from the furnace.
3. Heat lost by radiation and conduction.
4. Heat absorbed owing to endothermic reactions within the furnace.

(*B*) Heat-producing Factors.

1. Heat supplied to the furnace by the combustion of fuel either inside or outside the furnace.
2. Heat added by such solids and liquids as are periodically or continuously charged into the furnace.
3. Heat gained owing to exothermic reactions within the furnace.

The thermal efficiency of the furnace is represented by the ratio of the heat-absorbing factors to the heat-producing factors.

Heat Economy by Insulation.

A considerable reduction in the loss of heat by radiation (see *A*, 3, above) may be effected by building a 'wall' of insulating bricks (p. 537) between the lining and the exterior of the furnace.

Latent Heat of Fusion of Metals.

The latent heat of fusion is the number of gram calories required to convert one gram of substance from solid into liquid without change of temperature :—

Mercury	2·8 calories.	Platinum	27·1 calories.
Lead*	5·5 ,,	Sodium	31·7 ,,
Bismuth*	10·2 ,,	Palladium	36·3 ,,
Cadmium*	10·8 ,,	Manganese*	36·7 ,,
Tin*	13·8 ,,	Antimony*	38·9 ,,
Potassium	15·7 ,,	Copper	41·0 ,,
Gold*	15·9 ,,	Nickel*	56·1 ,,
Iron	(See note).	Cobalt*	58·2 ,,
Silver*	26·0 calories.	Aluminium*	94·0 ,,
Zinc*	23·0 ,,		

NOTE.—The latent heat of fusion of iron as determined by Campbell (and confirmed by Oesch) from freezing-point depression data is 20·1. C. Brisker (1908), as a result of an examination of Carpenter and Keeling's freezing-point determinations of the iron-carbon system, has arrived at the value 31·6 for this element. Grumer gives values of 23 and 33 for gray and white cast iron respectively. Wüst obtained the value 49·4 for this factor.

Heat and Electrical Energy required for Fusion of Metals.

The following table (after Stansfield) gives the heat and electrical energy required to melt various metals, per lb. :—

	Calb.†	Watt-hours.		Calb.†	Watt-hours.
Tin	28	15	Copper	162	85
Lead	16	8	Cast iron (gray)	245	129
Zinc	68	36	Tool steel (1 % C.)	300	158
Aluminium	258	136	Wrought iron	343	181
Brass	130	69			

(See also p. 2665.)

* Values after Wüst. *Stahl und Eisen*, 1918, 38, 177.

† *Calb.*—The amount of heat required to raise one pound of water through one degree Centigrade.

Calorie.—The amount of heat required to raise one gram of water through one degree Centigrade.

TEMPERATURE CONTROL OF FURNACES—PYROMETRY.

Determination of Calorific Intensity.

The calorific intensity of a substance is the theoretical maximum temperature attained during the perfect combustion of the same in air at 0° C. and 760 mm. pressure, and is inversely proportional to the time occupied in attaining to this temperature. The calorific intensity of a substance may be determined by calculation or by experiment.

Calculation.

Let C = the calorific power of the substance,
T = the rise in temperature during combustion,
$w, w', w'', \ldots$ = the weights of the products of combustion,
$s, s', s'', \ldots$ = the specific heats of the products of combustion,

then,

$$T = \frac{C}{ws + w's' + w''s'' + \text{etc. etc.}}$$

for the fuel at 0° C. and 760 mm. pressure.

The calorific intensity of a fuel (by formula) will be seen to be directly proportional to the calorific power of the fuel and inversely proportional to the weights and the specific heats of the products of combustion.

The calorific power can be raised by

(*a*) Superheating the fuel.
(*b*) Superheating the air needed for the combustion of the fuel.
(*c*) Using a minimum of excess air.
(*d*) Increasing the proportion of oxygen in the air.
(*e*) Reducing the proportion of incombustible material in the fuel.

Experiment.

The calorific intensity of a fuel may be determined by experiment. For the purpose in question a variety of instruments has been designed, almost every thermal property of matter having been employed as a basis for the construction and calibration of these instruments, which are generally known as pyrometers.

Reference may be made to the Bulletin of the United States Geographical Survey, No. 54 (1889), where the following classification of the properties on which the construction of pyrometers has been founded is given :—

1. Dilatation of solids:
   (*a*) A single solid.
   (*b*) Two solids acting differentially
2. Dilatation of liquids.
3. Dilatation of gases:
   (*a*) Expansion measured in volume, manometrically.
   (*b*) Expansion measured in pressure, manometrically.
   (*c*) Expansion measured in volume, by displacement.
4. Vapour tension.
5. Dissociation.
6. Fusion.
7. Ebullition.
8. Specific heat.
9. Heat conduction.
10. Heat radiation.
11. Viscosity:
    (*a*) Of solids.
    (*b*) Of liquids.
    (*c*) Of gases.
12. Spectrophotometry and colour. Rotary polarisation.
13. Acoustics (wave length).
14. Thermo-electrics.
15. Magnetic moment.
16. Miscellaneous.

Expansion Type Thermometers.

The mercurial thermometer is most important for use at about atmospheric temperatures, largely on account of the wide range of temperatures through which mercury is liquid, —39° C. to 357° C. If a high-grade mercurial thermometer has been calibrated at the National

Physical Laboratory, it is possible to measure temperatures throughout its range to an accuracy of 0·001° C. By the use of inert gases (nitrogen or carbon dioxide) under pressure in the tube of a thermometer, the boiling point of the mercury may be raised to allow temperatures up to 540° C. to be determined, at which temperature the glass softens. Quartz thermometers containing mercury under pressure can be used up to 700° C. By using tin instead of mercury the maximum limit may be raised to 1000° C. Steel tube mercurial thermometers, in which the capillary is attached to a form of a Bourdon pressure gauge, are not easily broken, and may be relied upon up to 540° C.

Fusion Pyrometers.

Observations of the fusion of metals, alloys, salts or mixtures of salts enable the observer to judge the temperature reached in a furnace at the moment of fusion, given that the temperature of fusion of the material employed is known prior to its introduction into the furnace. Fusion pyrometers are most suitable for the registration of maximum temperatures, after the attainment of which the source of heat may be eliminated and the furnace or heated object allowed to cool.

Metals.

The base metals have the disadvantage of ready oxidation; the precious metals offer only a limited number of definite temperatures.

Alloys.

Only eutectic alloys (see p. 2674) and solid solutions (see p. 2674) are of value. Base metal alloys being subject to oxidation, only precious metal alloys remain as suitable fusion pyrometers. Both the alloys of silver and gold and those of gold and platinum have been employed for pyrometric work, the latter, according to Séger, being satisfactory up to a temperature of 1200° C. only.

Salts.

The following are the melting points of a number of metallic salts that have found use in pyrometric work :—

Salt.	Melting Point.	
Calcium nitrate	561° C.	1042° F.
Strontium nitrate	570 ,,	1058 ,,
Barium nitrate	593 ,,	1099 ,,
Potassium iodide	705 ,,	1301 ,,
Potassium bromide	750 ,,	1382 ,,
Potassium chloride	790 ,,	1454 ,,
Sodium chloride	800 ,,	1472 ,,
Sodium carbonate	849 ,,	1560 ,,
Sodium sulphate	880 ,,	1616 ,,
Barium chloride	960 ,,	1760 ,,
Potassium sulphate	1050 ,,	1922 ,,

Mixtures of Salts.

Under this heading may be included two important types of fusion pyrometers :—

(*a*) Séger cones.
(*b*) Sentinel pyrometers.

Séger Cones.

These are small three-sided pyramids, each about 2½ ins. high and about ½ in. wide at the base. The term 'cone' is rather misleading, as they are more pyramidal than conical. They are made of a finely ground mixture of felspar, china clay, and flint, the composition of the mixture depending on the temperature to be indicated. For the lower members of the series other mixtures are used

These cones were invented by the late Dr. Séger of Berlin, in order to provide some means of recording the effect of heat on various porcelains. Their shape and composition are such that when heated to their indicating temperature at a reasonably slow rate and under suitable conditions they bend over slowly from the upright position possessed by them when placed in the kiln or oven and gradually form an arch. When the top has almost reached the same level as the base the indicating temperature is reached. A further rise in temperature will cause the cone to collapse and form a shapeless, glazed mass.

It is customary to employ three different cones at a time; the first will indicate a temperatur about 20 degrees Cent. below the one required to be known, the second cone will indicate th desired temperature (such as the finishing temperature of a glaze) and the third cone will serv as an indicator that the required temperature has not been exceeded by 20 degrees. The com position of the cones is such that the difference in temperature shown between two successiv cones is about 20 degrees, though they are not quite regular in this respect.

It is important to remember that Séger cones do not serve as strict indicators of temperatu in the sense that a thermometer does. If heated too rapidly a much higher temperature may b reached than is normally required to bend a cone, and which they are supposed to indicate. Unde ordinary conditions of use, however, it is easy to find which cones correspond to the temperature or conditions of heating which it is required to control, and Séger cones are, therefore, invaluabl when they are rightly used. They serve as excellent indicators of the effect of heat on potter and similar materials, and as it is this, rather than the mere momentary temperature which i important, they have advantages not possessed by a pyrometer or high temperature thermomete

They were originally made only at Dr. Séger's laboratory in Berlin, but since 1914 they hav also been made at the Pottery School, Stoke-on-Trent, and sold by Messrs. Keeling & Walke Sutherland Mills, Stoke-on-Trent.

Owing to their cheapness and the difficulty of ensuring their accuracy when made by amateur it is usually better to purchase the cones rather than to attempt to make them.

The following temperatures are those nominally associated with Seger cones, but, as explaine above, it is preferable to refer to the number of the cone rather than to the temperature.

SÉGER CONES AND TEMPERATURES.

Séger Cone.	Deg. Cent.	Deg. Fah.	Séger Cone.	Deg. Cent.	Deg. Fah.	Séger Cone.	Deg. Cent.	Deg. Fah.	Séger Cone.	Deg. Cent.	Deg. Fah.
022	600	1112	07*a*	960	1760	9	1280	2336	29	1650	3002
021	650	1202	06*a*	980	1796	10	1300	2372	30	1670	3038
020	670	1238	05*a*	1000	1832	11	1320	2408	31	1690	3074
019	690	1274	04*a*	1020	1868	12	1350	2462	32	1710	3110
018	710	1310	03*a*	1040	1904	13	1380	2516	33	1730	3146
017	730	1346	02*a*	1060	1940	14	1410	2570	34	1750	3182
016	750	1382	01*a*	1080	1976	15	1435	2615	35	1770	3218
015*a*	790	1454	1*a*	1100	2012	16	1460	2660	36	1790	3254
014*a*	815	1499	2*a*	1120	2048	17	1480	2696	37	1825	3317
013*a*	835	1535	3*a*	1140	2084	18	1500	2732	38	1850	3362
012*a*	855	1571	4*a*	1160	2120	19	1520	2768	39	1880	3416
011*a*	880	1616	5*a*	1180	2156	20	1530	2786	40	1920	3488
010*a*	900	1652	6*a*	1200	2192	26	1580	2876	41	1960	3560
09*a*	920	1688	7	1230	2246	27	1610	2930	42	2000	3632
08*a*	940	1724	8	1250	2282	28	1630	2966	—	—	—

The chemical composition of the older Séger cones Nos. 1 to 36, together with the ingredients used in the manufacture of the same, are given in the following table for the convenience of those unable to obtain cones readily, but who may have raw materials available. The ingredients are finely divided before mixing. Dextrin is employed as a binder. The materials as employed by Dr. Séger, and considered to be sufficiently pure for the purpose in question, gave the following analyses:—

	Rostrand Feldspar.	Zettlitz Kaolin.	Norwegian Quartz.	Carrara Marble.
	Per cent.	Per cent.	Per cent	Per cent.
Silica	64·32	46·87	98·52	1·00
Alumina	19·41	38·56	1·04	0·12
Ferric oxide	0·14	0·83	0·04	
Lime	trace	trace	—	54·93
Magnesia	0·35	trace	—	0·20
Potash	12·90	1·06	0·40	—
Soda	2·10		—	—
Loss on ignition	0·57	12·73	—	—
Carbon dioxide	—	—	—	43·76

Cone No.	K_2O	CaO	Fe_2O_3	Al_2O_3	SiO_2	Feld-spar.	Mar-ble.	Quartz	Fe_2O_3	Zettlitz Kaolin.	Melting Point.
1	0·3	0·7	0·20	0·3	4	83·55	35	66	16·0	—	1150° C.
2	0·3	0·7	0·1	0·4	4	83·55	35	60	8·0	12·95	1170° C.
3	0·3	0·7	0·05	0·45	4	83·55	35	57	4·0	91·43	1190° C.
4	0·3	0·7	—	0·5	4	83·55	35	54	—	25·90	1210° C.
5	0·3	0·7	—	0·5	5	83·55	35	84	—	25·90	1230° C.
6	0·3	0·7	—	0·6	6	83·55	35	108	—	38·85	1250° C.
7	0·3	0·7	—	0·7	7	83·55	35	132	—	51·80	1270° C.
8	0·3	0·7	—	0·8	8	83·55	35	156	—	64·75	1290° C.
9	0·3	0·7	—	0·9	9	83·55	35	180	—	77·70	1310° C.
10	0·3	0·7	—	1·0	10	83·55	35	204	—	90·65	1330° C.
11	0·3	0·7	—	1·2	12	83·55	35	252	—	116·55	1350° C.
12	0·3	0·7	—	1·4	14	83·55	35	300	—	142·45	1370° C.
13	0·3	0·7	—	1·6	16	83·55	35	348	—	168·35	1390° C.
14	0·3	0·7	—	1·8	18	83·55	35	396	—	194·25	1410° C.
15	0·3	0·7	—	2·1	21	83·55	35	468	—	233·10	1430° C.
16	0·3	0·7	—	2·4	24	83·55	35	540	—	271·95	1450° C.
17	0·3	0·7	—	2·7	27	83·55	35	612	—	310·80	1470° C.
18	0·3	0·7	—	3·1	31	83·55	35	708	—	362·60	1490° C.
19	0·3	0·7	—	3·5	35	83·55	35	804	—	414·40	1510° C.
20	0·3	0·7	—	3·9	39	83·55	35	900	—	466·20	1530° C.
21	0·3	0·7	—	4·4	44	83·55	35	1020	—	530·95	1550° C.
22	0·3	0·7	—	4·9	49	83·55	35	1140	—	595·70	1570° C.
23	0·3	0·7	—	5·4	54	83·55	35	1260	—	660·45	1590° C.
24	0·3	0·7	—	6·0	60	83·55	35	1404	—	738·15	1610° C.
25	0·3	0·7	—	6·6	66	83·55	35	1548	—	815·85	1630° C.
26	0·3	0·7	—	7·2	72	83·55	35	1692	—	893·55	1650° C.
27	0·3	0·7	—	20·0	200	83·55	35	4764	—	2551·13	1670° C.
28	—	—	—	1·0	10	—	—	240	—	129·50	1690° C.
29	—	—	—	1·0	8	—	—	180	—	129·50	1710° C.
30	—	—	—	1·0	6	—	—	120	—	129·50	1730° C.
31	—	—	—	1·0	5	—	—	90	—	129·50	1750° C.
32	—	—	—	1·0	4	—	—	60	—	129·50	1770° C
33	—	—	—	1·0	3	—	—	30	—	129·50	1790° C.
34	—	—	—	1·0	2·5	—	—	15	—	129·50	1810° C.
35	—	—	—	1·0	2						1830° C.
36	—	—	—	1·0	1·5	Zettlitz Kaolin		Rackonitz Shale Clay			1850° C.

The composition of Rackonitz shale clay is as follows:—

ilica .	52·50 per cent.	Magnesia .	0·54 per cent.	Potash and soda .	traces
umina .	45·22 „	Lime .	0·50 „	Loss on ignition .	0·78 per cent.
on oxide .	0·81 „				

SENTINEL PYROMETERS.

These are small cylinders, measuring about $\frac{3}{4}$ in. by $\frac{1}{2}$ in. and manufactured from salt ixtures of definite melting points. Only such mixtures can be utilised as are formed of salts that ither dissociate nor corrode when in the molten state. Brearley states that 'mixtures of salts, ter being melted together and ground to a very fine powder, may be made into an adhesive paste th vaseline, and applied to many purposes for which no ordinary pyrometer is available. In the nith's hearth, for example, a tool may be heated to low redness and smeared near the point th a small portion of a paste whose melting point is, say, 770° C. The tool is then reheated rectly in the fire or protected from the coke by a piece of scrap, wrought or cast iron piping, until e white mark left by the thin layer of the salt mixture disappears. This indicates that the steel lf has nearly reached the desired temperature and may be quenched.'

The following are the melting points of a number of mixtures of salts:—

Salt.	Parts by Weight.	Salt.	Parts by Weight.	Deg.
Potassium carbonate .	50	Potassium chloride	50	580 C.
Sodium chloride . .	30	Ditto	70	625 C.
Ditto	42	Ditto	58	655 C.
Potassium sulphate .	20	Sodium sulphate	80	825C.
Ditto	30	Ditto	70	830 C.
Ditto . . .	50	Ditto	50	850 C.

Heat Radiation Pyrometers.

In this type of instrument the relation between the effect of radiant heat on suitably chose thermal elements and the temperature of the radiating body is observed. The Féry Radiatic Pyrometer is an example of this class of instrument.

In this pyrometer the rays from the hot body are received on a concave mirror, which can s be adjusted that the rays form a heat image which covers a small sensitive element permanent fixed on a line through the axis of the mirror. The sensitive element consists of a delicate adjusted thermo-couple, which delivers current to a millivoltmeter, calibrated, if desired, read the temperature of the body, whence the heat rays are emanating, directly. In both cas suitable means are provided for ensuring that the sensitive element is completely covered by t image of the radiant body.

In order that correct results may be obtained when using pyrometers of the radiation type it necessary that the hot body sighted should be enclosed within a vessel whose walls are approx mately at the same temperature as the body itself. If this precaution is not observed the readi obtained will be lower than the true temperature of the body, the degree of inaccuracy bei dependent almost entirely on the nature of the surface of the body in question.

Optical Pyrometers.

Approximate estimations of the temperatures of incandescent bodies may be made by visu observation. Numerous colour scales have been proposed, but those due to Howe and Taylor a White are generally accepted as the most accurate. The following table (based on one by How is of value in this connection.

Taylor and White.		Howe.	
Name of colour.	Degrees C.	Name of colour	Degrees C.
—	—	Lowest visible red in the dark	470
—	—	Lowest visible red in daylight	475
Dull red, blood red, low red	566	Dull red	550–625
Dark cherry red	635	—	—
Cherry, full red	746	Full cherry	700
Light red, bright cherry, light cherry	843	Light red	850
Orange	899	—	—
Light orange	941	—	—
Yellow	996	Full yellow	950-1000
Light yellow.	1079	Light yellow.	1050
White	1205	White	1150

The design of optical pyrometers is dependent on the fact that the intensity of the light ray emitted from an incandescent 'black body' is directly proportional to the temperature of the 'body

The Mésuré and Nouel Pyrometric Telescope consists of two suitably mounted Nicol prisms, s adjusted that their planes are at right angles to one another when the scale of the instrument is a zero and between which is placed a quartz plate cut perpendicularly to its axis. When the incand escent body is observed through the instrument it is necessary to rotate one of the Nicols in orde to extinguish the emitted light. The angle of rotation is proportional to the thickness of the quart plate, which is a constant for any given instrument, and inversely proportional to the square roo of the wave length of the observed light. The wave length of the observed light being proportiona to the intensity of the light, the angle of rotation of the analyser or polariser is a measure of th temperature of the incandescent body.

The Cornu-Le Chatelier Photometric Pyrometer is designed to measure the intensity of th light emitted by an incandescent body by reducing this intensity until it corresponds to tha of the light emitted by a standard lamp. The reduction required is inversely proportional to th temperature of the hot body.

The Wanner Photometric Pyrometer likewise compares the intensities of the lights emitted by the incandescent body and a standard body respectively. In this instrument, however, spectr of the two sources of light are, firstly, broken up into two polarised planes at right angles to on another; secondly, adjusted so that only the narrow red bands of each spectrum are transmitte

rther; and, thirdly, so brought into vision that the intensity of either field, both being in visual ontact, can be strengthened or weakened, until they are equally intense, by rotation of a Nicol rism. The amount of rotation, which can be observed on a suitably situated scale, serves to ieasure the intensity of the emitted light, and hence to define the required temperature.

The Cambridge Optical Pyrometer is, in principle, the same as the foregoing, and is invaluable or temperature measurements between 700° and 4000° C.

Thermo-Electric Pyrometers.

This type of pyrometer is dependent for its action upon the fact that a current is produced vithin a closed circuit formed of two dissimilar metals when the junction between the two metals is eated, the current being proportional to the absolute temperature of the junction.

The essential features of this pyrometer are two thin insulated rods or wires of dissimilar ietals coupled at one of their ends and connected at their other ends to separate leads. The onnection between the two metals and the leads, which is known as the 'cold-junction,' is nclosed within suitably designed apparatus that can be retained at a known constant tempe- ature. The leads from the 'cold-junction' pass to some form of electrical instrument capable f registering or recording changes in the P. D. produced in the now closed circuit when the hermo-couple is heated or cooled.

The number of metals and alloys available for the manufacture of thermo-couples are few. The ollowing are among those most generally employed :—

Couple.	Range.
Platinum—platinum rhodium	Up to 1400° C.
Platinum—platinum iridium	„ 1000 „
Nickel—nickel chromium	„ 800 „
Silver constantan	„ 600 „
Copper constantan	„ 500 „
Iron constantan	„ 500 „

For the estimation of temperatures above the melting-point of platinum the iridium-iridium- uthenium couple has been suggested, but it is considered unlikely that the same would prove fficient, on account of the known volatility of iridium at such temperatures.

Union between couple *wires* is effected by fusion in the electric arc or oxyhydrogen flame n the case of couples having a platinum base, by soldering or brazing in the case of base-metal ouples or by twisting. Union between the wires and the leads can be effected as above or by ieans of electrical clamps.

The couple wires, when in use, are generally protected by tubes of nichrome, fireclay, silica r glazed porcelain, the last being particularly useful when it is desired to defend the wires gainst the deleterious action of hot gases. When necessary, protection is afforded these tubes y enclosing them in steel jackets.

Heavier types of thermo-electric pyrometers consist of a *rod* of one metal fitted tightly into ne end of a cylinder concentric with the rod and of another metal and insulated from the same y suitable means.

Calibration of thermo-electric pyrometers is effected by immersing the protected couple in ubstances or the vapour of substances whose melting or boiling points are known. The couple, eing subject to like thermal changes as the substance, causes a fluctuation in the current flowing vithin the closed circuit, which fluctuation is registered by the instrument within the circuit. For example, while solidification of a metal in which the protected couple is immersed is in progress constant reading is obtained on the instrument. This value is observed, and is recorded on a graph against the melting point of the metal as ordinate. A series of such points may be btained by employing a number of metals in similar manner to that already described, and, hese points being united, a curve is obtained from which the temperature corresponding to any iven reading of the instrument may be abstracted.

The following are the melting points on the thermo-dynamic scale used by the Washington Bureau of Standards as standard temperatures in the standardisation of thermometers and yrometers :—

Mercury	— 38·9° C.	Antimony	630·0° C.	Nickel	1452° C.
Tin	231·9 „	Aluminium	658·7 „	Iron	1520 „
Cadmium	320·9 „	Silver	960·5 „	Palladium	1549 „
Lead	327·4 „	Gold	1063·0 „	Platinum	1755 „
Zinc	419·4 „	Copper	1083·0 „	Tungsten	3000 „

At temperatures of 1000° C. the error is of the order of 0·1° C., at the melting point of platinum 5° C., at that of tungsten 100° C. A further table of other standard temperatures is given in which the following are included :—Normal boiling-point of oxygen 180·0°, sublimation of carbon

dioxide in an inert liquid 78·5°, normal boiling point of water 100°, of naphthalene 217·96°, of benzophenone 305·9°, of sulphur 444·6°, freezing point of sodium chloride 801° C.

In the *Physical Review* the melting point of rhodium is estimated to be at 1907 or 1968° C. and that of iridium as 2292 or 2388° C. That of silicon is placed at 1434 or 1452° C. and that of palladium at 1548 or 1576° C. The reason for the two figures is due to the fact that the calculations are based on different estimates of the melting-point of platinum, which has been placed at 1745° C. by some experimenters and at 1789° C. by others.

Electric Resistance Pyrometers.

In these instruments advantage is taken of the change of resistance of a wire with temperature. Platinum wire is generally employed. The essential features of the commercial apparatus are a coil of fine platinum wire, enclosed in a suitably designed protecting tube, a cell or accumulator for the supply of current to the wire and an indicator or recorder on which the temperature may be read off directly.

In the original type of this instrument errors due to the residual strain and impurities in the lead wires entered, but later instruments are designed with 'compensating wires,' whose component parts are equal in resistance to and are so arranged that they are heated to the same temperature as corresponding parts of the lead wires. Changes in resistance in the lead wires are compensated by equal changes in the 'compensating wires.'

The resistance pyrometer (after Callendar) is represented diagrammatically in fig. 13.

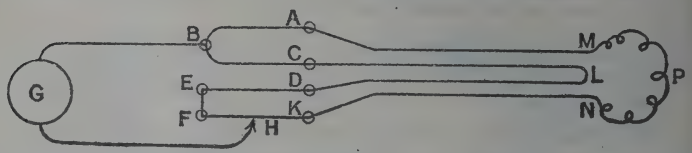

FIG. 13.

P represents the pyrometer coil; AM, KN the lead wires; CL, DL the 'compensating wires'; FK a bridge wire with scale, so arranged that 1 cm. length of the same corresponds to 1° C. rise or fall of the temperature, H the sliding contact piece, and G a galvanometer. AB and BC are wires of equal resistance. DE represents a set of resistance coils. In practice AB, BC and DE can be replaced by a post office box. Balance is obtained by the adjustment of the resistances in DE and the sliding of the contact piece H. The resistance of the pyrometer coil is given by the sum of the coils DE and the bridge wire scale reading.

Resistance pyrometers are accurate from 0° C. to 1000° C., and are employed industrially wherever reliable measurement is essential. They suffer owing to their high first cost and their fragile character. There are, however, large numbers of this type of pyrometer in use commercially.

METALS AND ALLOYS.

ALLOYS.

There are three well-recognised types of alloys:—

(i) Conglomerates of metals, or of metals and non-metals.
(ii) Homogeneous mixtures of metals, or of metals and non-metals.
(iii) Inter-metallic compounds, or compounds of metals with non-metals.

(i.)

In this type of alloy the component elemens or their compounds crystallise out from the molten alloy in a practically pure state, and the addition of one component to the other results —within certain limits—in a lowering of the solidifying point of the resulting alloy. The alloy having the lowest solidifying point in such a series is called the 'eutectic.' Lead-tin alloys are of this type.

(ii.)

In this type of alloy the component metals do not crystallise out from the molten alloy in the pure state, but contain on freezing more or less of each other in solid solution. Copper-nickel alloys are of this type.

(iii.)

Inter-metallic compounds behave similarly to pure metals, crystallising in like manner. Copper and zinc form a compound Cu_2Zn_3, which is extremely hard and brittle.

IRON.

IRON (FERRITE).

Chemically pure iron is not an article of commerce at the present time. Iron has been obtained by electrolytic deposition of a degree of purity greater than 99·9 per cent. iron, while the American Rolling Mills Co. manufacture a commercial product which they claim to contain 99·84 per cent. of iron.

Stead, by extrapolation, has arrived at the following figures for the approximate mechanical properties of pure unworked iron :—

Yield point	9 tons per square inch.	Elongation	51 per cent. (length/area = 8).
Maximum stress	17 ditto.	Reduction in area	84 per cent.

The term ' Ferrite ' is applied to pure iron when it is considered as a microscopical constituent of iron or steel. Pure iron is composed of polyhedral crystallites of ferrite.

Carbon, manganese, silicon, sulphur, phosphorus, arsenic, molybdenum, etc., all have effect on the iron in which they occur and are frequently added with a view to obtain alloys having more or less definite physical and mechanical properties.

INGOT IRON.

' Ingot Iron ' is the generic name of a commercially pure iron produced under patents owned by the International Metal Products Company. The manufacture of the metal in Great Britain is controlled by The Armco International Corporation, which company also undertakes the sale of the metal in various forms throughout the world, through suitable agents and representatives.

Ingot Iron, unlike Puddled Wrought Iron, is produced in the basic open-hearth furnace, and in view of a certain amount of difficulty in finding an acceptable definition of ' iron ' and in differentiating between ' iron ' and ' steel,' it is well to quote the definitions advanced by Dr. Albert Sauveur, who recently received the Bessemer Medal given by the British Iron and Steel Institute Dr. Sauveur says :—

' COMMERCIAL IRON is the element iron as pure as it can be commercially produced.

' INGOT IRON is commercial iron which has been produced in a fluid condition and cast.

' WROUGHT IRON is a ferrous metal which is malleable and which has been produced from a pasty condition.

' STEEL is an alloy of iron and carbon which is malleable, usually containing substantial quantities of manganese.'

'ARMCO ' INGOT IRON is ingot iron produced in the open-hearth furnace containing less than 0·02 per cent. carbon and less than 0·035 per cent manganese.

' Armco' Ingot Iron possesses many special characteristics, some or all of which will appeal to fabricators and users in many industries. The principal points of merit are as follows :—

Chemical Purity.—' Armco ' Ingot Iron contains less than one-sixth of 1 per cent. of impurities considering silicon, sulphur, phosphorus, manganese, carbon, copper, and the gases oxygen, hydrogen, and nitrogen.

Uniformity.—The method of manufacture of Ingot Iron and its freedom from impurities ensure uniformity of analysis ; this, coupled with the fact that the metal is free from slag inclusions, such as exist in even the best puddled irons to a greater or lesser degree, ensures mechanical uniformity.

Corrosion Resistance.—The conclusion that pure iron resists rust is not merely derived from theoretical inference, but represents the definite finding of many observers of the problems of corrosion, after fully investigating generations of service evidence in the form of old hand-wrought irons, such as, for example, the Iron Pillar of Delhi. These old irons were not rustless, but they resisted rust and corrosion to a remarkable degree, by reason of their freedom from corrosion-promoting impurities.

Workability.—Ignot Iron being a dense, ductile, and uniform metal, possesses exceptional working qualities.

Welding Properties.—The superior welding qualities of Ingot Iron are due to its purity and homogeneity. Being of perfectly even texture and density throughout, it welds evenly and easily.

Paint-Holding Surface.—It has been found in service that Ingot Iron sheets require painting less often than other iron and steel sheets. This is partly explained by its velvety surface, which grips and holds paint tightly, and partly by the degasification which the metal undergoes during manufacture, thereby reducing to a minimum occluded gases which in course of time tend to become liberated, and cause flaking of the paint film.

Enamelling Properties.—'Armco' Ingot Iron constitutes (it is claimed) the best base known for vitreous enamelling, for the following reasons:—

It is chemically and mechanically uniform.

Its velvety surface grips and holds the vitreous coating.

Its degasification during manufacture reduces the risk of pinholes, blisters, and other blemishes to a mimimum.

It shows less tendency to warp than other ferrous metals during the vitreous process.

Electrical Properties.—'Armco' Ingot Iron possesses a high magnetic permeability and low retentivity. It is further a better conductor of electricity than steel; in this connection the following is the result of tests undertaken by the National Physical Laboratory:—

Resistivity

By relative mass = 5·43. By relative volume = 6·17.

(Compared with the British standards for soft copper.)

This superiority in electrical conductivity renders the metal specially suitable for telegraph wire, bond wires, conductor rails, etc.

INGOT IRON can be supplied by *The Armco International Corporation* in the form of black and galvanised sheets, plates, billets, bars, shapes, wire, rods, welding rods, cold rolled strip, and welded tubes.

WROUGHT IRON.

Wrought iron is iron low in carbon content, which in course of production is in a pasty condition, owing to the fact of its being worked at a temperature too low to render it fluid. It contains a relatively large percentage of non-metallic impurities in the form of slag, which may be readily seen when the iron is examined microscopically, and which, therefore, serves, among other features, to distinguish this product from steel. The percentage of carbon in wrought iron rarely exceeds 0·15 per cent., and the total of other elements present in the metal is generally less than 0·25 per cent. Wrought iron is not appreciably hardened by quenching.

The fracture of wrought iron is fibrous in appearance and is occasionally characterised by the presence of somewhat large proportions of non-metallic inclusions.

WROUGHT-IRON (*or Mitis*) CASTINGS.

If a small amount of aluminium is added to a charge of wrought iron which has been heated until pasty, the iron immediately liquefies, and can be poured into castings having all the properties of wrought iron except fibre, and as sound as if of cast iron. These castings are called 'Mitis' castings because of their softness in contrast with cast-iron castings.

The best results are obtained by using Swedish scrap iron or English hematite iron, that is, materials containing less than 0·1 per cent. of phosphorus, which is a very injurious ingredient if present in much larger quantity. Using a mixture with poorer quality of iron, with phosphorus running up to 0·15 per cent., good results may still be obtained—that is, the castings still compare favourably with ordinary malleable castings. The following mixture for melting has been used:—Mitis scrap, 35 per cent.; hematite muck bar, 35; wrought-iron punchings, 12⅜; soft steel scrap (0·1 per cent. carbon), 12⅜, white pig iron, 3; ferro-silicon (10 per cent. silicon), 1; ferro-aluminium (6 per cent. aluminium), ⅜.

In general it may be said that if iron free from impurities is used very good castings are obtained; if iron is used with a large percentage of phosphorus, proportionately brittle and unsatisfactory castings result.

The ferro-aluminium used should be, for similar reasons, free from any considerable amount of such impurities as generally injure wrought iron.

PIG IRON.

Typical Analyses of Pig Iron, etc.

The following list of analyses is taken from Dr. W. H. Hatfield's book, 'Cast Iron in the Light of Modern Research.' It is published with the kind permission of the author and of the publishers, Messrs. C. Griffin & Co. Ltd.

West Coast Hematites.

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.	Mn.	Cu.
No. 1 .	3·750	·300	2·60	·02	·045	trace	·50	·04
„ 2 .	3·500	·460	2·40	·03	·045	trace	·50	·04
„ 3 .	3·250	·540	2·10	·04	·045	trace	·50	·04
„ 4 .	2·800	1·000	1 65	·10	·045	trace	·50	·04
„ 5 .	2·400	1·600	1 20	·20	·045	trace	·50	·04
Mottled	1·600	1·950	·90	·25	·045	trace	·20	·04
White .	trace	3 250	·65	·30	·045	trace	·10	·04
			From Native Ores only.				Average Actual Mn and Cu	
Special .	3·75	·300	2·60	·02	·02	0·500		

East Coast Hematites. ('Seaton.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.	Cu.
No. 1	3·725	·300	2·50	·02	·05	1·00	·05
,, 2	3·525	·450	2·25	·03	·05	1·00	·05
,, 3	3·150	·560	2·00	·04	·05	1·00	·05
,, 4	2·750	1·000	1·50	·10	·05	1·00	·05
,, 5	2·450	1·550	1·00	·20	·05	·75	·05
Mottled	1·500	2·050	·75	·25	·05	·50	·05
White	trace	3·150	·65	·30	·05	·50	·05
Special No. 1	3·525	·300	2·50	·015	·03	1·00	·05
,, ,, 2	3·350	·400	2·25	·020	·03	1·00	·05
,, ,, 3	3·00	·500	2·00	·025	·03	1·00	·05

Scotch Hematites. Welsh Hematites.

These are practically of the same composition as the East Coast Hematites.

Bessemer Basic. ('Carlton.')

G.C.	C.C.	Si.	S.	P.	Mn.
Traces	2·65	·35 to 1·00	·05	2·850	1·50

'Ferro' Alloys.

Brand.	C.	Si.	S.	P.	Mn.
Ferro-Manganese	6·640	·610	·028	·180	80·100
Ferro-Silicon	1·300	11·000	·040	·060	2·500
,, (Electro)	·270	28·520	·040	·040	·400
Silico-Spiegel	1·700	11·000	·040	·049	18·320
,, (Special)	·690	20·900	·018	·097	55·760
Spiegel	4·500	·900	·030	·070	18·000

NOTE.—Ferro-Manganese is usually 80·00 Mn.
Ferro-Silicon varies from 8·00 to 16·00 Si.
Silico-Spiegel varies from 10·00 to 14·00 and 18·00 to 20·00 Mn.
Spiegel varies from 10·00 to 25·00 Mn.

Scotch Pig Iron. ('Carron.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1	3·500	·140	2·800	·035	·880	1·450
,, 2	3·370	·250	2·275	·045	·907	1·450
,, 3 Soft	3·280	·180	2·650	·038	·902	1·400
,, 3 Foundry	3·350	·200	2·150	·055	·907	1·311
,, 3 Close	3·170	·280	1·750	·050	·905	1·420
,, 4	3·160	·290	1·570	·060	·905	1·450

Yorkshire Pig Iron. ('Clarence.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1	3·030	·30	3·170	·03	1·600	·50
,, 3	3·050	·30	2·800	·03	1·570	·60
,, 4 Foundry	2·990	·43	2·240	·06	1·540	·52
,, 4 Forge	2·750	·55	1·850	·10	1·560	·50
Mottled	1·490	1·65	1·270	·18	1·510	·40
White	·100	3·10	·880	·28	1·570	·38

Lincolnshire Iron. ('Redbourne.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 3 Foundry	3·100	·560	2·751	·038	1·326	1·680
„ 4 Foundry	2·816	·751	2·610	·045	1·318	1·589
Grey Forge	2·525	·895	2·508	·056	1·316	1·456
No. 4 Close	2·459	·945	2·452	·059	1·296	1·344
Mottled	1·480	1·520	1·325	·100	1·296	1·130
White	·675	2·285	·450	·155	1·295	1·100

Derbyshire Irons. ('Renishaw.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1	3·410	Trace	2·939	·036	1·680	·362
„ 2	3·260	1·79	2·146	·034	1·62	·707
„ 3	3·850	·112	2·333	·024	1·581	·572
„ 4 Foundry	3·300	·225	2·099	·053	1·771	·647
Close Forge	2·800	·330	1·819	·079	1·730	·520
Mottled	1·550	1·560	1·200	·200	1·500	·350
White	2·650	·100	·450	·250	1·350	·250
Glazy	3·450	Trace	4·500	·070	1·600	·610

Northampton and District Irons. ('Holwell.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1 Foundry	3·350	—	2·612	·022	1·190	·490
„ 2 „	3·650	—	2·473	·036	1·173	·403
„ 3 „	3·850	—	2·379	·041	1·190	·403
„ 4 „	3·350	—	2·333	·047	1·255	·389
„ 4 Forge	2·971	—	2·331	·056	1·088	·484
„ 5 „	1·750	—	1·376	·062	·929	·245
Mottled	1·540	—	1·261	·225	·970	·217
White	·840	—	1·049	·305	·937	·188
Glazy	2·500	—	4·850	·028	1·285	·532

Welsh Iron.

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
Grey Forge	3·02	Trace	2·56	·05	1·47	·43
Foundry	3·30	Trace	3·26	Trace	1·75	·34

Yorkshire Cold Blast. Ex. Sir I. Lowthian Bell.

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1	3·421	·583	1·708	·073	·630	1·606
„ 2	3·155	·581	1·646	·070	·635	1·472
„ 3	3·361	·393	1·382	·063	·602	1·475
„ 4	3·308	·319	1·381	·081	·602	1·169

Staffordshire Irons (Cold Blast). ('Glazebrook.')

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 1	3·07	—	1·48	·03	·43	·96
„ 2	3·04	—	1·27	·04	·34	·80
„ 3	3·12	—	1·16	·05	·44	·94
„ 4	3·03	—	·83	·04	·31	·27
„ 5	2·81	—	·57	·06	·29	·13

Staffordshire Iron (Semi-Cold Blast).

Brand.	G.C.	C.C.	Si.	S.	P.	Mn.
No. 3 . .	3·10	·75	1·50	·03	·25	·50
„ 4 . .	2·92	·81	1·22	·04	·49	·75
„ 5 . .	2·78	·51	·93	·03	·30	·68

Malleable Cast Pig Iron.

West Coast Refined.

Brand.	C.	Si.	S.	P.	Mn.
Grey	3·80	1·25	·10	·05	·10
Mottled	3·45	·70–1·00	·10–·25	·05	·10
White	3·20	·60	·30	·05	·10

East Coast Refined. ('S.C.M.')

Brand.	C.	Si.	S.	P.	Mn.
Grey	3·80	1·00	·08	·05	·80
Mottled	3·40	·50–·85	·10–·20	·05	·60
White	3·10	·45	·25	·05	·40

CAST IRON.

Foundry Practice.

1.

The physical and mechanical properties of the products of the cast-iron foundry are almost entirely dependent on the condition of the carbon in these products. The carbon in cast iron can occur either in a free state, as graphite, or in combination with iron, as a carbide of iron, Fe_3C, or with iron and manganese, as a double carbide $(Fe, Mn)_3C$. Foundry practice consists almost entirely of the control of the degree of graphitisation of the carbides present in the cast iron produced.

The graphitisation of these carbides tends to increase—

(*a*) With the temperature.
(*b*) With deceleration of cooling.
(*c*) With the content of silicon, nickel, or aluminium.
(*d*) With the number of graphite nuclei in the iron.
(*e*) With the total content of carbon

Graphitisation is prohibited—

(*a*) By the presence of sulphur, oxygen, vanadium, or chromium.
(*b*) By the presence of manganese under certain conditions.
(*c*) By acceleration of cooling.

It will be seen that by the variation of the above factors an immense number of conditions can be obtained. It is in the scientific control of these that much of the success in foundry practice lies.

2. The Influence of Carbon on Cast Iron.

The strength, hardness, density of structure, etc., of cast iron are dependent almost entirely on the relative quantities of carbide and graphite in the same.

An increase in the ratio $\frac{\text{Carbide}}{\text{Graphite}}$ leads to—

(*a*) An increase in hardness, brittleness, and density of structure.
(*b*) A decrease in machinability and ductility.

The strength of cast iron reaches a maximum when the combined carbon content is between 0·80 per cent. and 1·00 per cent.; if the combined carbon content given above is exceeded a reduction in strength, which only terminates when the carbon is entirely in the form of carbide is witnessed. The following figures, given by Howe, are of value in this connection :—

As the tensile strength increases	From less than 20,000 lbs. per sq. in.	To more than 35,000 lbs. per sq. in.	Or by more than 15,000 lbs. per sq. in.
The total carbon content decreases	from 3·69 per cent.	to 2·98 per cent.	or by 0·71 per cent.
The graphite content decreases	from 3·12 „	to 2·22 „	or by 0·90 „
The combined carbon content increases	from 0·57 „	to 0·76 „	or by 0·19 „

The above table classifies the results of an examination of 180 samples of cast iron taken without selection.

According to Dr. Stead (British Foundrymen's Association Proceedings, 1915), an increase of each 0·1 per cent. of graphite may reduce transverse strength by 2 cwts. and tensile strength by 0·8 ton per square inch.

The fusibility of the iron carbon alloys increases as the total carbon content increases up to about 4·30 per cent.; beyond this point the melting points of the alloys are raised by additions of carbon. Other effects of increased total carbon are decreased tensile strength, increased machinability and decreased chilling power. The last phenomenon is occasioned by the difficulty of retaining carbon as carbide, which naturally increases as the amount of carbon to be thus retained increases. Given suitable means for preventing graphitisation, every increase in the content of total carbon leads to an increase in the hardness of the chilled surface of the alloy in question.

The machining of cast iron containing more than 0·80 per cent. of combined carbon is practically impossible.

3. The Influence of Silicon on Cast Iron.

Silicon varies from 0·20 to 4·00 per cent. in cast iron, but rarely exceeds 3·50 per cent. or falls below 0·50 per cent. It is present in cast iron, in all probability, as silicide of iron (FeSi), which is dissolved in the pure iron, or ferrite, of the alloy. The presence of this compound tends to strengthen and harden the ferrite. Silicon, however, has the effect of rendering cementite unstable, with the result that there is a tendency towards the formation of ferrite and graphite. Starting with white cast iron, the addition of silicon up to 1·00 per cent. results in an almost proportional decrease in the chilling power of the iron. Again, the addition of silicon to white cast iron leads to an increase in the strength of the resulting irons; this factor reaches a maximum when the content of combined carbon in the alloy is between 0·80 per cent. and 1·00 per cent. As the silicon percentage is further raised so are the combined carbon content and the strength of the cast iron lowered. When the silicon content is above 2·00 per cent. its hardening effect on ferrite is noticeable, iron relatively hard to machine being occasionally improved by a reduction of the silicon content.

The presence of silicon leads to a depression of the melting-point of cast iron; in similar manner the percentage of carbon in the eutectic alloy is reduced from 4·30 per cent. to 3·40 per cent. as the percentage of silicon increases up to 3·00.

Silicon has the effect of reducing the shrinkage of cast iron.

As a means of determining the correct proportions of carbon and silicon in cast iron, the following formula has, according to Mr. F. J. Cook, been used with marked success in practical working :—

$$X = \frac{O}{4{\cdot}26 \times \frac{Si}{3{\cdot}6}},$$

where

O = *total* carbon in percentage;
Si = silicon in percentage.

The elements carbon and silicon are in the best proportion when the value of X is as given below :—

For Ordinary work such as pans, grates, easily machined casting and pipes	X = 0·9 to 1
Locomotive cylinder (maximum transverse strength)	„ = 0·83
Steam, gas, Diesel and hydraulic cylinders (maximum tensile strength)	„ = 0·76 to 0·82
Chilled castings	„ = 0·75 to 0·8
Acid resisting	„ = 0·85

4. The Influence of Sulphur on Cast Iron.

Sulphur combines with iron to form a sulphide having a low melting-point, which occurs in steel in the form of ovoids, oval laminæ or membranes enveloping the ferrite grains. The presence of this sulphide is the cause of red shortness.

In cast iron this sulphide may modify the properties of the alloy owing to its manner of aggregation, but it is deleterious chiefly on account of its tendency to segregate and its powerful effect on shrinkage, which it increases. Sulphur tends to restrain graphitisation, hence it increases the chilling power of cast iron and may, therefore, be termed a hardening agent. This element should, however, be employed with great caution, if at all, in this capacity, on account of the objectionable properties previously stated. The presence of sulphur makes the molten metal thick and sluggish, giving rise to blowholes, yet this element in fair proportions, say 0·12 per cent., adds considerably to the wearing properties and strength of the metal. In every case, however, sulphurous iron *must* be cast as hot as possible if trouble is to be avoided.

Manganese and silicon are employed to counteract the evil effects of sulphur. Manganese reacts with iron sulphide, with resulting formation of manganese sulphide and liberation of iron. Under certain circumstances manganese sulphide is removable from cast iron, but even when retained its effects are not so deleterious as are those of iron sulphide. Silicon, owing to its strong tendency to induce graphitisation, resists the effect of sulphur in tending to retain carbon in the combined condition; it does not remove sulphur, nor does it prohibit the shrinkage due to sulphur or reduce the tendency towards cracking.

Sulphur is frequently limited by specification to 0·05 per cent., but in the hands of experienced and careful workers as much as 0·20 per cent. can be allowed without ensuing unsoundness. If the sulphur content of an iron is to be low the conditions under which it is prepared must be such that sulphur tends to be eliminated. Hence, coke low in sulphur must be used and suitable fluxes should be employed in the furnace for removing sulphur from the metal, e.g. lime, fluor spar or manganous oxide.

5. The Influence of Manganese on Cast Iron.

Manganese and iron unite to form a series of solid solutions whose freezing-point curve lies entirely between the freezing points of the component metals. The freezing points of all the alloys of pure iron and pure manganese are below that of pure iron. The freezing point of cast iron is depressed by the addition of manganese, not only on the above account but also owing to an increase in the degree of solubility of carbon in cast iron, which is brought about by the fact that the affinity of manganese for carbon is greater than that of iron for carbon. The depression of the freezing point reaches a maximum when the percentage of manganese is about 13.

The alloys of iron and manganese (pure) are harder than pure iron. Manganese therefore would, normally, have the effect of hardening the ferrite of cast iron were it not for the fact that its affinity, firstly for sulphur, and secondly for carbon, prohibits its solution in the ferrite.

Manganese, when added to cast iron, combines in the first place with such sulphur as is present in the iron; any excess above that required for the formation of manganese sulphide unites with iron carbide, with the formation of a double carbide of iron and manganese.

The quantity of manganese required to effect the entire conversion of the iron sulphide in the alloy into manganese sulphide is considerably more than that indicated by the equation—

$$FeS + Mn = MnS + Fe.$$

Manganese sulphide is characterised by the following physical properties:—

(1) High melting point—1400° C.;
(2) Insolubility in molten iron;
(3) Low specific gravity;

all of which assist in bringing about the separation of both manganese and sulphur from the molten alloy. Rapid cooling of the molten alloy leads to the more or less complete retention of manganese sulphide in the resulting solid alloy; slow cooling assists in separating the sulphide and bringing it into contact with the slag found on the surface of the alloy when the same is, for example, in the ladle. When the metal does not remain long enough in the ladle, or is not hot enough for the above to take place quickly, the manganese sulphide will be found on the top part of the casting in the form of hard spots, which are difficult to tool. Iron sulphide is deleterious in its action upon iron and steel. Manganese sulphide, though not beneficial, is of a somewhat neutral character. Manganese is, therefore, valuable as a desulphuriser.

Such manganese as is present in cast iron in excess of that required for the transformation of iron sulphide into manganese sulphide combines with the carbide of iron to form a double carbide, as stated above. Manganese is generally considered to induce the retention of the carbon in combination. This is true, but this effect does not make itself felt until the manganese content is well above that usually found in foundry irons. Hence, though hardness is increased by the addition of manganese, the cause is not usually the retention of carbon as carbide.

On the whole it may be said that, owing to (1) the tendency of manganese to produce brittleness and coarse crystallisation, and (2) its activity as a deoxidiser, it is inadvisable to add manganese to cast iron for the sole purpose of increasing hardness and chilling power.

Manganese increases the shrinkage of cast iron.

6. The Influence of Phosphorus on Cast Iron.

Phosphorus combines with iron to form a number of compounds, of which one, that containing three molecules of iron to each molecule of phosphorus, is of common occurrence in cast iron. The presence of phosphorus effects a reduction in the melting point of cast iron and a reduction in the total carbon content of cast iron.

As the phosphorus content of cast iron is increased up to about 0·40 per cent. so is the strength of the cast iron increased. Further additions of phosphorus appear to have but slight effect on the strength of cast iron until the percentage reaches about 0·75 per cent. Above this point the alloys are liable to be brittle, and unless fluidity is more important than strength 0·75 per cent. of phosphorus should not be exceeded. For thin castings in general, which are not required to be strong, the phosphorus can be increased to 1·5 per cent. or more, but in thin castings such as automobile cylinders, which are required to withstand wear and tear, not more than 0·30 per cent. of phosphorus should be allowed, owing to the slight tendency towards segregation of high phosphide irons.

7. Semi-Steel.

Semi-steel is simply cast iron made from a furnace charge of cast iron to which mild steel or wrought iron has been added. Additions of from 10 to 25 per cent. of steel are usual, but 30 and occasionally 40 per cent. are not unknown. As steel is low in carbon, silicon and phosphorus, the final cast iron (for it is still a true cast iron) is low in these elements. The steel should be added as sheared clippings or other small pieces, but not as borings, which take up too much sulphur. Iron appears not to take up sulphur from gases, but only by direct contact with the coke, hence the air furnace gives irons lower in sulphur than the cupola and is specially suited for melting steel with pig irons. Perfectly good results are, with care, obtainable from the cupola. There is, however, a tendency for the more fluid portions of a cupola burden of cast iron and steel to run first. Hence the first tap from the cupola is generally higher in carbon content than succeeding taps.

Tests for Cast Iron.

(Abstract of paper read by Mr. F. J. Cook before the Staffordshire Iron and Steel Institute, January 20, 1917.)

Important tests which are of use as a guide to foundrymen are :—

(1) Keep's shrinkage test;
(2) Transverse test;
(3) Hardness test;
(4) Casting temperature or fluidity test;
(5) Impact test.

(1) **Keep's Test** consists of casting ½ in. square bars between iron yokes, the ends of which are 12 ins. apart. When the bars have cooled down the shrinkage is shown by the difference between the length of the bars and the gap in the yoke in which they were cast; this is usually measured by inserting a taper graduated wedge in the gap and measuring off the dimension of the space.

This test is quite a comparative one, and when the amount of shrinkage which is associated with the most satisfactory castings has been arrived at, any deviation can be rectified by a little addition of silicon if the shrinkage becomes too high and *vice versa* when it is too low.

Under normal conditions a shrinkage of 0·183 in. = 1 per cent. silicon, and, to take the other extreme, 3·5 per cent. silicon is associated with 0·123 in. shrinkage.

(2) **Transverse Test.**—The following table gives average particulars of shrinkage, deflection and breaking load obtained with various classes of iron :—

Class of Material.	Shrinkage.	Deflection.	Breaking load.
	in.	in.	lbs.
Tough strong Iron	0·160	0·25	550
Hard " "	0·168	0·22	630
Soft Iron	0·123	0·18	423
Mottled Iron	0·207	0·11	375
White Iron	0·226	0·08	250

from which it will be seen that to obtain a big deflection strong irons are necessary.

(3) **Hardness.**—The most handy and reliable form of test is the 'drill test,' as all other methods deal with surface hardness only. The test may be made as follows :—Cast the metal into bars 1½ in. diameter, ½ in. being shaped off one side to give a flat surface to work upon, and

nove the outside skin. Drill four holes ¾ in. diameter, to a depth of 1 in., then the number of evolutions required to drill to this depth (the mean of the four holes being taken) indicates the general hardness. The angle of the drill should be ground exactly the same for each test, by neans of a suitable guide on the grinding machine. It is also essential to keep the same drill 'or the purpose, and preferably, two drills should be used and two holes drilled with each, which ninimises many discrepancies which otherwise might come in. The efficiency of drills is naterially affected by the sharpness of their point, and as cast iron is often not homogeneous and nay contain more or less hard spots a false result may be obtained owing to the point becoming nduly dulled by striking a hard spot in the early stages of the test. To avoid this a hole ½ in. liameter should be first drilled, which affords clearance for the point of the drill and ensures the ull cutting edge coming into operation. It is obviously necessary that the same weight be ttached to the drill and also that it runs at the same number of revolutions per minute for each est.

(4) **Casting Temperature.**—Low silicon cast iron is very prone to the effects of asting temperature, and some irons employed for such purpose are also liable to liquid con- raction. A handy workshop test for casting temperature with this class of iron consists in naking bars of the general dimensions shown in fig. 14. When cold the bars are broken through he line AB, the condition of the fracture giving an indication of the temperature at which

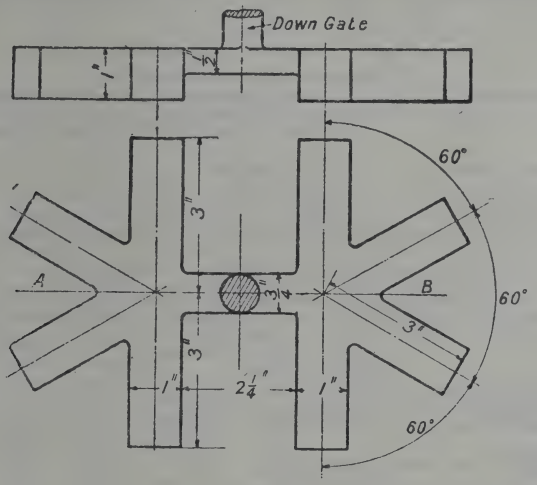

FIG 14.

ie metal was poured. Passing from the correct temperature (which is usually as hot as can be btained from the cupola) to very low, the following fractures will be observed—perfectly solid id homogeneous, then slight whitish centre, then brown centres of varying sizes and depth of lour as temperature is lowered and then black centre; with the latter is always associated open vities, and immediately above them is invariably found a gas hole.

For softer cast iron, which can be cast at a lower temperature without suffering the same fects as low silicon irons, a test bar in the form of a wedge is a very useful guide as to the uidity of the metal. Dimensions of such a test-bar used by the British Chuck and Piston ing Co. are length 9 ins., width 1 in., ⅜ in. thick at the largest end tapering to $\frac{3}{32}$ at the smaller, e bars being run from the thick end.

(5) **Impact Test.**—A satisfactory test is on bars 40 mm. square (1·57 in.) supported on ife edges 160 mm. (6·3 ins.) apart, and by dropping a weight of 12 kilos (26·5 lbs.) from a height 30 cm. (11·8 ins.) increasing the height of drop by increments of 5 cm. (1·9 in.) until such times the sample breaks, the height at which the bar eventually fractures being taken as the impact ure. Attached to the weight, in such a manner as to strike the bar parallel to the supporting ife edges, and the centre of same, is another knife edge. The face of all the knife edges should rounded $\frac{1}{16}$ in. radius.

A result of 55 cm. (21·5 ins.) is none too high for the work named, although this is quite a ere test. The maximum attained, as far as is known, has been 80 cm. (31·3 in.).

Analyses and Mechanical Properties of Cast Iron.

TABLE OF STANDARDS FOR BRITISH IRON CASTINGS.

	Steam Cylinders.	Frames.	Flywheels.	General
Total carbon	2·9	3·3	3·5	3·5
Combined carbon	0·9–0·95		0·37	
Silicon	1·1–1·3	1·6	2·0	1·7–2·2
Manganese	0·6–0·9	0·65	0·4–0·5	0·3–0·4
Phosphorus	0·4–0·6	0·5	0·9	0·4–1·4
Sulphur, under	0·15	0·15	0·15	0·15
Transverse load, cwt.	35–46	34–38	30–33	29–32
,, deflection, inches	0·5	0·5	0·35–0·45	0·3–0·5
Tensile, tons sq. in.	12–14	11–13	11–14	9–11

Transverse tests are made on bars 3 ft. span, 2 ins. by 1 in. rectangular section, 1 in. fa vertical.

TABLE OF TYPICAL ANALYSES OF BRITISH IRON CASTINGS.

(*F. M. Thomas, Birmingham Metallurgical Society.*)

Castings.	Combined Carbon.	Graphite Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur
Cylinders and hydraulic	·6–·75	2·5–2·8	1·0–1·3	·5–·7	·45–·7	·08–·12
Heavy machinery	·45–·60	2·8–3·0	1·2–1·5	·6–·85	·4–·6	·06–·08
General castings	·35–·45	3·0–3·2	2·0–2·25	·8–1·0	1·0–1·3	·06–·08
Ornamental, thin	·08–·15	3·2–3·6	2·5–2·8	·8–1·0	1·3–1·5	·03–·04

TABLE OF STANDARDS FOR AMERICAN IRON CASTINGS.

(*Dr. J. J. Porter's Report to the American Foundrymen's Association in* 1910.)

	Total Carbon.	Combined Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
Air and ammonia cylinders	3·0–3·3	—	1·0–1·75	·7–·9	·3–·5	U ·09
Motor car cylinders	3·0–3·25	·55–·65	1·75–2·00	·6–·8	·4–·5	U ·08
Bedplates	—	—	1·25–1·75	·6–·8	·3–·5	U ·10
Chilled castings	—	—	·75–1·25	·8–1·2	·2–·4	·08–·10
,, wheels	3·5–3·7	·6–·8	·6–·7	·5–·6	·3–·4	·08–·10
Engine frames	—	—	1·25–2·0	·6–1·0	·3–·5	U ·09
Flywheels	—	—	1·5 –2·25	·5–·7	·4–·6	U ·08
Gas engine cylinders	3·0–3·3	—	1·0 –1·75	·7–·9	·2–·4	U ·08
Gears, heavy	Low	—	1·0 –1·5	·8–1·0	·3–·5	·08–·10
,, small	—	—	2·0 –2·5	·6–·8	·5–·7	U ·08
Hydraulic cylinders, heavy	Low	—	·8 –1·2	·8–1·0	·2–·4	U ·10
,, ,, medium	Low	—	1·2 –1·6	·7–·9	·3–·5	U ·09
Locomotive cylinders	—	—	1·0 –1·5	·8–1·0	·3–·5	·08–·10
Machinery, cast, heavy	Low	—	1·0 –1·5	·8–1·0	·3–·5	U ·10
,, ,, light	—	—	2·0 –2·5	·5–·7	·5–·7	U ·08
Pipes	—	—	1·5 –2·0	·6–·8	·5–·8	U ·10
Pipe fittings	—	—	1·75–2·5	·6–·8	·5–·8	U ·08
Piston rings	Low	—	1·5 –2·0	·4–·6	·3–·5	U ·08
Pulleys, heavy	—	—	1·75–2·25	·6–·8	·5–·7	U ·09
,, light	—	—	2·25–2·75	·5–·7	·6–·8	U ·08
Steam cylinders, heavy	Low	—	1·0 –1·25	·8–1·0	·2–·4	U ·10
,, ,, medium	—	—	1·25–1·75	·7–·9	·3–·5	U ·09
Valves, large	—	—	1·25–1·75	·8–1·0	·2–·4	U ·09
,, small	Low	—	1·75–2·25	·6–·8	·3–·5	U ·08
Water heaters	—	—	2·0 –2·25	·6–·8	·3–·5	U ·08

NOTE.—U indicates ' under.'

TABLE OF STANDARDS FOR GERMAN IRON CASTINGS.

	Gas Cylinders.	Steam Cylinder. No liner.	Steam Cylinder. With liner.	Beds and Standards	General Machinery	Piston Rings and Special Small Work.
Total carbon	2·9–3·2	3·2–3·4	3·4–3·5	3·4–3·6	3·5–3·8	3·0–3·3
Silicon	·9–1·0	1·0–1·2	1·3–1·5	1·4–1·6	1·5–1·9	1·2–1·5
Manganese	·6– ·9	·6– ·8	·6– ·7	·5– ·7	·5– ·6	·7– ·8
Phosphorus	·1– ·2	·3– ·5	·4– ·5	·5– ·8	·8–1·0	·6– ·8
Sulphur	·08–·09	·08–·09	·08–·09	·08–·09	·08–·10	·07–·08
Copper, under	·05	·05	Trace	·06–·08	·08–·10	·03
Metal thickness, mm.	50–100	35–55	35–55	35–100	10–35	10–40
Tensile strength, tons	16·5–14·0	14·0–11·4	12·7–10·2	11·4–8·9	10·2– 7·6	14·0–11·4
Bending stress, tons	28·6–25·4	26·7–24·1	24·1–20·3	22·2–19·0	19·0–16·5	25·4–22·2
Deflection, mm.	22–7	18–8	15–10	18–8	16–10	25–12
Diam. test bar, mm.	40–100	40–80	40–80	30–80	30–50	30–50
Span " "	1,000	1,000	1,000	1,000	1,000	1,000
E., lbs. sq. in., about	12,100,000	15,600,000	14,200,000	13,500,000	13,100,000	12,800,000

E—modulus of elasticity.

The above is taken from the practice of a large German engineering firm as published in the erman technical press in 1908. The test bars are round, of the varying diameters stated: all oss-breaking loads being on one metre (39·37 ins.) span.

STEEL.*

(Contributed by Ernest W. Birch, A.M.I.A.E.)

The term 'steel' is applied in a general sense to those alloys of iron and carbon whose carbon present entirely, or almost entirely, in the combined condition and whose total carbon content oes not exceed 2·00 per cent. In a special sense the term is applied to alloys of iron and carbon ith elements which are generally in excess of the carbon and whose presence considerably modifies e resulting alloys; such alloys are generally referred to as 'alloy or special steels.'

Steel is always contaminated by some or all of the elements—manganese, silicon, sulphur id phosphorus, and the allowable percentages are given in the following specifications. Sulphur id phosphorus should be kept as low as possible owing to the detrimental effect of these ements.

Carbon renders the steel susceptible to hardening, although below 0·2 per cent. steel ows no appreciable hardening effect when rapidly cooled. As the carbon percentage increases, does the tenacity and hardness, with a corresponding reduction in the ductility and toughness.

Steel is generally graded according to the percentage of carbon present. A general classifi-tion is as follows:

Carbon under 0·10 per cent.	Dead soft steel, very mild or extra mild steel, very low-carbon steel.
Carbon 0·10 to 0·25 per cent.	Mild steel, soft steel, low-carbon steel.
Carbon 0·25 to 0·60 per cent.	Medium-carbon steel, medium high-carbon steel, half-hard steel.
Carbon 0·60 to 1·20 per cent.	High-carbon steel, tool steel, hard steel.
Carbon over 1·20 per cent.	Extra-hard steel, very high-carbon steel.

The classification is not rigid, as no attempt has been made to standardise the various grades. further classification is made with carbon tool steels, the steels being graded according to their emper.' (This term has no connection with the term 'tempering,' used in thermal treatment.) he Temper numbers are arbitrarily chosen by the makers, and the following is an example:

Temper No.	Carbon Content.
	Per cent.
1	1½
2	1¼
3	1⅛
4	1
5	⅞
6	¾

* See also 'Tool Steel,' p. 1136.

The critical points in a straight carbon steel are dependent on the amount of carbon presen and these critical points control the temperature for forging, annealing, hardening, and temperin The higher the carbon content the lower the critical temperatures and the more sensitive is t steel. For the before-mentioned steels the recommended working temperatures are as follows:

Carbon Content. Per cent.	Forging Temp. ° C.	Annealing Temp. ° C.	Hardening Temp. ° C.
1⅓	800	720	760
1¼	825	720	760
1⅛	850	720	770
1	875	720	770
⅞	900	750	785
¾	950	770	800

The tempering temperature depends on requirements. The higher the reheating (temperin temperature, the greater is the loss in hardness, with a corresponding increase in the ductility (s pp. 1137 and 1144).

Carbon Content.	Suitable for:
Per cent.	
1⅓	Special turning and planing tools.
1¼	The most suitable for turning and planing tools, twist drills and small cutters.
1⅛	For large turning tools, circular cutters, taps, small punches, reamers, screwing dies, and small shear blades.
1	For hot setts, large punches, large taps, cold chisels, etc.
⅞	For chisels, setts, dies, smiths' tools, large shear blades, masons' tools, etc.
¾	For hammers, general dies, and miners' drills.

Having selected the correct quality steel for the particular purpose, it is essential to give t correct heat treatment in order to obtain the best results. The hardening temperatures a given in the previous table. The following table gives the necessary tempering temperature:

Tempering Temperature, ° C.	Suitable for:
300	Springs.
298	Wood saws.
295	Circular saws for metal.
290	Cold chisels for wrought iron.
285	Moulding and planing cutters for soft wood, needles, cold chisels for cast iron
280	Firmer chisels, saws for bone and ivory, cold chisels and setts for steel, gimlets.
275	Hot setts, axes, and adzes.
270	Augers, pressing cutters, flat drills for brass.
265	Coopers' tools, wood borers, twist drills, stone-cutting tools.
260	Plane irons, gouges, planing and moulding cutters.
255	Moulding and planing cutters for hard wood, punches and dies, cups, snaps, and shear blades.
250	Penknives, chasers, mill chisels and picks, taps, rock drills, screw-cutting dies.
245	Leather-cutting dies, boring cutters, reamers.
240	Bone-cutting tools, milling cutters, drills, wood engraving tools.
235	Paper cutters, planers for iron.
230	Ivory-cutting tools, planes for steel, screwing dies for brass, hammer faces.
225	Light turning tools, steel engraving tools.
220	Scrapers and lathe tools for brass.

CARBON AND ALLOY STEEL SPECIFICATIONS.

The following data are based upon B.E.S.A. Report 5005–1924 and upon the very complete specifications prepared by the S.A.E. (Society of Automotive Engineers, U.S.A.).

The range of steels given covers practically all general requirements. The selection of a given steel for a given part must depend upon an intimate knowledge of a number of important factors, such as the detailed design of the part and the severity of the service to be imposed, whether the part is to be machined or forged, machinability, and the method of manufacture. From the data given, a steel can be selected from a consideration of physical properties, after which the final choice depends upon such considerations as machinability, heat-treatment, etc.

Carbon Steels.

Reference No.	Carbon Range.	Manganese Range.	Phosphorus. Max.	Sulphur. Max.
1	0·05–0·15	0·30–0·60	0·045	0·05
2	0·10–0·20	0·30–0·60	0·045	0·05
3	0·15–0·25	0·30–0·60	0·045	0·05
4	0·20–0·30	0·50–0·80	0·045	0·05
5	0·25–0·35	0·50–0·80	0·045	0·05
6	0·30–0·40	0·50–0·80	0·045	0·05
7	0·35–0·45	0·50–0·80	0·045	0·05
8	0·40–0·50	0·50–0·80	0·045	0·05
9	0·45–0·55	0·50–0·80	0·045	0·05
10	0·90–1·05	0·25–0·50	0·045	0·05
11	0·45–0·55	0·90–1·20	0·045	0·05
12	0·55–0·70	0·90–1·20	0·045	0·05
13	0·08–0·16	0·60–0·80	0·09–0·13	0·075–0·15
14	0·15–0·25	0·60–0·90	0·06– max.	0·075–0·15

Steels Nos. 1 and 2.—Used for tubing and pressings; they are soft and ductile and will stand much deformation without cracking. Low tensile strength in annealed condition, but the yield point can be raised considerably by cold-working. They do not machine freely and will tear badly in turning, threading, or broaching. Machining properties can be improved by quenching in water from 925° C. Suitable for case-hardening.

Steel No. 3.—Forges well and machines better than No. 1 and 2. Can be used for machined forged, and case-hardened parts where no great strength is required. Can be drawn into tubes and cold rolled, and for cold-worked shapes that do not require deep drawing. When cold worked, yield point 18–35 tons per sq. in. in rounds not over $\frac{1}{2}$ in. diam. or in flats $\frac{1}{4}$ in. thick. Heat treatment will refine the grain after rolling or forging. Particularly suitable for case-hardening.

Steels Nos. 4 and 5.—Suitable for forged, machined, or cold-worked parts requiring higher physical properties than No. 2, also more responsive to heat-treatment and machines better. These steels should not be used for case-hardened parts.

Steels Nos. 6 and 7.—Medium carbon steels possessing good machining properties, and are suitable for small and medium-size forgings. After heat-treatment Brinell range 174–212.

Steels Nos. 8 and 9.—Medium carbon steels suitable for large forgings. Can also be used for a wide range of parts from bar stock. After heat-treatment Brinell range 192–235.

Steel No. 10.—Suitable for leaf springs and certain coiled springs. Heat-treatment: heat to 760–780° C., quench in oil, water, or brine, depending on size and shape of part. Draw to required hardness.

Steels Nos. 11 and 12.—Suitable for helical springs made of round cold drawn wire up to $\frac{5}{16}$ in. diam. No. 11 steel is recommended for wire from 0·025 to 0·100 in. diam., and steel No. 12 for wire 0·100 in. diam. and larger.

Steels Nos. 13 and 14.—Suitable for 'screw stock'; they machine very sweetly and take a good finish, but owing to cold-shortness they are not suitable for parts subject to shock.

STRAIGHT NICKEL STEELS.

Reference No.	Carbon Range.	Manganese Range.	Nickel Range.
15	0·10–0·20	0·30–0·60	0·40–0·60
16	0·10–0·20	0·30–0·60	1·25–1·75
17	0·10–0·20	0·30–0·60	3·25–3·75
18	0·15–0·25	0·50–0·80	3·25–3·75
19	0·25–0·35	0·50–0·80	3·00–3·50
20	0·30–0·40	0·50–0·80	3·00–3·50
21	0·35–0·45	0·50–0·80	3·00–3·50
22	0·40–0·50	0·50–0·80	3·00–3·50
23	0·45–0·55	0·50–0·80	3·00–3·50
24	0·17 max.	0·30–0·60	4·75–5·25

In all cases sulphur max.: 0·045; phosphorus max., 0·040; silicon, 0·15–0·40.

Steels Nos. 15, 16 and 17 are suitable for case-hardening.

Steel No. 18 not recommended for case-hardening except for massive parts, owing to the reduced ductility of the core due to the increased carbon content.

Steels Nos. 19 and 20 are suitable for parts requiring considerable strength and toughness. Not suitable for case-hardening.

Steels Nos. 21 and 22. As the carbon content is higher than for steels Nos. 19 and 20, higher tensile strength and greater hardness can be obtained after treatment, but with a loss in ductile properties.

Steel No. 23 is suitable for large gears, etc.

Steel No. 24 is used for case-hardened parts that require an exceptionally tough core. When it is necessary to machine parts made of this steel after carburising, the nickel content should be kept as near the lower limit as possible.

NICKEL CHROME STEELS.

Reference No.	Carbon Range.	Manganese Range.	Nickel Range.	Chromium Range.
25	0·10–0·20	0·30–0·60	1·00–1·50	0·45–0·75
26	0·20–0·30	0·50–0·80	1·00–1·50	0·45–0·75
27	0·35–0·45	0·30–0·60	1·50–2·00	0·90–1·25
28	0·17 max.	0·30–0·60	3·00–3·50	1·00–1·50
29	0·20–0·30	0·30–0·60	2·75–3·5	0·50–1·00
30	0·35–0·45	0·30–0·60	3·25–3·75	1·25–1·75
31	0·10–0·20	0·30–0·60	2·75–3·25	0·60–0·95
32	0·45–0·55	0·30–0·60	2·75–3·25	0·60–0·95

In all cases sulphur max.= 0·04; phosphorus max. = 0·04; silicon = 0·15–0·40.

In general these steels give higher tensile values and greater toughness than the corresponding straight nickel steels. They are, however, more sensitive to heat treatment.

Steel No. 25 is primarily intended for case-hardening, but can also be used for structural parts with suitable heat treatment. Where these steels are used for gears where considerable strength and a high degree of accuracy are called for, the gears should be normalised before carburising.

Steels Nos. 28 and 31 are suitable for case-hardening when a core possessing great strength and toughness is required.

The remaining steels are suitable for such heat-treated parts, either machined or forged, as require exceptionally high physical properties, and must be capable of resisting severe dynamic stresses in service.

MOLYBDENUM STEELS.

Reference No.	Carbon Range.	Manganese Range.	Chromium Range.	Nickel Range.	Molybdenum Range.
33	0·25–0·35	0·40–0·70	0·50–0·80	—	0·15–0·25
34	0·35–0·45	0·40–0·70	0·80–1·10	—	0·15–0·25
35	0·45–0·55	0·40–0·70	0·80–1·10	—	0·15–0·25
36	0·10–0·20	0·30–0·60	—	1·5–2·0	0·20–0·30

In all cases sulphur max. = 0·045; phosphorus max. = 0·040.

In general these steels have similar physical characteristics to the corresponding nickel and ckel-chrome steels. Steel No. 36 is suitable for case-hardening.

CHROMIUM STEELS.

Reference No.	Carbon Range.	Manganese Range	Chromium Range.	Sulphur Max.	Phosphorus Max.
37	0·15–0·25	0·30–0·60	0·60–0·90	0·045	0·04
38	0·35–0·45	0·50–0·80	0·80–1·10	0·045	0·04
39	0·45–0·55	0·50–0·80	0·80–1·10	0·045	0·04
40	0·95–1·10	0·20–0·50	1·20–1·50	0·030	0·03

Steel No. 37. This steel is primarily for case-hardening. For structural purposes the romium content of this steel gives a deeper penetration of the effect of heat treatment than n be obtained in a straight carbon steel having a similar carbon content.

Steel No. 39 is an oil-hardening type of steel intended for heat-treated forgings that require eater strength and toughness than are obtainable with straight carbon steels, or with some of e simple alloy steels having a lower carbon content. It also has a wider heat-treating range an the other simple alloy steels.

Steel No. 40 is used chiefly for the races and balls or rollers of anti-friction bearings. The romium and carbon contents cause a maximum penetration of the effect of heat treatment d give a high degree of hardness.

CHROME VANADIUM STEELS.

Reference No.	Carbon Range.	Manganese Range.	Chromium Range.	Vanadium.	
				Min.	Desired.
41	0·15–0·25	0·50–0·80	0·80–1·10	0·15	0·18
42	0·25–0·35	0·50–0·80	0·80–1·10	0·15	0·18
43	0·35–0·45	0·50–0·80	0·80–1·10	0·15	0·18
44	0·45–0·55	0·50–0·80	0·80–1·10	0·15	0·18
45	0·90–1·05	0·20–0·45	0·80–1·10	0·15	0·18

Steel No. 41 is intended primarily for case-hardening and can be used for structural parts er suitable heat treatment.

Steels Nos. 42 and 43. These steels can be used in place of the nickel and nickel-chrome els of similar carbon content for heat-treated forgings requiring greater strength, toughness l resistance to fatigue than it is possible to obtain with straight carbon steels.

Steel No. 45 can be used for anti-friction bearings and is used extensively for machine-tool ts, being primarily a tool steel.

SILICO MANGANESE STEELS.

Reference No.	Carbon Range.	Manganese Range.	Silicon Range.
46	0·45–0·55	0·60–0·90	1·80–2·20
47	0·55–0·65	0·60–0·90	1·80–2·20

Sulphur and phosphorus = 0·045 max.

These steels are essentially spring steels, but may be used for gears. In either case the ste must be suitably heat-treated.

HEAT TREATMENT.

In order to obtain the desired physical properties from steels it is generally necessary to sul ject them to a thermal treatment. The subject of heat treatment embraces the operations (*a*) normalising, (*b*) annealing, (*c*) hardening, (*d*) cementing, carburising or case-hardening, (*e*) t tempering or drawing of hardened steels.

The nomenclature and definitions relating to heat treatment as given by B.E.S.A. Repo No. 5005–1924 are as follows :

(*a*) **Normalising.** Normalising means heating a steel (however previously treated) to temperature exceeding its upper critical range, and allowing it to cool freely in air. It is desi able that the temperature of the steel shall be maintained for about 15 minutes, and shall n exceed the upper limit of the critical range by more than 50° Centrigrade.

(*b*) **Annealing.** Annealing means reheating followed by slow cooling. Its purposes may
(1) To remove internal stresses or to induce softness, in which case the maximum temper ture may be arbitrarily chosen.
(2) To refine the crystalline structure in addition to the above, in which case the te perature used must exceed the upper critical range as in normalising.

(*c*) **Hardening.** Hardening means heating a steel to its normalising temperature, a cooling more or less rapidly in a suitable medium, e.g. water, oil or air.

(*d*) **Cementing.** Cementing means heating a steel above its normalising temperature a medium which will increase its carbon content. The core of a case-hardened bar is the interi portion of the bar which is substantially unaffected by the cementing process.

(*e*) **Tempering.** Tempering means heating a steel (however previously hardened) to temperature below its carbon change-point with the object of reducing the hardness or increasi the toughness to a greater or less degree.

(*f*) **Refining** (cemented parts). Refining means reheating a steel to its normalisi temperature, and is usually followed by quenching.

See also p. 2745.

Effect of Tempering.

3½ per cent. nickel steel, oil-hardened at 860° C. and tempered at the temperatures indicate

Tempered at. ° C.	Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	Elongation. %.	Reduction of Area. %.	Impact. Test. Ft.-lbs.	Brinell No.
Not tempered	102·0	116·0	10·0	23·0	6	514
200	92·5	101·0	10·5	32·5	5	461
300	83·0	92·5	12·0	40·0	5	415
400	66·4	76·3	15·1	50·0	11	352
500	54·5	63·5	20·0	59·5	50	285
600	44·0	53·0	25·0	64·5	73	241
650	40·0	49·0	27·0	66·0	82	235

Effect of Mass.

The effect of mass must receive serious consideration when dealing with the physical pr perties of any heat-treated steel.

The hardening operation consists of heating the steel through and just above its critical ran in order to obtain the condition of solid solution, and quenching with sufficient rapidity to reta this condition. With large masses it is practically impossible to obtain a uniform temperatu throughout the mass on heating, the interior portion always being at a lower temperature th the outside. On quenching the heat is absorbed from the outside, and in many cases it is i possible, even with the most drastic quenching, to remove the heat sufficiently rapidly to reta the desired structure in the core. Again, with very thin sections, the rate of cooling may sufficiently rapid if carried out in air. Only by experience can the effect of mass be correct estimated.

The following table shows the effect of mass on the physical properties of a 5 per cent. nicke ase-hardening steel. Bars of varying diameters were given exactly the same treatment and hen tested :

Size of Bar. In.	Heat Treatment.	Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	Elongation. %.	Reduction of Area. %.	Impact. Test. Ft.-lbs.	Brinell No.
¼	Carburised at 860° C.	40·0	51·0	27·0	66·1	55	235
¾	Reheated to 860° C.	34·5	44·6	31·0	68·3	90	212
1	Quenched in water	31·0	40·0	35·0	70·0	105	197
1¼	Reheated to 750° C.	27·8	37·5	36·7	72·2	111	179
1½	Quenched in water	26·7	36·2	36·8	73·5	111	174
1¾		26·5	36·1	37·0	73·5	110	174
2		26·2	36·0	37·0	72·5	104	174
2¼		26·0	36·0	37·0	72·0	90	170

ANALYSIS OF VARIOUS STEELS.

Type of Steel.	Analysis.								
	C.	Si.	S.	P.	Mn.	Ni.	Cr.	Va.	W.
Boiler plates	0·22	0·32	0·028	0·03	0·52	—	—	—	—
40-ton forging	0·36	0·41	0·035	0·032	0·80	—	—	—	—
Axle steel	0·28	0·28	0·030	0·026	0·90	—	—	—	—
Rails (railway)	0·48	0·36	0·038	0·036	0·72	—	—	—	—
,, ,,	0·59	0·32	0·052	0·023	0·75	—	—	—	—
Tyres, loco.	0·62	0·28	0·02	0·04	0·55	—	—	—	—
,, waggon	0·38	0·19	0·05	0·04	1·20	—	—	—	—
Turbine disc	0·30	0·20	0·05	0·034	0·83	—	—	—	—
High-tensile carbon steel	0·45	0·26	0·03	0·038	0·56	—	—	—	—
30-ton carbon steel	0·32	0·30	0·048	0·042	0·68	—	—	—	—
40-ton ,, ,,	0·51	0·33	0·040	0·036	0·59	—	—	—	—
Steel tubes for welding	0·20	0·42	0·039	0·027	0·51	—	—	—	—
Piano wire	0·60	0·10	0·022	0·026	0·45	—	—	—	—
Plough steel (for wire ropes)	0·85	0·14	0·01	0·01	0·60	—	—	—	—
Plough steel (for wire ropes)	0·58	0·16	0·032	0·033	0·41	—	—	—	—
Steel rolls	1·08	0·27	0·02	0·025	0·39	—	1·88	—	—
File steel	0·90	0·10	0·01	0·02	0·30	—	—	—	—
,, ,,	1·40	0·25	0·04	0·03	0·80	—	—	—	—
Carbon spring steel	0·89	0·22	0·022	0·024	0·43	—	—	—	—
Silico ,, ,,	0·50	1·72	0·038	0·033	0·68	—	—	—	—
Chrome ,, ,,	0·61	0·40	0·030	0·029	0·79	—	—	—	—
Silico-chrome spring steel	0·53	1·06	0·031	0·022	0·35	—	0·78	—	—
Chrome - vanadium spring steel	0·50	0·36	0·035	0·035	0·60	—	1·0	0·16	—
Silico-manganese spring steel	0·50	1·95	0·04	0·04	0·70	—	—	—	—
Magnet steel	0·82	0·28	0·012	0·014	0·31	—	—	—	5·3
Non-corrodible nickel steel	0·32	0·38	0·026	0·021	0·26	26·7	—	—	—
Nickel-vanadium steel	0·24	0·51	0·035	0·041	0·70	3·5	—	0·15	—
Chrome - vanadium forging	0·26	0·44	0·04	0·038	0·50	—	1·0	0·18	—
High-speed steel	0·72	0·17	0·022	0·018	0·21	—	4·4	—	14·3
Ball-bearing steel	1·12	0·015	0·017	0·019	0·19	—	0·25	—	—
,, ,,	0·95	0·014	0·018	0·019	0·25	—	1·25	—	—
Chrome exhaust valve steel	1·75	0·58	0·048	0·013	1·10	—	10·85	—	—
Nickel-chrome tube	0·30	0·16	0·03	0·03	0·45	1·10	4·0	—	—
Exhaust valve steel	0·37	0·10	0·03	0·02	0·35	—	2·5	0·32	16·53
,, ,, ,,	0·78	0·31	0·03	0·02	0·20	—	2·24	1·03	19·75
Chrome-molybdenum steel	0·40	0·35	0·04	0·032	0·41	—	1·0	0·35	—

Test Results Obtained from Heat-Treated Steels.

Abbreviations used: N = normalised at; WQ = water-quenched from; OQ = oil-quenched from; YP = stress at yield point, tons per sq. in.; US = ultimate stress, tons per sq. in.; E % = elongation per cent. on 2 ins.; R/A % = reduction of area, %; I = impact test, foot-pounds; B = Brinell No.

All tests made on bars 1⅛ in. diameter.

Type of Steel.	Analysis.							Heat Treatment.	Physical Properties.						Remarks.
	C.	Si.	Mn.	S.	P.	Ni.	Cr.		YP.	US.	E %.	R/A %.	I.	B.	
Dead mild case-hardening	0·06	0·01	0·25	0·01	0·05	—	—	N 920° C.	19·0	26·0	41·0	71·0	36	121	
								WQ 920° C.	—	35·0	30·0	67·0	50	167	
								OQ 920° C.	—	30·0	35·0	69·0	90	137	
								Cemented, WQ 920° C.; reheated, WQ 760° C.	—	33·0	33·0	68·0	—	—	Core test
Mild case-hardening	0·17	0·24	0·72	0·041	0·047	—	—	N 920° C.	20·0	31·0	38·0	64·0	80	137	
								WQ 920° C.	—	46·0	22·0	51·0	24	223	
								OQ 920° C.	—	36·0	31·0	65·0	92	170	
								Cemented, WQ 920° C.; reheated, WQ 760° C.	—	40·0	32·0	64·0	43	183	Core test
2% Nickel case-hardening	0·15	0·05	0·61	0·017	0·012	2·60	—	N 880° C.	24·0	32·0	37·0	69·0	95	143	
								WQ 880° C.	—	50·0	23·0	60·0	51	241	
								OQ 880° C.	—	38·0	30·0	70·0	100	179	
								Cemented WQ 880° C.; reheated, WQ 760° C.	—	44·0	28·0	61·0	84	202	Core test
6% Nickel case-hardening	0·17	0·39	0·34	0·014	0·014	6·0	—	N 860° C.	27·0	42·0	33·0	60·0	77	187	
								WQ 860° C.	—	87·0	15·0	49·0	31	388	
								OQ 860° C.	—	82·0	15·0	43·0	26	375	
								Cemented, WQ 860° C.; reheated, WQ 750° C.	—	75·0	17·0	48·0	35	331	Core test

5% Nickel case-hardening	0·07	0·06	0·18	0·02	0·008	5·1	—	N 860° C.	26·0	31·0	39·0	72·0	104	143	—
								WQ 860° C.	—	42·0	25·0	70·0	87	201	—
								OQ 860° C.	—	35·0	34·0	75·0	112	179	—
Mild carbon	0·26	0·30	0·75	0·044	0·05	0·15	—	N 900° C.	24·5	35·5	32·0	59·0	46	159	—
								WQ 900° C.	—	57·0	11·0	30·0	13	—	—
								OQ 900° C.	—	44·0	25·0	55·0	31	207	—
Medium carbon	0·45	0·32	0·78	0·02	0·025	—	—	N 870° C.	27·0	44·0	27·0	54·5	31	192	—
								WQ 870° C.	47·0	67·0	12·0	28·0	14	321	—
								OQ 870° C.	36·0	56·0	20·0	49·0	27	—	—
3% Nickel	0·17	0·05	0·34	0·033	0·023	2·9	0·2	N 860° C.	24·0	32·0	36·0	64·0	89	140	—
								WQ 860° C.	41·0	60·0	15·0	37·0	29	286	—
								OQ 860 C.	26·0	42·0	26·0	61·0	64	192	—
3½% Nickel	0·37	0·17	0·65	0·02	0·03	3·65	—	N 860° C.	27·0	44·0	28·0	56·0	36	196	—
								WQ 860° C.	—	124·0	9·0	25·0	4	514	—
								OQ 860° C.	—	116·0	10·0	22·0	6	495	—
1½% Nickel-chrome	0·28	0·08	0·40	0·02	0·018	1·52	0·80	N 850° C.	29·0	40·0	33·0	65·0	74	174	—
								OQ 850° C.	45·0	64·0	16·0	34·0	17	302	—
3% Nickel-chrome	0·31	0·14	0·70	0·027	0·030	3·27	0·82	N 820° C.	—	76·0	15·0	40·0	6	341	—
								OQ 820° C.	—	116·0	14·0	37·0	11	495	—
Air hardening nickel-chrome	0·32	0·12	0·46	0·017	0·014	3·70	1·42	Air hardened from 820° C.	80·0	115·0	13·0	40·0	18	477	—
								OQ 820° C.	87·0	91·0	13·0	52·0	17	418	—

The figures given after water- or oil-quenching represent the hardened condition. Intermediate values, ranging from the values given for the normalised condition to the hardened condition, are obtained by tempering, as shown in the following table, which gives the values for a 3½ % nickel steel.

Invar.*

Invar is a nickel steel containing about 36 per cent. nickel, together with about 0·5 per cen each of carbon and manganese, with metallurgically negligible quantities of sulphur, phosphoru and other elements. It is made either in the open-hearth furnace or by the crucible metho It melts sharply at 1425° C. Above some 200° C. to its melting point, invar may be considere to consist of a homogeneous solid solution of iron, nickel and carbon. Below 200° C. and a a temperature dependent on its history and exact composition it undergoes a reversible trans formation of such a nature that for any sample the transformation may be incomplete. Thi condition of thermo-chemical instability gives rise to both slowly changing and quickly changin values of its physical properties—changes which are particularly manifested in the expansion.

Invar can be forged, rolled, turned, filed and drawn into wires, and it takes a beautiful polish giving an excellent surface on which fine lines may be ruled. In general it should be worke slowly. It will withstand without spotting the corrosive action of water. Its density is abou 8·0 grm. per cm.^{3}, its electrical resistivity is of the order of 80 microhm per cm., or about eigh times that of pure iron, and its temperature coefficient of electrical resistance about 0·001 per degree centigrade. It is ferromagnetic, but becomes paramagnetic in the neighbourhoo of 165° C.

The mean coefficient of linear expansion between 0 and 40° C. is in the order of one millionth for the ordinary invar, and samples have been prepared with even small negative coefficients the amounts of carbon and manganese present appear to exercise considerable influence on th expansion. Above 200° C. the expansion of invar is approximately that of Bessemer steel.

Invar is subject to changes in length due to 'after effects' following cooling from a high temperature, and to changes in length following even slight alterations in temperature. Inva also gradually elongates with time, forged and drawn material behaving somewhat differently i this respect, so that there is a determinable, seasonal correction to be applied to its length when used as a length standard. It also shows marked magnetostriction phenomena or changes o length accompanying changes in strong magnetic fields.

Mechanical properties: Tensile strength, 22·5–36 tons per sq. in.; elastic limit, 3·1–13·5 tons per sq. in.; elongation, 40–50 per cent.; reduction of area, 40–65 per cent.; Brinell hardness 160; scleroscope hardness, 19; modulus of elasticity, 22,500,000 lbs. per sq. in.

Expansion of Nickel Steels (Guillaume).

Mean coefficients of linear expansion between 0° and t° C. Applicable between 0° and 38° C.

Per Cent. Nickel.	Mean Coefficient of Linear Expansion $\times 10^6$.
30·4	$4·570 + 0·01194\,t$
31·4	$3·395 + 0·00885\,t$
34·6	$1·373 + 0·00237\,t$
35·6	$0·877 + 0·00127\,t$
37·3	$3·457 - 0·00647\,t$
34·8 + 1·5 Cr.	$3·580 - 0·00132\,t$
35·7 + 1·7 Cr.	$3·373 + 0·00165\,t$
36·4 + 0·9 Cr.	$4·433 - 0·00392\,t$

Cobaltron Steel Alloy (Patent).

This alloy (patent) introduced by Messrs. Darwin and Milner, of Sheffield, is made by adding cobalt to chromium-carbon steel. The maximum temperature necessary for the hardening is 1000° C. (tungsten steel requires from 1250° to 1350° for the best results) and hardening is said to be satisfactory when the steel is allowed to cool naturally in still air. Analysis of cobaltron shows that the following elements approximate to the amounts stated below:—

Carbon	About 1·5 per cent.	Molybdenum	About 1·25 per cent.
Cobalt	„ 2·25 „	Tungsten	„ 0·25 „
Chromium	„ 11·0 „		

* Extract from Circular No. 58, Bureau of Standards.

'Heenan' Oil Coolers for Heat Treatment of Steel.

The continuous introduction of hot steel into oil quenching tanks naturally heats up the oil, which retains heat for a long time, and rapidly becomes too hot to permit of the process being carried on.

Owing to the poor heat conductivity of oil, such arrangements as water-jacketing the tank or inserting pipe coils through which water is circulated are ineffective, the cool surfaces affecting only that portion of the oil in immediate contact therewith, while allowing the main body to remain over-heated.

The 'Heenan' system of oil cooling is to extract the hot oil by means of a suitable centrifugal pump, and pass it through a 'Heenan' oil cooler before returning it to the quenching tank. This oil cooler is built up on lines similar to those of the water cooler described on p. 1296. In effect, oil is spread over a large cooling surface with which cool air from the surrounding atmosphere is then drawn into contact. Circulating water is not used.

This machine has been applied amongst other purposes to quenching processes in connection with the hardening and tempering of gun tubes, rifle barrels, steel tools, gear wheels, springs, aeroplane engine parts, etc.

Chromium Plating of Steel.

Using solutions of 3 grams per litre chromium sulphate and 200-400 grams per litre chromic acid, good adherent deposits of chromium on iron can be obtained. The cathode current density range for good deposits should be from 100–150 amperes per sq. ft.

Best results are obtained using Sargent's solution of 3 grams per litre chromium sulphate, 245 grams per litre chromic acid, and a current density of 125 amperes per sq. ft., the anodes being of chromium.

Chromium-plated iron and steel have a hard, bright, silver-like surface, resist atmospheric corrosion indefinitely, and are resistant to the action of fumes of nitric acid, hydrogen sulphide, and ammonia. They also resist the corrosive action of molten tin, zinc, and brass. Steel does not lose its temper during chromium plating.

(See also p. 2708.) (*Chemical and Metallurgical Engineering, April* 21, 1924.)

CASE-HARDENING.

The case-hardening of steel is dependent upon the fact that above certain temperatures the affinity of iron for carbon is so great that when iron or steel is heated at these temperatures in contact with suitably chosen carbonaceous materials ready absorption of carbon supervenes. The quantity of carbon that can be absorbed by iron or steel under the above conditions varies according to the following factors—

1. The composition of the iron or steel.
2. The temperature at which the process is conducted.
3. The length of time during which the process is continued.
4. The nature of the carburising material.

The Composition of the Iron or Steel.

Case-hardening, in the accepted sense, is rarely practised on steel containing more than 0·20 per cent. of carbon or 0·40 per cent. of manganese. The process is stated by Guillet to be hindered by the presence of nickel, silicon and aluminium, and hastened in the presence of manganese, tungsten, chromium and molybdenum.

The Temperature at which the Process is Conducted.

The process is best conducted at temperatures above the critical range of the iron or steel treated. The usual temperatures for carburisation vary from 900° C. to 1000° C. The higher the temperature of carburisation the greater the rate of absorption of carbon and the deeper the effect of absorption.

The Length of Time during which the Process is Continued.

This factor can only be determined by experiment. It is generally considered that the best results are obtained when the carbon content of the surface layers of the case-hardened material are of eutectoid composition (about 0·90 per cent. C.).

The Nature of the Carburising Material.

The carburising material may be either solid, liquid, or gaseous. Solid materials are employed more generally than are liquid or gaseous materials.

Solid Case-hardening Materials.

For the purpose of obtaining deep 'cases' the articles to be hardened are packed in a suitably designed box with solid case-hardening substances or mixtures of substances, of which the following are examples :—

Charcoal (animal or wood).
Charred leather.
Crushed bone or horn.
Barium carbonate 40 per cent. and charcoal 60 per cent. (Caron's mixture)
Charcoal (wood) 95 per cent. and soda ash 5 per cent.
Charcoal (wood) 90 per cent. and common salt 10 per cent. (Guillet).

As case-hardening composition is bought by weight, and is required to fill up the case hardening boxes, the specific gravity is an important consideration. The speed of conduction of heat through various depths of carburising material requires determining by experiment. A good case-hardening material should not diminish in volume appreciably during the carburising operation, and should be free from sulphur and phosphorus.

The box should be of plate iron not less than $\frac{1}{8}$ to $\frac{1}{4}$ inch thick. The lid of the box has two holes pierced in it for drawing testing-pieces out if required. For small articles a piece of wrought iron tube, plugged or capped at one end, may be used; the other end is closed by a second plug fastened with an iron pin passing through it and the pipe, the whole being luted with fine clay. The articles being previously finished, except polishing, are put into the box in alternate layers with the carburising mixture, commencing at the bottom of the box with carburising mixture to the thickness of about $\frac{1}{2}$ inch; upon this a layer of the articles is placed, then another of carburising mixture about one-third the thickness of the first, and so on until the box is nearly full, finishing with carburising mixture about the thickness of the first layer, leaving room every way for the expansion of the articles by the heat, otherwise they will bend each other in the box. The packing completed, the lid is put on, the box luted and placed in a suitable furnace. The contents of the box require to be very gradually and uniformly heated to redness, and retained at this heat for the period required for the depth of caburisation desired. The depth of carburisation depends on the length of time the temperature is kept up. For testing pieces plain pieces of the same kind of iron as the articles may be used. They require to be brightened, and are placed, at the time of the packing of the box, in the central part, in such a manner that they may be readily pulled out through the holes in the lid, either by a piece of iron wire attached or by being made long enough to project through the holes, so that they may be gripped with pliers; the holes are luted the same as are the other parts. When the articles are sufficiently carburised the box is drawn from the fire, the lid taken off, and the contents are immersed in pure cold water: taken out when cold they are ready for polishing. To prevent rusting, the articles may be dried by riddling in a sieve with dry sawdust, after which they are wiped with a greasy cloth. If the articles be immersed in oil instead of water they will be much tougher but less hard, though sufficiently so for some purposes. It is not necessary to immerse them direct from the box, as it answers equally as well to allow them to remain in the box till cool, and then reheat them in an open fire and immerse them separately.

When the case-hardening is required to terminate at any particular part of the article, the part needed to be soft may be bound with iron wire and cased with loam. This prevents the iron from absorbing carbon at that part. The loam requires to be gradually dried on the article previous to putting in the box, otherwise it will crack. 'Harbee,' in a letter to *Engineering* (August 15, 1913), states that, in order to 'stop off' that portion of the article required to be kept soft, a thin coating of copper (one thousandth of an inch in thickness is sufficient) electrolytically deposited will effectually resist any attack of the case-hardening material. After case-hardening the film of copper can be readily removed by the aid of a pocket knife. Copper plating, however, is expensive. Another method is to cover the part needing protection with a copper tube (this is the most satisfactory method when the shape of the work will allow the use of the tube) or to paint it with a protecting paint (paint can be made from china clay and blacklead or from sodium silicate and sand). A frequent procedure is to carburise an object and allow it to cool in the box, finally machining off the carburised portion before quenching wherever it is desired to keep the surface soft. It is of course necessary to leave sufficient metal on the object before carburising in order to ensure complete removal of all carburised metal before quenching. With long objects, one end of which requires hardening while the other is to remain soft, it is possible to carburise the entire length, then reheat and quench one end only, allowing the other end to cool in air.

For the purpose of superficial case-hardening it is necessary only to heat the iron or steel to be treated to redness, to sprinkle one or other of the following finely powdered compounds or mixtures on the surfaces to be hardened, and to plunge the iron so treated into pure cold water. This method is simple and speedy, but the case obtained is insufficiently thick to resist much wear.

Potassium cyanide.

Potassium ferrocyanide.

Potassium ferrocyanide and potassium bichromate.

Sodium ferrocyanide 90 per cent. and anhydrous sodium carbonate 10 per cent.

Sodium ferrocyanide 80 per cent., anhydrous sodium carbonate 10 per cent., and potassium ferrocyanide 10 per cent.

Liquid Case-hardening Materials.

The immersion of steel articles in a bath of molten potassium cyanide (the fumes of which are of a highly poisonous nature) heated to 850° C. results in the formation of very hard but shallow cases.

Gaseous Case-hardening Materials.

The following gases have been employed for case-hardening iron and steel—illuminating gas, carbon monoxide, acetylene and petroleum vapour. All, according to Brearley, are supposed to be more effective if they are led through a solution containing ammonia, or otherwise are partly saturated with ammonia gas before entering the furnace. By increasing the pressure of the gaseous mixture it is possible to increase the rate of carburisation.

Rap d Case Hardening Methods.

One of the best is to instal a container for sodium cyanide and common salt mixed. These salts used molten are very efficacious, and many small parts can be thus cased without going to the trouble and expense of casing in boxes. The sodium cyanide needs careful handling, but it is a simple matter to arrange for it to be placed into the equivalent of a fume chamber, a place fitted with a fan so that an adequate draught will take away all the poisonous fumes.

The immersion of clean machined steel parts in the mixture will produce a reasonably deep case in the course of ½ to 1 hour, and there is the additional advantage that the parts emerge from the bath quite clean and bright and can be quenched for hardening at once. Some trouble may be experienced in obtaining a suitable container for these molten salts, but the use of one of the nickel-chromium alloys will give excellent results.

Another good method of obtaining a reasonable case on steel consists simply of playing an oxy-acetylene flame on the steel, and a very few minutes at a temperature of 900–1,000° C. will produce an adequate depth of case. The flame must be suitably regulated so that there is no danger of the steel being cut, but an excess of acetylene in the flame will prevent this and will cause the casing to be formed much more quickly.

These methods are those by which small parts may be quickly hardened on their surface and are not intended to supplant the ordinary box carburising.

(*'Machinery,'* May 12, 1927.)

Thermal Treatment of Case-hardened Materials.

Quenching.—If the quenching takes place directly after the carburising operation, the resulting product is liable to possess a coarse structure in both the core and the case. In order to improve the structure it is better to allow the work to cool in the box after cementation, and then reheat it in a separate operation. The reheat may be made bare in the furnace, but with large objects which take long periods to obtain the desired temperature it is advisable to protect them from decarburisation by covering them with charcoal or old case-hardening mixture. This second reheat is most satisfactory at temperatures of about 780° to 820° C. It is claimed that very good results may be obtained by reheating twice, first with a view to refining the core and secondly to refine the case. A sample treatment of this description is :—

1. Carburise at 900° C. and allow to cool in box.
2. Reheat at 900° C. bare, and allow to cool in air.
3. Reheat bare for 20 minutes at 810° C. and quench in water.

Another common treatment which is said to yield fine core structures is to reheat twice and quench after each reheat, e.g. :—

1. Carburise at 920° C.
2. Reheat to 900° C. and quench in oil.
3. Reheat to 810° C. and quench in water.

In order to refine the cores of case-hardened articles it is advisable to heat the same to at least 875° C. (unless the carbon content of the core is above 0·20 per cent.) and quench. This treatment refines the core of the article but coarsens the case, hence it is necessary to reheat to a temperature somewhat above the critical range corresponding to the carbon content of the case (775° C. to 825° C.), subsequently quenching the article in water, or in oil.

Quenching in water results in a much more rapid cooling than oil quenching; the former i necessary for ball races, cams, and all parts which have to be subjected to hard wear and requir extreme hardness (80 to 90 scleroscope). Oil quenching of correctly carburised mild stee results in a hardness of 50 to 70 scleroscope. Small objects cool more rapidly, and therefor become harder than large objects undergoing the same treatment.

Tempering of the quenched articles still further improves the properties of the same.

Annealing.

To Prevent Oxidation and Scaling during Annealing.

It is sometimes desirable that steel should be thoroughly annealed without any oxidatio and scaling whatever taking place. The most popular method of doing this is to simply pacl the stampings in sand, but this method is not good, because, unless the sand be extremely fine air will eventually percolate through the grains of the sand. The following method has bee found to give first-grade results, and steel articles may be heated for many hours and com out with a perfectly bright surface. The packing mixture consists of finely powdered burn lime containing a trace of powdered charcoal. A thick layer of lime is tightly rammed down i the bottom of a box, similar to those used for case-hardening purposes. The articles are place in position on the lime and a further layer of lime is tightly rammed down on top of them, wit a sprinkling of powdered charcoal on top of the lime. Several layers of articles may be packe in this way till the box is full, when it is covered with a lid and luted up with clay. Althoug this process is not so quickly performed as some, it gives excellent results.

If such articles as small die castings or brass or bronze extruded sections require to be annealed the articles are dipped in a saturated solution of borax or boric acid in methylated spirit. Th spirit evaporates at once, and leaves a sound protective coating of the solid which coagulate on heating and effectively resists the deleterious action of oxidising and other gases at tempera tures up to some 750 deg. C., which is as high a temperature as is usually employed for the genera heat-treatment of non-ferrous metals and alloys.

The coating of the borax or boric acid is so extremely thin that there is usually no necessit to remove it after heating, but should this be necessary, hot water will suffice.

(*Met., 'Machinery.'*)

For Welding and Cutting, see p. 2747.

CORROSION OF METALS.*

Corrosion of Iron.

Professor T. Turner in his book on 'Iron' says the results of the experiments of the Admiralt Committees which issued reports in 1877 and 1880 led to the conclusion that common iron wa less affected by corrosion than best Yorkshire iron, which is in accordance with the statemen of Gmelin that phosphorus diminishes corrosion in iron.

In these experiments :—

Common iron resisted corrosion better than Yorkshire iron 9·6 per cent.

Yorkshire iron resisted corrosion better than mild steel, 16 per cent.

In another series of experiments conducted by D. Phillips, in Cardigan Bay, and lasting fo seven years, it was found that the average corrosion of mild steel during the whole period wa 126 per cent. more than wrought iron.

The independent experiments conducted by T. Andrews also showed that wrought iron cor roded less rapidly than mild steel when the cleaned metallic surfaces were exposed to the actio of the water.

Iron rusts very quickly when immersed in water from bogs and marshes which contain a larg quantity of carbonic acid, derived from decayed vegetable matter.

Iron does not rust in dry air.

Iron subject to vibration rusts slowly. Railway rails in running roads where trains ar passing frequently rust much less than those in sidings which are little used. Rails which ar kept in reserve and not in use rust more quickly still.

Thin iron rusts more rapidly than thick, because the expansion and contraction owing t changes of temperature throws off the scales more quickly.

In moist air, steel rusts more rapidly than wrought iron, and wrought rusts more rapidly tha cast. (See table, p. 284.)

Cast iron in salt water becomes in time soft and porous. The smoother the surface of iro the more slowly it rusts.

Once rust forms the process goes on more rapidly; rust being a porous substance it absorb moisture and acids from the atmosphere.

* See also p. 284.

Protection of Iron from Rust.

The types of coating applied to iron and steel for their protection may be classified as follows :—

1. Adherent coatings. 2 Compound coatings.

1. Adherent Coatings.

These may be metallic or non-metallic in character. Of methods for the production of metallic coatings of this type the following are the most noteworthy examples :—

(*a*) *Galvanising.*—This is a process which has for its object the coating of the material with zinc. Two processes, known respectively as hot galvanising and electro-galvanising, are employed for attaining the desired object.

Hot galvanising consists in the immersion of the object to be protected from corrosion in molten zinc or spelter, the surface of which is largely protected from oxidation by a supernatant layer of ammonium chloride. Modifications of the simple process briefly described in the last sentence are known under the following names, Winiwarter's process, Kufler's process, Bedson's process, Reese's process, Porter's process, etc.

The amount of zinc on modern galvanised sheets varies from 1 to 2·5 oz. per square foot coated. The coating generally contains from 0·25 to 1·00 per cent. of lead and from 2 to 6 per cent. of iron.

The most obvious disadvantages of galvanising are two in number: first, the iron or steel coated has to be raised in temperature for the desired effect to be attained; second, a layer of weak zinc-iron alloy forms at some point intermediate between the true zinc layer and the iron or steel upon which it is designed to rest. This thin lamina of weak alloy, mainly the compound $FeZn_7$, may be insufficient in a majority of cases to cause trouble, but a serious reduction in tensile strength is frequently brought about as a result of the presence of this weak material in fine gauge wires and sheets.

Electro-galvanising (cold galvanising) consists in the deposition of zinc electrolytically upon the object to be protected from corrosion, a soluble zinc salt being employed as electrolyte. The most important process under this head is that of S. Cowper-Coles, wherein an electrolyte of zinc sulphate is used, the electrolyte being continuously regenerated by circulation through tanks containing zinc dust. The methods of cold galvanising associated with the names of Heathfield, Powick, Pottkoff, Rawson, Wagner, Walker, etc., are worthy of note. Particulars of their processes are obtainable in the technical press.

The electrolytic process leads to the formation of an intermediate lamina of only minute thickness. In this particular the coating produced by the electrolytic process is an improvement upon that obtaining as a result of hot galvanising. It is, however, porous, and in this respect is inferior to the zinc coating produced in the dipping process. No marked superiority can be claimed for either of the processes.

Electro-galvanising has made great progress during the past few years, and may now be regarded as an efficient method of rustproofing. By its means a wide range of articles may be coated with a film of zinc which, while ample to protect from oxidation, does not affect ductility or tensile strength. The fact that perfect cleanliness must be achieved before the adherence of zinc can take place prevents dirty patches on the article becoming coated. The main cause of failure with hot galvanised work is the covering up, through the surface tension of molten spelter, of dirty or scaly places, which blister or otherwise fail in a comparatively short time. A commercially protective coating is obtained with a deposit of 4 oz. per square yard of surface. The deposit is practically pure, lead being the chief adulterant, then only in a fraction per cent. Accurately machined parts can be assembled after coating, this overcoming a difficulty ever present in the past. Hot galvanised bolts must have the thread bared before the nut will fit. Cold galvanising coats the thread so that the configuration is not destroyed, and unless the nut is a very tight fit the zinc remains on the thread and thus protects it against corrosion.

Admiralty specifications require a deposit of 0·86 oz. of electro-deposited zinc per sq. foot of surface of the articles treated.

(*b*) *Tin plating* is a process similar to hot galvanising, tin being the coating metal. The protection afforded to iron and steel by tin is less effective than is that of zinc.

(*c*) *Terne plating* consists of the coating of the material to be protected with an alloy of lead containing from 50 to 75 per cent. of tin (generally 70 per cent. tin).

(*d*) *Lohmanising*—in this process the metals to be protected are (i) pickled in an acid bath, (ii) dipped into a salt bath which deposits a metallic salt over the entire surface of the body, (iii) immersed in a bath of molten alloy of zinc, lead and tin heated to a temperature of from 500 to 600° C. The composition of the tin-lead-zinc alloy is varied to suit the material being treated.

(*e*) *Electro-plating*—the coating of iron and steel electrolytically with copper, nickel, etc., is well known.

(*f*) *Copper* '*clothing*'—the casting of copper round or the welding of copper to steel a the rolling of the resultant material to the required shape and dimensions has been practised, e Monnot process, Willis process, etc. (vide *Iron Trade Review*, vol. li. 479).

(*g*) *Nickel* '*clothing*'—processes similar to the Monnot and Willis processes have been succes fully applied to the coating of iron and steel with nickel and cupro-nickel.

(*h*) *Metallic spraying*—the application of liquid metal in finely subdivided form by a sprayi machine has been accomplished by M. U. Schoop, whose process, 'the Schoop process,' allows the coating of iron or steel with an adherent layer of tin, lead or zinc, the material being coat remaining meanwhile at the ordinary temperature. The material under treatment must scrupulously clean if adhesion of the finely-divided spray is to be perfected (vide *Me Industry*, vol. xvi. 41).

Of methods for the production of non-metallic coatings of this type the following are the mo noteworthy examples :—

(*a*) *Painting* (see page 2788)—The term 'paint' is applied to such substances as a employed as protective coatings in liquid form, but which under the action of oxygen dry a finally become hard and resistant. Paints are composed of :—

(*i*) solid substance in a state of fine division (pigment);
(*ii*) liquid in which the solid is held in suspension (vehicle); and, frequently,
(*iii*) salts of manganese, etc., for the purpose of hastening oxidation of the vehicle (drie

Friend (*Carnegie Schol. Mem.* vol. ix. 1918, 117) summarises the conclusions respecting paint ironwork exposed to atmospheric corrosion as follows :—

1. The practical value of acceleration tests is shown to be very small in the present state our knowledge. Reliable results can only be obtained from tests carried out under conditio closely resembling those required in practice.

2. Addition of pigment to oil increases the efficiency of the latter as a protective paint un a maximum is reached. After this, further addition of pigment causes deterioration. The be results are obtainable from paints possessing as high a percentage of good oil as is compatible wi good body and any other working property that has to be considered.

3. Linseed oil on setting expands by some 3·3 per cent.: this is the primary cause of crinklin Further oxidation causes a decrease in volume; this in time leads to cracking.

4. Linoxyn is permeable to moisture. The permeability is reduced by heating in absence air, the oil increasing in density, viscosity, and molecular weight.

5. Polymerised linseed oil affords a better protection than raw oil when used as a paint vehici

6. The functions of a pigment are to toughen the film and render it less permeable to wat vapour and oxygen. It also reduces the expansion of the oil on setting and thus minimises t tendency to crinkle.

7. A thick coat of paint protects the underlying metal more efficiently than a thin coa provided the coat is not so thick that running or crinkling takes place.

8. The very best results are obtained by multiple coats. Two thin coats are better than o thick one of equal weight.

9. Thinners enable thin coats of paint to be applied. Turpentine leaves a very slight residu behind upon evaporation, but its effect on the efficiency of the paint is small.

10. Other things being equal, the most permanent paints are those containing black or re pigments, since these absorb the shorter rays of light and prevent them from hastening th destructive oxidation of the linoxyn by the air.

11. Finer pigments afford more efficient protection than coarse pigments, since they are mo thoroughly in contact with the oil.

12. Iron structures should be painted whilst their scale is still on after loosely adherent flake and rust have been scraped off. The paint will last rather longer than if applied to the pickle or sand-blasted surface, and the labour of removing the scale is saved.

13. Experiments with rusty plates are not conclusive, but suggest that the rust need not b so carefully removed, prior to painting, as is usually thought to be necessary.

(*b*) Varnishing—the term 'varnish' is applied to such liquids as are produced by the solutio of gums, resins, etc., in volatile substances such as spirit, turpentine, fusel oil, etc. Varnishes ar open to the objection that they are not entirely impervious to gases and liquids. The applicatio of several coats of varnish and the stoving of such articles as have been varnished tend to increas the efficiency of these types of protective. The former method of treatment is, of course, costly the latter can only be employed where relatively small articles are being dealt with.

Frequently mineral oxides, etc., are added to give 'body' to varnishes, and such protectives re far preferable to the mere gum or resin solutions mentioned above. Provided the solvent tilised in manufacture is not too volatile and the substances employed to give 'body' to the arnish do not act injuriously upon either the iron or the solute, these varnishes are of considerable alue. Of materials employed to give 'body' to varnishes, calcined hematite ores and the mixture f finely-divided zinc and zinc oxide ('blue powder') obtained in the distillation of zinc, are the ıost effective. (*Lewes.*)

(*c*) Coating with bituminous substances—the substances tar, pitch and asphalt, together ·ith other tar products of like nature, form excellent protective coatings for iron and steel. Care ·quires to be taken to ensure the absence of acid or alkaline substances from these bituminous ıaterials. Where the articles to be coated can be heated without deleterious effect most excellent enamels' can be produced by applying warm tar to the same as hot. A variety of coatings may e obtained by altering the relative temperatures of the articles to be treated and the bituminous ıaterial employed in treatment (*cf.* Angus Smith's process, page 2794).

(*d*) Coating with Portland cement—the use of cements as a protective coating is frequent ·here the same can be afforded suitable support. In many cases the difficulty of attachment f the protective coating more than counterbalances the rigidity and adherent properties of the ement. Consideration must, of course, be taken of the possible effect of metallic expansion and ontraction upon the cement coating applied, and cement should only be utilised where it can be pplied in relatively thick coatings and where one can be assured that rupture of the hardened ement will be unlikely.

(*e*) *Enamelling.*—The enamelling of iron and steel is frequently conducted with a view to fford protection to the same. The enamels employed are boro-silicates of sodium, potassium, ılcium, and aluminium. Finely-divided glass, flint or quartz forms the general source of the lica; felspar or clay that of the alumina. To render enamels translucent fluorspar is added, ·hile borax furnishes the anhydride of boron required to complete the true enamel. Soda ash nd pearl ash are utilised as fluxes. As oxidising agents the nitrates of sodium and potassium nd manganese dioxide are used in light- and dark-coloured enamels respectively. To give dhesiveness to such enamels as come into direct contact with the metals to be coated, oxide of obalt is employed. The following oxides are used as colouring agents:—

White, oxide of tin; blue, oxide of cobalt; violet, oxide of manganese; brown, oxide of ıanganese; grey, oxide of nickel; green, oxides of copper or of chromium; yellow, oxides f uranium or of titanium; red, oxides of iron, selenium, or of gold.

The enamel is put on either as a powder or as a suspension. It may be applied in one coat ther by dipping, by spraying, or by powdering. Sometimes, however, a non-vitreous base ıaterial is applied and burned in to make it adherent, after which the true enamel is introduced) the surface to be coated. In any case the finely-divided particles which form the basis of the namel are fused together in a solid coating of boro-silicate by subjecting the same to a tempera- ure of about 1,000°C. The process generally requires from 3 to 4 minutes.

A process similar in some respects to that of enamelling is Ward's inoxidising process, which onsists of the application of a solution of a silicate to the iron or steel to be protected. The articles) prepared are heated to such a temperature as will cause partial fusion of the silicate to occur nd union of the same with the iron finally to ensue (*cf.* also Dode's inoxidising process).

It is obvious from the above that enamelling can be applied to relatively few articles of impor- ance to the engineer.

2. Compound Coatings.

The term 'compound' is applied here to such protective coatings as are produced by chemical ction, the ultimate result of which is the formation of a chemical compound, such, for example, s magnetic oxide of iron (Fe_3O_4), iron-zinc ($FeZn_3$), etc. The compounds formed may be, as lready noted, either chemical (in the general sense of the term) or intermetallic (in the specialised ense of the term).

Chemical Compounds.

Barff's process consists in passing superheated steam over the objects, which are heated in an ir-tight retort to about 260° C.; for the formation of a more perfect protective coating higher emperatures are necessary (650° C.). Articles so treated are said to be 'barffed.' Relatively mall objects only can be treated as above. The coating formed consists of the mixed oxides of ron (Fe_2O_3 and Fe_3O_4).

The *Bower-Barff* process is an improvement on the above, and consists in the heating of the bjects to be protected to about 900° C., at the attainment of which temperature superheated team is introduced to the same, which has the effect of producing a coating of the mixed oxide lready referred to. This operation having continued for about twenty minutes, carbon monoxide s injected into the retort for a period of from fifteen to twenty-five minutes, during which time he entire reduction of the coating to the condition of magnetic oxide of iron is completed.

The *Gesner process* treats iron and steel at a moderately high temperature (550° C. to 650° C in a retort whereinto may be introduced an atmosphere of steam. The preliminary heatin occupies twenty minutes; the steam is then allowed to react with the oxide formed in the fir operation for about half an hour, when naphtha is introduced and allowed to remain in conta with the material under treatment for about ten minutes. Finally, steam is again introduce The whole sequence of operations occupies about one hour and twenty minutes.

The *Parker 'dry' process.*—Under a patent assigned to the Parker Rust-proof Company, Detroit, the formation of an adherent coating of oxide may be obtained by first heating the objec to be treated to about 600° F. and then subjecting them to fumes of the acid metaphosphates strontium, molybdenum and tungsten.

The *Hans Renold process.*—Remove all grease or oil from the articles to be treated b suspending in a bath of hot lyco (11 oz. per gal.) for about three minutes, wash in cold runnin water for a few seconds, then suspend from cathode brass bars by steel hooks in an electrolyt bath (KCN, 98 per cent. pure, 4 oz. per gal. of water), iron plates forming the anodes. Leav here for five minutes, and when a current of 25 amps. at 8–10 volts is passed through the bat all foreign matter on the surface will be removed. Wash off the cyanide by means of hot water t facilitate drying.

Heat the articles to 700° C., then quench in cotton-seed oil by immersing in the main body the quenching tank for seven or eight seconds before allowing to fall to the bottom.

Dry by heated sawdust and hot-air blast (dried and filtered by passing through calciu chloride and cotton wool).

Insufficient oxidation results in the finished bodies having a grey appearance, due to th atmosphere of the furnace containing too much gas. Blistering is due to overheating.

Villon's process consists in subjecting the iron or steel to be protected to the vapour of sulphu as a result of which treatment the monosulphide of iron is found.

The *Bertand process* requires that the articles to be treated be thoroughly cleaned by sand blasting or similar means before they are immersed in a bath, such as will lead to the depositio of copper upon the same as a result of reaction between the iron and a suitable electrolyte. Th deposition may be achieved by the application of electricity or by more purely chemical mean After thorough washing the articles are heated in an oxidising atmosphere to a temperature about 600° C., which treatment leads to the formation of a fairly adherent coating of magneti oxide of iron.

The *De Meietin's process* depends upon the formation of a coating of magnetic oxide (Fe_3O_4) upon iron or steel which is placed as the positive pole in a bath of distilled water, maintaine at a temperature of from 70° C. to 80° C., a current of electricity being passed through it. Th oxide coating is adherent, provided the current density is not over great, and may be rubbed an polished. This method is of value in the treatment of such articles as cannot be submitted t any processes which might tend to temper or anneal the objects under treatment.

The *Parker 'wet' process* (patent) consists in the immersion of the iron or steel to be protecte in a bath of a 1½ per cent. solution of the acid metaphosphates of tungsten, molybdenum, or an of the metals of the third, fourth or fifth group of elements.

The *Coslett process* (*Coslettising*).—Cast iron or steel articles treated by this process are no only rendered rust-proof but improved in appearance.

The articles to be treated should be perfectly clean and free from tin, nickel, or grease.

The best results are obtained on a frosted surface, such as is left by sand-blasting or pickling Sand-blasting is to be preferred, as any traces of acid render the treatment ineffectual.

The coslettising bath is prepared by heating in a cast-iron or welded steel tank a sufficien quantity of distilled water to easily cover the articles to be treated. When boiling add fo every gallon of water in the bath (1) two ounces of phosphoric acid (syrupy sp. gr. 1·5); (2) on ounce of iron filings. This should be carried out in the open or under an uptake, as the reaction results in the formation of disagreeable fumes. When this reaction has ceased the bath is ready for use.

The articles should be placed in the bath as soon as possible after sand-blasting, and should be gently boiled for two hours.

A second tank should be prepared containing distilled water, which should be heated in time to wash the articles as taken from the coslettising bath.

At the expiration of the specified time the articles should be taken from the coslettising bath nd placed directly into the hot water and thoroughly scrubbed with a stiff bristle brush.

They may then be dried off, and if heavy will dry quickly themselves, but if light should be laced in an externally heated oven.

As soon as dry and while warm they should be dipped in a mixture of lubricating oil and irps substitute, in the proportion of 2 to 1, and left to drain. When cold, surplus oil may be moved with clean waste or wiper.

To allow for evaporation of bath a mixture similar to that in the bath should be made up nd added as required.

To keep the bath at the correct strength it is necessary to titrate a sample of the bath with normal sodium hydrate. To make this test, 10 c.c. of the bath should be placed in a nical flask, a few drops of phenolphthalein solution being introduced as an indicator. The $\frac{1}{10}$ rmal sodium hydrate should be added from a burette, until a permanent pink tinge is given to quid in the flask. The amount of sodium hydrate dropped into the flask should be noted, and if e bath is correct this amount will be 10 c.c. If more sodium hydrate is used, the bath is too rong and will require diluting with distilled water; if less is used, the bath is weak and will quire the addition of phosphoric acid and iron filings in the given proportion.

The appearance of the deposit obtained on the article is a rough guide to the state of the bath. he proper deposit is of a uniform dull black colour, but if the bath is too strong this black coat covered with a pearly white deposit which will not scrub off. If the bath is too weak e articles appear unevenly covered with a thin grey coat.

It is stated that in the present coslettising process (which cannot be used except under licence om the Coslett Anti-Rust Syndicate) phosphorised zinc, made under special conditions, is used stead of phosphorised iron, the solution otherwise being prepared in much the same manner. his newer process is said to give much better results, and the depth to which the articles are st-proofed to be considerably greater.

The need for the absolute cleanliness of the articles before treatment cannot be too strongly mphasised, and they should not be handled after cleaning, or before they are finally oiled.

Intermetallic Compounds.

Sherardising.—The articles to be coated are first cleaned and dipped in an acid bath as for lvanising; they are then put in a suitable retort which is, if possible, airtight, and are rrounded with 'blue powder'; the retort is then raised to a temperature of 500° or 600° F.

If the retort cannot be made airtight, about 3 per cent. of finely powdered carbon should be ixed with the zinc to prevent the formation of zinc oxide.

The heat is kept up for a few hours, after which it is allowed to gradually decrease.

A coating is formed which consists mainly of an intermetallic compound of zinc and iron $FeZn_3$).

Calorising.—A somewhat similar process to the above, in which aluminium powder is utilised the agent and wherein the resultant protective coating consists chiefly of an intermetallic mpound of iron and aluminium.

RUSTLESS IRON.

The composition of rustless iron (carbon, 0·7; silicon, 0·8; manganese, 0·12; chrome, 11·7, d nickel, 0·57) is, except for a variation in the carbon content, the same as that of the steel ssessing similar qualities.

Stainless Steel.

Stainless steel or rustless iron are not altogether stainless or rustless under all conditions. oreover, the 'rustless iron' is really a dead-mild steel containing a certain percentage of romium, which gives the steel its corrosion resisting properties. Mild stainless steel contains out 11 to 14 per cent. chromium, with 0·1 per cent. carbon and under, the other constituents, icon, sulphur, phosphorus, and manganese, being all more or less in normal percentages. pparently when the cast contains 0·1 per cent. and less of carbon it is called 'rustless iron,' d above that percentage 'rustless steel.')

One of the valuable properties of mild stainless steel is its behaviour at high temperatures When pieces of the material which have been polished are heated up gradually, temper colour appear on the surface similar to those obtained when ordinary carbon steels are heated up, bu in the case of mild stainless steel these temper colours appear at much higher temperatures, a shown by the following table:

Colour.	Mild Stainless Steel.	Ordinary Steel.
	° C.	° C.
Pale straw	290	225
Straw	340	235
Brown purple	390	265
Purple	450	280
Bright blue	530	290
Dark blue	600	315

Up to temperatures of about 825° C., mild stainless steel resists scaling to a remarkabl degree, but above this temperature the material begins to scale to some extent.

Hot Rolling and Forging of Mild Stainless Steel.

The most suitable hot rolling temperature for this material is 1050° C. to 1100° C., and it i essential that for rolling and forging the material should be brought up slowly to about 900° C and then slightly quicker to the rolling and forging temperature. It should be allowed to soa for a long period to ensure a uniform temperature through and through.

For forging, it should be worked quickly and with rapid blows between the temperature of 1150° C. and 900° C. Below 900° C. to 850° C. it is not so easily deformed, and if any heav work is put on the material after it has fallen below these temperatures it is very apt to b badly stressed or burst.

For drop stamping, it is advisable to work at a slightly higher temperature, and all stamping must be trimmed while hot, or annealed before trimming on account of the air hardenin properties of the steel. Otherwise, if an attempt to trim is made, cracking and splitting wil occur, as well as damage to tools.

Annealing.

The critical range of mild stainless steel runs from about 865° C. to 965° C.

To anneal mild stainless steel to obtain the maximum softness, it should be heated up slowl to about 1000° C. and held at this temperature for a period of time in proportion to the mass o metal, and then allowed to cool off slowly in the furnace, making sure that no currents of col air enter the furnace.

Although steel annealed this way has the maximum degree of softness, it is not in the bes condition for machining. The steel in this state is very soft and tough, and so drags and tear when machined, leaving a very rough surface.

To soften the material for good machining properties or cold drawing and cold rolling, i is best to anneal at 750° C. to 800° C., preferably about 780° C., and then to cool in the furnac or draw and cool in the open air.

Mild stainless steel has distinct air hardening properties, so that it should always be annealed or high temperature drawn at 750° C. to 800° C. as stated above, after it has cooled down fro a hot rolling or forging temperature, before it can be successfully machined or cold worked.

Cold Rolling and Drawing.

The material will cold roll, cold draw and deep draw, or press very well, but owing to th percentage of chromium in the metal, the depth of each draw, when the steel is being deep presse or drawn, obtained at each operation is only about half that got when working on mild steel before the material must be annealed.

In cold rolling and cold drawing, the reduction of one gauge at a pass can be used, but it i found necessary to anneal after every second or third pass.

As with all materials, a distorted surface is always more liable to rust, and the same applie to mild stainless steel, especially if the surface happens to be unevenly distorted.

In cold working, strains are always set up in the material, and sometimes strained parts ar not confined to the surface where they can be ground off, but are inherent in the steel and th strains must be removed by heat treatment. These strains are not only liable to cause rust but are apt to cause the steel to crack if put into service. It is thus evident that it is advisabl to anneal or high temperature draw at 780° C. all material which has been cold worked in any way

Pickling.

The proper pickling of mild stainless steel is a very important factor in the manufacture of ticles of this material. If the steel is left coated with scale, or has small pieces of scale left the surface it will rust wherever the scale is present. It is therefore essential that the finished rface should be free from all scale, roakes, seams, pits, or cracks, or even stamp marks, as herwise rusting will result.

The acid pickling baths generally used for this material are as follows :

1. 50 per cent. solution of hydrochloric acid used hot at 60° C. to 70° C.
2. 15 per cent. solution of sulphuric acid used hot at 60° C. to 70° C.
3. Ten minutes in a 50 per cent. commercial hydrochloric acid, then transfer without washing to 20 per cent. nitric acid for 25 minutes, both these solutions being worked cold.

Of these acid pickling solutions, No. 3 is the one which has given the most satisfactory results. ther methods which have been used for cleaning this steel are electrolytic pickling in an alkaline ath, which has been more or less successful for bars, etc., and articles of simple shape. Acid ckles containing chemical salts to accelerate the action, have also been used with considerable ocess.

Grinding.

The grinding of mild stainless steel must be carried out very carefully, as this material is more fficult to grind than ordinary steel. This metal dissipates heat very slowly, and great care ould be taken in grinding in order that grinders' ' scorch ' is not produced. Grinders' ' scorch ' due to harsh grinding and produces a brownish discoloration on the steel. This discoloration really a temper colour produced by the heat generated on the surface of the work, and will use rusting, due to the local distortion set up. Wet grinding is much better than dry grinding.

Etching.

In etching mild stainless steel, the following solutions have given very good results :

1. A saturated solution of ferric chloride in hydrochloric acid to which a little nitric acid has been added. This solution is used full strength.
2. A mixture of hydrochloric acid and nitric acid in the proportion of three to one and used full strength after allowing to stand for about 24 hours.
3. A saturated solution of copper sulphate in hydrochloric acid. This solution is used for light etching.

Physical Properties.

The physical properties obtained from mild stainless steel in the annealed condition, and so in the hardened and tempered state, cover a very wide range ; this will be seen from the llowing table :

TABLE OF TESTS OF TEMPERED BARS.

Tempered at.	Yield Point. Tons per sq. in.	Tensile Strength. Tons per sq. in.	Elongation. Per Cent.	Reduction of Area. Per Cent.	Izod Impact. Ft. lbs.	Brinell Hardness. Kg. per sq. mm.
° C.						
200	66·5	73·0	12·0	37·5	35	340
300	66·0	72·5	12·5	37·0	39	332
400	65·5	72·3	16·0	50·0	38	332
500	59·0	72·5	18·0	52·0	36	340
600	38·0	48·0	22·5	62·0	66	235
700	31·0	41·0	27·0	66·0	80	192
750	28·0	36·6	30·0	69·0	88	174

These tests were made on ' as rolled ' and ' annealed ' bars quenched from 950° C. in oil and mpered at various temperatures.

Welding.

Mild stainless steel can be welded by either the electrical process or by the oxy-acetylene ethod. It will not weld by the usual method of heating in a smiths' fire.

In welding, the temperature of the metal at the weld is raised to a fairly high temperature, that the material on cooling down will air harden and should be annealed before any turning, inding, or polishing is done.

(H. S. Primrose, A.I.Mech.E., M.Inst. Met., Paper read before the Manchester Association of Engineers, Friday, December 19, 1924.)

Colouring Metals Electrolytically.

Chiefly in grey, so as to give the effect of old metal, is largely carried out.

When the colouring is only to be partial, a shellac or asphalt varnish is applied to the parts i is desired to leave untouched. The *Ironmonger* points out that with cyanide baths the retentio of the varnish on the metal is almost impossible, and that in all such cases it is desirable to us a bath of acid reaction.

For a grey surface on iron a bath of the following composition is recommended :—

12 litres water.		100 grammes	white arsenic.
4 „	crude hydrochloric.	100 „	green vitriol.

1 litre of ferrous chloride solution.

As usual with acid baths, a considerable strength of current is required. Plates of carbon ar used as anodes.

The bath can be used for colouring silver, nickel, German silver, etc., and by altering th composition of the bath and the current from grey to a deep black is produced ; but the blac adheres very indifferently—a high current is necessary for the latter. (*Horobin.*)

Electro-Deposition of Iron.

A bath that will give very satisfactory results is composed of 75 grms. of ferrous ammoniun sulphate to 1 litre of water, with a current density of 1 amp. per 30 sq. cms. To ensure a uniform deposit the anode should be moved about the work by means of a small motor. A good anod is made up of 16 S.W.G. Swedish iron wire wound into the form of a cylinder and thoroughl annealed. The temperature of the solution should be kept above 63° F., and it is desirabl to decant and settle it every three days or so to remove oxides of foreign matter which caus roughness in the deposited metal.

It has been found possible to coat with a layer 2 mm. thick any cylindrical wrought iron o steel surface. Properly done this layer cannot be chipped off with a chisel, and when carbonise and hardened the dividing line, shown by microphotographs, entirely disappears. The surfac can be filed or ground and given a high finish.

(*B. H. Thomas, 'Institution of Automobile Engineers.'*)

COPPER.

Copper containing at least 99·95 per cent. of the pure element is produced on a commercia scale in large quantities. The average tenacity of cast copper is about 10 tons per square inch, tha of worked copper is about 15 tons per square inch, while Roberts-Austen quotes the following figure for the mechanical properties of slowly annealed, hammered, rolled bars of copper of a high degre of purity :—

Elastic limit	1·16 tons per sq. in.
Maximum stress	13·47 „
Elongation	37·0 per cent.
Reduction of area	61·0 „

Impurities in Commercial Copper.

Arsenic.

Arsenic increases the hardness and the tenacity of copper. When present in moderate quantities it increases the percentage elongation of the metal. It improves the rigidity and strength of copper at high temperatures, hence, for fire-box plates, the use of copper containing from 0·3 per cent. to 0·5 per cent. of arsenic is frequently specified. In copper that is to be employed in the manufacture of brass subsequently to be cold-worked, not more than 0·05 per cent. of arsenic should be allowed.

Antimony.

Antimony is similar in action to arsenic, but it should be limited to traces in such copper as is to be used for the manufacture of brass that is to be cold-worked.

Bismuth.

Bismuth being the most deleterious element that can be present in copper, owing to its tendency to induce red-shortness, not more than traces of this element should be allowed.

Iron.

Iron is rarely present in copper in more than traces.

Lead.

Lead is, after bismuth, the most objectionable impurity likely to be present in copper, although it is of value in metal that is to be rolled into sheets, on account of its softening effect on copper. Not more than the smallest quantities of this element should be allowed in copper for cold-worked brass.

Nickel.

Nickel hardens copper, but is in no way deleterious when present in such amounts as are usual
commercial copper.

Oxygen.

Oxygen in small quantity does not have any very radical effect on the mechanical properties
copper. It is important in bringing copper up to the 'pitch,' and in combining with deleterious
purities to form insoluble and infusible compounds, thus separating and distributing these
purities and rendering them harmless.

Sulphur.

Sulphur tends to embrittle copper, but is rarely present in refined copper.

Tellurium.

Tellurium is similar to sulphur in its action on copper.

Silver, Tin, and Zinc.

Silver, tin, and zinc are sometimes present in copper, but are rarely present in such quantity as
have much effect on the metal.

It has been found practically impossible to cast copper which is mechanically sound and of
gh electrical conductivity, on account of the porous metal that is obtained. By an addition of
ron this can be accomplished. One per cent. of boron suboxide flux—equivalent to 0·08 to
1 per cent. of boron suboxide—is added to the copper, and a casting that is commercially sound
obtained.

ZINC.

Zinc is marketed in two forms—as sheet zinc (see Sheet Zinc Trade Gauge, page 2817) and as
elter, i.e. flat rectangular ingots from 1 to 2 inches in thickness. The tenacity of zinc as
st is about 1 ton per square inch, and its elongation is practically nil. Zinc, after compression
der a stress of 20 tons per square inch at 100° C., has a tenacity of about 11 tons per square inch.
It is ductile between 212° F. and 302° F. and can then be shaped as required. But when
her above or below these limits it becomes brittle and unpliant, and therefore not adapted for
eatment. It melts at about 786° F. if volatilisation is guarded against.

Impurities in Commercial Zinc.

Arsenic.

Arsenic is a common impurity in spelter. It does not occur in such quantity as to have a
leterious effect upon the mechanical properties of spelter or of such alloys as contain it. It
however, an objectionable ingredient in such zinc as is to be employed in the production of
drogen.

Cadmium.

Cadmium is nearly always present in zinc; in electrolytic varieties of the metal it rarely exceeds
)7 per cent., in other varieties as much as 0·40 per cent. is found. The effect of this element
to harden spelter and to make it more brittle. Cadmium is, on this account, objectionable
nen the zinc has to be rolled into sheet or to be used for galvanising telegraph wires. In zinc
the manufacture of brass subsequently to be cold-worked as much as 0·20 per cent. of
dmium may safely be allowed.

Copper.

Copper tends to harden zinc, but is rarely present in quantity sufficient to effect radical change
the metal.

Iron.

Iron hardens and embrittles zinc. Its presence tends to the formation of dross in the
lvanising process.

Such zinc as is to be used in the manufacture of cold-worked brass should not contain above
.0 per cent. of iron. Electrolytic spelters rarely contain above 0·025 per cent.; as much as
5 per cent. of iron is, however, to be found in certain zincs.

Lead.

Lead is present in certain brands of zinc up to 2·5 per cent. The purer brands of spelter contain
to 0·20 per cent. of lead. The presence of lead is not deleterious where the spelter containing it
to be used for general brass manufacture, but where brass is to be cold-worked or specially
ated care must be taken that the spelter used has not too high a content of lead.

Lead in moderate quantity tends to make zinc softer in rolling. When present in quantities
excess of 0·7 per cent. it tends to the production of serious cracks in slush castings of zinc.

Other elements occasionally present in spelter in traces are sulphur and carbon.

TIN.

The London Metal Exchange form of contract (1911) for the purchase of tin recognises tw classes of tin—Class A, tin assaying not less than 99·75 per cent. of pure metal; Class B, ti assaying not less than 99 per cent. of pure metal.

The tensile strength of cast tin varies (according to Thurston) from 2,000 to 6,000 lbs. pe square inch. The elongation is, for all practical purposes, nil.

The principal impurities in commercial tin are lead, iron, copper, and arsenic. Sulphur, silve bismuth, and antimony are of frequent occurrence.

NICKEL.

Nickel containing small quantities only of impurities is a commercial article. On account of it readiness to occlude carbon monoxide and other gases, and its affinity for carbon, it is difficult t obtain nickel in a pure state in the cast condition. Parker, experimenting on pure, dead soft wrought nickel, has arrived at the following figures for the mechanical properties of nickel:—

Elastic limit	6–10 tons per sq. in.
Maximum stress	18–20 ,,
Elongation	8–15 per cent.

Nickel Plating.

According to the American Bureau of Standards, if nickel plating be made considerabl thicker than is necessary or customary on brass parts, the protective value can be materiall increased. It is believed that 0·001 in. is the minimum thickness that should be employed.

Impurities in Commercial Nickel.

Carbon.

Carbon is present in nickel up to 0·20 per cent., though it rarely exceeds 0·15 per cent. It ha an embrittling effect on nickel when in the form of graphite, but when combined with nickel a nickel carbide it has a strengthening effect.

Cobalt.

Cobalt has a strengthening and hardening effect on nickel, but in the quantities—up to 1·0 per cent.—usually found in commercial nickel, this element has but little effect.

Copper.

Copper is similar to cobalt in its action, but rarely exceeds 0·20 per cent. in amount.

Arsenic.

Arsenic should not exceed about 0·025 per cent. in such nickel as is to be subjected to cold work, or in alloys for a similar purpose.

Iron.

Iron has an effect on nickel similar to that of cobalt and chromium, but, being rarely presen in quantities in excess of 0·75 per cent., its presence is scarcely noticeable.

Silicon.

As much as 0·30 per cent. of siliceous matter can be present in commercial nickel. Its effec on the properties of the nickel is uncertain.

Sulphur.

Sulphur is occasionally noted in samples of nickel.

Nickel, if it is to be satisfactory for the manufacture of copper-nickel alloys for cold-working, should be free from all unreduced oxides.

CHROMIUM.

The colour of chromium is silver-white. Nickel has a little more of a yellow tinge to it than chromium. On the other hand, chromium will hold its colour indefinitely. Nickel will turn almost black in a laboratory atmosphere, and chromium will stay bright indefinitely. It is about the only metal known that will stay bright in a laboratory atmosphere. Not even platinum will stay as bright. See also p. 2689.

Electro-Deposition of Chromium.

In an article in the *Iron and Coal Trades Review* Mr. C. H. S. Tupholme gives the following hints on the electro-deposition of chromium. The cathode used was of iron, the bath at atmospheric temperature, and no mechanical stirring was used. In these conditions the most satisfactory concentration was obtained at 245 grammes per litre of chromic acid together with 3 grammes per litre of chromium sulphate. With this solution standardised the effect of varying the current density over the range between 2·7 and 54 amperes per sq. dm. or 25 to 500 amperes per square foot was tried, and it was found that good deposits were obtained up to 16 amperes per square dm. or 150 amperes per square foot. Beyond this current density the deposits were not so satisfactory, as the deposits were dark in colour and ultimately exhibited a tendency to crack. To obtain a bright deposit the most satisfactory current density was found to be between 100 and 125 amperes per square foot, using the electrolyte at ordinary atmospheric temperature.

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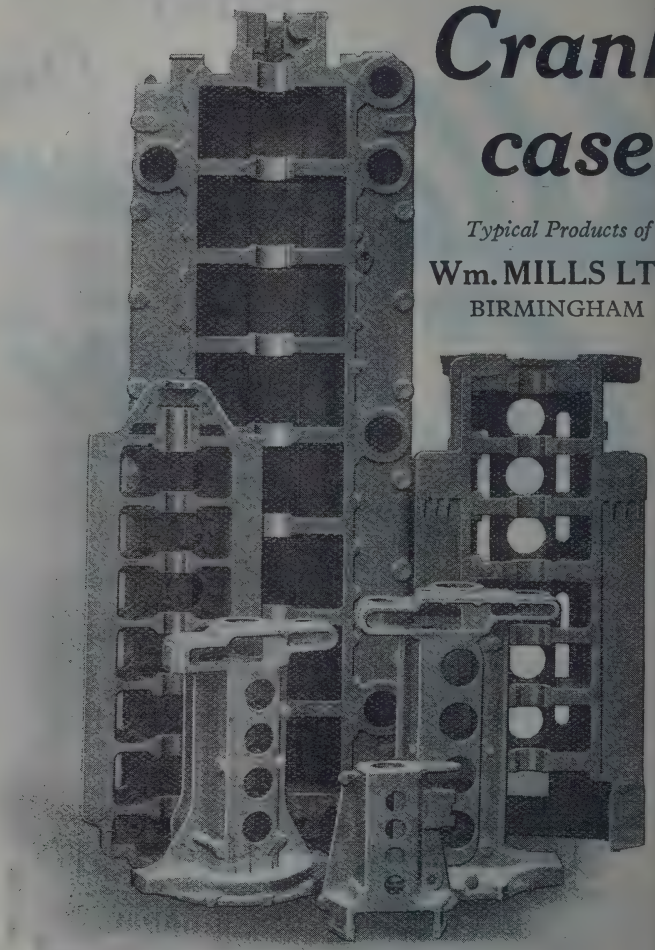

Write for booklet—
'The Lighter Way—'

(See previous page)

F. 2709

ALUMINIUM.

Aluminium which contains up to 99·9 per cent. of the pure element can be produced on a commercial scale, but the commercial metal is rarely above 99·5 per cent. pure. The impurities generally present in primary aluminium pig are: copper, iron, silicon, sodium, zinc, nitrogen, and a typical analysis is as follows:

Aluminium	99·57 (by difference)
Copper	0·0465
Iron	0·1973
Silicon	0·2246
Nitrogen	0·092
Sodium	trace
Zinc	0·0024

The mechanical properties of cast aluminium are as follows:

Elastic limit	3–4 tons per sq. in.
Maximum stress	5–7 ,,
Elongation	3–4 per cent.

The tenacity of hard-rolled aluminium can be as high as 18 tons per square inch.

Primary aluminium is not used in the cast condition for constructional purposes. It is used as a deoxidiser in the manufacture of steel, and in the form of powder and dust in the thermit process and in paint. The principal use is in the wrought form, such as sheets, tubes, mouldings, rods, wire, etc. As commercially pure aluminium has extensive application in the brewing and chemical industries, and also for domestic purposes, it is important to consider the action of acids upon it, which may be briefly stated as follows:

Hydrochloric Acid.—Attacked with great rapidity hot or cold and at all concentrations.
Hydrofluoric Acid.—Rapidly attacked.
Sulphuric Acid.—Attack slow with concentrated acid. Appreciably attacked with hot dilute acid.
Nitric Acid.—Attack very slow, the metal becoming passive (can be used for containers for cold strong HNO_3).
Acetic Acid.—Attack slow with cold acid, increases with use of temperature.
Lactic Acid.—Attacked very slowly (suitable for milk containers).
Oleic Acid.—Practically no effect.
Action of Air.—Attack very slow in fairly pure air, increases considerably in impure atmospheres. (The oxygen forms a thin film of oxide which tends to retard further action.)
Action of Alkalies.—Potassium and Sodium Hydroxide.—Rapidly attacked. Ammonium Hydroxide.—Attack slow. Alkaline Water.—Attacked appreciably by water in which alkalies or soap have been added.

Most metals will alloy with aluminium, but only a few definite alloys (aluminium—copper, iron, manganese, magnesium, nickel, silicon, tin, zinc) are used to a large extent. These include the binary alloys Al–Zn, Al–Cu, ternary alloys Al–Cu–Zn, Duralumin and related alloys, silicon and certain complex alloys. The so-called heavier alloys are the aluminium brasses and bronzes. Certain iron-aluminium bronzes and manganese-aluminium bronzes are also used.

Annealing Sheet Aluminium.

1. Prepare a mixture of ordinary whiting and oil, mixed to the consistency of thick paste. Coat the metal on both sides with this preparation, and place it on a clean fire or in a furnace. Allowing it to remain until the oil in the paste becomes ignited. When this occurs withdraw the work from the furnace and allow it to cool gradually. The coat of whiting should then be removed from the surface of the metal by washing and brushing.

2. Heat the metal to a dull red colour, perceptible in the dark, and cool slowly. With this method care must be exercised to get an equal annealing temperature distributed over the entire surface of the work.

3. Heat the sheet aluminium until pine-wood sawdust just glows when sprinkled on it, which indicates a temperature of about 750° F. At this temperature a dry match-stick will just char when rubbed on the metal. (*A. Eyles*, '*Machinery*,' *Aug.* 11, 1921.)

The Protection of Aluminium from Corrosion.

Aluminium and its alloys can be efficiently protected against atmospheric corrosion under the most severe conditions only by the use of an enamel or varnish paint. Oil paints are very inferior in protective power to those referred to above.

MAGNESIUM.

Magnesium, which is a lighter metal than aluminium, promises to play an important part in the future of light alloys, particularly for aircraft construction.

NON-FERROUS ALLOYS.

COPPER AND ZINC.

The alloys of copper and zinc containing over 50 per cent. of copper are generally termed 'brasses.' The mechanical properties of these alloys have been the subject of numerous investigations; in this connection such authorities as Thurston, Charpy, Lohr, Guillet, etc., should be consulted.

Below are given the results of Guillet's tests on the brasses. His tests were carried out upon material which was worked, then heated for ten minutes at 750° C. in a salt bath and finally cooled in air.

Alloy Composition.	Yield Point.	Max. Stress.	Elongation per cent. on 100 mm.	Hardness.
Copper.				
100 per cent.	2·09	14·28	52·5	48/49
98 ,,	1·64	14·41	58·0	48/50
96 ,,	2·59	15·27	57·5	52
90 ,,	3·54	16·43	54·0	55/58
85 ,,	3·35	16·43	58·0	57/58
80 ,,	4·17	18·52	72·0	60/63
75 ,,	4·49	19·47	77·0	60/62
72 ,,	4·69	19·59	77·5	60/61
70 ,,	4·65	19·59	73·5	60/64
67 ,,	4·49	19·02	72·5	56/60
65 ,,	4·69	19·25	73·0	62
62 ,,	6·59	23·06	57·0	80/81
60 ,,	6·95	23·76	50·0	81/82
58 ,,	4·27	25·15	51·0	92/95
56 ,,	7·33	21·06	40·0	121/131

Figs. 15 and 16 (pp. 2711 and 2712) show the relation existing between the mechanical properties of the pure brasses and their copper content.

The casting temperatures of these alloys are of exceptional moment. The following tests show the influence of varying casting temperature on the tensile properties of 40·5 per cent. zinc-copper alloy castings poured from one crucible within a short interval of each other. Chemically the three castings were identical.

Casting Temperature °C.	Maximum Stress Tons per Square Inch.	Elongation per cent.
1,038	12·45	6·0
943	16·28	9·5
934	18·88	15·0

In every case with other alloys similar temperature variations have a similar effect on the mechanical properties. The following results obtained from manganese bronze were obtained by Guillemin :—

Casting Temperature °C.	Maximum Stress. Tons per Sq. In.	Elongation per cent.
1,400	15·2	13
1,300	19·7	45
1,250	21·6	35
1,200	22·9	30

In judging a suitable pouring temperature the appearance of the alloy in ladle or crucible may be used as a guide. With manganese bronzes this appearance is somewhat confused by the aluminium present, for, as is well known, this imparts a characteristic skin to the surface of the molten alloy. The practical effect of this is to make the alloy appear colder and less fluid than is really the case. Careful observation readily overcomes this difficulty.

There is little doubt that the pyrometer is, in the hands of careful workers, the best means of determining the temperatures of metal or alloy in the ladle or crucible.

(See also Zinc-Tin Alloys, page 2730.)

Cast Brass.

Cast brass is somewhat variable in composition, but usually contains about 66 per cent. of copper, this percentage being that found in English standard brass.

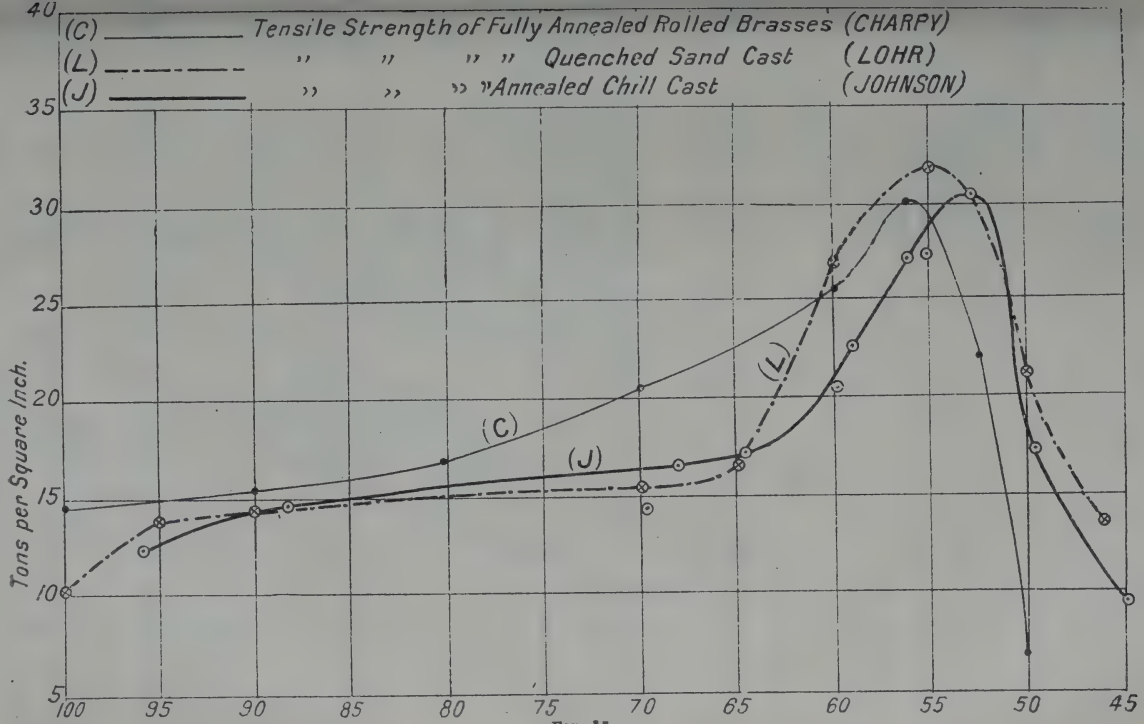
(C) Tensile Strength of Fully Annealed Rolled Brasses (CHARPY)
(L) " " " " Quenched Sand Cast (LOHR)
(J) " " " " Annealed Chill Cast (JOHNSON)
Tons per Square Inch.
40
35
30
25
20
15
10
5
100
95
90
85
80
75
70
65
60
55
50
45
(C)
(J)
(L)

FIG. 15.

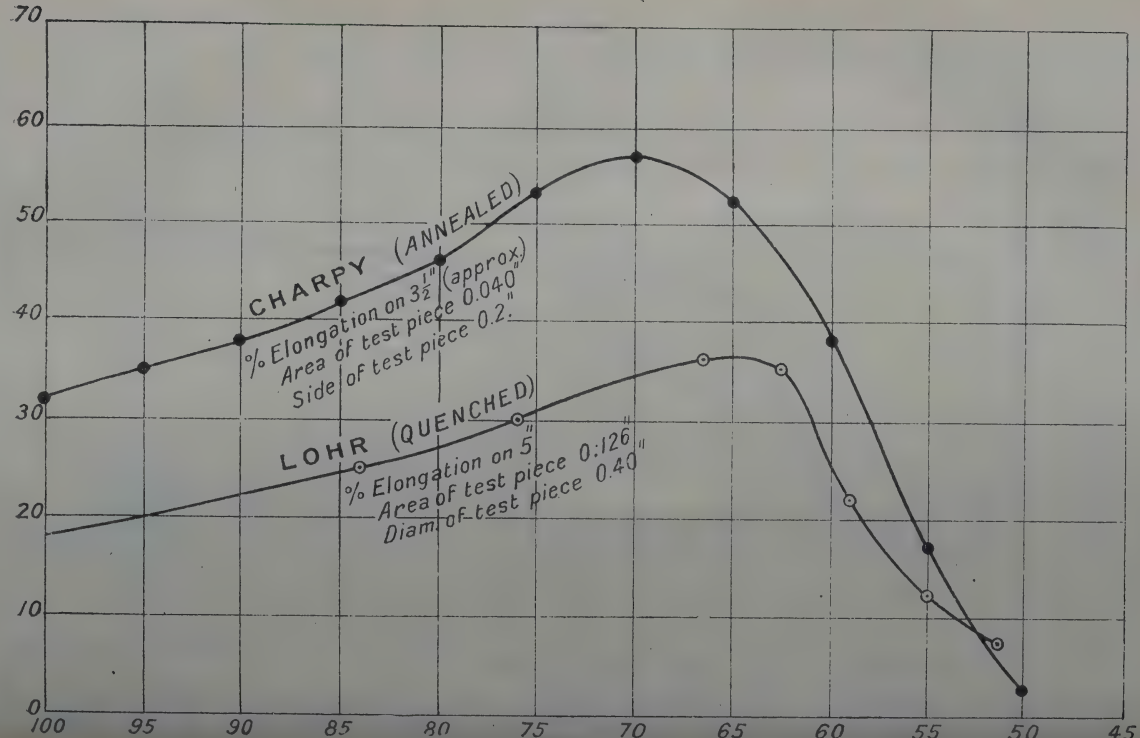
70
60
50
40
30
20
10
0
100
95
90
85
80
75
70
65
60
55
50
45
CHARPY (ANNEALED)
% Elongation on 3½" (approx.)
Area of test piece 0.040"
Side of test piece 0.2"
LOHR (QUENCHED)
% Elongation on 5"
Area of test piece 0.126"
Diam. of test piece 0.40"

FIG. 16.

The metals employed in the production of cast brass are not generally selected with such care as are those used in the manufacture of malleable brass. Lead, tin and iron are common impurities.

Lead in proportions varying from 1 to 3 per cent. is frequently added for the purpose of facilitating machining. It reduces the tenacity and hardness and increases the corrodibility of the resulting alloy, and is liable to segregate in those parts of the castings that solidify latest on cooling.

Tin tends to harden brass and is added in quantities up to 3 per cent., though 2 per cent. is not generally exceeded.

Iron hardens and increases the tenacity of brass.

The presence of more than one of these elements in quantity is to be deprecated, as their combined effects on the mechanical properties of the resulting alloy are likely to be injurious.

The mechanical properties of cast brass of average composition (66 per cent. of copper) and containing only small quantities of impurities or added elements are :—

Yield point, 6 tons per sq. in.; Tenacity, 14 tons per sq. in.; Elongation, 40 per cent.

A number of alloys, adapted for particular purposes, are tabulated below :—

Alloy.	Cu. Per cent.	Zn. Per cent.	Other Metals. Per cent.
Very delicate castings	86·00	14·00	—
Good yellow brass	75·00	25·00	Sn. 2·00
Name plates	86·00	9·00	Sn. 3·00; Pb. 2·00
Small castings (red)	90·00	10·00	,, ,,
Taps, cocks, etc.	78·00	14·00	Sn. 3·00; Pb. 3·00
Fine castings (yellow)	71·00	24·00	Sn. 2·00; Pb. 3·00
Hydraulic pumps	58·00	38·00	Sn. 2·00; Fe. 2·00

Ductile Brass.

The brasses containing upwards of 63 per cent. of copper are ductile and malleable at ordinary temperatures, provided that the metals used in the production of the alloys be of the best quality, and that the alloys be well annealed during working. The most suitable annealing temperatures for ductile brass are between 650° C. and 700° C.

Lead is admissible in alloys that are to be rolled into sheet, but is injurious in alloys that are to be drawn into wire. It should not be present in such quantity as is liable to create trouble at the annealing furnace.

The most ductile of the brasses contains 70 per cent. of copper and possesses the following mechanical properties when fully annealed subsequent to rolling :—

Yield point . . 10 tons per sq. in.; Elongation . . 60 per cent. on 2 ins.;
Maximum stress . 23 ,, ; Hardness (Brinell) 120.

Hot-forgeable Brass.

The alloys of copper and zinc containing from 59 to 61 per cent. of copper are characterised by their ability to withstand hot rolling at temperatures ranging from 500° C. to 800° C. They are employed in sheet form for the sheathing of wooden ships and in bar form for the manufacture of bolts, fastenings, etc. They are forgeable under the drop hammer and, hence, are frequently used in the manufacture of stampings. In this last connection it is particularly noteworthy that constancy of composition must be attained, on account of the large variations in machining properties accounted for by small changes in the copper content. The alloys in the range 57 to 63 per cent. of copper are forgeable, though not capable of withstanding rolling, in the temperature range already stated, and may be considered here.

All the above alloys are retained in a harder, stronger, and less ductile condition if quenched from temperatures between 750° C. and 800° C. than if allowed to cool slowly. They are liable to spontaneous cracking if worked at temperatures below 600° C., which liability, if thought to be inherent, can be lessened if the alloys are annealed at temperatures between 200° C. and 300° C., subsequent to working. The best temperatures for annealing, with a view to reducing variations in the mechanical properties due to variations in the mechanical and thermal treatment, are below rather than above 650° C. The temperature range (750° C.–800° C.) is, according to Stead, a dangerous one in which to conduct the annealing of hot-forgeable brass.

The average mechanical properties of fully annealed cast 60/40 brass are as follows :—

Yield point . . . 10 tons per sq. in.; Elongation . . . 35 per cent.;
Maximum stress . 25 ,, ; Hardness (Brinell) . 85.

Drawn rod of 60/40 composition is obtainable having the following average mechanical properties :—

Yield point . 28 tons per sq. in.; Elongation . . 20–30 per cent. on 2 ins.;
Maximum stress . 32 ,, ; Hardness (Brinell) 140.

The last factor appears to be dependent on the diameter of the rod in question, being least when the diameter of the rod is greatest. On account of the almost infinite variety of hot- and cold-working possible in the treatment of these alloys almost infinite variations in mechanical properties are obtainable.

Effect of certain Metals on Brass.

TIN.

Naval Brass.

Tin raises the tenacity, increases the hardness and resistance to corrosion and lessens the elongation of the 60/40 alloy, to which it is added commercially to make Naval brass. The latter contains 60–62 per cent. copper, 1–1½ per cent. tin, and the rest zinc. Not more than 2 per cent. of tin should ever be present; 4 per cent. induces great brittleness.

IRON.

Iron increases the tenacity and hardness of brass. The difficulty of dissolving iron in brass was first overcome by a special process, the invention of Dick (see also p. 2716), whose alloy, generally containing 55–57 per cent. copper, 42 per cent. zinc, 1–2 per cent. of iron and traces of phosphorus, is well known.

Iron is now generally added to brass in the form of ferromanganese, an alloy of iron and manganese which is readily dissolved in molten brass.

MANGANESE.

Manganese 'Bronze.'

Manganese is added to brass with a view to improve the mechanical properties of the same. The resulting alloys are divisible into two classes:

(*a*) Alloys in which either no manganese or traces only of manganese are present, i.e. alloys to which the element has been added for purposes of deoxidation.

(*b*) Alloys in which appreciable quantities of manganese are retained in solution. These may be subdivided into (i) such as are suitable for rolling into rod and containing up to 0·05 per cent. of manganese, and (ii) such as are suitable for casting and containing less than 60 per cent. of copper, and up to 2·0 per cent. of manganese.

The manganese is introduced into the alloys by the addition of ferromanganese or cupro-manganese.

These alloys are forgeable when heated to temperatures above 750° C. They resist the corrosive action of sea water, and are employed in the manufacture of ships' propellers. Iron, aluminium and tin are generally present in manganese 'bronze.'

The analyses of the alloys known under this name are varied in accordance with the character and nature of the purpose for which they are combined, and as the results depend entirely upon expert treatment in handling, we have obtained through the courtesy of the Manganese Bronze and Brass Co., Ltd., London, the tests on manganese bronzes recorded below.

TESTS OF MANGANESE BRONZE (CARRIED OUT BY MESSRS. BURSTALL & MONKHOUSE AT THEIR LABORATORY IN WESTMINSTER.)

STEAM CASTINGS—FOR SUPERHEATED STEAM.

Test.	Maximum Stress Tons per sq. in.	Yield Point Tons per sq. in.	Elongation in 2 ins. Per cent.
Immadium Alloy			
Cold Test	36·0	17·0	15·0
Temperature Test 500° F.	23·5	9·5	22·5
Gun-metal (for comparison)			
Cold Test	16·5	9·25	15·0
Temperature Test 420° F.	14·0	3·50	11·0

NOTE.—The Immadium temperature test pieces were maintained at a temperature of 500° F. for two hours before test was carried out, and the yield point is assumed to be reached when a permanent set of 0·003 in. on a length of 2 ins. is obtained. In Immadium the elongation is increased at high temperature, while a reduction is shown in gun-metal.

Valve Spindles and Pump Rods.

Diameter of test piece, 0·563 in. (Steel), 0·550 in. (Immadium).
Length of parallel part, 10 ins. „ 10 ins. „

Torsion Test.	Actual Twisting moment in inch tons.		Stress per sq. in. on Outer Fibre.	
	At Limit	At Break	At Limit	At Break
			Tons.	Tons.
Immadium Alloy . . .	0·345	1·105	10·61	33·89
Steel Test (or comparison) .	0·375	1·07	10·71	30·59

Tensile Test.	Quality.	Tensile Strength per sq. in.	Elastic Limit per sq. in.	Elongation. in 2″.
		Tons.	Tons.	Per cent.
Immadium Alloy . . . . (Hot rolled or forged) . .	No. I. High	40	20	20 to 25
	No. II. Medium	37	18	25 to 30
	No. III. Mild	34	17	30 to 35

Solid Drawn Tubes and Cylinder Castings.

Test.	Diameter.	Thickness.	Test Pressure.
Pressure.	Ins.	Ins.	Lbs. per sq. in.
Parsons No. 1 Alloy Solid Drawn Tubes	1·625	$\frac{3}{16}$	10,000 without leakage.
Parsons No. 2 Alloy Cylinder Castings.	Tested satisfactorily up to		8,000 „ „
Parsons No. 2 Alloy Recoil Cylinder Castings	„	„	6,500 „ „

NOTE.—Ultimate tensile strength of above mentioned alloys—from 30 to 34 tons per sq. in. Yield point 15 to 20 tons per sq. in., elongation 20 to 30 per cent. in 2 inches.

General Castings—Heavy.

Test.	Maximum Stress Tons per Sq. In.	Yield Point. Tons per Sq. In.	Elongation in 2 Ins. per Cent.
Turbadium	40 to 42	19 to 20	15 to 18
Immadium alloys	33 „ 40	17 „ 19	15 „ 21
Parsons No. 1 alloy . . .	32 „ 35	16 „ 17	15 „ 25

Crotorite Bronze.

This new alloy, one of The Manganese Bronze & Brass Co.'s specialities, is zinc free, of steel-ce qualities, and particularly recommended for bars and forgings exposed to corrosive fluids and igh temperatures.

Delta Brand Alloys.

The metals and alloys sold by the Delta Metal Co., Ltd. (of London and Birmingham), under heir registered trade-mark 'Delta,' are employed for a very great variety of purposes, the omposition varying widely according to the requirements and purposes for which each of these etals or alloys is more particularly adapted. Some of them are based upon the introduction nd chemical combination of definite quantities of iron and other elements in copper-zinc alloys. he effect of iron on brass has already been noted; the difficulty of introducing it in definite uantities was first overcome by the late Mr. Alexander Dick, the founder of the Delta Metal o., Ltd., who adopted the name 'Delta' (the Greek equivalent of the initial letter of his name) s a trade-mark. In most of the alloys which may be classed under the 'Brasses,' the copper ontent lies between 57 and 62 per cent., that of zinc between 42 and 38 per cent., whilst some ontain iron, phosphorus, manganese, or other metals, up to a total of about 2 per cent.

The following alloys, designated by the trade name 'Delta,' and manufactured by the Delta etal Co. Ltd., find wide application.

Delta Bronze Nos. I and IV are practically incorrodible, and consequently of very great urability, even when used in strongly corrosive mine-waters, etc.; they are not attacked by sea-

water, and resist acids much better than other copper alloys. On account of their great strengt and resistance to corrosion, these alloys are largely used for parts of marine engines an mining and hydraulic plant which require a strength not less than that of the best steel, but the same time freedom from corrosion—such as pump rods, piston rods, shafts, cranks, plunger spindles, rams, etc. For propellers and propeller blades, Delta bronze is in great demand, and is also successfully used for parts of ordnance, etc.

These alloys are malleable bronzes of very great strength, exceeding, even in the cast stat the strength of mild steel. They can be cast with facility, and will produce perfectly sound an homogeneous castings. When heated to a dull red heat, they become soft and highly malleabl and can then be readily forged, stamped, rolled, or pressed, to any extent required. These oper tions increase the strength considerably, as will be seen by the following copies of tests.

Description of Metal.	Diameter. In.	Area. Sq. in.	Ultimate Strength. Tons per sq. in.	Elongation in 2 ins. Per cent.	Reduction of Area. Per cent.
		Delta Bronze, No. I.			
Cast . . .	0·500	0·1963	41·30	20·0	20·4
Extruded bars .	0·502	0·1979	49·82	26·0	24·9
		Delta Bronze, No. IV.			
Cast . . .	0·611	0·293	23·89	21·0	20·1
Extruded bar .	0·500	0·1963	37·1	27·0	20·0

Extrusion Process.

The process of extruding copper and its alloys, the invention of the late Mr. Alexander Dic developed and worked by the Delta Metal Co., Ltd., of London and Birmingham, under numero subsequent new patents and improvements, consists of the pressing or squeezing of heat metals through dies of any desired cross-section, by hydraulic pressure varying according the section to be produced and the character of the metal operated upon.

Dick's extruded bars have a perfectly smooth and uniform surface, free from cracks or oth defects; size and shape are of the greatest accuracy, and owing to their superior finish, machini is reduced to a minimum. The Company are able to produce extruded rods as ordinary round pinion wire weighing a fraction of a pound per foot per run, to heavy round, square or hexag rods, or other sections, more or less complicated, weighing as much as half a cwt. and over per foo The facility of manipulation ensures rapid output, so that sections not regularly kept in stock c be supplied at very short notice.

The Delta Metal Co., Ltd., are not only the original, but claim to be also the largest man facturers of extruded rods and sections. They supply these in various metals and alloys: 'Delta' bronzes Nos. I, II, IV, and VII, Heagard bronze, manganese and aluminium bronz brass, yellow metal, naval brass, etc.

They make a speciality of high-speed turning and screwing brass ('Delta' Brand a 'Dixtrudo' Brand) in every variety of shapes and sections. This material, like the stampin and pressings in brass, bronze, and copper made by the Delta Metal Co., Ltd., is used large for repetition work and mass production, and supersedes castings.

Bull's Metals.

(Bull's Metal & Melloid Co. Ltd., Glasgow.)

Bull's Metals are strong, malleable alloys of good casting qualities, and equal to good gunmet in resistance to corrosion. They are manufactured in two qualities, No. II and No. III.

Alloy No. II is suitable for founding purposes, and extensively used for propellers and pr peller blades, parts of guns and gun carriages, requiring the strength of cast steel with gre toughness and resistance to corrosion.

Alloy No. III is very malleable and can be rolled, forged, stamped, or otherwise wrought at red heat; this metal also casts well. Its composition ensures great resistance to corrosion a wear. It is absolutely non-magnetic.

Rolled in round, hexagon, angle, and section bars, or into sheets and plates; forged stamped Bull's metal is used for pump rods, centrifugal pump spindles, rams, stern shaft sluice valve spindles, parts of marine and hydraulic machinery generally. Forged propell blades, propeller studs and nuts. Bolts, nuts, screws, studs, and nails. Parts of torpedo and torpedo boats, ordnance, ammunition, etc. Condenser plates, strainer plates, doct blades. Hull plates and angles for launches, torpedo boats, yachts, sailing and rowing boa

The elastic and ultimate resistance to tensile, crushing, and torsional stresses are greater in t case of wrought Bull's metal than in mild steel, and higher working strains may therefore be us with Bull's metal. Where resistance to the action of water or chemicals enters as an importa factor, Bull's metal, whether wrought or cast, becomes specially superior to steel.

TENSILE TESTS OF BULL'S METALS.

Dimensions.	Area. Square inch.	Reduction area at fracture.	Extension.	Ultimate Stress.	Remarks.
Diam. Inch.		Per cent.	Per cent.	Tons per sq. in.	
0·749	0·4406	22·1	23·6 on 8 ins.	31·41	Forged.
0·623	0·3048	37·9	8·1 ,,	39·93	Rolled, hard finish.
0·690	0·3739	37·8	20·0 ,,	35·01	Rolled, medium finish.
0·688	0·3717	30·6	29·0 on 6 ins.	31·47	Cast medium.
0·750	0·4418	24·2	22·0 on 3 ins.	38·68	Cast hard.

'MELLOID.'

(Registered Trade Mark.)

This alloy is a malleable genuine bronze containing no inferior metal; its resistance to corrosion very great. Its tensile strength in a rolled state when suitably finished is as high as that of mild eel; the strength is not appreciably affected at the temperature of high-pressure steam, whilst pper at such heat is very much reduced in strength and elasticity.

The alloy is perfectly malleable at *all* temperatures, from cold to blood-red heat; it has no ittle stage at a black heat like most metals and alloys, and at a red heat it is much superior in ength and toughness to mild steel under such conditions, and the alloy, under all conditions, is ceedingly tough.

'Melloid' meets the mechanical requirements referring to copper, naval brass, and rolled onze specified by the Admiralty, the principal railway companies, and consulting engineers.

It is claimed that 'Melloid' will be found superior to all brass alloys, including naval brass, llow or Muntz metal, and also to wrought copper, wherever a combination of toughness, eat strength, and a maximum resistance of corrosion is required.

NICKEL ALLOYS.

Nickel Silver.

The alloys of copper, nickel and zinc containing from 45 per cent. to 65 per cent. of copper, per cent. to 30 per cent. of nickel and 15 per cent. to 25 per cent. of zinc are of commercial portance and are classified under the general title of 'nickel silver.' The metals employed the manufacture of these alloys must, if the same are to be used in the production of cold-rked articles, be of the highest degree of purity. For the manufacture of castings, metals a lesser purity may be used.

Lead, tin, iron and unreduced oxides are the impurities generally present in nickel silver. ad is occasionally added to nickel silver in quantities up to 3 per cent. when the same is to employed for casting. Tin in quantities upwards of 2 per cent. has a hardening and em-ttling effect on the alloy, while iron in similar quantity has a hardening effect only. The dition of any of these elements results in injury rather than benefit to the alloys and especially reases the corrodibility of the same.

The effect on the mechanical properties of nickel silver of almost constant copper content increasing the nickel content has been admirably shown by Thompson (Institute of Metals, rch 1916), from whose paper on 'The Annealing of Nickel Silver' the following table is taken :—

TENSILE TESTS ON CAST BARS.

Cu.	Zn.	Ni.	Mn. added.	Yield Pt. Tons per sq. in.	Maximum Stress. Tons per sq. in.	Elongation. Per cent. on 2 ins.	Reduction of area. Per cent.
60·6	31·7	7·6	—	7·16	16·88	34·5	37·2
60·2	31·8	7·8	0·25	6·60	15·28	46·5	46·9
61·8	21·7	16·4	—	9·00	17·80	39·5	32·7
61·2	23·2	15·5	0·25	8·12	18·36	39·0	45·9
61·6	15·9	22·4	—	8·52	17·20	24·5	26·7
61·6	18·5	19·8	0·25	8·24	19·36	32·5	33·5
55·7	26·7	17·4	—	9·04	17·12	33·5	37·8
54·3	29·7	15·8	0·25	8·92	16·88	38·5	40·0
56·2	27·6	16·3	1·50	9·04	17·96	44·0	41·1
61·2	9·8	28·6	—	8·76	19·72	32·0	36·7
60·4	11·4	27·9	0·25	10·32	23·68	29·0	29·7
60·9	13·2	26·7	1·50	10·88	24·16	35·0	33·1

Other results of his research show that the tendency of commercial nickel silver to 'burn increased (*a*) by increasing the nickel content, (*b*) as the ratio of the zinc to the copper increased, and (*c*) with the amount of impurities present.

The following alloy is stated to be possessed of the best all-round properties :—

Copper, 46 per cent. ; Nickel, 39 per cent. ; Zinc, 20 per cent.

Monel Metal.

This is a natural nickel alloy which resists corrosion and has a high tensile strength. It mined in Ontario, Canada, and is smelted and refined under careful technical control witho separation of the virgin metals.

It has an average composition of :

Nickel . . . 67 per cent. Copper . . . 28 per cent.

and contains iron, manganese, carbon, etc., but no tin, lead, or antimony.

Its physical characteristics are as follows :

Melting point, 1300° C.	Heat conductivity, $\frac{1}{15}$th that of copper.
Specific gravity, 8·87.	Brinell hardness :
Weight per cu. in., ·323 lbs.	Cast material, 120 to 140.
Co-efficient of expansion, ·0000137 per 1° C.	Hot rolled rods and sheets, 150 to 190.
Shrinkage allowance for castings, $\frac{1}{4}$ in. per foot.	Izod test, 107–115 ft.-lbs. (unbroken).

The average tensile strength and elongation : hot rolled rods, 35–40 tons per sq. in., elongatio 36–51 per cent. ; hot rolled sheets, 30 tons per sq. in., 15–40 per cent. ; castings, 19–25 tons p sq. in., 10–20 per cent.

The hardness and tensile strength of Monel Metal can be greatly increased by cold drawing. Brinell of 237 and a tensile strength of 58 tons have been obtained in this way.

Monel metal is used on account of its great strength at high temperatures for equipmer controlling superheated steam, *e.g.* valves, valve seats, valve stems, turbine blading, nozzle condenser tubes, etc., and, on account of its resistance to corrosion, for pump rods, spindl and impellers, etc. ; also, because of its great resistance to acids and alkalies, for jacketed pan dyeing machines, etc. ; and, on account of its ornamental appearance, for shop fronts, counter and hotel, restaurant and hospital equipment—such as tables, urns, sinks, dish-washing machine cooks' tables, hoods, and canopies, operating tables, sterilizing drums, basins, shelves, etc. ; it available in all general engineering forms.

Platnam.

Consists of 54 per cent. nickel, 33 per cent. copper, and 13 per cent. tin. It is used for th manufacture of valve seats and valves which have to withstand the action of superheated steam.

Nickel Chromium.

These alloys have a composition which varies considerably according to the purpose for whic they are required, but in those of commercial utility the nickel content lies within the limits o 60 per cent. and 80 per cent. and the chromium content between 12 per cent. and 22 per cen The balance consists mainly of iron, with small percentages of manganese, silicon, aluminium and carbon, other elements being present only as traces of impurity.

A typical alloy has the approximate composition of nickel 66 per cent., chromium 20 pe cent., iron 10 per cent., the balance consisting of the above-mentioned minor components.

Physical Properties.

Tensile strength in cast state . . .	25 to 30 tons per sq. in.
Melting-point	1300° to 1350° C.
Density	·29 lbs. per cu. in.
Specific heat	·11

These alloys have two outstanding properties which have great commercial value, namely their strength is well maintained at high temperatures, and they are chemically inactive under a wide range of conditions even at high temperatures. Thus they resist the attack of furnace gase to a marked degree, and unless sulphur is present in unusually large quantities, their life at tem peratures up to 1200° C. is very considerable.

The actual life of articles made of this alloy is greatly dependent upon conditions, but a perio approaching 10,000 hours at such temperatures is by no means unusual.

The above properties make the alloys eminently suitable for the manufacture of such article as pyrometer sheaths, case-hardening boxes, furnace parts, retorts, muffles, in which rôles they have been of great assistance to engineers in overcoming difficulties due to the severe condition of temperature and corrosion which modern works practice produces.

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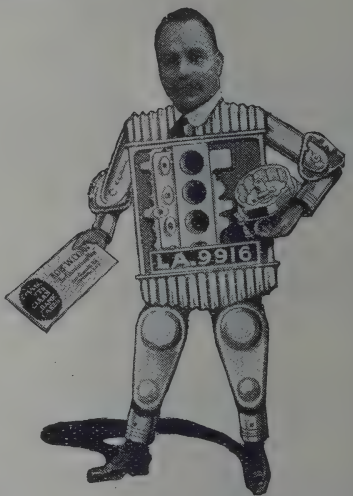

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Such alloys have long been recognised, when drawn into wire or rolled in strip form, to be tremely valuable for such electrical purposes as windings for electric furnaces and stoves.
The alloys are frequently of service to chemical engineers for use with corrosive fluids at rmal temperatures, and have found application in the manufacture of such articles as acid mps and valves subject to attack by acids and acid vapours.
An alloy designated the 'Emperor' chrome nickel alloy is manufactured by Messrs. Sutcliffe, eakman & Co., Ltd., and is of great durability.
A large number of pyrometer tubes, case-hardening boxes, and similar utensils made of the oy are in use in some of the principal works of the country.

Platinite.

Platinite is an alloy of iron, nickel, and carbon, which is used extensively for scientific instruments for standard measurements of length because of its peculiar quality of being practically n-expansive when heated to high temperatures. It is also used in incandescent electric lamps ere the wire connections fused into the glass must have so small a coefficient of expansion not to cause fracture in the glass. This alloy contains about 46 per cent. of nickel and 54 per t. of iron, with a very small percentage (0·15 per cent.) of carbon.

A Platinum Substitute.

A white alloy, 'Palorium,' says *Industrial and Engineering Chemistry*, is very difficult to tinguish from platinum in appearance. The temperature co-efficient, hardness and tensile ength of the alloy compare not unfavourably with those of platinum. The alloy is ductile, lleable, and homogeneous, it melts at 1,310° C., and is superior to platinum in its resistance the action of potassium hydroxide fusions and concentrated sulphuric acid. The loss in ght of a specimen subjected to the action of concentrated hydrochloric acid was only 0·9 ligram after 40 minutes, and after 1 hour, 1·0 milligram, so that its powers of resistance are se enough to those of platinum to make it a desirable substitute.
Another property of the material, and one which is of considerable advantage for plant or oratory use, is that it retains its stiffness when heated and does not soften like platinum. orium gives excellent results in electrolytic determinations, but is only suitable for the cathode. is obtainable in commercial form as crucibles, dishes, sheet, wire, and contact points, while cost of the manufactured article is some 45 per cent. less than where platinum is employed.

Platinoid.

Platinoid, introduced by Mr. F. W. Martin, is a kind of German-silver, with an addition l to 2 per cent. of tungsten. The latter, in the form of phosphor-tungsten, is first melted ether with a certain quantity of copper. In order to remove the phosphorus and a part of tungsten, both of which separate dross, the resulting compound is several times remelted. ally an alloy of a beautiful white colour is obtained, which when polished closely resembles er, and retains its lustre for a long time. Platinoid has the properties of German-silver a pre-eminent degree. It shows great electrical resistance, which remains almost constant ifferent temperatures, and is about 1½ greater than that of German-silver.

ALUMINIUM.

Aluminium Brass.

Aluminium acts as a deoxidiser and is added to cast and hot-forgeable brass, for the purpose nproving their mechanical properties, in quantities varying from 0·3 to 1·5 per cent.
Typical tests of cast aluminium brass, containing 38 per cent. of zinc, 2 per cent. of aluminium, 2 per cent. of lead, are :—

Yield point	18 tons per sq. in.
Maximum stress	34 ,,
Elongation	12 per cent.

Melting Points of Commercial Brasses.

(*Gillett & Norton.*)

	Copper.	Zinc. (as desired).	Tin.	Lead.	Copper.	Zinc. (by analysis).	Tin.	Lead.	No. of Tests.	Melting Point.
brass	85	5	5	5	—	—	—	—	8	970°C.
-grade red brass	82	10	3	5	81·5	10·4	3·1	5·0	4	980°C.
f yellow, half red	75	20	2	3	75·0	20·0	2·0	3·0	3	920°C.
yellow brass	67	31	—	2	66·9	30·8	—	2·3	4	895°C.
al brass	61·5	37	1·5	—	61·7	36·9	1·4	—	5	855°C.
ganese brass	Copper 56, Zinc 41, Iron 1·5, Tin 0·9 per cent. Aluminium 0·45, Manganese 0·15 per cent.								6	870°C.

COPPER AND TIN ALLOYS.

Gun-metal.

The alloys of copper and tin containing upwards of 86 per cent. of copper are possessed high tenacity and elasticity. Those containing from 89 to 91 per cent. of copper are the mo important and are known as ' gun-metals.'

The addition of tin to these bronzes results in an increase in the hardness of the resulti alloy. Gun-metal is rarely manufactured from specially selected metals and frequently contai lead, zinc, etc. The Admiralty specification for gun-metal is as follows :

Copper	88 per cent.
Tin	10 ,,
Zinc	2 ,,

the specified tests for this material being

Maximum stress	14 tons per sq. in.
Elongation	7½ per cent.

Gun-metal containing 90 per cent. of copper and 10 per cent. of tin should give the followi tests :—

Yield point	7 tons per sq. in.
Maximum stress	15 ,,
Elongation	15 per cent. on 2 ins.

Bell-metal.

The alloys of copper and tin containing from 75 to 86 per cent. of copper are used in the man facture of bells ; iron, zinc and lead are frequently added to the alloys either for cheapness variety of tone.

Effect of Certain Elements on Bronze.

ZINC.

Gun-metal, Bearing Metal, etc.

The alloys of copper, tin and zinc are rarely, if ever, free from elements such as lead, iron, et These alloys may be divided into two classes :—

(i) Alloys containing from 7 to 12 per cent. of tin, up to 6 per cent. of zinc, and up to 2 per cent. of lead. These alloys, among which may be noted gun-metal to the Admiralty specific tion, are used in the manufacture of castings, such as cocks, stuffing-boxes and pump barre and for bearings which are subject to but little friction.

(ii) Alloys containing from 12 to 20 per cent. of tin, up to 5 per cent., though rarely more th 2·5 per cent., of zinc and up to 5 per cent. of lead. These alloys are used in the manufactu of heavy bearings, e.g. railway wagon and locomotive axle boxes. The majority of alloys of th class contain from 14 to 16 per cent. of tin and from 1·5 to 2·5 per cent. of zinc.

Zinc combines with the oxides and free oxygen of the bronzes, producing greater fluidi in the molten state, and hence freedom from ' pinholes ' in the solid state.

LEAD.

Bearing Metal, etc.

The best bronzes should contain not more than 0·15 per cent. of lead, on account of its del terious effect on the mechanical properties of these alloys generally.

Bearing metals having a bronze matrix and containing up to 40 per cent. of lead are in comm use. A usual composition for bearings of this type is :—

Copper	64 per cent.
Lead	30 ,,
Tin	5 ,,
Nickel	1 ,,

The nickel is added to prevent the liquation of the lead. It increases the rate of cooling the alloy and thus assists in the retention of the lead in the finely divided form.

Lead does not alloy with bronze, but separates out of the molten mass, as the same cools, the form of globules. The lead bronzes may, therefore, be considered to consist of a netwo of bronze whose meshes enclose the lead content of the alloys in question.

PHOSPHORUS.

Phosphor Bronze.

Phosphorus acts as a deoxidiser and is added in small quantities for the purpose of deoxidation to copper. Not more than 0·15 per cent. is allowable.

The term 'phosphor bronze' is applied to the alloys grouped below.

(i) Bronzes to which phosphorus has been added as a deoxidiser and containing either no phosphorus or merely traces of the element.

(ii) Bronzes containing less than 9 per cent. of tin and up to 0·25 per cent. of phosphorus. These alloys are forgeable and are relatively non-corrodible. They are employed for rolling and drawing into wire and rod, and in the manufacture of general castings; in the latter case lead is occasionally added in quantities up to 5 per cent. The forgeable alloys of this group generally contain less than 5 per cent. of tin.

(iii) Bronzes containing from 8 to 14 per cent. of tin and from 0·25 per cent. to 1·00 per cent. of phosphorus. These alloys are employed for casting purposes in the manufacture of machine parts likely to be exposed to great friction. Lead up to 5 per cent. is added in certain cases.

Phosphorus is added to these alloys in the form of phosphor copper or phosphor tin.

The tensile strength of phosphor bronze varies from 14 to 18 tons per square inch, and the elongation from 6 to 10 per cent.

'Delta' Brand Alloys.

(The Delta Metal Co. Ltd.)

Delta Bronze No. V is an improved bearing metal of great strength and durability, and comparatively low price. It is particularly suitable for reducing friction at heavy pressures and high speeds, and is used for worm wheels for large cranes and other heavy machinery, hot neck rolls, locomotive slide valves, axle box, coupling, and connecting rod bushes, railway and carriage bearings, bushes, sliding surfaces, and other parts of machinery subject to heavy frictional wear. The metal is easy to tool, and requires no special precautions in casting.

Another metal used in lieu of phosphor bronze or gun-metal is 'Delta' Bronze No. VI, which produces fine, close-grained castings of great strength.

Melting Points of Commercial Bronzes.

(Gillett & Norton.)

	Copper.	Tin. (as desired).	Lead.	Zinc.	Copper.	Tin. (by analysis).	Lead.	Zinc.	No. of Tests.	Melting Point.
Gun-metal	88	10	—	2	—	—	—	—	4	995°C.
Leaded gun-metal	85·5	9·5	3	2	85·4	9·7	3·0	1·9	6	980°C.
Leaded bronze	80	10	10	—	—	—	—	—	3	945°C.
Bronze with zinc	85	10	—	5	84·6	19·4	—	5·0	4	980°C.

COPPER AND ALUMINIUM ALLOYS.

Aluminium Bronze.

The alloys known as the 'aluminium bronzes' are solid solutions of copper and aluminium containing not less than 88 per cent. of copper. Of these alloys that containing 10 per cent. of aluminium is the strongest, though the alloys containing less than this percentage are of industrial importance. These 'bronzes' are of use, firstly, on account of their valuable mechanical properties and, secondly, on account of their resistance to corrosion. They are malleable both when hot and when cold; the alloys containing between 8 and 12 per cent. of aluminium are affected in a marked degree by heat-treatment.

Following are tabulated the mechanical properties of some of these alloys:—

Percentage of Aluminium.	Yield Point. Tons sq. in.	Max. Stress. Tons sq. in.	Elongation. Per cent. on 4 in.	Remarks.
2·5	—	20·0	40·0	Cast.
5·0		25·0	55·0	Cast.
10·0	18·0	35·0	25·0	Cast in chill.
10·0	18·0	46·0	25·0	Cast rod reduced 25 per cent. by forging hot. Annealed.
10·0	15·0	40·0	30·0	Rolled bar.
10·0	40·0	50·0	3 0	Rolled bar quenched at 900° C.

The following are tests of the 'R3' and 'R4' aluminium bronzes, manufactured by the British Aluminium Company:—

R3 Bronze.—Average breaking load, 34·04 tons; average elongation, 21 per cent.; maximum

breaking load, 37·6 tons; maximum elongation, 35 per cent.; minimum breaking load, 32·8 tons minimum elongation, 12·5 per cent.

R4 Bronze.—Average breaking load, 41·8 tons; average elongation, 9·75 per cent.; maximum breaking load, 43·7 tons; maximum elongation, 13 per cent.; minimum breaking load, 39·8 tons minimum elongation, 6·5 per cent.

COPPER AND MANGANESE ALLOYS.

Manganese Bronze, Manganin.

The term 'manganese bronze' is applied to copper-zinc alloys of 60/40 composition to which small quantities of manganese have been added (see Manganese Bronze, p. 2714). There are, however, alloys of copper and manganese of industrial application which rightly should be admitted under this heading. The alloys of copper and manganese containing up to 5 per cent of the latter element are harder and tougher than is copper. Those containing from 2 to 4 per cent. of manganese are frequently employed in situations where high temperatures are existent on account of their retention of their mechanical properties under these conditions.

The following figures represent the results obtainable by stamping certain of these alloys at a red-heat (*circa* 800° C.):—

Copper.	Manganese.	Maximum Stress.	Elongation. Per cent.
97	3	18·5	32
96	4	21·0	60

Manganin is the name applied to an alloy of copper, manganese, nickel and iron, characterised by low electrical conductivity and almost zero temperature coefficient. It is employed in the construction of electrical resistance coils. The composition is somewhat variable, but the following figures will serve to indicate its approximate analysis:—

Copper	80 to 84 per cent.	Nickel	up to 12 per cent.
Manganese	4 to 15 ,,	Iron	Difference.

COPPER AND NICKEL ALLOYS.

Cupro-nickel, Constantan, etc.

The alloys of copper and nickel containing upwards of 50 per cent. of copper are of industrial importance. The alloys may be divided into three classes.

(i) Alloys containing up to 5 per cent. of nickel and having the property of resisting high temperatures without undue deterioration. Of these alloys those containing from 2 to 3 per cent of nickel have been employed in the manufacture of locomotive firebox tubes. Following are the mechanical properties of the 2 per cent. alloy:—

Maximum Stress.	Elongation. Per cent.	Remarks.
45·0	5·0	Hard rolled.
30·0	45·0	Hard rolled and annealed at 650° C.

Those of the 5 per cent. alloy are very similar in character.

(ii) Alloys containing from 15 to 25 per cent. of nickel and valuable on account of their ability to withstand cold working.

For the best results with these alloys only the purest metals should be employed, as small quantities of such elements as iron, silicon and sulphur are detrimental to the malleability and ductility of the resultant alloy. The maximum percentages of impurities allowable in nickel for this high-class work should be 0·050 per cent. of arsenic, 2 per cent. of cobalt, and 1·5 per cent. of other metallic impurities. The metal should be free from all unreduced oxides. Cupro-manganese, 25–50 per cent., is commonly employed as a deoxidiser in the manufacture of these nickel copper alloys, upwards of 0·25 per cent. being added to charges containing 30 per cent. of scrap. Following are the mechanical properties of the 20 per cent. alloy:—

Maximum Stress.	Elongation. Per cent.	Remarks.
40·0	5·0	Hard rolled.
20·0	35·0	Hard rolled and annealed.

The alloy containing 25 per cent. of nickel has been successfully employed in the manufacture of firebox plates.

(iii) Alloys having low electrical conductivities and whose temperature coefficients of electrical conductivity are practically nil. The 40–45 per cent. nickel alloy, known as 'constantan,' can be drawn into wire, and is employed in the construction of resistance coils and base-metal thermo-couples. Another alloy of this type, containing only 25 per cent. of nickel and 0·5 per cent. of iron, is known as 'nickeline.'

ALUMINIUM AND ZINC ALLOYS.

The alloys of aluminium and zinc are of importance as light alloys, their specific gravities varying uniformly from 2·7 to 3·3 as their zinc content increases up to 30 per cent., which may

be considered the limiting percentage for those alloys of this series that may be termed 'light.' All those alloys containing upwards of 70 per cent. of aluminium are forgeable at temperatures between 300° C. and 400° C.

These alloys do not allow of their use in casting into intricate shapes, but for all plain casting purposes they are quite satisfactory. Under certain conditions these alloys corrode rapidly; the use of high-grade spelter in their manufacture eliminates this defect. The machining properties of these alloys improve as the zinc content increases.

Below are tabulated certain of the results of tests reported by Messrs. Rosenhain and Archbutt to the Alloys Research Committee of the Institution of Mechanical Engineers.

Zinc. Approx. Per cent.	Condition of Alloy.	Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. Per cent. on 2 ins.
5	1	2·70	5·20	16·0
	2	2·80	6·60	29·0
	4	4·30	7·48	33·0
11	1	6·40	9·41	8·0
	2	5·00	10·24	16·0
	3	9·42	13·78	33·0 (on 1 in.)
15	1	9·60	11·14	2·0
	2	5·80	11·69	8·5
	3	11·61	17·92	31·0 (on 1 in.)
	4	6·80	16·38	33·0
20	1	10·00	13·07	0·7
	2	7·80	13·87	4·0
	4	17·30	22·64	20·5
25	1	nil	16·26	1·0
	2	9·10	13·50	3·5
	3	20·24	24·03	27·0 (on 1 in.)
	4	25·00	27·09	16·5
30	1	11·70	16·63	1·5
	2	10·30	17·92	3·0

1. Sand-casting.
2. Chill-casting.
3. Hot-rolled bars, $\frac{1}{2}$ in. diam.
4 ditto $1\frac{1}{2}$ in. diam.

The addition of copper to certain of the aluminium-zinc alloys improves the mechanical properties of the same. The average results of certain tests on chill-castings of the aluminium-zinc-copper series are given below.

Zinc. Per cent.	Copper. Per cent.	Yield Point. Tons sq. in.	Max. Stress. Tons sq. in.	Elongation. Per cent.
19	1	9·5	14·9	5·5
19	2	12·5	16·5	5·7
20	2	10·4	14·0	3·3
20	3	11·5	16·8	4·5
20	4	10·4	15·3	3·8

ALUMINIUM AND COPPER ALLOYS.

Like the zinc alloys, the commercial alloys are not simple binary alloys, but generally contain iron and silicon, and may also contain Mg, Mn, Ni, Zn, etc.

Al.	Cu.	Use.
91·5	7–8·5	General castings.
92	8	General castings, tendency to be brittle.
96	4	General castings, less brittle than 92 : 8 alloy; suitable for rolled sheets, sand-cast cooking utensils.
89·5	9–10·5	Light alloy pistons } American automobile practice.
86·5	11–13·5	Manifolds }
90	10	Die castings. Permanent mould castings.
88	12	
50	50	'Hardness' or rich alloys; not used for constructional purposes, but used in the foundry for the purpose of introducing copper into aluminium or aluminium into copper.
60	40	

(See 'Aluminium Bronze,' p. 2721.)

The specific gravity increases with increase of copper from 2·7–2·85 for sand-cast alloy for 0–8 per cent. copper. The specific gravity of sand-cast alloys is less than that of chill casting and that of rolled and drawn alloys is approximately equal to chill cast. In sand-cast alloys th strength increases with increase of copper at the expense of the elongation. In the hot-rolle condition the tensile strength increases up to about 6 per cent. copper and then decreases. Th physical properties of these alloys are indicated by the following figures :

92–8 alloy. Ultimate strength, 18,000 lbs. per sq. in.; elongation, 1–1·5 per cent.

97–3 alloy (forged). Yield point, 16,000 lbs. per sq. in.; ultimate strength, 24,000 lbs. p sq. in.; elongation, 4 per cent.

96–4 alloy (rolled, annealed). Ultimate strength, 15,000–28,000 lbs. per sq. in.; elongatio 34–16 per cent.

Tensile strength of hot-rolled bars, 21,000–37,000 lbs. per sq. in. (for 1–6 per cent. copper elongation varies from 30–18 per cent. For cold-drawn bars—tensile strength, 29,000–45,000 lb per sq. in. (for 1–4 per cent. copper); elongation, 14·5–6 per cent.

ALUMINIUM AND SILICON ALLOYS.

A striking property of these alloys is their low contraction, due to the silicon expanding freezing. Yield exceptionally sound sand castings. Iron should be a minimum, as it has a deti mental effect. The specific gravity of these alloys is less than that of aluminium. Strength an elongation good, but the yield point is rather low.

These alloys appear under the trade name of 'Alpax' in America, and 'Silumin' and 'Alada on the Continent.

Method of preparation of these alloys has a great effect upon their properties. (1) Norm alloy, made by simply melting together aluminium and zinc. (2) Modified alloy, made by direc electrolytic reduction or by the addition of an alkali fluoride or with sodium or potassium to th melted normal alloy.

The silicon in (1) appears as relatively large plates, and in (2) in high dispersion.

For 'normal' castings—composition, 95–90 Al, 5–10 Si.

For 'modified' castings—composition, 90–85 Al, 10–15 Si.

The simple Al–Si alloys are difficult to machine, and Al–Cu–Si alloys have been developed overcome this.

OTHER ALLOYS OF ALUMINIUM.

Magnalium.

Magnalium is the name applied to a series of alloys having an aluminium-magnesium bas containing from 1·5 to 10·0 per cent. of magnesium and varying proportions of other element *e.g.* copper, tin, nickel, lead.

The table below gives the analyses of certain of these alloys, together with the uses to whi they are generally put.

Use of Alloy.	Magnesium.	Copper.	Nickel.	Tin.	Lead.
Strong castings . .	1·60	1·76	1·16	nil	nil
General ditto . .	1·60	1·76	nil	traces	traces
Rolling and drawing .	1·58	0·21	nil	3·15	0·72

'Vickers' Duralumin.'

(*James Booth & Co. (1915) Ltd.*)

'Vickers' Duralumin' is the trade name applied to a series of quaternary alloys of aluminiu copper, manganese and magnesium, containing over 90 per cent. of aluminium and possessed high tenacity and hardness. The presence of magnesium confers the property of cumulativ hardening on certain aluminium alloys—*i.e.* subsequent to suitable thermal treatment the har ness of the alloy increases slowly to a maximum, which is attained after several days.

Following are typical analyses of 'Vickers' Duralumin' :—

Copper.	Manganese.	Magnesium.	Silicon.	Iron.	Aluminium.
3·62	0·35	0·87	0·62	0·045	Diff.
3·00	1·00	2·00	—	1·000	Diff.
3·60	0·40	—	0·50	0·600	Diff.

The specific gravity varies between 2·77 and 2·84. The melting point is about 650° ('Vickers' Duralumin' can be rolled, forged, and drawn when hot or cold. According to th purpose for which it may be required, the composition can be modified and the treatment s

"Vickers" Duralumin"

(REGISTERED TRADE MARK)

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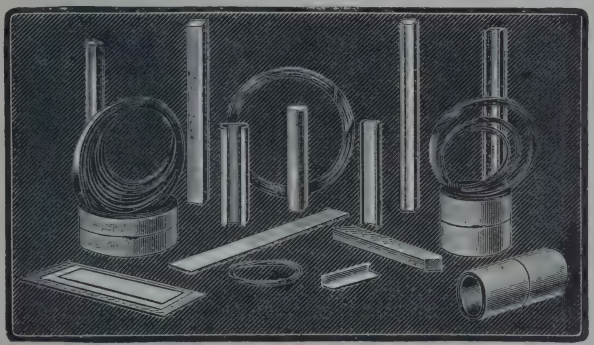

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(See Editorial pages 2729.)

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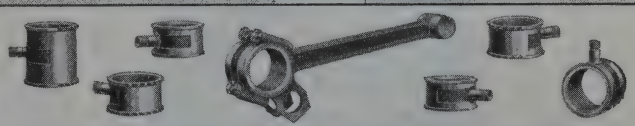

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We also manufacture solid whitemetal bearings, known as **Chill Cast Bearings,** which have come much into use during the last four years for Petrol Engines, also for Gas and Oil Engines. They show a great reduction in cost over the old method of lining a gun-metal shell, with whitemetal, which required machining all over.

These Chill Cast Bearings are supplied cast exactly to size, equipped with oil holes, steady pegs, oil grooves, and backed-off at the joint, thus being quite ready to go into the hands of the engine erector.

They are produced by a very special process of our own by forcing the metal into chills while in a plastic state, and then rapidly cooled while in the chill, thus producing a dense homogeneous casting, perfectly smooth on the surface, and absolutely free from blow holes.

rranged that the materiai is susceptible to forging, rolling, and drawing, or it may be arranged hat the greatest hardness, with corresponding smaller extension, can be produced. The following able gives a summary in which the properties of 'Vickers' Duralumin' vary by such modifica- ions in the composition and treatment.

Description of the Alloy.	Specific Gravity.	Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. Per cent.	Contraction.	Brinell Hardness.
H	2·77	12·06	22·25	23	34	98
681d	2·84	16·5	29·20	18	26	125

These valves are for soft rolled plates of 7 mm. thickness.

'Vickers' Duralumin' is supplied in sheets, bars, wires, strips, forgings, stampings, various ections and tubes.

Wolframinium.

Wolframinium is an alloy of tungsten, copper and aluminium. Its specific gravity (2·74) about the same as pure aluminium; its tensile strength cast in sand 10 tons per square inch, chills 12 to 13 tons per square inch, forged 15 tons per square inch, rolled or drawn 16 to 20 ons per square inch. Its elongation is 3 to 5 per cent. when hard, but 10 to 20 per cent. when roperly annealed. It can be worked as easily as copper, can be forged, rolled, and drawn either ot or cold, takes a high polish and does not tarnish.

Romanium.

Romanium is an alloy of tungsten, nickel and aluminium. Its specific gravity (2·75) is a ittle higher than that of pure aluminium, its melting point about the same, its tensile strength qual to that of Wolframinium, but it is much harder and is also of greater elasticity. It can e worked either hot or cold, forged, rolled, drawn, stamped, etc. etc. It is specially recommended for large castings, large plates and angle bars for shipbuilding and machinery.

BEARING METALS.*

The requisite properties of good bearing metals are hardness, to resist wear; strength, bear compression; and plasticity, to allow of ready adjustment of the supported body on ie bearing.

Two types of bearing metal are known:—

(*a*) Bearing metals in which the hard constituents of the alloy are distributed indiscriminately throughout a soft matrix.

(*b*) Bearing metals of spongy character; the network of the sponge being moderately hard nd tough, the meshwork being soft and plastic.

These types can be grouped according to composition as follows:—

(i) Brasses and bronzes containing compounds of copper with tin, phosphorus, etc.

(ii) Bronzes containing appreciable quantities of lead.

(iii) Alloys having a tin base and containing compounds of tin with antimony, copper, etc.

(iv) Alloys having a lead base and containing compounds of tin with antimony, etc.

(v) General alloys possessed of the characteristics required of a bearing metal.

Of the above, types (i) and (ii) have been considered under the heading of 'Brass' and 'Bronze' .v.), types (iii) and (iv) are known as 'white' metals, while the majority of the alloys of type) can be termed 'white metals.' Of types (iii), (iv) and (v) it has been observed that metals hose atomic weight divided by their specific gravity gives a high number are good anti-friction etals, while the reverse is the case for metals which have a low quotient. Hence the use of ad and antimony for bearing alloys. In using white metal for bearings the best practice is to se the bearings wholly of white metal, discarding the cast-iron shells and using up the old bear- igs with the addition of a small further quantity of the more volatile constituents. White etal must be melted in a clean vessel and at as low a temperature as possible. Dross and scum the metal tends to rapid heating in service. For the metals to be properly alloyed the high

* See also Bearing Pressures, page 1039.

as well as the low melting points of these must be reached, but care must be taken not to ove heat the alloy. For a thorough alloying a temperature of about 500° C. (930° F.) and less ha been found to be sufficient. The molten metal should be stirred with a stick of pine, and a lay of charcoal always kept on the surface to prevent oxidation. The rate of cooling affects th size of the crystals and also the wearing quality. As a general rule cooling too slowly and pourin too cold produces a coarse crystal formation which is liable to heat quickly in use. In the cas of the tin-antimony alloys it has been found that the best size for the tin-antimony compoun cubes is 0·25 mm. edge. Pouring too hot on the other hand results in a soft metal. The she should be heated to a temperature of 100° C. to 150° C. (212° F. to 300° F.) before pouring th metal into it, as this not only prevents blow-holes, but reduces the tendency of the lining shrinkin away from the shell. The bearing should not be disturbed while the lining is solidifying, sinc vibration tends to enlarge the crystals and produce brittleness. The matrix of the lining shou be just stiff enough to support the crystals, and the latter should be as numerous as is consisten with these, lying clear of each other and thereby causing brittleness. A Brinell hardness o 23·5 for an alloy with a lead base and 30 for a tin base has been found to give excellent result

ALLOYS HAVING A TIN BASE.

Tin-Antimony Alloys.

These alloys, which are of type (*a*) above, are the basis of Britannia metal. The followin table indicates the uses of certain of these alloys.

Tin.	Antimony.	Use of Alloy.
86	14	For seats of stop-cocks.
80	20	For plugs of stop-cocks.
79	21	Metal for bearings.
67	33	Very hard alloy, which forms the extreme limit of the ordinary tin-antimony alloys (*Hiorns*).

Babbitt, Genuine.

This alloy, whose composition is as follows,

Tin, 83·3 ; Antimony, 11·1 ; Copper, 5·6 ;

is used on important bearings under heavy loads, such as crank-shaft, crank-pin and cross-hea pin journals. Closely similar alloys are employed for the axleboxes of the leading railways the world. Several of the French railways, however, use the following alloy, which is low in tin.

Tin, 67 ; Antimony, 22 to 11 ; Copper, 11 to 22.

Babbitt Metal, General.

In cast-iron boxes, for light work: 50 parts tin, 5 parts antimony, 1 part copper ; for heav work : 46 parts tin, 8 parts antimony, 4 parts copper. In brass boxes: 64 parts copper, 8 par tin, 1 part zinc. The bearing to be lined with the metal is first tinned with the Babbitt met mixed with twice its weight of tin.

Babbitt Metal, Plastic Metal, and Phosphor Bronze.

(*The Delta Metal Co. Ltd.*)

These metals are supplied by the Delta Metal Co. Ltd., in various grades ; phosphor bronze i supplied in three qualities, A, B and C. The A quality is a hard bearing metal specially suitabl for worm-wheels, bushes, crank pins, bearings, etc. ; B quality phosphor bronze is a bearin metal more suitable for general purposes, whilst the C grade is adapted for large pinions, worms, etc The Company also supply various grades of Babbit, plastic, and other lining metals, for variou speeds and pressures.

Admiralty White Metal.

Tin, 86·0 ; Antimony, 8·5 ; Copper, 5·5.

ALLOYS HAVING A LEAD BASE.

Lead-Antimony Alloys.

These alloys should not contain more than 18 per cent. of antimony if they are not to be brittle. Such as do contain upwards of 18 per cent. of antimony must be given suitable support. The following table indicates the increase of Brinell hardness numbers of these alloys with increase of antimony.

Antimony. Per cent.	Brinell Hardness Number. 10 mm. 100 kilos.
2	9 approx.
5	12 ,,
10	16 ,,
15	17 ,,
20	21 ,,

The 25 per cent. antimony alloy is used by the Eastern Railroad of France as a lining for cross head slides, rod brasses and axle-bearings.

'Magnolia.'

Lead, 80; Antimony, 14; Tin, 6.
Lead, 79; Antimony, 20; Tin, Copper, etc., 1.

Other Ternary Alloys having a Lead Base.

Following is a list of ternary alloys of lead, tin and antimony, showing the mechanical properties of the same:—

No.	Lead (by difference).	Tin.	Antimony.	Yield Point. Tons per sq. in.	Tenacity. Tons per sq. in.	Elongation per cent. $l = 4\sqrt{a}$	Compression. Load in Tons required to compress to Half Length.	Brinell Hardness Number. 10 mm. ball, 200 kilos.
1	88·0	4·1	7·9	2·14	2·41	1·5	12·7	15·2
2	86·5	8·6	4·9	2·14	3·22	3·0	N.O.	15·1
3	81·3	13·1	5·1	2·68	3·35	2·0	N.O.	16·7
4	76·8	14·8	8·4	2·81	3·08	1·0	N.O.	18·0
5	72·6	22·1	5·3	N.O.	2·41	—	8·9	16·8
6	65·7	28·7	5·6	2·95	3·75	1·5	N.O.	15·1
7	85·2	4·6	10·2	4·01	6·17	10·5	12·6	23·2
8	82·0	8·9	9·1	3·86	6·43	13·0	11·0	25·4
9	75·1	14·7	10·2	3·75	6·43	5·5	N.O.	26·4
10	71·0	18·6	10·4	4·01	5·09	1·5	9·0 C.	23·2
11	66·8	23·0	10·2	3·75	5·36	1·0	N.O.	24·0
12	79·6	4·5	15·9	3·08	5·22	4·0	N.O.	25·6
13	77·1	8·6	14·3	Broken in machining			11·6	31·0
14	66·4	19·0	14·6	3·48	5·36	—	10·7 S.C.	32·0
15	66·0	18·9	15·1	3·48	5·36	1·5	9·7 S.C.	27·6
16	70·1	4·6	25·3	Broken in machining			12·5 S.C.	26·6
17	68·8	9·1	22·1	4·55	4·55	—	9·8 *	37·0
18	64·1	13·9	22·0	4·28	5·09	—	10·0 *	35·6
19	72·2	4·5	23·3	3·48	3·48	—	8·8 *	27·8
20*	65·0	10·0	25·0	Broken in machining			8·3 *	33·6
21	64·2	5·9	29·9	3·75	5·62	1·0	6·5 *	28·8

N.O.—Not observed. C.—Cracks in compression test-piece.
S.C.—Slight cracks in compression test-piece. * Failed without compression to half length.

The results contained in this table are considered sufficient to merit the following conclusions (1) that the effect of the presence of the tin-antimony compound in these alloys is such as to render the same brittle and weak; (2) that the general mechanical properties of the lead-tin-antimony alloys containing less than about 15 per cent. of tin are improved by the addition of antimony in quantities not exceeding about 10 per cent.

Hughes recommends the following alloy for metallic packings :—

Lead, 70 ; Antimony, 13 ; Tin, 17;

while the following alloys are used as lining by the Eastern Railroad of France :—

	Lead.	Antimony.	Tin.
1	70	20	10
2	80	8	12

1. For eccentric straps and bronze slide valves.
2. Special alloys for metallic rod packing.

Ternary alloys of lead, antimony and copper are also in use. These alloys should contain from 15 to 25 per cent. of antimony and not more than 10 per cent. of copper.

Anti-Friction Alloys.

Delta Anti-Friction Alloys.

(The Delta Metal Co. Ltd.)

Delta White Antifriction Metals, Nos. 1X and IXa, are used for lining bearings, bushes, etc., and are particularly suitable for heavy bearings such as those of marine engines, for railway trucks, dynamos, etc., as they do not wear, heat, or cut the journals ; they are also cheap.

The application of the metals presents no difficulties whatever; the parts required to be lined should be thoroughly cleaned, and when the metal is melted (which may be done in a ladle, over a slow fire, taking care not to overheat it) it is applied in the usual way. The melting point is about 450°C.

Fry's Anti-Friction Alloys.

(Fry's Metal Foundries, Ltd.)

These anti-friction alloys cover the whole range of white metals employed in engineering practice ; commencing with lead-free alloys of high tin content with sufficient antimony and copper to provide necessary hardness and wearing qualities combined with great toughness (as in the O1 brand) which are used for special service, as in the big end bearings of engines for aircraft or high-powered cars, and ending with the finest quality of lead-base alloys of the Magnolia class.

The series includes bearing metals suitable for every class of service, heavy and light loads, high speeds and slow-running machinery, and plastic metal for emergency and special services. The high-tin alloys are self-tinning. All but the first alloy in the series have a structure consisting of a matrix of tough and durable alloy with cuboid antimony-tin crystals regularly embedded throughout. The first is a tin-antimony solid solution with crystals of copper-tin and copper-antimony constituents interspersed in dendritic or needle-shaped formation. The constituent of dendritic crystal form is actually present in all well-balanced alloys of this character, adding greatly to their toughness and durability, and also serving to ensure the even distribution of the cuboid antimony-tin constituent. Finally, hard and highly resistant zinc-tin rock crusher bearing metal of great endurance can be furnished.

The following table shows a selection of bearing metals for particular purposes and for design work :

	Constituents, per cent. A = Tin ; B = Antimony ; C = Copper ; D = Lead.				Tensile Test.		Brinell Hardness. Number. 10 mm. Ball 500 Kilos.	Compression Test. Tons per sq. in.	
					Tons per sq. in.	Elongation per cent. in 2".		Yield Pt. 0·001 in.	Compressed to half length.
No.	A	B	C	D					
1	93	3·5	3·5	—	5·12	11·6	24·9	3·569	14·732
2	86	10·5	3·5	—	6·65	7·1	33·3	4·372	17·232
3	83	10·5	2·5	4·0	5·60	—	34·5	4·284	17·640
4	80	11·0	3·0	6·0	5·70	—	32·1	4·640	17·500
5	60	10·0	1·5	28·5	5·04	—	27·1	3·696	12·856
6	40	10·0	1·5	48·5	4·58	—	21·8	3·660	11·284
7	20	15·0	1·5	63·5	5·48	—	31·3	4·016	12·212
8	78	11·0	11·0	—	6·36	—	37·0	4·550	17·856
9	5	15·0	—	80·0	4·69	2·8	24·9	3·590	13·356

Richards' Plastic White Metal.

The chief qualities and advantages of this metal are durability, adhesiveness, self-tinning and antifrictional properties, minimum of contraction and linear expansion when passing from the plastic to the solid state.

This alloy can be applied to many kinds of metals, including gun-metal, steel, wrought and cast iron, also aluminium, by its own self-adhesiveness, and when properly applied no abrasive force will remove it, thus dispensing with the trouble and expense of recessing or pegging, an important matter when time for repairs is limited.

It can also be used for lining up worn parts of machinery in addition to bearings. It has a low coefficient of friction, thus saving very considerably on the cost of lubrication.

Even should lubrication be neglected for a period, the metal will not run out of the bearing, but being of a plastic character, when it becomes over-heated, will simply deposit from one place to another, and thus solidify itself when in contact with lower temperatures surrounding the body of the bearing. By this means it also prevents the possibility of cutting the crankshaft or other parts that may come in contact with it.

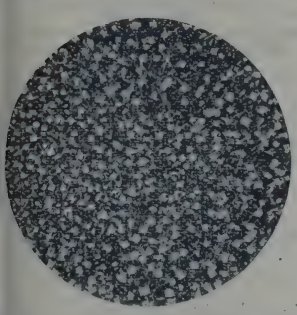


Fig. 17.—Micrograph of Richards' Plastic Metal (Magnified 50 Diameters).

The metal being self-tinning, no tinman's solder or tin is required to first coat the parts to be relined.

Its specific gravity being as much as 33 per cent. lighter than a lead basis alloy, less weight of metal is necessary for lining.

The metal itself has a particularly fine structure, which is attained by a special process of alloying. This structure is not affected by reheating, during its period of use, or when remelting, unless an exceedingly high temperature is attained. It can therefore be used over and over again.

This plastic metal has been extensively used for motor transport engines, aero engines, stationary engines, and pump work, for lining up bearing shells, and for die casting. It is particularly suitable for this last purpose. In order to produce solid die castings it is essential that the metal should be cast under pressure at a low temperature so as to preclude, by the retention of the metal as a solid rather than a fluid, the possibility of air holes and segregation of the alloy.

Richards' Plastic White Metal lends itself to these conditions. After prolonged trials it has been found that bearings made by this process are eminently suited to the onerous duties to which aircraft bearings are subjected.

The manufacturers of this alloy and bearings are Messrs. J. H. Richards & Co. Ltd., Cato Street North, Saltley, Birmingham.

Hoyt's Metals.

Hoyt's Standard Babbitt or Anti-friction Metals are made in eight qualities, this range being sufficient to meet the conditions in every class of machinery. The two highest qualities are 'Number Eleven' Alloy and the I.C.E. ('Internal Combustion Engine') Brand.

'Number Eleven' Alloy was, during the war, largely used for the bearings of aircraft engines, nearly 800 tons being supplied in 1918 for this purpose alone. This metal is also stated to give excellent results in the bearings of automobile engines, marine petrol and oil engines, steam turbines, marine steam engines, Diesel engines, etc. Its specific gravity is 7·34, the weight per cubic inch being ·268 lb. Approximately 100 lbs. of 'Number Eleven' Alloy will go as far as 113 lbs. of a high-grade metal of, say, 8·5 specific gravity.

'Number Eleven' Alloy is in use by the British Admiralty for certain important work. It is of higher quality than the Air Ministry's *Specification L.* 9 for Anti-friction Metal for Aviation engines.

The I.C.E. ('Internal Combustion Engine') Brand has been used extensively for many years by British and Continental motor-car manufacturers. It was used during the war by the British Army Mechanical Transport, the I.C.E. Brand being adopted as standard after many tests. The metal is largely used for high-speed steam engines, locomotives, steam pumps, marine engines, air compressors, etc.

Miscellaneous Metals for Bearings and Engine Parts.

The following special mixtures are stated to be satisfactory for the duty mentioned:—

For Lining.	Tin.	Lead.	Zinc.	Antimony.	Copper.	Bismuth.
Dynamos—high speed	88	—	—	8	3·5	0·5
Marine engines	77	17	—	3	3	—
Eccentrics	5	78	—	15	2	0·25
Submerged bearings	40	48	—	10	2	—
Main bearings	34	44	—	16	6	—
Slides, thrusts	63	—	30	2·5	2·5	—
Railway trucks	42	—	56	—	2	—
Axle-boxes (by analysis)	74·22	13·50	1·80	6·55	3·60	—
Loco and carriage bearings (Italian Railways)	38	37	—	25	—	—
Carriage bearings (German Railroad)	20	60	—	20	—	—
Bearings for rock-breaking machinery	10	—	80	10	—	—
Loco. bearings (A. Allan & Sons)	5·5	35	—	—	59·5	—
Cross-head slides and rod bearings (Eastern Railway, France)	0	65	—	25	10	—
Axle bearings and connecting rods for heavy engines (Eastern Railway, France)	83·3	—	—	11·12	5·5	—
Eccentric straps and slide valves (Eastern Railway, France)	10	70	—	20	—	—
Passenger and freight car bearings (A. Allan & Sons)	4·5	45	—	—	50·5	—
Loco. bearings (Dewrance)	33	—	—	45	22	—
Loco. and wagon axle boxes (Fenton's alloy)	14·5	—	80	—	5·5	—
Bearings, sleeves, slides and guide gibs (U.S. Navy)	12·5 to 14·5	1	2·5 to 4·5	—	82 to 84	—
Pivot bearings (Hoyle's alloy)	46	42	—	12	—	—
Lining, bearings and crank pin bearings (moderate speed) (Parsons' white brass)	68	0·5	30·5	—	1	—
Metallic rod packing (Eastern Railway, France)	12	80	—	8	—	—
Piston packing rings	—	50	—	—	50	—
	13	1	1	—	85	—
Pump and pump chambers and gun-metal valves	10	1·5	1·5	—	87	—
Cog wheels	9	25	—	—	56	—
	10	10	—	—	80	—
Anti-acid metal (by analysis)	78·84	14·75	—	Trace	3·70	—
Plastic metal	80	10	—	1	8	1
Genuine Babbitt (hard)	80	—	—	10	10	—
" " (No. 2)	83	—	—	9	8	—
Universal bearing metal	6	78	—	16	—	0·25
Anti-friction castings	24	—	80	—	4	—
Bearings for high-speed machines	—	—	14 to 18	—	82 to 86	—
" " "	17	—	—	77	6	—
" " "	18·5			76	5·5	

ZINC-TIN ALLOYS.

Zinc and tin form a series of eutectiferous alloys, some of which are of value as bearing metals. The alloys, in common with all bearing metals, are very susceptible to differences in casting

emperature, as may be gathered from the following table, which gives in detail the effect of arying the temperature of casting an alloy of 70 per cent. of zinc and 30 per cent. of tin :—

Casting Temperature.	Maximum Stress.	Elongation. Per cent.	Stress to compress to half length.
525° C.	5·09	3·0	7·7
500° C.	6·17	3·0	13·6
475° C.	6·56	8·0	15·4
450° C.	7·37	17·5	14·8
425° C.	7·37	35·5	15·0
400° C.	7·24	20·0	15·8

The above figures are for chill castings.

The alloys of zinc and tin containing from 25 to 75 per cent. of zinc possess, when in the chill ast condition, tenacities varying from 6·0 to 6·5 tons per square inch, percentage elongations arying from 30 to 45, and are compressible to half-length under stresses (calculated on the original reas of the test-pieces) varying from 13 to 17 tons per square inch. The eutectic melts at about 00° C. and contains 16 atomic per cent. of zinc.

In order that these alloys may approximate more closely to type A (*q.v.*) bearing metal, the nc-tin series containing no relatively hard constituent, copper and antimony are frequently added. he addition of one or both of these constituents results in the formation of a bearing metal in hich the hard compounds of antimony and zinc, etc., are indiscriminately distributed throughout ie eutectiferous matrix. The following are analyses of certain alloys of this type :—

Zinc.	Tin.	Copper.	Antimony.	Use of Alloy.
80	14·5	5·5	—	Fenton's alloy for locomotive axle-boxes.
69	26·0	5·0	—	Propeller bush.
88	2·0	8·0	2·0	Bearing metal for general use.

In this connection it may be noted that ternary alloys generally are far preferable to complicated ixtures and usually fulfil all the requirements of good bearing metals.

A French report on new anti-friction metals includes trials of alloys consisting chiefly of uminium, cadmium, magnesium, and especially of zinc. Such alloys were designed to reduce far as possible the use of copper, tin, lead, and antimony, and the most satisfactory results e stated to have been given by a compound of 63·3 per cent. of zinc, 21·3 per cent. of tin, per cent. of lead, and 3·3 per cent. of copper.

FUSIBLE METALS.

With the following combinations of metals, which form 'eutectiferous' alloys, it is possible to epare an alloy having a melting point lower than that of any member of the series.

Series.	Alloy with Lowest Melting Point (Eutectic).	Melting Point.
Bismuth-lead	57·4 per cent. Bismuth	124·5° C.
Bismuth-tin	56·7 ,, ,,	137° C.
Bismuth-cadmium	60 ,, ,,	146° C.
Cadmium-tin	52 ,, Cadmium	177° C.
Lead-tin	38·5 ,, Lead	180° C.
Cadmium-lead	17·4 ,, Cadmium	247·3° C.

By the addition of one or both of the residual metals to any of the above combinations, systems of ternary and quaternary alloys, having individual members with melting points lower than those of all other members of these systems and less than those of the eutectics given above, may be obtained. These ternary and quaternary alloys are the true 'fusible metals.'

The alloys of lead, tin and bismuth are of value for the following purposes :—

(i) The manufacture of casts of delicate objects that would be damaged if subjected to high temperatures. The following alloys are recommended for this purpose :—

Bismuth	59·2	50·0	50·0	50·0
Lead	27·3	31·2	30·0	25·0
Tin	13·5	18·8	20·0	25·0

These alloys expand considerably on cooling and are valuable also for the taking of impressions from dies, medals, etc.

(ii) Fusion pyrometers. Parkes and Martin recommend the following fusible metals as pyrometers for the tempering of steel tools. The article to be treated is placed on a plate of the alloy, which is heated till it melts. The tool, being then in the required condition, is quenched in water.

TABLE OF MELTING POINT OF BISMUTH-LEAD-TIN ALLOYS.

Bismuth.	Lead.	Tin.	Melting Pt.	Bismuth.	Lead.	Tin.	Melting Pt.
50·0	31·2	18·8	94° C.	16·6	33·2	50·2	158° C.
47·0	35·5	17·7	98° C.	16·0	36·0	48·0	155° C.
42·1	42·1	15·8	108° C.	15·3	38·8	45·9	154° C.
40·0	40·0	20·0	113° C.	14·8	40·2	45·0	153° C.
36·5	36·5	27·0	117° C.	14·0	43·0	43·0	154° C.
33·3	33·3	33·3	123° C.	13·7	44·8	41·5	160° C.
30·8	38·4	30·8	130° C.	13·3	46·6	40·1	165° C.
28·5	43·0	28·5	132° C.	12·8	49·0	38·2	172° C.
25·0	50·0	25·0	149° C.	12·5	50·0	37·5	178° C.
23·5	47·0	29·5	151° C.	11·7	46·8	41·5	167° C.
22·2	44·4	33·4	143° C.	11·4	45·6	43·0	165° C.
21·0	42·0	57·0	143° C.	11·2	44·4	44·4	160° C.
20·0	40·0	40·0	145° C.	10·8	43·2	46·0	159° C.
19·0	38·0	43·0	148° C.	10·5	42·0	47·5	160° C.
18·1	36·2	45·7	151° C.	10·2	41·0	49·5	161° C.
17·3	34·6	48·1	155° C.	10·0	40·0	50·0	162° C.

(iii) Soft solders. For the union of metal to glass, e.g. in the manufacture of paraffin lamps, the following alloy has been suggested :—

Lead, 40·0; Bismuth, 33·4; Tin, 26·6.

(iv) Fusible plugs.

The above alloys are nearly all of a brittle character. For the manufacture of ductile fusible alloys the use of cadmium in place of bismuth is recommended.

The following table includes the best known of the other fusible metals :—

Alloy.	Cadmium.	Lead.	Tin.	Bismuth.	Melting Pt.
Fusible alloy . .	12·5	25·0	12·5	50·0	55·5° C.
Lipowitz's alloy .	10·0	26·6	13·3	50·0	60–68° C.
Woods' alloy . .	15·4	30·8	15·4	38·4	71° C.
Fusible alloy . .	34·5	27·5	10	27·5	75° C.
,, ,, . .	6·2	34·5	9·3	50·0	77° C.
,, ,, . .	25	25	50	—	86° C.
,, ,, . .	16·6	—	33·3	50·1	95° C.
,, ,, . .	11·1	—	33·3	55·6	95° C.
,, ,, . .	25	—	25	50	95° C.

Spence's Metal.

This compound is obtained by melting the three sulphides of iron, zinc and lead with sulphur. he product is a dark grey mass of great tenacity, small power of conducting heat, a specific ravity of 3·4, a melting point of 160° C. In congealing it expands like bismuth and type metal, nd resists in a remarkable degree the action of atmospheric influences, alkalies and acids, even of quaregia, its surface scarcely being affected after having been exposed to the action of the latter r four weeks. Its property of expanding in congealing, and therefore filling completely all epressions of the mould, makes it particularly available for castings. If the compound is poured n a plate on which the impression of the hand has been made, the cast will show all the lines nd the pores of the palm.

The metal has been used for jointing gas and water pipes.

For further particulars see Patent Specification No. 2706, 1879.

Type-Metal.

Metal.	Parts.								
	Lead.	Anti-mony.	Tin.	Copper.	Zinc.	Nickel.	Cobalt.	Bis-muth.	Alu-minium.
Ordinary . .	75–80	20–25	..	0·4					
French . .	55	30	15						
English, No. 1 .	55	22·7	22·3						
,, No. 2 .	61·3	18·5	20·7						
,, No. 3 .	69·2	19·5	9·1	1·7					
Ehrhardt's, No. 1 .	3	..	4	4	80				
,, No. 2	2	..	3	2	93				
Besley's . .	100	30	20	8	..	8	5	2	
Cambrien's . .	..	..	..	50	..	..	..	..	10

Non-Magnetic Alloys.

These alloys are used as substitutes for steel wherever it is employed in the works of watches. he composition of the alloys varies from 45 to 75 parts of palladium, 15 to 30 parts of copper, 0 to 25 parts of silver, with sometimes the addition of small proportions of iron, steel, nickel, gold nd platinum. These alloys are claimed to be unoxidisable in moist air, to preserve their elasticity ndefinitely, not to vary sensibly with changes of temperature, and to remain uninfluenced by roximity to dynamos.

Another non-magnetic alloy, recently brought out by Messrs. Ostermann & Lacroix, of Geneva, Switzerland, is made of from 30 to 40 parts of gold, 30 to 40 parts of palladium, 0·1 to 5 parts of

rhodium, 10 to 20 parts of copper, 0·1 to 5 parts of manganese, and the same proportions of silver and platinum. The copper and manganese are first mixed, after which the other articles are added; or all the metals may be put into a crucible at the same time, the manganese being used for the bottom layer.

A non-magnetic variety of 'Bull's Metal' is manufactured and sold as No. III. and is being adopted for funnels and other erections of warships where the material must possess the mechanical properties of steel without its magnetic influence.

The Delta Metal Co. Ltd., supply under their "Delta" Brand non-magnetic metals (bronze and brass) to meet special requirements.

GENERAL ALLOYS.

Alloy.	Copper.	Zinc.	Tin.	Nickel.	Lead.	Antimony.	Bismuth.
Babbitt's metal	3·7	..	89	..	..	7·3	
Bell metal (bronze)—							
Musical bells	87·5	..	12·5				
Gongs	81·6	..	18·4				
House bells	77	..	23				
Church bells	69	..	31				
" "	80	5·6	10·1	..	4·3		
Brass, red	87	13					
" common	75	25					
" wire	67	33					
" yellow, fine	66	34					
" Muntz metal	60	40					
" sheathing metal	55	45					
" red	86	11·1	2·9				
" rolled	74·3	22·3	3·4				
" white	69·8	25·8	4·4				
" yellow	67·2	31·2	1·6				
" statuary	91·4	5·5	1·4	..	1·7		
Britannia metal	..	..	25	..	..	25	
When fused, add	..	..	..	..	..	25	25
Bronze, gun-metal, small	93	..	7				
" medals	93	..	7				
" mathematical instruments	92·2	..	7·8				
" gun-metal, large	90	..	10				
" wheels, valves	90	..	10				
" machinery bearings	87·5	..	12·5				
" lathe bushes	80	..	20				
" telescope mirrors	66·6	..	33·4				
" rivets	64	..	36				
" very tenacious	88·9	2·8	8·3				
" common	84·3	5·2	10·5				
" " hard	79·3	6·4	14·3				
" machinery bearings, hard	77·4	7	15·6				
" speculum metal	50	21	29				
Chinese white copper	40·4	25·4	2·6	31·6			
German-silver	33·3	33·4	..	33·3			
Alloy that expands in cooling	..	..	..	..	75	16·7	8·3
Pewter, best	..	..	86	..	..	14	
" common	..	..	80	..	20		
Printing type	..	..	..	..	80	20	
Type and stereotype plates	..	..	..	..	69	15·5	15·5
White metal	7·4	7·4	28·4	..	..	56·8	

SOLDERS AND SOLDERING.

The following notes are published with the kind permission of the Editor of 'The Metal ndustry.' (See 'The Metal Industry,' vol. 9, No. 4.)

Points to be Observed for Successful Soldering.

Attention should be paid to the following points if success is to be attained in soldering or razing :—

1. In the preparation of the solder, uniformity of composition should be aimed at. Readily olatile or oxidisable constituents should be retained.

2. In the choice of the solder, consideration should be taken of the fusibility of the solder. The elting point of the solder should be less than that of the metal to be soldered. It should be oted, however, that the more nearly the melting point of the solder approaches that of the etal to be soldered the better is the union obtained, although the more difficult is the operation f soldering. It should be considered whether the solder will mingle perfectly with the surfaces o be united. One having mechanical and physical properties as nearly as possible approximating o those of the metals to be united should be used. One whose mechanical and physical roperties will not be subsequently modified by any treatment—thermal or otherwise—should be mployed.

3. In the operation of soldering, thorough mechanical and chemical cleanliness of the surfaces o be united must be obtained, e.g. by scraping, filing, grinding, etc., and by dipping in suitable hemical reagents. A source of heat both smokeless and sufficiently hot to raise the temperature f the sections to be united above the melting point of the solder is necessary. A suitable flux ust be used.

Fluxes.

Fluxes are used to protect the surfaces of the metal to be united from the oxidising action of he atmosphere during the process of heating. The presence of any non-metallic materials, such s oxides or carbonates, on the surfaces to be joined, effectually prohibits perfect union. As the rocess of heating a metal in the air always leads to the formation of a film of oxide on its surface leans must be employed to protect the surface. Use is made of readily fusible salts and of oils hat are non-volatile at the temperature of soldering for this purpose. For hard-soldering borax practically the only flux employed. It is applied as a paste with a brush to the surfaces of nall articles, and as a powder to those of larger articles. For soft-soldering a variety of naterials is used, the following list giving the most important of these, together with their uses.

(i) Zinc chloride is used for the soldering of sheet metal, copper alloys and bright iron. It is oisonous and corrosive, and is on these accounts unsuited (*a*) for the soldering of tins destined o contain food, and (*b*) for the production of delicate work, e.g. electric fuses.

Zinc Chloride Solution.

Kill 2 quarts hydrochloric acid with all the zinc it will take up. Add a quart of water or add art until zinc is fairly dissolved. A quart of glycerine which has been mixed with a quart f alcohol is then added to the solution.

This fluid is used for all kinds of soldering, especially with greasy and dirty connections and on. It is claimed that glycerine prevents rust, which plays havoc with other soldering solutions ntaining hydrochloric acid. (*Street Railway Journal.*)

Zinc Chloride Paste.

1 lb. vaseline or petrolatum ; 1 oz. (fluid) saturated solution of chloride of zinc.

The use of petrolatum instead of vaseline is recommended. While they are identical in composition, the name 'vaseline' is registered as a trade-mark, and commands a higher price on this account. Petrolatum is much cheaper. The chloride of zinc solution is made by dissolving as much zinc in strong muriatic acid as it will take up. An excess of zinc should be present, and all the acid neutralised. This will form a thick, oily solution. The petrolatum and chloride of zinc are mixed and thoroughly incorporated by means of a mortar and pestle or by vigorous stirring. The advantage of this soldering paste lies in the fact that it does not spatter and is not corrosive.

(ii) Ammonium chloride is used as a flux when soldering copper and iron.

(iii) Ammonium phosphate is used when treating with tin, zinc, copper and brass ware. It is non-corrosive and non-poisonous, but is somewhat refractory.

(iv) Hydrochloric acid is employed when dealing with zinc and zinc-coated ware.

(v) Lactic acid is useful in connection with copper and its alloys, but has the disadvantage of producing a tarnish on the surfaces adjacent to the soldered surfaces.

(vi) Venice turpentine and Gallipoli oil are used (separately) when soldering pewter or britannia metal.

(vii) Russian tallow is employed when soldering heavy lead work.

(viii) Palm oil is employed in the treatment of light lead work.

(ix) Resin is an advantageous flux when subsequent corrosion is likely to be deleterious. It is used on soft alloys and tinware.

Hard Solders.

The hard solders may be divided into two groups, each of which will be considered separately in succeeding paragraphs—brazing or 'spelter' solders and silver solders.

Brazing or 'Spelter' Solders.

The basis of the brazing or 'spelter' solders ('spelters' they are commonly called) is brass. As the percentage of zinc is increased in the brasses so does their utility as solders for the more readily fusible metals and alloys increase. There is, however, a limit beyond which the addition of zinc to these alloys serves no useful purpose, owing to the fact that the resulting alloys are, on account of their brittleness and weakness, of no practical value. This limiting value is at about 45 per cent. of zinc. The particular alloy which is in most general use contains 50 per cent. of zinc and melts at about 875° C. (1607° F.). It is employed in brazing general brass work, which is possessed of melting points varying from about 890° C. (1634° F.) to about, 1000° C. (1832° F.). For brazing metals, etc., having higher melting points than the above brasses containing a less percentage of zinc are used. Thus, for the soldering of general ironwork the brass containing 35 per cent. of zinc is used, while for the brazing of copper and light ironwork that having 40 per cent. of zinc is employed. The most malleable solder contains some 30 per cent. of zinc, but its refractory nature somewhat subtracts from its value.

For certain purposes, the above alloys, owing to their yellow colour, are prohibited. Occasionally—e.g. in the brazing of nickel silver and iron—whiter alloys are required. For this purpose alloys containing nickel are employed, of which the following are examples :—

Copper per cent.	Zinc per cent.	Nickel per cent.
37·50	50·00	12·50
35·00	57·00	8·00

Other white solders, for use in the brazing of brass and more fusible than 'spelters,' contain a percentage of tin. Two such solders are given below :—

Copper per cent.	Zinc per cent.	Tin per cent.
43·34	6·66	50·00
57·50	25·00	17·50

The British Engineering Standards Association has issued a Specification (No. 263—1926) covering two grades of brazing solder. The copper contents for the two grades range from 53 to 55 per cent. and from 49 to 51 per cent. respectively, maximum limits being specified for the tin, antimony, arsenic, bismuth, iron and lead permitted in the alloy. A table is included as an appendix to the specification giving a range of grain sizes of granular solder to which it is recommended that the material be ordered.

Silver Solders.

Silver solders are employed for soldering gold, silver, copper, iron, and their alloys, the flux generally used being borax, though with very hard solders—i.e. solders having high melting points—powdered glass is sometimes of value.

Such as are suitable for general soldering and brazing, and containing an excess of base metal, are tabulated below :—

Copper per cent.	Silver per cent.	Zinc per cent.	Uses.
90—95	10—5	—	Solder for thin sheets of mild steel.
55·0	45·0	—	Alloy for instrument-makers ; tough and fluid.
50·0	30·0	20·0	Solder for small brass work.
46·0	38·5	15·5	Solder for bronze and nickel silver.
43·0	9·0	48·0	Solder for general work on copper alloys.

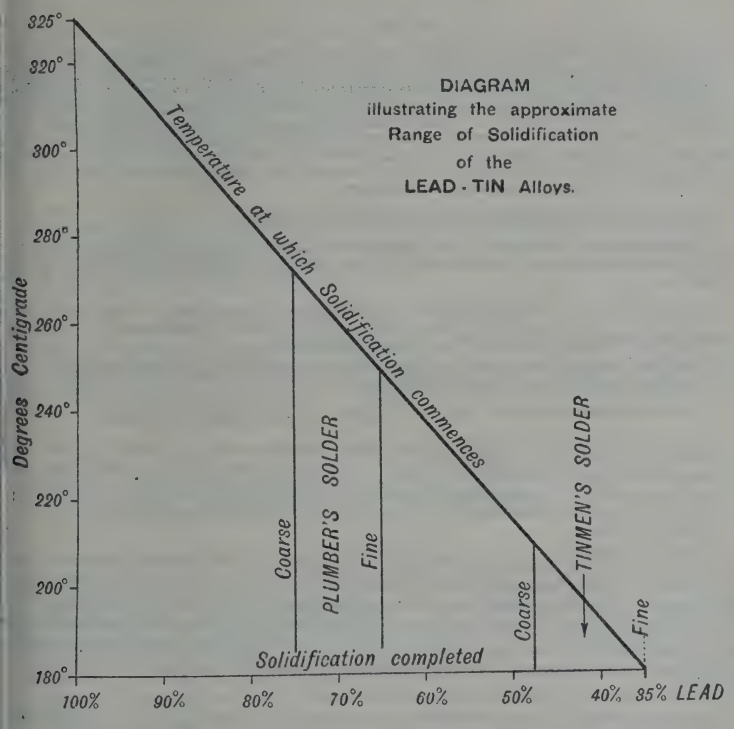
Tin-Lead Solders.

Tin and lead form a series of alloys, of which only those containing upwards of 35 per cent. of lead are employed as solders. These alloys may be divided into two classes, those that solidify at practically one definite temperature and those which are pasty over a considerable range of temperature before they become compeltely solid. The former are used as tinmen's solders, the latter as plumbers' solders, their value to each of these craftsmen being dependent on the properties associated with their solidification already mentioned. The diagram on page 2737 indicates the ranges of composition of the two types of solder already mentioned.

It will be seen that fine tinmen's solder solidifies at a definite temperature of 180° C. (356° F.) while coarse tinmen's solder commences to solidify at about 209° C. (408° F.), passes through a

sty stage, and finally completely solidifies at 180° C. (356° F.). Soft solder is the name given the alloy containing 50 per cent. of lead, whilst the fine plumbers' solder, used in making 'iped' joints, which commences to solidify at about 250° C. (482° F.), contains 66·6 per cent. lead. A solder frequently used for the union of tinplate contains about 90·0 per cent. of lead, id hence has a very marked pasty range of temperature.

The appearance of the tin-lead solders affords some idea as to their value. The surface of ood solder should be smooth and even and rectangular castings of the same should have a stinct furrow along the centre of their upper surface. The presence of zinc, though only traces this metal be present, causes the free surface of the solder to become minutely crystalline.



ismuth, copper, and silver do not affect the surface condition of solders when present in uantities varying from 0·2 per cent. in the case of the last metal to 1·0 per cent. in the case of ie first, while antimony up to 2·0 per cent. improves, rather than otherwise, the surface ondition. The presence of any of these elements leads to a reduction of the melting point of ie solder.

To Prevent Solder Sticking to Work.

To prevent hot solder sticking to work, mix common whiting or cold-water paint with wood lcohol, and paint the part that is to be protected. The hot solder will not stick, even if the iece is held in the melted alloy. Water will do as well as alcohol to mix the paint; but alcohol the most convenient, inasmuch as it can be used without waiting for the paint to dry. If ater is used the paint must be thoroughly dry, as otherwise the moisture will cause the solder fly.

Bismuth Solders.

These solders are alloys of bismuth, tin and lead, and are in general more fusible than the tin-lead solders. The useful alloys contain from 20 per cent. to 65 per cent. of lead, from 12 per cent. to 55 per cent. of tin, and from 12 per cent. to 55 per cent. of bismuth. The alloys containing the higher percentages of bismuth are the most fusible of these solders, which are employed for general pewtering. The solder containing about 50 per cent. of bismuth and 20 per cent. of tin has the lowest melting point of the series, its value being 96° C. (205° F.).

Aluminium Soldering.

The only process that can be recommended for the uniting of aluminium when the union is to be possessed of strength and durability is welding (see p. 2761). In certain instances the soldering of aluminium to itself or to other metals may, however, be resorted to. The process of soldering is considerably cheaper than is that of welding, and this, of itself, is worthy of consideration. The soldering of aluminium, however, presents numerous disadvantages owing (i) to the ready oxidation of aluminium and the difficulty of removing the oxide formed when the metal is heated, and (ii) to the rapid disintegration under the influence of moisture of soldered joints owing to the electropositive nature of aluminium with respect to those metals that may be usefully employed in the manufacture of solders.

The aluminium solders may be divided into four main groups.

1. Alloys having an aluminium-zinc base and containing varying proportions of copper. These alloys contain from 50 per cent. to 95 per cent. of zinc and from 5 per cent. to 30 per cent. of copper.

2. Alloys having a zinc-tin base and containing small proportions of such elements as aluminium (up to 12·5 per cent.), copper (up to 2·5 per cent.), phosphorus (in traces), etc. These alloys contain from 30 per cent. to 80 per cent of tin..

3. Alloys of cadmium and zinc or possessed of a cadmium-zinc base. The cadmium content n these alloys rarely, if ever, exceeds 30 per cent.

4. Alloys that are members of none of the above well defined groups of alloys.

Of group 1 solders, those aluminium-zinc alloys, containing from 3 per cent. to 30 per cent. of aluminium, have been largely employed for general soldering. For light aluminium work, where somewhat stronger solders are required, an alloy consisting of 80 per cent. of zinc, 12 per cent. of aluminium, and 8 per cent. of copper has been found to be of value, while for heavier aluminium work a solder containing 90 per cent. of zinc, 6 per cent. of aluminium, and 4 per cent. of copper is useful.

Of group 2 solders, the most satisfactory alloy (according to the *Iron Age*) consists of 69 per cent. tin, 2·5 per cent. of 10 per cent. phosphor tin, 26 per cent. of zinc, and 2·5 per cent. of aluminium. To avoid loss of the more easily volatile of these metals, the aluminium is melted first, zinc is then added in small pieces, then tin in small pieces, and lastly the phosphor tin. No acid is used, the solder being self-fluxing, but the surfaces to be soldered or joined are covered with a thin coat of solder in the usual way, and then brought together, heated with a soldering copper (iron), blow-pipe, or torch, until the solder already upon them is melted, when pressure is applied and the joint is made. The aluminium must be heated to about 660° F. before it can be soldered.

Of group 3 solders, it can be stated that most satisfactory results have been obtained with the alloys of cadmium and zinc containing from 20 per cent. to 30 per cent. of cadmium, both as regards strength and durability.

In preparing aluminium for soldering, the parts to be united must first be scraped or filed in order that the thin skin of oxide always present on aluminium that has been exposed to the atmosphere may be completely removed.

It is scarcely necessary to state that all oil, grease, or organic matter must be completely removed from the parts to be soldered. In practically all cases solders for aluminium are best applied without a flux. Generally speaking, the process of soldering aluminium is identical with that of ordinary soft soldering. It is well, however, in the case of aluminium soldering, to heat the parts to be united until the solder will just melt upon the surfaces to be joined and then to rub the solder into the metal with a wire brush or rod, in order that intimate contact may be made between the solder and the metal to be soldered. The strength of the joint depends to a large extent on the thoroughness with which this preliminary treatment is conducted. Soldering is then continued in the usual manner.

Cold Solder (amalgam Solder).

By shaking finely-divided copper with mercury in a little dilute sulphuric acid an amalgam ın be prepared which may be used to unite joints at ordinary temperatures. The amalgam is ɔrmed into pellets, which are heated till mercury begins to exude from the surface. These ellets are wiped free from mercury and are then rubbed to a soft paste in a mortar. The ırfaces to be united are first treated with sodium amalgam (sodium 2 per cent.), the soft paste f copper amalgam being then applied. The surfaces to be joined are then tightly pressed together, ıe union being completed in about three hours.

Soldering Aluminium Bronze.

To solder aluminium bronze with ordinary soft (pewter) solder: Cleanse well the parts to be ɔined from dirt and grease. Then place the parts to be soldered in a strong solution of sulphate f copper, and place in the bath a rod of soft iron, touching the parts to be joined. After a while copper-like surface will be seen on the metal. Remove from bath, rinse quite clean, and righten the surfaces. These surfaces can then be tinned by using a fluid consisting of zinc ıssolved in hydrochloric acid in the ordinary way with common soft solder. If the surface is ot coppered an aluminium alloy must be used.

Soldering Cast Iron.

(1.)

If the part of iron to be soldered is cast iron that is hard and thin, it should be polished on n emery wheel and made clean and bright. Then dip it in potash water, after which dip it for n instant in clean water, and wash quickly with undiluted hydrochloric acid of the ordinary ɔrength; go over it with powdered resin and solder made from half tin and half lead. This must e done quickly, before the surface has time to dry.

(2)

File the surface clean, and wash as before; wipe it over with a flux made of sheet zinc dis-ɔlved in hydrochloric acid until it is surcharged, or is a saturated solution and has been diluted ith its own quantity of water; then sprinkle powdered sal ammoniac on it, and heat it on a ıarcoal fire until the sal ammoniac smokes. Dip it in melted tin, and then remove, and rap off ıe surplus tin.

CASTING AND FOUNDING.

Moulding-sand.*

(1.)

1 cubic foot sharply burnt and pulverised pure fire-clay; 60 cubic inches sugar; 2 quarts water; quart paraffin oil. No lime or charcoal must be included in the mixture. Thoroughly mix. uitable for castings of ingot iron.

(2.)

93 parts pure quartz sand; 7 parts clay free from lime; the latter acts as a cement for ıe former.

(3.)

For small castings:—Red sand, 3 parts by measure; coal dust (finely sifted), 1 part by ıeasure.

(4.)

For large castings:—Red sand, 3 parts by measure; coal dust (finely sifted), 1 part by ıeasure; chopped straw, or dried horse manure, ¼ part by measure.

The latter makes the sand light and porous, facilitating the release of the gases. As the sand ecomes impoverished by being burnt, the coal dust is renewed from time to time. If paraffin s used to damp the mould, black sand will bind and can then be dried as when red sand is used.

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* For further information on Moulding Sands see "Sands and Crushed Rocks," by *A. B. Searle*, *Oxford University Publications*).

Moulding-sand which has partially lost its cementing power may have it restored by mixing with fresh sand.

Green, or floor sand that has ' gone dead ' (dehydrated) is frequently revived with Birmingham or Mansfield sand. Bunter sand, and also Barrow sand, have been found very good for the same purpose.

When the metal touches the clay bond the clay is undoubtedly killed, but not so the ferruginous bond, and long-life sand is generally rich in the latter.

Ferruginous bond in moulding sand is usually the cause of the production of a smooth, sound surface to the casting, particularly in the case of steel. In non-ferrous practice it is usual to ensure the smoothness of the skin by painting the surface of the mould or ' facing ' it with a layer of finer sand (facing sand) or a wash.

The washes used for painting the mould in non-ferrous work have usually either china clay or a graphitic substance as base. Graphite (plumbago) is itself used at other times. ' Scotch blacking,' which is a mixture of charcoal and graphite, is employed.

A suspension of the powder in water may be assisted by the addition of a little borax or molasses.

Cores.

For the making of ' cores ' in British foundries a ' compo ' moulding sand is made from ordinary sand such as Mansfield and broken fragments of graphite crucibles ground and mixed.

The admixture of the coarser material ensures good venting of cores; at times the sand alone is used.

Oil-bonded cores (where the oil is generally a commercial linseed, such as ' Baltic seed oil '), unlike those used in steel founding, have not met with much success in non-ferrous founding at home, but are adopted extensively in America, where a fairly coarse high-silica sand is the base. Sands from Lumberton and Howell, N.J., are so used. (*Horobin.*)

Testing Moulding Sands.

Methods of testing moulding sands are described in ' Sands and Crushed Rocks,' by A.B Searle (Oxford University Publications). A rough-and-ready test for voids and porosity consists in putting 50 c.c. of water in a glass measuring cylinder and 50 c.c. of the sand (previously passed through a 12-mesh sieve) into a graduated glass cylinder holding 100 c.c. The water is added to the sand and the cylinder with its contents is violently shaken until the water and sand are thoroughly mixed. The mixture is allowed to settle and the total volume is then measured. The reduction in volume is a measure of the volume of voids or pores in 50 c.c. of the sand.

By watching carefully, the time taken for the grains of different sizes to settle may also be noted.

To Repair Castings by Burning on.

A piece of machine-framing, the necks of rolls, or a standard which has been broken or found defective, may be repaired as follows : First cut away the defective parts down to the sound metal; build a coke fire round the part of the casting which is to be repaired until it is brought to a bright red-heat, then dust over the surface of the cut metal with powdered glass or borax. Then apply a hollow loam mould of the desired part to the casting, properly secured in position and provided with a hole for the exit of the metal. Pour very hot liquid cast iron into the mould, and allow it to flow away until the cut surface of the original metal of the casting can be felt with an iron bar to have become soft and pasty by contact with the hot liquid iron. Then stop the exit hole and allow the metal in the mould to set. If the operation has been properly performed the casting should, when struck, ring with the same sound as a single good casting, thus showing that the old and new metal are perfectly united.

Sealing up Cracks in Castings and Cementing Joints.

Cracks in the walls of pressure vessels may be patched by bolting on a plate with a thickness of sal ammoniac and iron borings beneath it. Many an external firebox sheet has been patched in this way.

A cast-iron cylinder for a hydraulic press in which the iron was so porous that, under 2,000 lb. ressure, the water ran down the outside in rivulets, has been sealed by filling the cylinder with ater containing a large quantity of sal ammoniac and letting it stand for a couple of days. At ie end of that time the cylinder was perfectly tight.

The sal ammoniac treatment has been used in railway shops for stopping cracks in bushing ylinders. In one instance an 18 × 22 in. cylinder was patched that way. It was an old cylinder iat had been bored out and a cast-iron bushing inserted. A coat of white lead was spread on ie outside of the bushing and after it was in place it was stayed to the cylinder wall by drilling oles through the wall and bushing and screwing in brass plugs. Some time later a crack running ngthwise between the plugs in the outer shell opened up for about 15 in. This was made tight y removing the piston, closing the ends of the cylinder and pouring a sal ammoniac solution rough the ports until the cylinder was full. This was allowed to stand for ten days, then ie cylinder was drained and refilled with a weak solution of muriatic acid and allowed to stand gain for about ten hours. The purpose of the muriatic-acid solution was to complete the work egun by the sal ammoniac. It was presumed that the acid would cut away the coating of ist produced by the sal ammoniac, and that the particles would gravitate toward the pressure. nd apparently this is what happened.

White lead has been used with advantage in making up threaded pipe joints and when press- g the brasses into locomotive driving boxes, placing driving pins in the wheels, etc. In the tter case the white lead acts as a lubricant while the job is being done, and later on, after it as set, it serves to cement the part pressed in. For many uses red lead is preferable to white, id next to litharge, is best for holding anything. If a threaded pipe joint is made up, say a in., with white lead, after a year's time it will still be possible to remove the fitting, but if the me fitting is made up with red lead, and it is desired to take it off after the lead has hardened, ie fitting will have to be broken unless sufficient heat can be applied to cause it to loosen from ie pipe.

There is no cementing effect when graphite and oil is used on a pipe thread. With graphite id oil on a thread a fitting can be made up tighter than would otherwise be possible. Also, ie graphite is squeezed compactly into the interstices in the joint and its very compactness olds it against blowing out under pressure, but it does not anchor the fitting. Therefore, no reater stress is necessary to remove the fitting at any time than was used to put it on.

Litharge will make a threaded pipe joint absolutely leak-proof against any kind of fluid and gainst any pressure that the pipe will stand.

(*Power*, *July* 1, 1924.)

Pattern Composition

A composition that has many advantages over wood for making small patterns can be made follows:—With hot water mix into a thick paste three parts by volume of starch, one part round glue, two parts fine resinous sawdust. The sawdust should not be added until the starch id glue have been dissolved by the water. After the ingredients are thoroughly mixed, heat ie whole to 190° F., and continue the heating until the whole becomes a hard mass, then allow cool, and remove from the receptacle. The resulting composition is a strong, hard, horn-like ibstance, that can be machined, sand-papered and varnished just as can wood. The principal lvantages of this composition over wood lie in the fact that it has no grain, and therefore turned id complicated patterns made from it do not have to be built up or glued together, and that r the same reason it is easier to turn and machine, and offers a smoother surface when finished. is also more fireproof than wood and not so readily affected by atmospheric changes.

(*American Machinist.*)

Shrinkage of Castings.

The allowance for shrinking in casting should be for each foot in length:—

	Parts of an Inch.		Parts of an Inch.
or cast-iron pipes	·125 = $\frac{1}{8}$	Brass	·17 = $\frac{3}{16}$
„ beams and girders	·1 = $\frac{1}{10}$	Lead	·31 = $\frac{5}{16}$
„ cylinders, large	·094 = $\frac{3}{32}$	Zinc	·25 = $\frac{1}{4}$
„ „ small	·06 = $\frac{1}{16}$	Copper	·17 = $\frac{3}{16}$
thick breadth	·156 = $\frac{5}{32}$	Tin	·25 = $\frac{1}{4}$
thin breadth	·156 = $\frac{5}{32}$	Bismuth	·156 = $\frac{5}{32}$

Cleaning Castings.

A large proportion of the loose sand on castings may be removed in the 'tumbling' process, but the adhering sand and scale of oxide, which soon destroy the cutting edge of the tools, are best reduced by a pickle; the following have met with general approval.

Sulphuric Acid Pickle.—Ordinary commercial sulphuric acid and water in the proportion of 1 of the former to 30 of the latter. In this case the castings are required to remain in the pickle for about 10 hours, and are then washed with hot water to remove all trace of the acid and prevent rusting.

Hydrofluoric Acid Pickle.—This acid is slower in its action and not so liable to cause corrosion as the above. The castings, however, should be first tumbled in order to remove loose sand (as the sand neutralises the solution very much more quickly than the iron) and then immersed in a mixture containing 1 of hydrofluoric acid to 15 of water. The bath should be maintained at a temperature of 120°F. by a steam coil. The castings are then washed in clean hot water and sometimes in hot water with a small proportion of lime (about 1 lb. of lime to 8 gallons of water).

The baths are best made of oak, wood pinned, with no exposed metal fastenings and well lined with asphaltum. The attendant should be furnished with wooden clogs, strong leather apron and rubber gloves to protect him from the acid.

The acid should be added *very slowly* to the *water* and well stirred in the process. Never add the water to the acid, otherwise the acid vapour will be carried all over the place.

An American factory is using high-pressure water for cleansing castings of sand and cores. A centrifugal pump, driven by a 50-h.p. motor, delivers 250 gallons per minute at a pressure of 250 lb. per sq. in., and the work is carried on in a closed chamber with glass windows. It is said that a casting which previously took a whole day to clean can be finished with the water jet in half an hour.

(See also 'Lubrication Troubles,' p. 1065.)

Dips for Castings.

Special for Electro-galvanising.—For preparing work for electro-galvanising the following can be used with advantage, but for no other solution except, perhaps, copper: Add to the dilute acid ½ lb. of sheet zinc to each 25 gals. of solution, adding additional amount occasionally as it works out.

Bright Dip for Iron.—Work that has been pickled in the ordinary way to remove sand and scale, and then dried, usually has a dull-black appearance. If the work is to be polished, the black will be removed and the colour restored in the polishing process; but if it is to be plated, or if it is to be left with parts of iron showing, the work should be run through the bright dip. This will bring it out white, improving the appearance and tending to make it take on a white deposit if it is to be nickelled. This dip is composed of :—

Hydrofluoric acid, 24 oz. Nitric acid, 10 oz. Metallic zinc, 2 oz. Water, 2 gals.

Work that is to be dipped should be strung on copper wire, and swirled around in the solution for a few seconds, rinsed in cold and then very hot water, and dried in sawdust. Articles should not be allowed to stay in the dip any time, as they would be spoiled and the solution ruined.

Satin-finish Dips.—Brass work requiring a satin finish may be dipped for a few seconds into a mixture consisting of :—

(1) Hydrofluoric acid, 1 part; Water, 3 parts;

then dried and run through the bright dip (4) to give it a lustre. If not satined enough the operation may be repeated.

(2) Hydrofluoric acid, 2 parts; Nitric acid, 1 part; Muriatic acid, ½ part; Water, 5 parts. After which the work may be rinsed, dried, and run through the bright dip (4) if necessary.

(3) Hydrofluoric acid, 2 parts; Nitric acid, 1 part; Water, 10 parts.

The following is a *bright dip* for copper, brass, bronze, or German silver :—

(4) Hydrofluoric acid, 4 quarts; Nitric acid, 3 quarts; Common salt, small handful.

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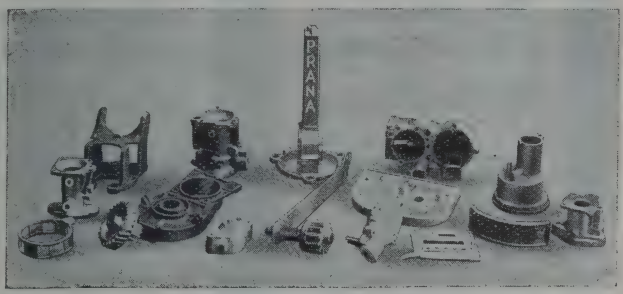

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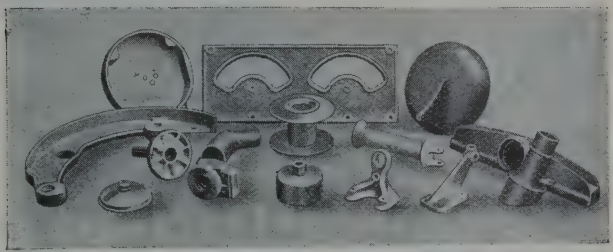

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Protection of Copper Castings.

The best method for protecting copper castings from oxidation in air, resulting in a coating ! verdigris, is for the casting to be done under hot water, with the metal at a very high tempera- ıre. This method, largely employed in Japan, forms a coating of red cuprous oxide, which as been known to give protection for upwards of thirty years.

Die-Casting.

ontributed by A. H. Mundey, Assoc.Inst.C.E., F.C.S., M.Inst.Met., of Fry's Metal Foundries Ltd.

Die-castings have been defined as castings produced by pumping metal into metallic dies at pressure higher than that of the atmosphere. This distinguishes them from the class of castings ıade by the permanent mould process into which the metal is simply poured, also sometimes :ferred to as die-castings and on other occasions as chill castings. There is, however, a tendency ow to make the phrase 'die-casting' embrace both the methods, and to distinguish the sections s 'gravity die-castings' and 'pressure die-casting.'

The equipment for die-casting includes a melting pot (usually of cast iron), gas-heated, placed ear the die-casting machine, for supplying the molten metal to the reservoirs of the caster.

The casting machines are of two general classes, those in which the metal is forced into the die r mould by the action of a plunger or pump, and the other in which compressed air is used for ıis purpose.

The reservoir attached to the machine is heated by gas, the pump being in direct contact ith it; the plunger is actuated, by means of a long lever, by the operator, the metal being forced om the pump chamber through a suitable nozzle into the dies. The moulds are attached to a ınged plate which swings away from the reservoir and pump nozzle, after each cast, to allow the orkmen to remove the tang and clean the metal passages.

The swinging plate is securely gripped to the reservoir at the moment of casting.

The mould is held to the swinging plate by means of a toggle joint, and varies in form and esign according to the particular castings; it is always at least a two-part mould, but usually also fitted with elaborate cores and drawbacks and mechanism for working them, which make ıe production of complex castings possible.

The dies are made in mild steel, alloy steel, and occasionally in cast iron, according to the loy and character of the work in hand. Sometimes the dies are heated, for other work they :e required to be water-cooled, so that no hard and fast line can be set in this respect.

The compressed-air type of die-casting machine consists of an air-tight cast-iron chamber ır the metal, suitably heated to keep the metal at the desired temperature. This chamber is ınnected with the die by one opening, and with the compressed-air line, by another. In the tter opening a valve is fitted with a lever for the sudden release of the air into the metal chamber. his valve also permits of a gradual decrease of the pressure on the metal after it has filled the die. his type of machine may be used on metals cast by the plunger type, but is especially suitable r metals that cannot be cast in the plunger type of machine on account of their high melting- ›int or corrosive action on the cast-iron plunger.

A die-casting die consists essentially of two parts which are brought together and maintained . perfect register by means of the usual dowel pins.

Internal threads are produced by screwed cores and externa' ones by removable screwed ıllars, whilst the holes which are usually drilled in machine-made fittings are in these cases ·rmed by means of retreating cores; the latter may be of almost any shape.

Small cores are operated by levers, large cores by a rack and pinion; they are always locked hilst the casting operation is proceeding. A vital consideration is the proper venting of the .e; the position and form of the vents can only be determined by experiment.

Great accuracy is obtainable; it is quite possible to produce castings to a limit of 0·001 inch.

Alloys used for Die Castings.

The alloys generally used are of considerable variation, according to the special purpose ıd circumstances; those of the white-brass or zinc-base group are usually approximately:

86 per cent. zinc; 7 to 10 per cent. tin; 4 to 7 per cent. copper; with 0·5 to 1·0 per cent. aluminium.

Increased tin gives greater ductility, whilst increased copper renders the alloy harder.

The tin-base alloys are (*a*) bearing alloys of all the usual grades of white anti-friction meta and (*b*) alloys specially designed to withstand the corrosive effect of chemicals in food-stuff certain gases, and even acids.

An alloy which is largely employed is :

90 per cent. tin ; 4 per cent. copper ; 6 per cent. antimony.

Of the aluminium group the most commonly used alloy is that known as No. 12, consisting of

92 per cent. aluminium ; 8 per cent. copper.

Sometimes a small quantity of magnesium is added and also frequently from 1 to 3 per cen of nickel.

The finish or skin of the casting is smooth and in a large measure satisfactory, but polishing plating, and bronzing are frequently employed, for protective as well as decorative purposes.

Shrinkage is an important consideration ; this varies greatly with the alloys used. Approx mate allowances are :

White brass or zinc base alloys . . .	0·0035
Lead base alloys	0·002
Aluminium alloys	0·007

The alloys generally used for die-castings are of relatively low melting-point and are of such constitution that they have a period of plasticity during the process of solidification. This add much to the chance of the production of sound castings.

Temperature of working is an important factor ; if too high, splashing results, with productio of long fins, oxidation, and discomfort in working. Too low temperature produces bad finis with little folds and creases on the surface, due to premature solidification.

The metals known as yellow metal—that is, high copper alloys—are cast almost exclusivel by the gravity process ; great accuracy is not obtainable for long runs, owing to the wear of th dies at the high temperature employed.

The alloys of this character usually employed are : copper, 90 to 95 per cent. ; aluminium, 1 to 5 per cent. ; also copper, 60 to 65 per cent. ; zinc, 40 to 35 per cent.

Mechanical Treatment of Metals and Alloys.

Method of Treatment.	Details of Method to be avoided.	Consequences of Details of Method of Work.
Hot working . .	1. Excess 'reduction' or rate of 'reduction.'	Cracking of metal.
	2. Deficient 'reduction' or rate of 'reduction.'	Coarse, weak metal.
	3. Excess temperature at commencement.	Weak, brittle metal and formation of fissures therein.
	4. Deficient temperature at conclusion.	Internal strain and consequent hardening. Possible 'season cracking.'
	5. Retention of scale on metal during operations.	Rough and pitted surface and possible cracking.
Cold working . .	1. Excess 'reduction' or rate of 'reduction,' without annealing.	Surface cracking and hollow drawing. Strain-hardening.
	2. Deficient 'reduction' or rate of 'reduction.'	Insufficient hardening — where hardening is expected.
	3. Unequal 'reduction' . . .	'Season cracking' or cracking during annealing.

Heat Treatment of Metals.

Method of Treatment.	Details of Method to be avoided.	Consequences of Details of Method of Work.
Annealing . .	1. At too high a temperature .	'Burning' and 'over-heating' in steel and brass. Brittleness and sponginess generally, owing to abnormal grain size.
	2. At too low a temperature . .	Insufficient structure change.
	3. For too long a period — at correct temperature.	Diffusion and aggregation of micro-constituents of metal or alloy.
	4. Careless charging in or firing of furnace.	Sudden access of heat may lead to cracking of cold metal.
	5. In an injurious atmosphere or in contact with injurious substances.	Copper is injured by reducing gases, steel by oxidising gases. Water and oil have injurious effects in many cases.
Quenching . .	1. From too high a temperature .	Cracking, warping and brittleness.
	2. From too low a temperature .	The object of the operation is defeated.
	3. Unequal	Warping.
Tempering . .	1. At too high a temperature .	Removes the effects of quenching.
	2. At too low a temperature . .	Does not remove the effects of quenching sufficiently.
	3. Unequal	Lack of uniformity and consequent failure.

See also p. 2690.

SECTION XL

PART II

WELDING AND CUTTING.

(Contributed by D. Richardson, Wh. Exh., A.M.I.M.E., Capt. R.A.F.)

OXY-ACETYLENE WELDING.

The term ' autogenous welding ' is a cumbersome and loose description for the process, which s become synonymous with oxy-acetylene or gas welding, although its real meaning, ' self-)ducing,' does not fully apply. The term was chosen to describe a process in which two sections metal are melted together by means of a blowpipe in contrast with the then existing methods, which a joint was made by the addition of a different metal, as in brazing. The term ' fusion ' onsidered to be much more appropriate than ' autogenous,' and is applied to a weld worked the fluid or vapour state.

The easy control and intensity of the oxy-acetylene flame, the low cost of operation, the atively inexpensive equipment required, the range of metals which can be welded, and the equate supplies of carbide of calcium, oxygen, etc., available, are factors which have led to its ny and varied applications.

The industrial development which has taken place can also be attributed to the increased ciency of the welder and the efforts that have been made to reduce the art of welding to a re scientific basis. The uncertainty of the results, upon which opposition and criticism are ally based, can be traced to the following causes: (*a*) inefficiency of the welder; (*b*) use of ective or unsatisfactory apparatus; (*c*) use of defective or unsuitable filling materials; (*d*) of proper supervision and maintenance of the generating plant and equipment; (*e*) un-ability of the material to be welded.

It is not difficult to eliminate these causes, and a well-trained welder using good apparatus, rect filling materials, etc., can produce welded joints on mild steel, cast iron, copper, brasses, nzes, aluminium and aluminium alloys, lead, etc., with mechanical and physical properties roaching those of the base metal, and in which the strength and service of the joint are olutely reliable.

Equipment.

The apparatus required for an oxy-acetyline installation depends upon several factors, such (*a*) the class of work to be welded; (*b*) whether a portable or stationary installation meets case; (*c*) whether production or repair work, or both, are possible applications; (*d*) the ilities for installing equipment and for handling the work in prospect. In general, the aratus and accessories will comprise a generator for generating the acetylene gas, which be a fixed or portable plant—the most portable type of plant uses compressed or dissolved ylene in portable cylinders instead of a generator; chemical and mechanical purifying aratus; oxygen apparatus for the production of oxygen, or oxygen in cylinders; oxygen ulators for lowering and regulating the pressure of the gas after it leaves the cylinder, to pressure required for the blowpipe, and, in the case of dissolved acetylene, an acetylene ulator for the same purpose; hydraulic safety valve or other safety device for dealing with losive mixtures of oxygen and acetylene or air and acetylene; welding and cutting blow-s of various capacities; accessories, such as flexible tubing, goggles, welding benches, blow-support, preheating devices, tools jigs, fluxes and filling materials, carbon paste and blocks, protection, protective equipment, etc., etc.

Fig. 1 shows in diagrammatic form an elevation and plan of the general lay-out of a acetylene welding and cutting installation. The letters refer to the same details in both views.

The acetylene generator, shown at A, is usually automatic—that is, the generation of gas i controlled entirely by the gasholder regulating the water supply or the carbide supply; B i

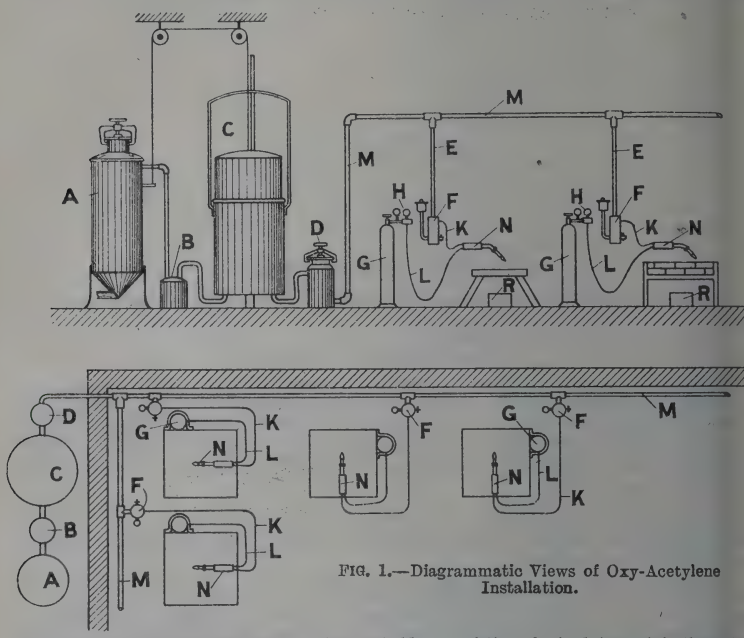

FIG. 1.—Diagrammatic Views of Oxy-Acetylene Installation.

a condenser, washer, and water-seal; C is a gasholder, consisting of a tank to contain the wate seal and a bell to store the gas; D is a purifying chamber and filter. The main piping, M, connected to the purifying chamber and forms a complete circuit of the welding shop; branc pipes, E, are taken from the main for supplying acetylene to each welding station; F is th

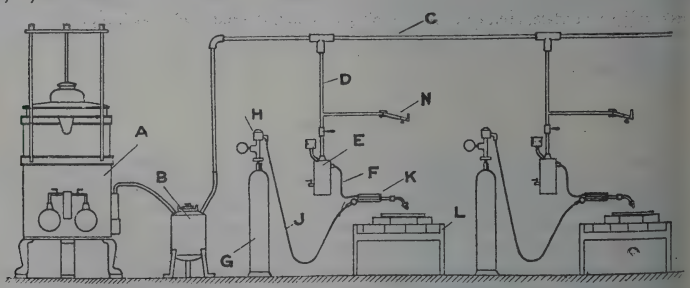

FIG. 2.—Diagrammatic View of Low-Pressure Oxy-Acetylene Installation.

hydraulic safety valve or other safety device; a flexible tube, K, connects the hydraulic safet valve to the welding or cutting blowpipe, N; G is the oxygen cylinder, on to which is screwe the oxygen regulator H; a flexible tube, L, connects the oxygen supply to the blowpipe N; tw common types of welding benches, with blowpipe cooling tanks R, are shown.

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For comparatively small installations, the generator, condenser, washer, water-seal, and gas-holder form a single piece of apparatus, as shown at A in fig. 2. The diagram shows at N a pilot light bracket attached to the branch tube D. An acetylene jet burner consuming about 5 litres of acetylene per hour, screwed into the bracket, forms an efficient and economical method of lighting the blowpipe. The burner should be at least 18 inches from the hydraulic safety valve and not more than 6 ft. above floor level.

An installation of the type described is known as a low pressure installation, to distinguish it from the type in which the acetylene is obtained from cylinders, known as the high pressure system.

Fig. 3 shows the equipment for the high pressure system. After passing through suitable acetylene and oxygen regulators the gases are conveyed to the blowpipe by means of flexible tubes.

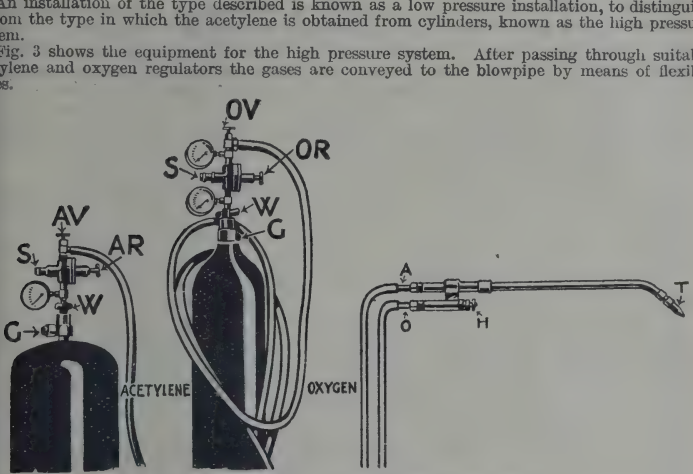

FIG. 3.—High Pressure or Dissolved Acetylene Installation.

OXYGEN SUPPLY.

The oxygen may be obtained in cylinders or may be produced on the premises. There are three methods of production, namely :—(1) chemical processes; (2) the electrolytic process; (3) the liquid air process. The older chemical processes are practically obsolete as regards oxygen for welding and cutting. Modern chemical processes are represented by the Oxygenite, Oxylithe, and Epurite processes. The Oxygenite process consists in the liberation of oxygen in a closed vessel by the self-combustion of a powder called Oxygenite, which is composed chiefly of potassium perchlorate, to which are added small quantities of powdered carbon and fullers' earth. One pound of Oxygenite will set free a little more than 5 cu. ft. of oxygen of 95–96 per cent. purity. In the Oxylithe process the chemical is brought into contact with water and the gas is liberated in a similar manner to the production of acetylene from calcium carbide. In the Epurite process the Epurite, which is a mixture of chloride of calcium, sulphate of iron, and sulphate of copper, diluted with water, produces oxygen. The main objections to chemical processes are the cost and impurity of the gas. The effect of impure oxygen in welding is to retard the welding operation, and thus increase the cost, and a tendency to produce blowholes. In cutting operations the purity of the oxygen is a most important factor, and tests have shown, for example, that with oxygen of 91 per cent. purity the cutting speed is halved when compared with oxygen of 98 per cent. purity. Simple and cheap apparatus is available for rapidly and accurately testing the purity of the gas.

The electrolytic and liquid-air processes may be used for producing oxygen on the premises. The gas can then be charged into cylinders or piped into the welding shop from large receivers into which it has been compressed, or it may be piped direct from the oxygen-producing plant. For information on 'Industrial Oxygen' reference should be made to a paper read by T. Campbell Finlayson on the subject before the Institution of Chemical Engineers, in June 1923, and the Report of the Oxygen Research Committee, Department of Scientific and Industrial Research, Sept. 1923.

Oxygen produced by the electrolytic or liquid air processes has a purity of the order 99 per cent. Unless the consumption is very large the first cost of an oxygen installation is comparatively high, and the majority of users obtain the gas in cylinders from the manufacturers. The cylinders supplied by the manufacturers for welding and cutting usually contain 100 cu. ft. of gas at a pressure of 1,800 lbs. per sq. in. (120 atmospheres). The Gas Cylinders Research Committee of the Department of Scientific and Industrial Research have made a series of recommendations for ordinary commercial cylinders used for the storage and transport of gases, including oxygen,

and are at present engaged on the standardisation of the fittings of gas cylinders.* They have also issued a Second Report dealing with the periodical heat-treatment of gas cylinders.† The Oxygen Research Committee have issued a Report mainly dealing with the storage and transport of liquefied gases, but also including a summary of the recommendations relating to compressed oxygen.‡ The British Engineering Standards Association have also formed a committee with a view to standardising cylinder valves and fittings.

In handling oxygen cylinders care must be taken against leakages, and particular care must be exercised not to oil or grease any part of the oxygen apparatus or supply line. Dust and moisture should be expelled by opening the cylinder valve before the cylinder is put into use. Repairs to cylinder valves should not be attempted by the user, and full cylinders should be handled carefully. All oxygen cylinders are fitted with valves having right-hand connections, and are generally painted black. No attempt should be made to transfer oxygen from one cylinder to another by rigging up some form of communicating tube. In the majority of cases a separate cylinder is used for each welding station or blowpipe in use. In some cases a number of oxygen cylinders are manifolded together, the gas being supplied to the shops through a system of piping. Oxygen manifolds should be able to withstand a pressure of at least 3,000 lbs. per sq. in., and each cylinder connection should be equipped with a high-pressure shut-off valve. It is extremely advisable that the necessary manifolds be purchased from a responsible manufacturer or made to specification. A cylinder valve should never be opened suddenly when the oxygen regulator is attached. In the event of the oxygen supply being restricted owing to the freezing of moisture in the cylinder valve, hot water only should be used to put it right. Leakages can be discovered by the hissing noise produced by the escaping oxygen, by the use of soap-suds spread over likely places, or by closing the valves on the blowpipe, cylinder and regulator, and noting how long the pressure holds up the gauges. Cylinders should be placed where they cannot be easily knocked over, and never near sources of heat. Spare cylinders should be safely and properly stored, care being taken not to store them near radiators, oil, grease, or combustible materials.

For estimating costs of welding, the following table will be found useful. The table gives the number of cubic feet of oxygen remaining in a 100 cu. ft. cylinder corresponding to various readings of the high-pressure gauge on the oxygen regulator. The amount of oxygen indicated by the gauge reading is more or less approximate as it depends upon the temperature of the oxygen. For practical work the deviations can be ignored, and would not affect the usefulness of the table. In general, the volume of oxygen in a cylinder is nearly proportional to its pressure, and thus, in the absence of the table, the volume of gas remaining in a cylinder can be determined by observing the gauge. A regulator provided with a pressure gauge which serves the double purpose of registering the pressure of the gas in the cylinder and indicating the amount which has been used on a welding or cutting operation, can be used.

Gauge Pressure in Atmospheres.	Cubic Feet of Oxygen in Cylinder.	Gauge Pressure in Atmospheres.	Cubic Feet of Oxygen in Cylinder.
10	8·3	70	58·4
20	16·7	80	66·7
30	25·0	90	75·0
40	33·4	100	83·4
50	41·7	110	91·7
60	50·0	120	100·0

At atmospheric pressure and temperature oxygen is rated at 12·08 cu. ft. per pound.

The idea of distributing oxygen in a liquid state and allowing it to gasify under control on the premises is being advocated, but there are many difficulties in actual practice which outweigh or eliminate the theoretical advantages claimed for this system.

Oxygen is supplied to the trade at prices which vary according to the size of the cylinder, quantity purchased, and other conditions. Cylinders are loaned, or may be purchased outright. Demurrage charges are made on hired cylinders when retained above a certain period. Oxygen cylinders are conveyed by the railway companies under strict regulations and conditions.

Acetylene Supply.

The acetylene may be obtained compressed in cylinders filled with a porous material, the pores of which hold a film of acetone in suspension, it is then known as dissolved or compressed acetylene, or may be generated on the premises. The precautions in handling acetylene cylinders are much the same as for oxygen cylinders. The gas should not be drawn off at too high a rate; in other words, the greater the demand the larger the cylinder. A recent investigation has been made to determine the percentage of acetone vapour in dissolved acetylene at varying temperatures and pressures. The figures show that the output of the flame diminishes by 1·8 per cent. for

* *First Report of the Gas Cylinders Research Committee* (1921).
† *Second Report of the Gas Cylinders Research Committee* (1926).
‡ *Report of the Oxygen Research Committee* (1923).

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1 per cent. of acetone vapour in the flame. The temperature of the cylinder should be kept low and the cylinder pressure should not fall too low in order to keep the percentage of acetone vapour low. For heavy continuous work two or more cylinders should be manifolded together by means of special adaptors supplied by the manufacturers. For general work cylinders containing 100 to 250 cu. ft. of gas are advisable. All acetylene cylinders used for oxy-acetylene welding are provided with valves screwed with left-hand threads. Cylinders for welding and cutting can be hired or purchased.

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Type.	General Purpose.	Gas Capacity (approx. cu. ft.)	External Dimension of Shell without Valve.		Approximate Net Weight without Gas (lbs.).
			Length (inches).	Diameter (inches).	
M.S. 1	Signalling	2½	6½	3½	3
X. 1	Motor Cycle Lighting	4	10	3	3¾
Z. 1	Motor Cycle Lighting	6	12½	3	5
A. 1	Motor Cycle and Auxiliary Car Lighting	12	12½	4	8¼
B. 1	Motor Car and Commercial Vehicle Lighting, and Air-Acetylene Processes	40	22	6¼	31½
X.C.	Welding Metal Cutting	100	33	8¼	74
L.Y.	Air-Acetylene Processes	125	39½	8½	101
X.D.	Marine Lighting	200	44½	10½	158
M.Y.	Portable Lighting Etc., etc.	250	49½	10¾	162

Before the gas is compressed into cylinders it is first purified and dried by several processes, and then compressed into solid drawn seamless steel cylinders.

The acetylene and oxygen being under high pressure, a perfectly uniform mixture of both gases can be maintained in the blowpipe and the pressure varied according to requirements. The elimination of the injector device, necessary in low-pressure blowpipes, and the hydraulic safety valve are advantages claimed for dissolved acetylene. Dissolved acetylene can be used with any type of oxy-acetylene blowpipe, but it should be recognised that the device for dealing with back-fires and flash-backs does not, as a rule, form part of the details of low-pressure blowpipes.

No demurrage charges for the use of cylinders are made on hired cylinders returned within thirty days of despatch, so that it is not necessary to purchase cylinders, although these can be supplied. Acetylene is supplied to users of purchased cylinders of 100 cu. ft. capacity and upwards at reduced prices.

The amount of acetylene in a cylinder cannot be determined, as in the case of oxygen, from the pressure gauge reading. The only accurate method of calculating the gas used from, or left in, a cylinder is by weighing before and after use. The empty and full weights are shown on a label fixed to each cylinder after charging. For calculating the volume of acetylene used the following are the equivalents:

1·1 oz. of acetylene = 1 cu. ft. (approx.)
1 lb. ,, ,, = 14·5 cu. ft. ,,

By means of an acetylene generator acetylene is produced by the interaction of calcium carbide and water. There are three general types of acetylene generators which may be classed under the heads of water to carbide type, carbide to water type, and the dipping or displacement type. They can also be classified as low-pressure and pressure generators. Briefly, low-pressure generators deliver acetylene to the blowpipe at a pressure of about 8 ins. water pressure (0·036 lb. per sq. in.), whilst pressure generators deliver the gas up to a maximum fixed by regulations at 250 ins. water pressure (9 lbs. per sq. in.). The latter are not in general use.

The design and layout of a generating plant must be such that the acetylene reaches the blowpipe in a good condition, in sufficient quantity and at sufficient pressure, otherwise the welds may be porous, brittle, and burnt. The acetylene generator should be of good and solid construction, and the gasholder capable of storing all gas generated under working conditions or after stoppage of work. There should be no signs of polymerisation or overheating of the gas even when working at the maximum delivery. The cross-section of tubes, pipes, and passages through valves should be such that the gas flows normally at the maximum delivery without loss

of pressure. The pressure of gas should be as high as possible, and at least equal to 6 ins. of water pressure in the case of small plants, and 8 to 10 ins. in larger plants. The pressure should remain practically constant during working and not vary more than $\frac{1}{2}$ in. water pressure. The charging and cleaning of the plant should not result in any appreciable waste of gas, and be made without introducing sufficient air to interfere with the proper working of the blowpipe. The generator should comply with the Regulations of the British Acetylene and Welding Association. The size of carbide suitable for the type of generator should be used. For commercial purposes carbide is broken and packed in the following sizes: 80/120, 50/80, 25/50, 15/25, 7/15, 4/7, 2/4, and 1/2 millimetres. The figures refer to the approximate mean thickness of a lump in millimetres. The 50/80 size is in general use for welding and cutting generators. The choice of carbide-to-water, water-to-carbide, etc., generating plants depend on several factors, such as location, class of work, etc.

The Carbic system of generation is based upon the use of a carbic cake, which consists of specially prepared and treated carbide compressed into cylindrical cakes. It is claimed that the process renders every particle of carbide impervious to moisture, so that generation can only take place while water is in actual contact with the cake. Freedom from danger in handling, and from after-generation, convenience in handling, elimination of waste, and purity of gas are factors which have led to the success of the system.

Overloading of the plant is a common cause of defective welds. In carbide-to-water generators an allowance of not more than 1 cu. ft. of acetylene per hour for each pound of carbide in the rated charge is recommended. In the case of water-to-carbide generators the maximum rate of gas consumption should be half this value. In well-designed generators the yield of acetylene gas from the generator will be 85 to 90 per cent. of the carbide yield. Practically, for every 10 lbs. of carbide used in the generator a yield of 4·0 cu. ft. of gas at the blowpipe can be assumed. The proper care, cleaning, charging, and maintenance of generators is of first importance if reliable welds are required. Leakages of acetylene should be traced by means of soap-suds and never with naked lights.

The acetylene generating plant should be installed in a well-ventilated shed or building, or in a lean-to having no direct communication with a workshop or adjacent building, and no unauthorised person should be allowed to enter the building or enclosure. Where artificial light is required in a generator house or near a generator, electric incandescent bulbs, encased in outer gas-tight globes, should be used. A conspicuous notice prohibiting lights or smoking should be exhibited on the outside of the generator house. Generators should be cleaned and charged in daylight. Electric switches, fuses, etc., should be placed outside a generator house, or they should be so constructed that risks due to sparking or fusing are avoided. To comply with existing regulations, a licence under the Petroleum Acts must be obtained from the local authority for the storage of carbide. A sliding scale of licence fees, varying from 5*s.* to £5, according to the quantity stored, has been fixed, and severe penalties for contravening any condition printed or endorsed on the licence by the local authority are included. A raised platform in the generator house should be provided for the storage of carbide. Drums containing carbide should not be placed in the welding shop or near a flame. Care must be exercised in opening drums to avoid striking sparks; a proper drum opener should be provided for this purpose. When the contents of an opened drum are not entirely used in charging the generator, the remainder should be transferred to a storage bin which can be sealed.

All users and prospective users of oxy-acetylene equipment should consult the memorandums issued by the Factory Department of the Home Office* and the Board of Trade.†

Purification of Acetylene.

The chief impurities found in acetylene gas are (*a*) those which affect the quality of the weld, such as sulphur, phosphorus, silicon, finely subdivided lime; and (*b*) those which affect the cost of the weld, such as hydrogen and hydrogen compounds, nitrogen and nitrogen compounds, and water vapour. An efficient chemical purifer must be provided capable of removing sulphur and phosphorus compounds, the acetylene must pass through an efficient water-scrubber to remove or partially remove the impurities soluble in water and, finally, the gas should be filtered to remove solid impurities not eliminated by washing or chemical purification. A first-class purifying material will generally remove chemical impurities, moisture, and lime dust which are a common cause of defective welds.

Purification of the gas must be efficient, and the care and maintenance of the purifying chamber is very important. The cross-sectional area of the purifier should be ample, and the depth of purifying material should not exceed that specified by the makers, otherwise loss of pressure and overheating of the gas will take place. The quality of the gas can be simply and quickly tested by the use of a white absorbent paper, saturated with a 10 per cent. solution of silver nitrate, exposed to the gas. Should the paper turn black after a few seconds' exposure, the gas is unsuitable for welding purposes.

Among the best known purifying materials are Heratol, Catalysol, Klenzol, and Suder. The three last are distinguished by their regenerative properties—that is, they recover their activity by simple exposure to the air, and thus can be used over and over again. In purifying acetylene the cost should be based on the volume of gas purified and not on the first cost of the material.

* Dangers from the use of acetylene gas and in oxy-acetylene welding in factories (Form 1704).
† Instructions to Surveyors. Repairs to Boilers (Circular 1596).

Preservation of Acetylene Apparatus.

The question of preventing the corrosion or deterioration of the material used in the manufacture of acetylene generators, purifying vessels, and other parts of the generating plant is important in view of the fact that according to the efficiency of the coating the life of the plant may be a question of months or years.

There are five cases to be considered, namely: (*a*) preservation of the external parts of the apparatus; (*b*) preservation of the immersed parts; (*c*) preservation of parts in contact with moist and impure gas; (*d*) preservation of the interior of purifying vessels; and (*e*) preservation of carbide containers. With regard to (*a*), good ironwork paints give good results when applied well to properly prepared surfaces. At least two coats should be applied. If the apparatus is exposed avoid paints used for woodwork, plaster, etc. For (*b*) it is necessary to use a waterproof paint which will resist the prolonged action of water. The best results are obtained when the base consists of tar and graphite. For (*c*) the paints used for immersed parts of acetylene apparatus give the best results, but the work must be done with great care. For (*d*) the majority of industrial preservative paints give satisfactory results, except those containing a zinc or similar base. Several coats are necessary, and great care is required in applying the coats on to well-prepared surfaces. For (*e*) tests have shown that no paint or coating will satisfactorily resist the action of the lime residue at the temperatures usually present, and that the lime residue appears to have a preservative action on the parts with which it is in contact. It is therefore unnecessary to protect these parts.

Oxygen and Acetylene Regulators.

Regulators in common use to reduce the pressure of gases are of the diaphragm type, and may be roughly divided into two classes—first, where the pressure of the gas closes the inlet, and, second, where the inlet is closed by a spring. They are designed to automatically deliver gas to the blowpipe at any uniform pressure to which the regulator is set. They should be designed for working over a wide range of pressures, and should be sensitive even at low pressures. Oxygen regulators are usually equipped with two gauges, a high-pressure gauge, which shows the pressure of gas in the cylinder, and a low-pressure gauge. Pressure gauges should be provided with a check to prevent a sudden inrush of gas. For successful welding the regulator should be provided with a low-pressure gauge, giving the pressure at which the gas is delivered to the blowpipe. The range of the low-pressure gauge should not be too great, and a maximum reading of 75 lbs. per square inch will be sufficient for the majority of welding and cutting operations. Regulators must be kept in good order, otherwise defective welds are inevitable. Regulators intended for use when welding should not be used when cutting unless the work is within the range of the regulator. It is dangerous to use oil, grease, or any organic material for lubrication. If it becomes necessary to lubricate the pressure-regulating screw, or to repack a needle valve, a little glycerine should be used. The pressure-adjusting screw should always be released after ceasing work and before changing from one cylinder to another. Creeping regulators or regulators with leaky valve seats should be overhauled, because they are likely to become dangerous and uneconomical. The gradual increase of pressure when the blowpipe is shut off indicates a creeping regulator. Regulator gauges should be tested at regular intervals but never tested with an oil-testing pump.

Acetylene regulators are usually painted red and have a left-hand screw thread corresponding with that on the standard valves of acetylene cylinders. Regulators for oxygen are usually painted black and have a right-hand screw thread. Any possible confusion is obviated by this distinction.

Cylinder valves should be opened very slowly so that pressure does not suddenly come on to the gauges or diaphragm. The proper working of regulators largely depends upon the care given them. They should not be left in places where dirt or dust may get into the interior and be deposited on the seat or inlet nozzle, and they should never be repaired by inexperienced workmen.

Hydraulic Safety Valves.

These are indispensable in low-pressure and medium-pressure installations, i.e. where the acetylene is generated on the premises. Their function is to provide a water-seal and to prevent explosive mixtures entering the acetylene piping or generating plant. The valve should be chosen so that the maximum supply of gas is obtained without burning the metal. Safety devices based on mechanical principles, such as valves, etc., may more or less prevent the return of the flame, but are not infallible in preventing explosive mixtures forming in the generating plant.

Hydraulic safety valves should be charged and examined daily, and should be installed so as to facilitate filling to the proper level. The local authority responsible for issuing the carbide licence generally insists on the provision of a metal shield for the valve, to avoid accidents in the event of the valve being fractured. In general, the valve should be charged with water whilst the acetylene tap admitting gas to the valve is open. The design should be such that no water is carried over with the gas. A recent investigation has shown that the water vapour contained in the gas rises with the temperature, and can attain 7 per cent. when the gas is at 97° F. With a 5 per cent. of water vapour, there is a reduction of over 8 per cent. in the speed of welding. No safety valve should have more than one outlet to which a blowpipe can be connected.

Pressure relief valves or safety valves used on pressure generators should be tested periodically; they do not replace the hydraulic safety valve, which is still required in a modified form.

Piping and Flexible Tubes.

The acetylene piping should be large enough to avoid loss of pressure. The size of pipi should be dependent upon its length and the maximum supply of gas required. All piping shoul when possible and convenient, be run overhead. When piping has to be run underground should be placed in properly ventilated trenches. Piping and connections should be installed l workmen experienced in the installation of acetylene apparatus. Piping should be so arrang that any moisture will drain back to the generator, and where low points cannot be avoided the must be drained through drip cups closed with screw caps or plugs. No pet cocks should be use A main gas cock should be arranged where it can be conveniently reached and near the point entrance, so as to allow for shutting off the gas supply from any workshop. Gas cocks shou be provided on the branch tube leading to the hydraulic valve so that a valve may be remov without discharging the line. All cocks, valves, unions, and joints should be full bore, and t installation should be thoroughly tested when the system is completed, and at regular interval It should not show a loss of pressure exceeding two inches of mercury within twelve hours wh subjected to a pressure equal to a column of fifteen inches of mercury. Acetylene piping shou be painted a distinctive colour. Galvanised iron pipe with welded or threaded connections shou be used for piping acetylene. The pipes should be of uniform diameter, and bends—the numb of which should be as small as possible—should be used in preference to square elbows. Co pressed oxygen should never be used for testing or cleaning acetylene piping. If compressed a is used for this purpose the acetylene plant should be disconnected.

The following table will serve as a guide in installing acetylene piping for welding purpos Manufacturers of welding equipment will supply full particulars as to pipe sizes suitable for a particular lay-out.

Acetylene Main Piping.

Approximate Diameters of Service Piping. For working pressure of 6 in. to 10 in. water column

Consumption of Acetylene per hour.	Length of Pipe.	Internal Diam. of Piping.
Cubic feet.	Feet.	Inches.
15	100	$\frac{1}{2}$
40	100	$\frac{3}{4}$
80	100	1
140	100	$1\frac{1}{4}$
225	100	$1\frac{1}{2}$
400	200	2
1000	200	3
2500	200	4

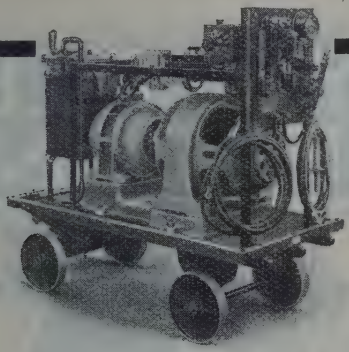
Ordinary black steel piping may be used for low-pressure oxygen, and extra heavy steel pi for high-pressure lines. The suitability of steel piping for this purpose is being investigated. N oil or grease must be used for the connections; litharge and glycerine should be used. Th diameter of oxygen piping will depend on the length of the lines. A $\frac{3}{4}$-inch pipe is suitable f supplying twenty welding stations provided the length of the line is not more than 300 ft. an the maximum consumption is not more than 500 cu. ft. per hour.

The flexible tubes conveying the gases to the blowpipe should not be too long, too flexibl or too rigid. The strength should be such that for welding purposes the tube should withstand pressure of 100 lbs. per sq. in. without bursting, swelling, or leaking, and for use in cutting operatio it should withstand 300 lbs. per sq. in. Armoured or wired hose is not necessary or recommende for ordinary welding and cutting operations. Three-ply tubing with a core of pure rubber satisfactory for ordinary work, and for welding and cutting in confined spaces fire-resisting ho should be used. Avoid greasing the ends of the tube to facilitate fixing to the blowpipe or oth connectors; use water. Tube clips should be used in preference to wire, etc., for securing th tube firmly to the connectors.

Flexible tubing should be examined regularly, and defective tubing should never be use Avoid tangling or kinking the hose, long lengths—about 10 ft. lengths are suitable for stationar equipment and 15 ft. for portable—dragging the hose along the floor, and exposing it where it likely to get damaged. Special care should be taken to avoid the interchange of the oxygen an acetylene tubes when connecting up to the blowpipe. Both acetylene and oxygen tubing shoul be blown through occasionally, so that dirt and dust will not get carried into the blowpipe, an tubing should be tested periodically.

Welding Blowpipes.

Welding blowpipes are classified in relation to the pressure of the acetylene. Low-pressur blowpipes are those fitted with an injector to aspirate the acetylene, which is supplied from generator under a pressure of 6 to 12 inches of water. Medium-pressure blowpipes, sometime called positive pressure, use acetylene generated from a pressure generator at a pressure up t



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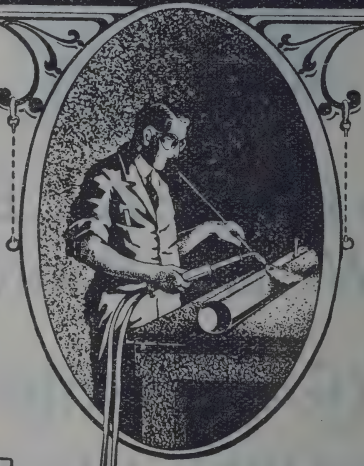

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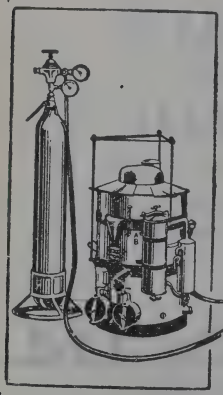

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9 lbs. per sq. in. An injector or partial injector forms part of the blowpipe. Recent developments have led to the introduction of blowpipes which use the acetylene at a pressure little different from that used with positive pressure blowpipes, but with the important difference that the oxygen pressure is considerably reduced, being, in fact, less than the acetylene pressure. High-pressure blowpipes use the acetylene supplied from acetylene cylinders, and are designed to mix acetylene and oxygen in equal volumes. No injector is required, and a change of nozzle with a corresponding adjustment of pressures is all that is required when changing over from welding one thickness of material to another.

In the low-pressure system thorough mixing of the gases in the blowpipe is very necessary. To obtain this, well-designed blowpipes carefully adjusted to the oxygen pressure recommended by the maker are essential. A typical low-pressure blowpipe working on the injector principle is shown in fig. 4.

The size or power of blowpipe which should be used depends upon the thickness to be welded. By power is meant the amount of acetylene consumed per hour. Too small a power produces the defects of adhesion, inclusion of oxide, overheating, and burning of the welds. Too large a power produces a molten bath which is much too large, holes, and adhesion in the lower part of the weld.

The figure denoting the power of blowpipes is usually supplied by the maker, and is sometimes marked on the blowpipe. In welding materials other than wrought iron and steel the power of blowpipe to be used is dependent upon the material, its dimensions, and whether the job has been preheated; as a general rule the power of blowpipe for a given thickness of material is greater, as in melting, for example, cast iron, copper, or aluminium, more heat is required to melt a given weight of the metal, and, in addition, the high temperature part of the flame is held farther from the molten metal.

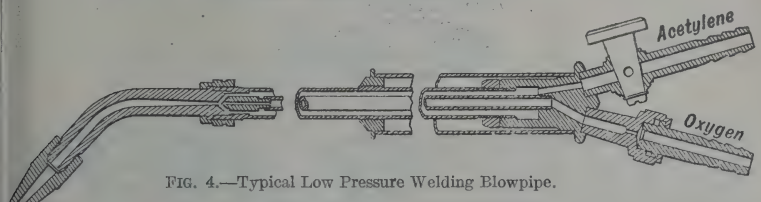

FIG. 4.—Typical Low Pressure Welding Blowpipe.

All blowpipes should be carefully handled and treated as precision tools. The procedure to be followed in lighting and extinguishing the blowpipes varies with the design and type of blowpipe. The manufacturer's instructions should be closely followed. Lighting devices are convenient and safer than matches. A blowpipe should never be put down, unless a blowpipe stand is provided, until the gases are turned off, and should never be hung from regulators or other equipment. Gas economisers which serve the purpose of a stand and automatically cuts off the gases, except sufficient acetylene for a pilot jet, are valuable, especially in repetition work. Carefully avoid the use of grease or oil, and never dismantle a blowpipe with a view to overhauling, as this may lead to irregular working after assembling. In the event of obstruction of the nozzle, a soft brass wire should be used for cleaning. Dust in the interior of the blowpipe can be removed by blowing oxygen through from the nozzle end.

In the case of back-firing or flash-back due to overheating, the tip should be cooled in water, taking care to close the acetylene valve and to leave the oxygen valve slightly open. By back-fire is meant the momentary return of the flame into the blowpipe tip, which may relight immediately upon withdrawing the blowpipe away from the work or necessitate the reignition of the gases by means of a lighter. By flash-back is meant a sustained back-fire, the flame burning in the mixing chamber with a squealing sound accompanied by a smoky, sharp-pointed flame, necessitating the immediate cutting off of the gas supply, to prevent severe heating and possible destruction of the blowpipe head, and the subsequent cleaning to remove carbon deposits. An iron or steel wire should never be used for cleaning the nozzle.

Back-firing and flash-backs, which are a common cause of defective and expensive welds, may be due to one of the following causes:—

(*a*) Faulty design and manipulation of the blowpipe.
(*b*) Enlarging the nozzle orifice when removing obstructions.
(*c*) Working in confined spaces or with an accumulation of slag on the nozzle.
(*d*) Necessity for overhauling and internal cleaning.
(*e*) Restriction and fluctuation in the acetylene supply due to bad lay-out, exhausted purifier, etc.
(*f*) Defective hydraulic safety valves leading to air and moisture being carried with the gas.
(*g*) Defective oxygen regulators.
(*h*) Presence of solid matter in the gas either from the acetylene generator or inferior flexible tubing.

Oxy-Acetylene Flame Characteristics.

The combustion of acetylene in oxygen produces a flame which consists of two parts—an inner cone, incandescent, clear, and well defined; and a non-luminous outer envelope which may be transparent or more or less opaque according to the purity of the acetylene. The exact character of the flame will depend on the proportion of the oxygen and acetylene as they emerge from the nozzle. The oxygen and acetylene should mix in approximately equal proportions. Gas-ratio, or the ratio of the oxygen to the acetylene consumption, is an important factor in determining the quality and cost of welds. Varying proportions of the gases produce three characteristic types of flames, commonly known as carbonising, neutral or normal, and oxidising. These are shown in fig. 5. It is important that at all times the flame should be neutral—that is, there

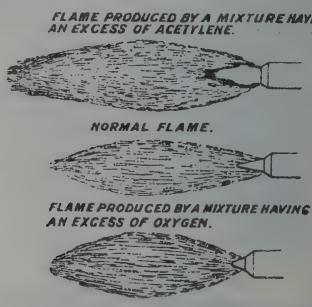

Fig. 5.—Flame Characteristics.

should be no excess of oxygen or acetylene. Defective welds are produced with carbonising and oxidising flames. It is particularly important that there should be no excess of oxygen, which not only tends to produce weak welds, but also to blow the metal forward and produce adhesion. Regulation of the flame during important welding operations is essential, as very few blowpipes maintain a neutral flame under welding conditions, and further, the operator has a tendency to adjust the flame oxidising. It is advisable to adjust the flame whilst wearing dark glass goggles.

It is necessary to emphasise that the white cone of the flame should never be brought into contact with the molten metal, and that its distance from the molten metal depends, in general, upon the metal being welded and its thickness.

Goggles and Protective Equipment.

For welding with acetylene it is necessary to protect the eyes with goggles fitted with suitable coloured glasses. There are a great many different kinds of special safety glasses on the market and many combinations of ordinary coloured glass are in common use. The eyes must be protected from injurious rays, the heat and glare from the work, and from particles of hot metal that fly up from the weld. To obtain the clearest definition or visibility with the least amount of glare, the selection of the colour tint in safety glasses should properly be decided by an expert; the depth of the tint may be determined best by the operator himself, owing to the individual difference which will permit one man to see clearly through a glass that would be too dark for another man. Amber, dark-amber, or dark-amber-green glasses give efficient protection. Glasses showing blue or violet tints should be avoided, except in certain combinations where they are used to obscure other colours.

Welders employed on heavy work should be supplied with fireproof gauntlets and aprons, as a protection against radiated heat, and where welding is being performed in the interior of some structure or confined space all the outer clothing should be fireproof.

Filling Materials.

The necessity for employing the best materials for every welding operation cannot be too strongly emphasised. It is only by using the most suitable filling-in wires, rods, and fluxes, specially manufactured and controlled for each particular metal or alloy, that the most satisfactory work can be done.

Thin material is frequently welded by bringing the edges into contact and melting them together, but generally a filling material or 'welding rod' is melted into the groove or crack.

Filling materials must, where possible, not only be of the correct chemical requirements to replace loss in the molten zone, to counteract the tendency of the metal to oxidise, to assist in

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making the molten metal flow readily, or to break down oxides when formed, but they should also act satisfactorily under the blowpipe. As a general rule, the welding wire or rod should have practically the same composition as the material to be welded.

The choice of the right size of welding wire or rod is important, and melting of both should take place in the molten bath and not in the flame. The following table gives the sizes of wire for 'forward' welding iron and steel. In the case of other metals the figures hold good, except for very thin material, when a size of not less than $\frac{1}{16}$ in. should be used.

SIZES OF WELDING WIRE FOR IRON AND STEEL ('FORWARD' WELDING).

Thickness of Material.	Size of Welding Wire.		
	S.W.G.	Decimal equivalent.	Nearest $\frac{1}{64}$.
Gauge 20 to Gauge 18	16	0·064	4
$\frac{1}{16}$ inch	15	0·072	5
$\frac{1}{8}$ "	12	0·104	7
$\frac{3}{16}$ "	9	0·144	9
$\frac{1}{4}$ "	6	0·192	12
$\frac{5}{16}$ "	5	0·212	14
$\frac{3}{8}$ "	3	0·252	16
$\frac{7}{16}$ " to $\frac{1}{2}$ "	2	0·276	18
$\frac{9}{16}$ " to $\frac{5}{8}$ " to $\frac{3}{4}$ "	0	0·324	21

The following table also gives the sizes of wire for 'backward' welding; it should be pointed out that this method of welding is more reliable and economical than 'forward' welding, and is rapidly displacing the latter for welding iron and steel of medium and heavy thicknesses.

SIZES OF WELDING WIRE FOR IRON AND STEEL ('BACKWARD' WELDING).

Thickness of Material.	Size of Welding Wire.		
	S.W.G.	Decimal Equivalent.	Nearest $\frac{1}{64}$.
Gauge 20 to $\frac{1}{8}$ in.	14	0·081	5
$\frac{3}{32}$ in.	11	0·116	8
$\frac{1}{4}$ to $\frac{5}{16}$ in.	8	0·160	10
$\frac{3}{8}$ in.	6	0·192	12
$\frac{9}{16}$ to $\frac{3}{4}$ in.	4	0·232	15

Fluxes.

It is not always possible to include deoxidisers and special elements in the welding rod itself. By using a combination of chemicals in the form of a powder, liquid, or paste, known as a flux, the difficulties of producing sound and reliable welds are frequently overcome. A flux is used for (*a*) cleaning the parts to be welded; (*b*) eliminating and preventing the formation of oxide; (*c*) replacing elements burnt out by the flame; (*d*) facilitating the flow of the metal, and, when melted, (*e*) protecting the surface of the molten metal from the action of the flame and preventing blow-holes. The mantle of a well-regulated and well-manipulated flame protects, in a measure, the molten metal from oxidation. A flux is necessary in welding steel (except in cases where the steel welding wire contains deoxidising materials, as, for example, Ferrox), cast iron, copper, aluminium, etc.; for successful welding the proper flux should be used, and as the welding rod and flux are important factors in welding they should only be obtained from reliable manufacturers.

Preparation of the Work.

One of the first principles of sound welding is securing complete fusion and perfect union o the filling material and the edges of the parts to be welded. To ensure this, good preparation i necessary, which includes, as a rule, the cleaning of the edges and the welding wire, the bevelling or chamfering of the edges, the adjustment and maintenance of the parts in position, and allow ance for expansion and contraction effects. In general, the preparation of the parts varie according to the thickness and nature of the metal and with the organisation and equipmen of the workshop.

Cleaning the parts to be welded and the welding wire or rod is essential. Bevelling is necessary for materials $\frac{1}{8}$ inch and above in thickness. Bevelling ensures good penetration, increase i ductility and strength, economy, and reduction in the overheating effects. The angle of th bevel depends upon the thickness of material and whether 'forward' or 'backward' welding i practised. All metals from $\frac{1}{8}$ inch up to $\frac{3}{8}$ inch, and in some cases $\frac{1}{2}$ inch, should be bevelled fron one side only. Where possible, pieces exceeding $\frac{1}{2}$ inch should be bevelled from both sides In forward welding the V formed by the two bevelled plates should be about 90°. In backward welding for material up to $\frac{1}{4}$ inch an angle of about 45°, and above $\frac{1}{4}$ inch an angle of 60°, can be used. The bevel should extend to the bottom of the plate, and thorough penetration and complete fusion should be obtained. In repair work preparation of the work is a very important feature and will save considerable time and keep the cost of welding low. Should it be necessary to re-weld a joint previously welded, it is essential that the weld metal be entirely removed, and on old work the same instruction applies, and corroded metal must be removed. In the case of aluminium repairs, for example, good judgment, as shown by the preparation, means success and bad judgment a ruined casting.

Expansion and Contraction.

It is impossible to produce satisfactory work unless expansion and contraction effects are properly allowed for. Warpage and residual stresses, followed by failure, are the common result of welders failing to master this subject. The methods commonly employed are, in the case of thin sheets, tacking; in the case of heavier material and castings, setting the plates so as to form an angle, heating the entire work, partial heating, heating restraining members, breaking a member so that expansion and contraction can take place freely, bending or springing the material, etc.

If expansion can take place in all directions, it will give the welder no trouble, but he should operate so as to leave practically no residual stresses. If, however, welding takes place at a point that is confined by various parts or by the particular construction of a piece, it is necessary to give it due consideration.

The effects of contraction must be considered equally with those of expansion, as failures, cracks, etc., can often be traced to neglect of this property.

Preheating.

This may be partial or total, depending upon the work in hand, and is mainly employed with a view to (*a*) allowing for expansion and contraction, (*b*) decreasing the cost of welding, and (*c*) producing a more homogeneous joint. Preheating is usually carried out with the welding blowpipe, oil or gas burners, charcoal, or other suitable fuel. Where fuels such as charcoal are used for preheating, the combustion gases should, where possible, be carried away. In any case ventilation should be provided to avoid the harmful effects of the gases produced by combustion. The method used should be governed by the particular work in hand.

No general rules can be given for preheating temperatures, as the degree of heat necessary will, of course, depend upon the size and shape of the object to be welded. As a general rule, however, cast iron should be preheated to a dull red heat for small and simple castings, and to a blood-red heat for large or complex castings; aluminium and its alloys should be preheated very carefully, as too high a temperature will lead to the collapse or distortion of the article being welded.

Preheating machines burning paraffin and giving a flame of high calorific value, smokeless and transparent, give satisfactory results where portability and a powerful flame are required.

After-Treatment of Welds.

Improvement in the structure of welds with a consequent increase in strength and ductility is the result of proper after-treatment of welds. Thermal or mechanical treatment, or both, carried out in a correct manner is invariably beneficial, except in the case of defective welds.

Strength of Welds.

With proper equipment and suitable filling materials, the strength of a weld will depend mainly upon the care and skill of the operator. A good operator should be able to obtain welds 95 per cent. the strength of the original material on material of good weldability; for the average welder 85 per cent. should be taken as the lower limit of strength.

Recognition of Materials.

Some of the means by which the materials of the parts to be welded may be recognised are follows: colouring, appearance of surface, contour, grinding spark test, chisel cut, fracture, owpipe test. The identification of the metal, especially in repair work, is invariably indispens-le. Once the metal or alloy is known the next step is to get familiar with all the facts relating its weldability and, in case of doubt, proceed to the necessary tests for determining these.

Steel Welding.

The welding of wrought iron and mild steel is apparently simple; in reality it is somewhat fficult to produce strong and reliable welds. Oxidation and inclusions are the most serious fects, and must be reduced to a minimum. Welding wires containing a small percentage of nadium or nickel are used with highly satisfactory results. To produce the minimum oxida-n the blowpipe must be well designed and handled efficiently and the parts to be welded must thoroughly cleaned. Expansion and contraction must receive proper consideration. The e of a flux in the form of a powder has not proved satisfactory. It has been found that de-idising materials in the form of a liquid gives excellent results. The product known as 'Suder' specially prepared for use with a welding wire which does not contain deoxidising elements. t the high temperature of the flame it slags the oxide, keeps the surfaces clean, and prevents e inclusion of oxide. The weld can be carried out rapidly, thus reducing overheating effects. ne liquid is applied by means of a brush to the edges of the plates and the welding wire previous welding. The welding wire should be a material low in phosphorus and sulphur, and free m oxide. The use of ordinary iron or mild steel is unsatisfactory, and welding wire, such as tylax,' 'Suder' or 'Ferrox,' made especially for the oxy-acetylene process, should be insisted on. It will be found that economy is on the side of the scientific but slightly more stly, and dependable, product.

The following abstract from a specification for a welding wire for iron and mild steels is of terest and represents the American Welding Society's Specification for the welding wire for oxy-etylene welding mild steel, structural work, plates, bars, low carbon steel forgings and castings. ne surface of the wire is to be smooth, of uniform homogeneous structure, free from irregularities surface hardness, segregation, oxides, pipe, seams, etc. Diameter shall not vary more than 3 per cent. of the diameter specified. The chemical composition to be within the following nits :—

Carbon	not more than	0·06 per cent.
Silicon	,,	0·08 ,,
Manganese	,,	0·15 ,,
Sulphur	,,	0·04 ,,
Phosphorus	,,	0·04 ,,

The surface shall be smooth and free from scale, rust, oil, or grease. In the hands of an perienced welder the wire shall demonstrate good weldability, and shall flow smoothly and enly without any unusual characteristics.

For welding mild steel and to produce a weld of greater strength but of lower ductility than at obtained with ordinary welding wire, the wire should contain 0·15 to 0·25 per cent. of carbon, 25 to 3·75 per cent. of nickel and 0·5 to 0·8 per cent. of manganese.

A simple test to indicate the fitness of welding wire is made by laying the wire flat on a clean rface and applying a good neutral oxy-acetylene flame to the wire in such a manner as to heat up for a distance of about 3 or 4 ins., playing the flame backwards and forwards until the wire red and then slowly melting the wire, moving the flame so that the wire only melts halfway rough its diameter. If the flame is withdrawn as soon as the metal begins to melt, the impurities n readily be seen being thrown off in the form of sparks, or a boiling action in the case of in-rior metal; and in some cases the metal will not flow together, but 'runs away.' The metal om gas absorbing wires will, when cold, contain numerous spongy, volcano-like irregularities. n the case of clean metal free from impurities the wire will melt and flow evenly without any isturbing action.

The following table is useful when ordering welding wire:

Size. Inches	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$
Lbs. per 100 ft. .	1·04	2·3	4·1	6·5	9·3	16·7	26	37·5
Ft. per 100 lbs. .	9,615	4,273	2,403	1,537	1,067	600	383	266

The flame must be carefully regulated and held so that the tip of the white cone is about $\frac{1}{8}$ in. om the surface of the molten metal.

A good practical rule in welding steel is that the hourly consumption of acetylene should e 4½ to 5½ cu. ft. (120 to 160 litres) for every $\frac{1}{16}$ in. in thickness.

The following useful table is made up from these figures, in which the approximate bore of ne nozzle orifice is included:

POWER OF BLOWPIPE FOR IRON AND STEEL.

Thickness of Material in Inches.	Consumption of Acetylene per Hour.		Bore of Nozzle in $\frac{A}{64}$ inch.
	In Litres.	In Cubic Feet.	
22 gauge	60–80	$2\frac{1}{8}$–$2\frac{3}{4}$	2
$\frac{1}{16}$	120–160	$4\frac{1}{4}$–$5\frac{1}{2}$	3
$\frac{1}{8}$	240–320	$8\frac{1}{2}$–11	3 full
$\frac{3}{16}$	360–480	$12\frac{3}{4}$–$16\frac{1}{2}$	4
$\frac{1}{4}$	480–640	17–22	5
$\frac{3}{8}$	720–960	$25\frac{1}{2}$–33	6
$\frac{1}{2}$	960–1280	34–44	7
$\frac{3}{4}$	1200–1600	$42\frac{1}{2}$–55	8

The blowpipe must be given a motion which will cause the flame to describe a series of ove lapping circles in the case of light and medium sheets, and oscillated in a series of overlappin semicircles in the case of heavy sections. This is known as 'forward' welding. A variation c these movements has been introduced which gives more economical and better welds. Th welding wire, in this case, follows the flame instead of preceding it, and the flame is directe towards the starting point instead of towards the finishing point. The blowpipe is given a sligh gyratory motion, whilst the welding rod is given a more or less elliptical or longitudinal motion This method of welding is known as 'backward' welding. Subsequent thermal treatment, whic may consist of annealing or normalising, according to the particular requirements, will improv the structure of steel welds and materially increase the strength and toughness of the weld Hammering may be resorted to with good effect, provided the hammering is not too vigorous o done at too low a temperature.

The following table gives the speed at which the welding of mild steel plates can be don under average conditions:

Thickness of Plate in Inches.	Speed of Welding.	
	Feet per Hour.	Feet per Hour for Average Day's Work.
$\frac{3}{64}$	30 to 33	23 to 26
$\frac{5}{64}$	20 „ 21	16 „ 20
$\frac{1}{8}$	15 „ 16	13
$\frac{5}{32}$	13 „ 15	10
$\frac{13}{64}$	10 „ 12	9
$\frac{1}{4}$	9 „ 10	$7\frac{1}{2}$
$\frac{9}{32}$	8 „ 9	$6\frac{1}{2}$
$\frac{21}{64}$	7 „ $7\frac{1}{2}$	6
$\frac{3}{8}$	$5\frac{1}{2}$ „ 6	5
$\frac{13}{32}$	$4\frac{1}{4}$ „ $4\frac{1}{2}$	$3\frac{1}{4}$
$\frac{1}{2}$	$3\frac{1}{4}$ „ $3\frac{1}{2}$	$2\frac{1}{2}$ to 3
$\frac{19}{32}$	$2\frac{1}{4}$ „ $2\frac{1}{2}$	$1\frac{1}{2}$ „ 2

Owing to metallurgical changes that take place when melting medium and high carbon steel with the blowpipe, the welds obtained are invariably unsatisfactory. As a general proposition, the lower the carbon content of the steel, the more successful the welding operation. It is possible to get fair results on medium steels, but a flux, rapid welding, and thermal after-treatment, which requires skill to properly carry out, are necessary.

The data at hand show that for welding medium carbon steel, welding wires having a carbon content ranging from 0·06 to 0·60 per cent. are of no particular value.

For welding high carbon steel and worn surfaces where great resistance to abrasive wear is desired and where machining is not necessary, a welding wire containing 0·60 to 0·75 per cent. of carbon and 0·60 to 0·90 per cent. of manganese is desirable.

Alloy steels, such as chrome and manganese steel, are weldable, provided the percentage of carbon does not bring them into the range of medium and hard steels, which is frequently the case. The welding wire should be of the same character as the steel, and a flux must be used. In the case of nickel steel it is necessary to use a flux which will form a varnish over the molten metal and prevent the absorption of the gases from the flame of the blowpipe. It is important to recognise that alloy steels are used largely because of the excellent physical properties that are developed by suitable heat treatment, and that the uneven heat treatment produced by welding temperatures may produce considerable variations in quality. Hence they should be welded with a full knowledge of the alloy and the results likely to be obtained. This also applies to the welding of stainless steel.

Cast-Iron Welding.

The two principal defects in cast-iron welding are the production of hard spots and blowholes the weld and subsequent cracks or fractures in the weld or adjacent metal. The oxide formed ust be removed or destroyed by the use of a flux. The welding rod must be of good material id specially made for cast-iron welding. One great trouble with cast-iron rods in general is iat the quality is by no means uniform. This is especially true with the cheaper and uncon- olled products. Rods made from ordinary cast iron produce blowholes and hard spots. Special ds containing titanium, producing sound, soft, and reliable welds, are obtainable. Expansion id contraction should be considered as of great importance. Preheating should be used to some :tent in all cast-iron welding. It is advisable to weld in position after preheating. The welder protected by making use of asbestos sheet or simply plate. Specially designed blowpipes of nsiderable length are available for this class of work, and two or three welding rods are welded gether. The parts must be thoroughly cleaned, and in the case of cracks their extension must be evented by drilling holes a short distance from the ends in the direction the crack would follow. ie weld should be arranged horizontally, and where this cannot be arranged carbon blocks ould be used to prevent the metal flowing away. Carbon products, in the form of blocks, wder, or paste, play an important part in modern welding operations. They are far superior to e-clay or fire-bricks, which are liable to melt under the blowpipe and invariably cause blowholes. rbon compound, in powder form, which can be made into a plastic mass with water, is valuable r making moulds, dams, etc., and for lining up repairs and holding parts in position. To pro- ct machined surfaces during preheating operations, they should be coated with flaked graphite d oil. This can be made into a paste and painted on, or the surfaces can be oiled and the aphite dusted on. The graphite must be coarse, as fine flake is not satisfactory. The flame ist be held so that the tip of the white cone is between $\frac{1}{4}$ and $\frac{3}{4}$ in. from the molten metal, the stance depending on the thickness of the metal. The after-treatment consists in annealing or owing the metal to cool very slowly. In well-executed welds on cast iron the quality of the ld is generally superior to that of the metal of which the casting is made. The grain is finer d the welded zone is sound, homogeneous, and can be easily worked.

Certain cast irons of great strength and in which the carbon is in the combined state are actically unweldable. Cast iron which has been submitted to the heat of a fire for a consider- le time is frequently unweldable. The metal in both cases melts under the blowpipe in a dis- ctly different manner from ordinary cast iron, and the welder should have no difficulty in cognising that the blowpipe should not be applied to make a joint. The bronze 'welding' cast iron, iron, steel, etc., is a process in which the oxy-acetylene flame is used in conjunction th a copper-zinc alloy, such as Tobin or manganese bronze, to produce joints which would be ficult or expensive to obtain by the usual method of melting the parent metal. The procedure making joints is very much the same as in actual welding. The 'V' opening need only be out 15 degrees. See also p. 2019.

Malleable Cast Iron.

It is difficult to produce satisfactory joints on malleable cast iron by welding. The welds are ed, brittle, and porous. The best results are obtained by brazing with the oxy-acetylene wpipe, using the same methods of preparation as for cast iron, and using manganese bronze a filling material. The two pieces to be joined are brought to a point just below fusion, great e being taken that they do not become fused. When the edges are at a right temperature, rod of manganese bronze is fused into the groove with the aid of a good flux.

The introduction of acetylene for brazing purposes provides a fuel which has the highest own flame temperature and high calorific value. By using dissolved acetylene with a special azing blowpipe no air-bellows or oxygen is necessary, as the blowpipe is atmospheric and a an and relatively small flame of suitable power is obtained.

Aluminium Welding.

Sheet aluminium welding can be handled in very much the same way as steel as regards paration and allowance for expansion and contraction. The principal difficulty lies in the mation of the oxide, which must be dealt with by an energetic and reliable flux. The filling terial is pure aluminium wire; before starting to weld, the wire and parts to be welded must thoroughly cleaned by scraping. A delicate touch and considerable practice are necessary, ecially on thin material. Material under 22 gauge is best welded after flanging the edges. e flanged edges should practically have no radius, so as to leave the minimum of space between underside of the sheets. The depth of the flange should be about two and a half times the ckness of the sheet. The white cone of the flame should be level with the surface of the plates d the blowpipe held so that the flame is inclined to the horizontal at about thirty-five degrees. he methods are correct the upper and lower surfaces of the weld appear identical. The power the blowpipe to be used is not in direct ratio to the thickness of the metal as in steel welding. r example, on 16 to 19 gauge material a blowpipe consuming 2 cu. ft. of acetylene per hour uld be satisfactory, whilst for material $\frac{1}{8}$ in. thick 10 cu. ft. is required, and for $\frac{1}{4}$-in. material cu. ft. per hour. The flame must be carefully regulated, and the tip of the white cone uld be from $\frac{1}{4}$ to $\frac{3}{4}$ in. from the molten metal. After welding, the welds should be thoroughly shed with warm water and, where possible, internal strains should be removed by annealing.

The structure and strength of the metal in the welded zone are improved by hammering whe cold. Subsequent corrosion of the welded seams may be due to the physical condition of th aluminium sheet.

Pure aluminium is not usually employed for castings subject to stress. In order to raise th tensile strength and increase the hardness varying percentages of zinc, copper, or nickel are adde There is an endless variety of aluminium alloys, but from a welding point of view they fall int two classes, viz., those containing zinc as their principal hardening medium and those containin copper. The material expands greatly and is very weak at high temperatures, consequentl contraction strains are likely to produce cracks and distortion unless the work is properly handle In welding castings—crank cases, for example—it is often necessary to preheat them eithe completely or partially. The preheating must be done carefully, otherwise the casting ma collapse. For supporting the casting evenly and lining up, carbon putty is useful. For missin parts, and where the welder is not well skilled in this class of work, it is advisable to back u with sheet copper or galvanised iron. In rigging up jobs for repairs, care must be taken tha expansion and contraction effects are not interfered with. The parts should be carefully cleane and free from oil and grease. The repair of oil saturated castings is frequently one of consider able difficulty. Cleaning, by dipping in caustic soda, followed by washing in scalding hot wate and drying, bevelling to a larger angle than usual and sweating out the oil and scraping it awa indicate the methods which lead to successful repairs. A good grade of filling material of averag composition is necessary; pure aluminium wire should not be used. The acetylene should b pure and the blowpipe should give a soft, non-oxidising flame. Two methods of welding ar adopted, one known as the flux and the other as the puddle method. In the former a flux used in the ordinary way and in the latter no flux is used, a steel rod and paddle being used t remove or break down the oxide and to smooth the weld respectively. All traces of flux mus be washed off. The casting should be reheated slightly to remove any local strains and the allowed to cool very slowly. For finishing off a single cut-file or a 'dreadnought' file is mo suitable.

The welding of the well-known aluminium alloy known as 'Duralumin,' which contains coppe manganese, magnesium, etc., is satisfactory or not according to the mechanical properties r quired in the joint. The alloy has important properties which are reduced, and in some cas almost eliminated, by welding operations. The metal should not be welded when the joints a subject to bending action, shocks, or when the full properties of the metal are desired.

Copper Welding.

Copper may be welded, but only satisfactorily where the operator is familiar with the techniqu Many failures can be attributed to the commercial metal being in an unsatisfactory conditi for welding. Where possible, a sample strip two or three inches long should be tested by maki a weld and applying a bending test. It is necessary to clean and bevel the edges and to suppo the underside of welds made on thin material, copper tubes, etc., by means of a mandrel co sisting of an iron tube on which is wound or fixed asbestos, which must be perfectly free fro moisture. Owing to its lack of strength when hot, the tacking of copper welds should be do carefully. For the same reason welds should not be started at the edges of the sheets, but at point about one-third the length of the seam. The power of the flame should be practically the sam as that used for welding steel of the same thickness. The flame must be carefully regulated. T melting should not be too rapid or too slow. Without a correct welding rod, which contains small quantity of phosphorus, it is impossible to satisfactorily weld copper. A flux is usefu Preheating to avoid adhesion is necessary. The tip of the white cone should be about $\frac{1}{4}$ i from the surface of the molten metal. The welds should be hammered at a dull-red heat improve their ductility and strength, and afterwards annealed. The technique for the repa of copper fireboxes and tube plates has been worked out and applied with great success. A goo sense of fusion, the addition of the metal in thin layers, and satisfactory equipment are essenti for success. Welds can be obtained with mechanical properties almost identical with those the metal welded. Such welds can be planished, stamped, spun and, in general, submitted the ordinary workshop operations carried out on sheet copper.

Brass and Bronze Welding.

Brasses and bronzes are only welded indifferently without the correct welding wire rods. The filling material should be practically of the same composition as the metal to welded, which, in the case of brass, should contain a little aluminium, and in the case of bronze little phosphorus and traces of aluminium. Bronze filling materials are cast. Fluxes shou be used in both cases, and the power of the flame is less than that used for the same thickne of copper—that is, distinctly less than for steel plates of the same thickness. The regulation the flame is very important: a slightly oxidising flame will give a surface free from wrinkles. T position of the flame is the same as for copper. The after-treatment of the welds consists annealing at definite temperatures. Identification of the particular brass or bronze to welded is important in view of the importance of choosing the correct welding wire or ro Reclaiming castings and repairing worn or broken parts, such as gear wheels, bearings, etc., co stitute the general run of the work on bronzes. In the case of castings similar methods to tho outlined for the repair of cast iron are necessary.

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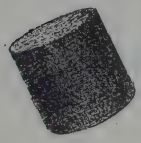

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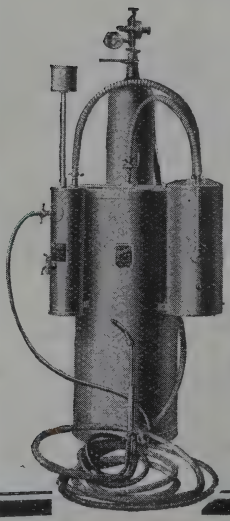

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Lead Welding.

The oxy-acetylene blowpipe is rapidly supplanting the older methods of welding lead, or lead burning,' as it is generally called. It has proved superior in convenience, quality of joints, nd economy. A small type of blowpipe is required, consuming from $\frac{1}{2}$ to 6 cu. ft. per hour. When it is necessary to fill up a hole or to build up any part of a lead object, the work is facilitated by using a mould or a backing of steel plate. When welding patches in repair work avoid rectangular patches on vertical faces, which make two edges of the patch horizontal. The patch should be made lozenge shape, so that the welds are done on the incline. The welding wire or rod should be of the same metal as the sheet. Special outfits have been designed for lead burning, using dissolved acetylene; they are very compact and portable.

Nickel Welding.

Nickel when melted has the property of readily absorbing gases, especially oxygen. Various methods have been tried to protect the molten metal from the gases of the blowpipe and to prevent their absorption. The welds obtained are very porous, and it is extremely difficult to obtain satisfactory welds. A method which has given fair results consists in placing the two parts to be welded on a heated anvil and then heating the parts to a white heat with the blowpipe, afterwards carefully hammering the parts together.

Machines for Welding.

Acetylene welding machines for the manufacture of tubes have been in use for many years. The development of automatic welding machines for the manufacture of tanks, etc., is more recent. For repetition work machines have been designed which accomplish the work in less time with comparatively unskilled men. The machines consist of two parts, (*a*) holding device for the work, and (*b*) apparatus for moving the blowpipes, with or without oscillatory motion, over the seam.

Recent developments in welding machines have been mainly in the direction of the use of multi-jet blowpipes. In order to obtain speed it was recognised that more than a single jet of flame should be employed, and from two jets in tandem it has become customary to employ a large number of jets extending for a considerable distance along the line of the weld. The defects of this method have been overcome by distributing the heat on both sides of the centre line of the seam. The welded section produced in this way is wider, stronger, and more certain to penetrate than is the case with the narrow weld made by a central line of flame.

Training Welders.

An oxy-acetylene welder has been defined as a person who has the requisite manipulative skill and technical knowledge successfully to operate welding and cutting apparatus, and, at the same time, has skill in the operation of hand tools used in the preparation and finishing of the work in connection with welding, and also has a reasonable amount in ingenuity. He must also have a knowledge of accuracy commensurate with the type of work to be welded. Naturally, a trade in which so much depends on the personal equation has drawn attention to the need of training men to produce sound work. No doubt the best method is that which expounds principles followed by practice under expert supervision. Welding skill grows rapidly under a well-worked-out system of exercises which aim at developing skill in making typical welds on various metals. Testing the welds is also an important requisite of a training course. Classes for training welders are held in the principal centres, and manufacturing concerns who train their workmen must follow methods depending upon the size of shop and class of work.

A common error is to attempt work, especially repair work, in a shop where the tools and apparatus for successful all-round welding are not provided, or to endeavour to repair jobs which are beyond the capacity of the welder. It is much more economical, in such cases, to hand over work of this character to firms specialising in general repairs who have the necessary equipment for carrying out and testing the work, and welders who are not mere blowpipe operators.

Testing Welds.

The importance of testing welds has, in recent years, become very great. It is well known that the quality of a weld cannot be assumed from the general appearance, finish, etc., although considerable information can be obtained from the visual inspection of welds. At the present time the usual methods of testing include tensile and impact tests on specimens welded

under identical conditions, microscopic examinations of specimens, bending and hammering test and X-ray examination. In the latter the actual welds can be examined, and flaws, blowhole and other defects discovered. Recent investigations indicate that electrical and magnetic tes for the non-destructive examination of welds will soon find commercial application.

The American Bureau of Welding have drawn up Standards for Testing Welds which ar intended primarily to serve as a standard uniform basis for testing and comparing sample weld as distinguished from welds on structures. The testing of the latter must necessarily be b non-destructive methods, which would therefore be, in general, quite different from those employe in examining sample welds made for the purpose of testing a welder's proficiency, comparin welding wires, or comparing welding methods. For the shop standard a bending test is recom mended ; for the commercial standard, a bending and tensile test on approved lines.

Miscellaneous Applications.

There are numerous applications of the oxy-acetylene process not included in the term weld ing, but which have a direct or indirect connection with it and are worth consideration. Th oxy-acetylene flame, for example, is a convenient and simple method of applying local hea for numerous workshop operations, such as forging, straightening, riveting, expanding fo shrinkage fits, heat-treatments, etc.

Brazing operations are more efficiently carried out with the oxy-acetylene flame than by th older methods. Case-hardening and surface hardening can also be efficiently and economicall done with the flame.

OXY-ACETYLENE CUTTING.

Wrought iron, steel, and steel castings can be cut with the ordinary cutting blowpipe, an with a special cutting blowpipe or the ordinary cutting blowpipe operated in a special manne cast iron can be cut.

The cutting blowpipe usually consists of a compound jet made up of one or more heatin flames with a pure oxygen jet in the centre. The purity of the oxygen is of much greater import ance when used for cutting than when used for welding. As the purity decreases the oxyge consumption and time increases, and the speed of cutting decreases as the following figures, whic represent tests on steel plates 5 feet long by 1 inch thick, show :

No. of Test.	Purity of Gas. Per cent.	Time in Seconds.	Oxygen Consumption in Cu. Ft.	Remarks on Cuts.
1	99·7	280	8·0	Very smooth and clean.
2	99·4	291	8·8	Smooth.
3	99·1	315	9·8	Satisfactory.
4	98·0	334	11·3	Good but rough
5	96·0	365	13·2	Not smooth.
6	95·0	412	15·4	Very irregular.
7	90·0	644	20·0	Rough, surface bad.
8	87·0	675	23·0	Very rough, surface bad.
9	85·0	696	25·8	Very rough, unsatisfactory.
10	82·5	—	28·4	Very rough & not through.

A spot on the metal is first heated to a bright red heat with the heating flame, and then th oxygen jet is turned on. It has been proved that only partial combustion takes place, the pheno menon of cutting being really a disintegration by the current of gases from the blowpipes. Th oxy-hydrogen or oxy-coal-gas flame is often used for cutting in place of acetylene. Material up to 36 ins. has been cut. The same acetylene equipment is used for cutting as for welding. Fo heavy cuts special oxygen regulators are required. There are two kinds of cutting blowpipes known as the 'central' and 'following jet' types. Mechanical contrivances have been devise for special forms and shapes and for heavy cutting. Automatic cutting machines using the oxy acetylene or oxy-coal-gas blowpipe, with or without preheated cutting oxygen, have reached a high degree of perfection. These machines usually have the full range of movements found on universal machine tool and have a degree of accuracy such that accurate gear teeth can be cut and any desired number of thousandths can be left for finishing.

The following is an abstract from a manufacturer's table of cutting data :

TABLE OF APPROXIMATE METAL-CUTTING RESULTS.

(*British Oxygen Co., Ltd.*)

Thickness of Plate.	Oxygen Pressure at Regulator Outlet.	Consumption of Oxygen per Hour.	Foot-run of Metal Cut per Hour.	Oxygen consumed per Foot-run of Cut.
Ins.	Lbs. per sq. in.	Cu. ft.	Ft.	Cu. ft.
¼	20	42	66	0·63
½	25	50	60	0·83
1	35	88	48	1·8
1½	40	110	40	2·75
2	45	150	30	5
3	55	200	24	8·5
4	60	230	20	12
5	65	250	19	14
6	70	270	18	16
8	90	400	16	28
9	100	500	15	33
11	120	620	12	52
14	140	900	10	85
17	160	1,350	8	150

Blowpipes can be obtained for cutting steel under water. Under-water cutting is based on the fact that the water must be forced away from the heating flame and cutting jet. Up to recently compressed air has been used for this purpose, and the latest type of under-water cutting blowpipe makes use of the products of combustion. The cooling action of the water necessitates using a heating flame five to seven times as powerful as that used for cutting the same thickness of material in the ordinary way. With an efficient arrangement an ordinary hand-cutter can be adapted for cutting under water. In salvage work steel plates have been cut at a depth of 40 ft. Various devices for lighting the flame under water when it becomes extinguished have been successfully introduced, the most recent being in the form of a pilot light burning continuously and forming part of the blowpipe.

Cast iron can be cut by means of the oxygen lance or by a special oxy-acetylene blowpipe. In the former case an iron tube from 6 to 12 feet long, $\frac{3}{8}$ in. external and $\frac{3}{16}$ in. internal diameter, containing three wires of 12 gauge, is supplied with oxygen at a pressure of from 70 to 150 pounds per square inch, according to the thickness to be cut. The point at which the cut is to be started and the end of the tube are raised to a red heat by means of an oxy-acetylene blowpipe, the oxygen turned on and the heating blowpipe removed. Combustion of the cast iron and the tube proceeds rapidly ; it takes 20 seconds to penetrate a piece of cast iron 4 inches thick and less than 2 minutes for material 24 inches thick. In the second method a cutting blowpipe with a flame having a distinct excess of acetylene is used, or a blowpipe in which the cutting jet is modified and not the heating flame. In the latter type a certain quantity of acetylene is introduced into the cutting jet and leads to an increase in the temperature of the oxygen.

The following is an abstract from a manufacturers' table of cutting data :

TABLE OF APPROXIMATE RESULTS FOR CAST IRON CUTTING.

(*British Oxygen Co., Ltd.*)

Thickness of Metal.	Oxygen Pressure.	Cutting Speed.	Gas Consumption per Foot-run of Cut.	
			Oxygen.	Acetylene.
Ins.	Lbs. per sq. in.	Ft. per hour.	Cu. ft.	Cu. ft.
Up to 1½	110	7	40	7·2
1½ to 3	120	6	80	12·5
3 to 5	130	5	110	17·6
5 to 8	140	4	160	23
8 to 11	150	2½	200	48
11 to 14	150	2	300	75
14 to 16	160	1½	400	105

ELECTRIC WELDING.

Electric welding processes can be placed in two distinct groups, one producing heat by th resistance of the metal being welded to the passage of the current, the other using the heat the electric arc. They are known as Resistance Welding and Arc Welding, respectively. Thes two main groups have formed the basis for many processes of welding. The differences re entirely on methods and special applications. The subdivisions are as follows:

Arc Welding.

(1) Carbon or graphite electrode.
(2) Metallic electrode.
  (*a*) Bare electrode.
  (*b*) Coated electrode.
  (*c*) Covered electrode.
(3) Electric blowpipe.
(4) Atomic hydrogen.
(5) Shrouded arc.
(6) Gas shielded.

Resistance Welding.

(1) Butt welding.
  (*a*) Flash welding.
  (*b*) Upset welding.
  (*c*) Automatic butt or contact flash.
(2) Mash welding.
(3) Seam welding.
  (*a*) Butt seam welding.
  (*b*) Lap seam welding.
  (*c*) Bridge seam welding.
(4) Percussive welding.
  (*a*) Electro-static.
  (*b*) Electro-magnetic.
(5) Spot welding.
  (*a*) Lap spot welding.
  (*b*) Bridge welding.
  (*c*) Button welding.
  (*d*) Disc depression welding.
  (*e*) Point welding.
  (*f*) Multiple point welding.
  (*g*) Multiple electrode welding.
  (*h*) Ridge welding.
  (*i*) T spot welding.
  (*j*) Duplex spot welding.

The many systems of welding which have developed from these main groups are generall associated with the inventor's name or company exploiting the process, such as :

Benardos System.	Thomson System.	Quasi-Arc Process.	Ferro-Arc Process.
Slavianoff System.	Premier Electric System.	Daysohms System.	A.C. Welding System
Kjellberg System.	Alloy Welding Processes.	Cyc-Arc Process.	Fluxode System.
Zerener System.	Plactic-Arc System.		

ARC WELDING.

Commercial efficiency of arc welding processes is estimated by the relation that the qualit of the work bears to the cost. The principal factors which decide the quality of the work are (*a*) electrodes; (*b*) current (D.C. or A.C.); (*c*) welding equipment; and (*d*) efficiency of th welder. In assessing the cost the principal factors are: (*a*) capital expenditure; (*b*) depreci tion and maintenance charges; (*c*) wages; (*d*) cost of electrodes; and (*e*) cost of electrical energy The speed of welding enters into the question of cost provided increased speed is not obtaine at the expense of welding efficiency. The absolute requisites for good work are: (*a*) low voltage (*b*) a short arc; and (*c*) constant heat per unit area in the weld. An arc welding circuit shoul possess the following characteristics: (1) Ease of arc establishment when the work and electrod are cold; (2) freedom from undue tendency to freezing of electrode or extinguishing of arc wit maintenance of short arc streams; (3) stable arc with maintenance of short arc streams (4) limited current increase with growth of liquid globule; (5) limited increase of current at th instant and during the period the globule short circuits the arc stream; (6) the arc voltage shoul increase rapidly at the instant of globular detachment or on breaking a momentary short circui in order to facilitate re-establishment of a stable arc.

Carbon Arc Welding.

The characteristic principle of this process, commonly known as the Benardos process, i that an electric arc is held between the metals to be joined, which forms one electrode of th circuit, and a carbon rod or pencil manipulated by the welder which forms the other electrode By placing the carbon electrode in contact with the metal, thus closing the circuit, and instantly withdrawing it again, an electric arc is formed between the two electrodes and, owing to th high temperature of the arc, the metal is melted. Steel up to $\frac{3}{32}$ in. is satisfactorily melted togethe without using a filling material, but for greater thicknesses a 'melt bar' is melted into plac by the heat of the arc. Automatic machines for repetition work on thin materials and equippe with carbon electrodes are in use. Experience has shown that the metal to be welded shoul be the positive electrode, and the carbon the negative electrode. If this order is reversed, shorter arc is obtained and particles of carbon can enter the molten metal and cause brittleness

The current used is direct, the voltage being from 60 to 90, and the amperes vary from 25 to 600, depending upon the thickness of the metal.

The use of graphite electrodes in place of hard carbon electrodes is increasing as the merits of ıe graphite electrode are more widely known. The chief advantages are: (*a*) breakage in ıandling and in operation is appreciably reduced; (*b*) breakage and cracking due to sudden ıanges of temperature is eliminated; (*c*) less carbon is carried into the weld; (*d*) the arc is much eadier; (*e*) the life is from two to three times as long as for an amorphous carbon electrode of ıe same diameter; (*f*) electrical conductivity is four times that of the carbon electrode of the ıme cross-section, consequently the heating caused by resistance is negligible and much higher ırrent densities can be carried. Considerable development is being made in the art of carbon 'c welding where graphite electrodes are used, and an automatic graphite electrode arc welding achine has been placed on the market. The single or double graphite arc has proved useful in ıe welding of non-ferrous metals.

Metallic Arc Welding.

The use of metallic electrodes for arc welding has proved more satisfactory than the use of ırbon or graphite electrodes, which necessitate feeding the new metal into the arc by means : a rod or wire. A very wide variety of metal electrodes are used and can be classified as follows:) bare wire; (*b*) coated electrodes manufactured by dipping in, or spraying with, a liquid;) coated electrodes, which are wrapped with a refractory material or otherwise encased in a much eavier covering than that used for coatings. They can also be classified as: (*a*) heavy slag epositing electrodes; (*b*) light slag depositing electrodes; (*c*) flux-coated electrodes which de- osit no slag; and (*d*) bare wire. The effect of surface materials on electrodes from the standpoint some of the scientific laws governing the metallic arc has been investigated and it has been own that the presence of non-metallic materials on the surface is required. Generally speaking, ıere is a sphere of utility for each type, and provided care is exercised in their selection, a weld maximum efficiency should be obtained.

Bare Electrode.

The Slavianoff System, using a bare metal electrode, has not been developed in this country any extent. There is considerable discussion as to the efficiency of bare electrodes, and although may be possible to successfully weld mild steel with such electrodes, where toughness is desirable necessary, or for the welding of steel alloys, a coated or covered electrode will give better and many cases, the only successful results. The decision of Lloyd's in approving the use of covered ectrodes has not caused the adherents of the bare-metal electrode to abandon their position. he bare electrode imposes a minimum thermal load, but requires the presence in the equipment a high stabilising factor. The following is an abstract from a specification for bare iron and eel electrodes for welding mild steel, steel forgings and castings, plates, bars, etc.:

Carbon	0·06	per cent. maximum.
Manganese	0·15	,, ,,
Phosphorus	0·04	,, ,,
Sulphur	0·04	,, ,,
Silicon	0·08	,, ,,

In the hands of an experienced welder electrodes should demonstrate good weldability in flat' and 'overhead' positions, and should pass through the arc smoothly and evenly without ny unusual characteristics.

The data at hand show that bare steel electrodes having a carbon content between 0·18 and ·85 per cent. are of no particular value.

Coated and Covered Electrodes.

The use of coated and covered electrodes aims at improving the metal in the weld, permitting ıe use of alloy steels, non-ferrous metals, etc., as electrodes, facilitating electrode manipula- ion and the use of alternating current. Covered electrodes may be placed in two general classes, ıe first class being the electrode which has a heavy covering of scientifically prepared material ontaining a deoxidiser. The second class of covered electrode is of the type which has a very hin coating on the wire and aims at obtaining the same results as the heavy covered electrodes ithout manipulating the heavy coating of slag deposited during the welding operation. It is ossible to obtain as many as twenty different types of flux-covered electrodes, each specially esigned for depositing a particular material. As a result of research work, electrodes are now vailable for the purpose of welding and depositing non-ferrous metals.

Kjellberg System.

The effect of refractory coverings on the metal electrode was first discovered by Kjellberg In the Kjellberg process, controlled by the *Anglo-Swedish Electric Welding Co., Ltd.*, the stee rod is covered with a coating or sleeve of normally non-conducting materials—that is to say conductors of the second class—the junction of the cover being, amongst other things, to direc the metal where it is required, to protect the fused metal from oxidation, and to make up th loss in the arc of certain constituents of the iron or steel forming the object.

In carrying out the process the covered rod is held in a clip or holder connected to a con tinuous current supply, and forms the positive pole, the object forming the negative, though i some cases the poles are reversed.

The covering is removed from the end of the rod to enable the current to pass, and an arc struck between the rod and the object. As soon as the arc is struck a portion of the metal the object, having an area approximately equal to the section of the rod, fuses together wit metal from the end of the rod, and at the same time the covering, which is of a friable natur partly fuses and breaks away at the same rate as the metal of the rod is deposited. In this wa metal can be gradually deposited on an object until a sufficient quantity has been obtained f the purpose required. From time to time the deposited metal is hammered so as to consolida it in exactly the same way as a weld made in the fire.

A further advantage of the covering on the rod is that the tensile strength of the weld ca be varied within certain limits to suit the purpose required. For example, by this process tensile strength of from 20 to 35 tons per sq. in. can be obtained. It is possible also to obta various degrees of hardness merely by altering the composition of the covering.

'Quasi-Arc' Electrodes.

These electrodes are the special product of *The Quasi-Arc Company, Limited*, and are patent throughout the world. The company also supply special plants which enable electric arc weldi to be carried out with both A.C. and D.C. supplies of any voltage in the most economical an efficient manner.

'Quasi-Arc' Electrodes consist of a special steel wire coated with a mineral flux havi distinct physical and chemical properties whereby a weld of the highest mechanical streng and purity is obtained.

In making a weld or reinforcing a worn surface the electrode is held in an insulated hold connected by a flexible lead to the positive pole of an electric generator, and an arc stru between the electrode and the work which carries the negative connection. The welding operati is continued by holding the point of the electrode just under the surface of the molten slag a feeding down uniformly the electrode as the metal is deposited on the work.

The flux covering of the 'Quasi-Arc' Electrode has special properties to enable a low curre to be used in fusing the electrode. The fused covering is acid in reaction, automatically removi any mill scale or iron oxide from the work; it is also reducing in its chemical character, so that absorbs oxygen, and prevents atmospheric gases from causing defects in the weld metal and at t weld junction. The electrode therefore deposits a maximum possible amount of metal free fr defects with a low current consumption, so that welding is not only reliable but very economic The aluminium wire incorporated with the electrode further prevents oxidation of and remov gases from the weld metal. The low current used not only gives economy but prevents lo overheating and embrittleness in the adjacent steel of the work, so that the weak brittle zo formed in the work when using many other types of electrodes is absent.

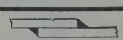
The metallurgical principles of the 'Quasi-Arc' Electrode follow closely those used in mode steel-melting practice.

Apart from Mild Steel Electrodes, the company manufacture special electrodes for weldi Cast Iron, Carbon Steel, Manganese Steel, Stainless Steel, and Special Boiler Electrodes. T latter are a recent production, and are used for constructions which are subject to high inter pressures and for work which is stressed at a high temperature.

The following table gives the comparative strength of riveted joints and joints made w 'Quasi-Arc' Electrodes. These figures are the results of official tests carried out by Lloy Register of Shipping, and it was on the excellent results obtained that 'Quasi-Arc' Electrod were the first to be approved for welded ship construction.

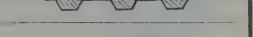
ABLE SHOWING COMPARATIVE TENSILE TESTS OF LAP JOINTS OBTAINED BY RIVETING AND THOSE OBTAINED WITH 'QUASI-ARC' MILD STEEL ELECTRODES.

WELDED WITH 'QUASI-ARC' ELECTRODES.



Specimens of Mild Steel.	Dimensions.			Sectional Area.	Tons. Max. Stress.		Remarks.
	Overlap.	Breadth.	Thickness.	Sq. in.	Total.	Per sq. in.	
Plain bar	—	5·5 in.	0·25 in.	1·375	39·3	28·55	
Welded bar	1·5 in.	5 in.	0·25 in.	1·25	36·15	28·9	Broke 4½ ins. clear of weld.
Plain bar	—	2 in.	0·50 in.	1·0	28·4	28·4	
Welded bar	2 in.	5 in.	0·50 in.	2·5	64·75	25·9	Broke 6 ins. clear of weld.
Plain bar	—	2 in.	0·75 in.	1·5	42·0	28·0	
Welded bar	2·25 in.	5 in.	0·75 in.	3·75	89·5	23·85	Broke through plate at weld due to bending.

TREBLE RIVETED.



Specimens of Mild Steel.	Dimensions.			Rivets.		Sectional Area. Sq. in.	Tons. Max. Stress.		Remarks.
	Overlap.	Breadth.	Thickness.	Diameter.	Spacing.		Total.	Per sq. in.	
Plain bar		2 in.	0·50 in.			1·0	27·4	27·4	
Riveted bar	7·5 in.	18·25in.	0·526 in.	¾ in. dia.	2·625 in.	9·6	165·5	17·21	Broke through outer line of rivet holes.
Riveted bar	9 in.	18·625in.	0·489 in.	⅞ in .dia.	3·125 in.	9·1	172·0	18·91	

The use of 'Quasi-Arc' Electrodes has been authorised by the British and Foreign Admiralties, Lloyd's Register of Shipping, the British Corporation for the Survey and Registry of Shipping, Det Norske Veritas, and Nederlandsche Scheepvaart-Inspectie Bureau, for use in the more important parts in ship construction.

'Quasi-Arc' Electrodes were exclusively employed in the construction of the all-welded motor ship *Caria* (ex *Fullagar*), of 400 gross tonnage. This vessel, built in 1920, has each year successfully passed Lloyd's Annual Survey, and is at present in service at British Columbia, having been recently renamed *Shean*.

Among later achievements by the use of 'Quasi-Arc' Electrodes is the application to a completely welded 3,000,000 cu. ft. gasholder, 200 ft. in diameter, 100 ft. high, with three lifts. Since this gasholder was satisfactorily completed, others have been constructed by the same method, together with the whole of the necessary framework. In addition, gasworks plant, including retort houses, condensers, gas mains, etc., have also been welded with 'Quasi-Arc' Electrodes. Hydro-Electric Pipe Lines have also been completely welded with 'Quasi-Arc' Electrodes and a number of oil storage tanks, the largest being 100 ft. in diameter.

'Quasi-Arc' Electrodes are used in all the Royal Dockyards and by the principal railway and tramway companies, collieries, mines, engineering firms, and shipyards in Great Britain and abroad.

An impact or alternating impact and bending test gives a much better measure of the quality of a weld, especially the toughness, than a tensile test. Moreover, such a test conforms more to service conditions. A 'Quasi-Arc' weld being of sound and pure metal gives a very high result under such a test, whereas a weld made with an electrode not having a special reducing flux gives a value, due to the oxide defects present in the metal, sometimes a third of that given by a 'Quasi-Arc' weld.

Note on Corrosion, in relation to Joints made with 'Quasi-Arc' Electrodes.

In view of the importance which the subject of corrosion bears to that of welding, the following notes on this matter may be added:

Fundamentally, corrosion is electrolytic in character, and depends on the difference in potential of contiguous areas.

Commercial iron and steel contain areas which in the presence of an electrolyte (which may be merely atmospheric moisture) are capable of forming voltaic circuits, the necessary condition being afforded by the presence of small defects of iron oxide, etc., or by local conditions of strain in the metal itself. These impurities or strains give rise to areas of higher electrolytic potential, and form electro-positive points which are first attacked by the corroding agent. Thus in a caulked joint, corrosion will commence at the caulking, and similarly a riveted joint will be attacked round the rivet head, owing to the local strains in the metal at these points.

In a welded joint, if the metal at the weld be less pure than the surrounding metal, the weld will be first attacked. Similarly, if the added metal be not homogeneous, local differences in potential in the weld itself will cause corrosion at the weld.

A microscopic examination of the metal deposited by 'Quasi-Arc' Electrodes shows it to be of great purity, and the usual laboratory tests show it to be always electro-negative to the surrounding metal. Hence it follows that this weld metal will have a high factor of resistance to corrosive influences.

In order that the best results may be obtained with 'Quasi-Arc' Electrodes it is essential that the electrical conditions be satisfactory. The Quasi-Arc Company have carried out a considerable amount of research work in order to determine the best designs for various types of plant. Although primarily the electrode governs the quality of work carried out by the arc welding process, it is of great importance that the plant be able to provide the correct amperage for the electrode in use, and that the arc remain stable at this current. The Quasi-Arc Company supply special D.C. generators of the drooping voltage type for single operator installations, and also constant voltage machines for multiple welder sets which fulfil these conditions in every way. These can be supplied as motor generators for A.C. or D.C. supplies or self-generating units driven by internal combustion engines.

The company have also paid particular attention to static transformer equipment for A.C. supplies, and can offer sets with which it is possible to carry out with 'Quasi-Arc' Electrode welding of quality equal to that effected with a D.C. current.

They have recently brought out a welding unit for A.C. welding of particular interest, which is known as a Compensated Rotary Transformer. This machine supplies an alternating current to the arc, and generally has the economic advantages of static transforming plant. It has, however, several additional features which render it suitable for use on supply systems where static plant is not advisable. These may be summarised as follows: (1) The load taken from a polyphase supply is perfectly balanced; (2) the power factor is of a value equal to that taken by well-designed induction motors; (3) the ease of welding operation is increased by supplying the arc with current at a frequency three times that of the frequency of supply.

All 'Quasi-Arc' plants have been designed to obtain a maximum electrical efficiency with the simplest methods of control, so that the welder can adjust his welding current without difficulty and without electrical knowledge.

Alloy Welding Processes System.

'A.W.P.' electrodes are flux-covered, and have, in general, a spiral winding of asbestos yarn as a basis of the covering. Asbestos in itself is a flux, as it fuses and combines with iron oxide forming a compound silicate, which reaction assists the operation of the flux coating. This spiral asbestos winding makes an excellent vehicle and support for the covering; which contains various valuable constituents, and is the chief feature of 'A.W.P.' electrodes. A suitable binder is used making a tough-coated and concentric sheath to the metal core. These electrodes, therefore, travel and handle without damage to the covering. They are approved by Lloyd's Register of Shipping, the British Corporation for the Survey and Registry of Shipping, and Bureau Veritas, and give equally good results on either direct or alternating current.

The chief problem in electric arc welding is to prevent as far as possible the partial combination of the molten metal with oxygen and nitrogen—in other words, to avoid the formation of metallic oxides and nitrides, as these compounds are, in general, very detrimental to the success of the welding.

By the aid of the flux covering, the molten metal is shielded from contact with the air, and is properly chosen it also serves the purpose of disposing of whatever oxides or nitrides may have unavoidably formed.

These fluxes, however, when carefully chosen not only tend to eliminate undesirable elements in the welded metal, but can be made effective in producing any desirable chemical composition in the deposited metal.

The 'A.W.P.' process has made it possible to lay down deposited metal of any predetermined composition, and to duplicate in the weld such metals as manganese steel, high-carbon steel, high speed steel, stainless steel, etc., and other steels of very special qualities, which it would be impossible to secure with an electrode having a core of alloy steel. This subject is fully dealt with in the company's bulletins, which can be obtained on application.

'A.W.P.' electrodes are made in twenty different types to suit all classes of work.

A·W·P

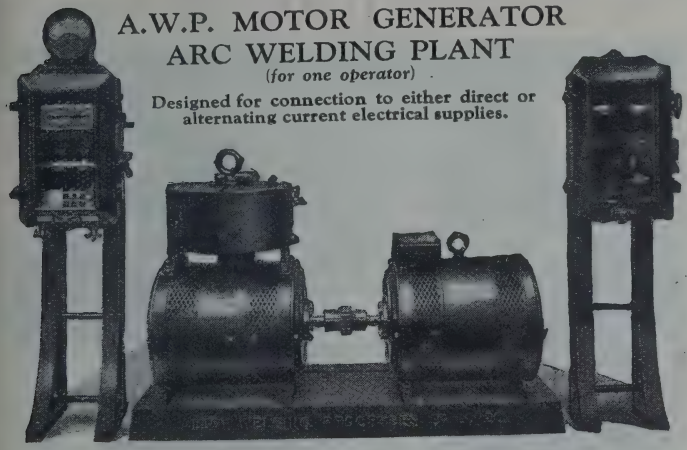
ELECTRIC ARC WELDING

approved by
LLOYD'S REGISTER OF SHIPPING
British Corporation & Bureau Veritas.

A.W.P. MOTOR GENERATOR ARC WELDING PLANT

(for one operator)

Designed for connection to either direct or alternating current electrical supplies.



ELECTRODES

MADE IN 23 TYPES

Special Electrodes for Mild and High Tensile Steel, Carbon, Manganese and Stainless Steel, Cast Iron, Copper, Brass and Bronze.

Please ask for Plant Catalogue and Electrode Price List.

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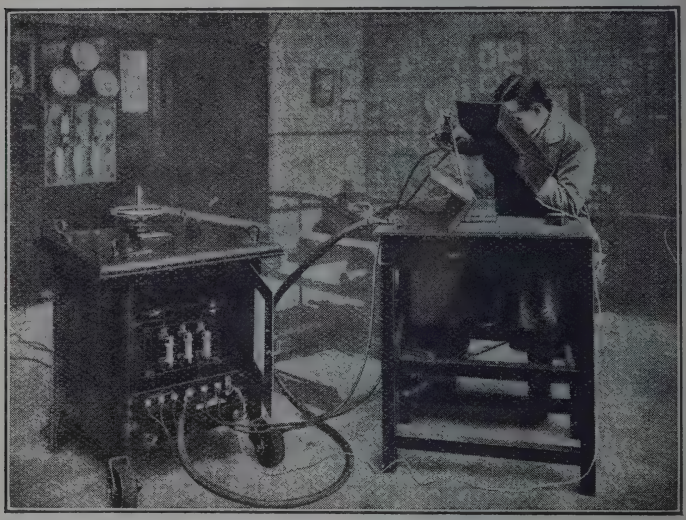
Q & 5

A·W·P

ELECTRIC ARC WELDING

The New Polyphase System



Operator about to commence welding with the new "A.W.P." Polyphase System.

Note the Double Electrode and the two cables to electrode holder.

Obtainable only from

ALLOY WELDING PROCESSES LTD.,

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The growing importance of arc welding in engineering operations has caused *Alloy Welding Processes, Ltd.*, to give special attention to the design and construction of a welding generator, which besides being light in weight, and therefore easily portable, will be capable of meeting every requirement of the welder in regard to its ability to handle electrodes of any make and any size within the range at present manufactured.

The 'A.W.P.' patent welding generator is a plain shunt-wound machine without separate exciter, or reverse compound winding. It is of the drooping characteristic type, having an open circuit voltage of approximately 70, which, however, drops to the pressure required at the arc immediately welding commences.

The machine can be adjusted, by means of a shunt regulator, to suit any size of electrode at present made.

On top of the dynamo frame is fixed a casing containing an oil-immersed transformer, the primary of which is connected in series with the main circuit and the secondary connected in the shunt field circuit.

The object of this transformer is to inject voltages into the shunt winding during sudden changes of load in the main circuit. This it does so effectively that the tendency for the main current to vary is checked immediately, in consequence of which a very stable arc is obtained. With a machine of this description there is a complete absence of spluttering at the arc, and the metal deposited is homogeneous and free from holes or sponginess.

The 'A.W.P.' dynamo can be supplied direct coupled to engine-driven plants for portable use, as motor generator sets fitted with either an A.C. or D.C. motor, or arranged for belt drive.

Alloy Welding Processes have also specialised in welding with alternating current and are the proprietors of the Daysohms patent A.C. welder, which is fully described in the following paragraph.

Daysohms' System.

This system is designed to work on ordinary alternating current supply circuits, and is portable or stationary as desired. One of the advantages claimed is the special adaptability of the device for the efficient welding of very thin metal; strips of mild steel, No. 20 S.W.G., have been welded in angle form at the rate of 1 ft. in 2 mins., the current being 27 amperes at 65 volts on open circuit with a power factor of 0·45. The supply current is transformed to the necessary voltage and then passes through a choking coil. This has a straight core, with pivoted keeper which can swing, the speed of its movement being controlled by a dashpot. Limits can be set to the movement on each side by means of cam-form stops. With passage of current the keeper of course tends to be attracted towards the core, and the nearer it approaches, the lower the flow of the current, owing to the increased choking effect. The limit of the approach is set by the adjustable cam, and in this way any welding current within the limits can be obtained. The other cam, which controls the striking current, similarly regulates the distance by which the keeper can move away from the core by gravity or spring. As has been stated, the speed of the movement is controlled by the dashpot, and this can be regulated by means of a perforated disc in the piston. Consequently both striking and welding currents can be adjusted independently, and the keeper is free to move between the stops under the control of an adjustable dashpot, so that the characteristic curve connecting volts and amperes is the resultant of the two curves which would have been obtained if the keeper had been fixed in either position. The consequence is that it is possible to weld with a lower open-circuit voltage and, in addition, to weld thinner material without burning through, as the striking current can be set so as to be very little in excess of that required for the actual welding operation. In working the firm recommend that the current for welding should be adjusted first and then the striking current reduced until there is just sufficient excess to enable the arc to be struck easily.

These welding machines are available in two standard sizes, one for currents between 25 and 100 amperes with infinite gradation, and the other similarly for currents up to 200 amperes. The machine is supplied as a complete unit ready for connection to the supply main, and any ordinary flux-covered electrode can be employed.

Premier System.

The standard electrodes manufactured by the Premier Electric Welding Co., Ltd., are composed of a steel alloy of carefully controlled composition and coated externally with a thin layer of non-metallic substances. This volatile coating ensures that the molten metal is protected to a considerable extent from oxidation and nitrogenation, and the composition of the electrode itself ensures that a sound weld with good mechanical properties is produced.

The Premier system of arc welding aims at distributing the current at the required welding voltage without any mechanical control whatsoever. This is obtained by the use of a dynamo of a special type connected with the arc through a special reactance coil in the main circuit. This coil absorbs no appreciable energy, but effectively damps out any sudden rise in current, and at the same time helps momentarily to build up the current when any sudden reduction takes place.

The company manufacture a plant of the multiple operator type which does away with large and wasteful series resistances. It is claimed that as a result the power consumption of the equipment is lower than that of other multiple plants, and the method of operation is briefly as follows:

The main welding generator develops current at 35 volts and is direct coupled to a small arc striking generator which gives a small current at an additional 35 volts. By means of the special Brookhirst Contactor Gear which is fitted to this plant, a combined voltage of 70 is at all times available, for either or both welders, for the purpose of striking the arc, and, as soon as an arc is struck, the contactor gear previously referred to automatically cuts out the arc striker, and welding proceeds on the main generator.

It will thus be seen that the new plant is effective for welding at 35 volts; thus effecting considerable economy in running costs. Approximately 7½ h.p. is required per welder, this figure being slightly more in case of plants for a small number of operators and slightly less in case of plants employing six or more operators. First-class welding results are obtained without causing the slightest difficulty in striking and maintaining the arc and without any trace of interference between welders.

Ferro-Arc System.

The Ferro-Arc system employs electrodes with a coating of flux and slag-forming materials. The core metal of Ferro-Arc electrodes is of the highest quality and made to an exact specification for arc welding. The principal component of the flux is powdered blue asbestos fibre specially treated and combined with other substances which control the melting point of the asbestos and enhance its power of dissolving oxides of iron and other impurities. Blue asbestos is peculiarly suitable for use as a flux, and it is doubtful whether any other material or combination can give such successful results in arc welding.

Ferro-Arc flux fuses evenly and level with the melting of the metal core, and when molten is fluid, free, and mobile, entirely covering and protecting the deposited metal. The flux has definite deoxidising properties which, together with its powerful solvent action for oxides, ensures the deposition of clean metal free from impurities. The scavenging action of the flux removes scale and rust from the surfaces to be welded, and so results in perfect fusion and interpenetration of weld and parent metals. The necessity for a substantial coating on the electrode for the achievement of best results should be emphasised. It is not possible to deposit sound metal free from oxides and impurities and which is thoroughly united to the parts to be welded without an adequate amount of flux and slag. A substantial coating in no way hinders the operator. On the contrary it assists him greatly, improving both the speed of deposition and ease of manipulation, while ensuring the soundness of the deposit and the neatness of finish. Valuable ingredients may be imparted to the weld from the coating.

The company manufactures three grades of electrodes for the welding of mild steel, i.e. Types A, B and C, which vary in quality and price. The flux coating is in each case based on blue asbestos powder. In addition there is type AA for welding mild steel where exceptionally high strengths are required or where it is required to hot-forge the part after welding.

All the above types may be used on any standard plant using either direct or alternating current. Remarkably good results are obtained with these electrodes, the outstanding features of which are smoothness of working, penetration of the metal, neatness of finish, and high strength of the weld.

For the welding of cast iron two types of electrode are made. The standard type is specially designed to deposit a true cast iron in the weld, while Type D deposits a nickel-copper alloy which has the great advantage of forming a soft machinable deposit without preheating; with this electrode cast iron may be welded 'in the cold' without the formation of hard spots, particularly in the line of junction.

Electrodes to deposit 14 per cent. manganese steel and 0·5 per cent. and 0·8 per cent. carbon are also supplied.

A new development is an extremely successful electrode for welding stainless steel, particularly 'Staybrite.' This electrode deposits a metal containing 10 per cent. nickel and 15 per cent chromium. The composition of the electrode could be suitably altered so as to give other desired combinations of nickel and chromium. In working it is particularly smooth, fusion is perfect and neatness of finish remarkable. The deposit is very tough and entirely free from blowholes. Its resistance to corrosion is as high as that of the metal on which it is deposited. It may be used for the welding of mild steel to stainless steel.

The Ferro-Arc Welding Company's system of electric arc welding employing Ferro-Arc electrodes has been tested and approved by Lloyds Register of Shipping.

A.C. System.

The A.C. welding system is one which embodies novel features. The nature of a welding arc is such that the use of bare wire with alternating current for welding purposes is impossible unless special provision is made to counteract the effect of the periodic cessation of power.

Before the introduction of the A.C. welding system, the use of alternating current for welding purposes was condemned as inferior to D.C., and was only used in conjunction with heavy slag-forming electrodes.

A paper which was read before the Institution of Welding Engineers* explained the theory

* *Theories and Facts to Aid in the Choice of an Efficient Arc Welding System*, by D. T. Smout A.M.I.E.E

THE SIX ESSENTIALS
OF A
FIRST-CLASS ELECTRODE

THE CORE **1.** Of best quality metal, tested before use in manufacture of the electrode.

THE FLUX COATING **2.** Should form a protective sheath round the arc, preventing access of atmospheric gases.

3. Melt uniformly and evenly with the metal core.

4. Provide a stable arc giving operator steady directional control.

5. Ensure chemically clean surfaces, permitting true and complete union of metals, and should include a deoxidiser.

6. Form a freely moving fluid slag, present in sufficient quantity, and easily removed.

Ferro-Arc Electrodes

Conform in every way to the requirements set out above, which are borne in mind at every stage of manufacture.

The Ferro-Arc System of Welding

Using Ferro-Arc Electrodes, has been approved by the Committee of Lloyd's Register of Shipping.

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A.C. *is* BETTER *than* D.C.

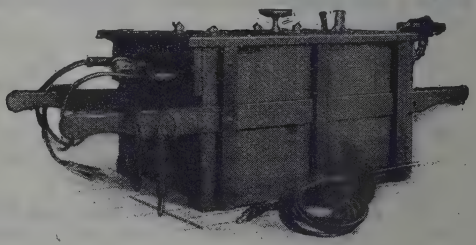
The "ALTERNARC" Machine gives

Higher Welding Efficiency.
Greater Speed of Welding.
Greater Penetration.
The Choice of any Electrode
(Bare or Coated)
Greater Arc Stability.
Less Expense.

System approved by Lloyds and Bureau Veritas.

Plants and Safety Devices to Home Office Regulations under all conditions of risk.

For Portability and Electrical Efficiency see table below.



TYPES
LW
SW
HW
CW

Complete Equipments from

£45

TYPE	CONTINUOUS RATING AMPERES	CURRENT RANGE AMPERES	ELECTRICAL EFFICIENCY %	WEIGHT LBS.	DIMENSIONS 60-50 CYCLE INCHES
GS	75	30-125	70	110-115	12×12×20
LW	125	10-150	75	200-250	32×24×18
SW	175	50-200	80	250-300	32×24×18
HW	225	60-275	80	300-350	34×26×20
CW	300	75-350	80	350-400	34×26×20
HC	500	300-600	85	400-500	42×30×28
EHC	900	600-1200	90	600-800	48×32×30

Machines built for any voltage and any periodicity.
Machines can now be supplied in single units for two operators.
Write for full particulars. Call for demonstration.

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A-C WELDING COMPANY,

CITY MILLS,
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F. 2773

of arc stability, and showed the difference between the A.C. welding system and the transformer and fixed reactance stabiliser, which had hitherto been in vogue. It also shows that the tendency of the arc to die out is counteracted by the method of arranging the choking effect in the circuit as a variable quantity instead of being a fixed value. The 'Alternarc' transformer of the A.C. system can be adjusted to have a certain average value for its reactance, and this governs the average value of the power supply to the arc, in the same way as a fixed reactance choke coil is designed to determine the value of the power supply to the arc. The reactance of the 'Alternarc' transformer, however, is not a fixed quantity, but varies with the current over the whole load cycle, in such a way that when the current is at minimum the reactance value is a minimum, and *vice versa*.

The effect of this method of arc control is to give very high arc stability; so high, in fact, that it is claimed possible to do equal, and even more efficient, welding work with alternating current than with direct current.

Alternating current has been condemned for welding on many occasions, owing to the fact that the arc stability factor supplied by the transformer and choke combination was so extremely low. This bad feature of poor arc stability has now been overcome by the A.C. system, and consequently, with maximum welding efficiency possible with alternating current, coupled with the desirable features of high electrical efficiency, portability, and low first cost, the A.C. welding system offers a most efficient and economical welding system.

The way in which the variable reactance control is arranged is as follows:—The 'Alternarc' transformer consists of a primary winding wound on one limb of a closed core, having two secondary windings, one of which is wound to have high mutual inductance and low leakage inductance with the primary coil, and giving a heavy leakage flux on full load. In some cases an alternative path is arranged for the leakage flux by extending the core yokes between which extensions a movable flux-diverter is arranged. Both sections of the primary windings are tapped at intervals to give adjustment to the voltage and also to the current, the movable flux-diverter giving a fine adjustment for accurate work.

The material used in the construction of the transformer is fireproof, the windings being composed of asbestos-covered wire, insulated with pure mica. Each of the larger type machines is provided with a cooling fan, and is enclosed in an oak case arranged with Sedan handles, in such a way that a whole apparatus is a portable unit.

To summarise, the claims made by the A.C. Welding Company for their system are—maximum welding efficiency, maximum arc stability (giving the choice of any electrode on the market); maximum electrical efficiency (giving minimum running cost); minimum upkeep (there being no adjustments of brushes, attention to commutators, etc.), and no maintenance charges. The machine is guaranteed against burning-out, and can only break down under wilful bad treatment.

The machines are normally supplied with an open circuit voltage ranging from 60 to 100, according to the settings of the secondary connections, but if required they are supplied with a standard 'Alternac' safety device, which limits the open circuit voltage to a maximum of 25 volts.

Electric arc cutting has been developed on the A.C. system. The system of cutting consists in the use of special cutting electrodes, which liberate free oxygen at the arc, steel being the basis of the electrodes on currents of 300 amperes, and carbon on currents from 600 to 1000 amperes.

Wilson Plastic-Arc System.

A wide and varied range of arc welding machines are manufactured on this system by *Messrs. G. D. Peters & Co., Ltd.* A special feature of all Wilson Plastic-Arc Welders is the Control Panel, which gives the machine welding qualities available in no other way. These panels, which have a range of adjustment to suit the particular welder, give close current regulation without the use of a separate exciter or brush moving. The whole equipment, which includes all accessories, is compact and built for service and can be supplied with a motor of practically any characteristics to suit the local source of power supply, or the generator can be supplied without a motor, to be driven by any means locally available, such as, for example, a belt. Alternately the unit can be petrol driven, and portable petrol sets are a speciality of the firm.

The electrodes supplied by the firm have a world-wide reputation and are known as the Wilson 'Colour-tipt' Welding Metals. The composition of each grade of metal, which covers all welding requirements, is the result of exhaustive experiments to provide an electrode having proper flowing qualities, penetration, and characteristics as deposited metal, to produce a sound, mechanical weld. The packing and marking of these electrodes has received considerable ingenuity and attention which ensures economy and their ready identification under practically all conditions of use.

Fluxode System.

The Fluxode system, Engineering Developments, Ltd., uses flux-covered and bare-wire electrodes which can be used with any arc welding plant. Mild steel, high carbon and manganese electrodes of both types suitable for high-class welding with high tensile strength or where a hard deposit, such as for reinforcing or building up tramway and railway rails, is required.

Arc welding plant to meet all conditions and for use on alternating or direct current has been designed from the point of view of economy and efficiency. The single operator set, for example, is suitable for any standard voltage on direct or alternating current supply varying from 100 to

500 volts. The set consists of an electric motor coupled to a specially wound welding generator which possesses a variable voltage characteristic similar to that obtained by the combination of a level voltage supply with a stabilising resistance in series with the arc. There is a reduction of about 50 per cent. in the cost of electrical energy as compared with a generator using a stabilising resistance. Owing to the special winding, an unskilled operator can make a much more efficient weld than with the ordinary generator.

Electric Blowpipe Welding.

In this process the electric blowpipe is essentially a horizontal-flame arc lamp using two carbons mounted like the letter V. The process was introduced by Dr. Zerener in 1890, and is usually known as the Zerener system. The flame of the arc was directed away or deflected downwards by means of an electro-magnet in series with the arc. The apparatus is bulky and complicated, and for even moderate-sized work it must be suspended from above. This method of welding eliminates the passage of the current through the work. It has not proved as successful as the methods already mentioned, and has been superseded by them. The Voltex Process is a variation of the Zerener method, in which the carbon electrodes are impregnated with metallic oxide which is vaporised by the flame of the arc.

Arc Welding Equipment.

Electric-arc welding may be done with a direct-current or alternating-current arc, having a reasonable degree of stability and sufficient amount of heat to accomplish fusion. The effect of the 'type' of current on the efficiency of metal deposition by the arc is threefold. It affects the speed of deposition, the amount of penetration or fusing of the metal, and arc stability. The design of the welding generator or transformer affects the cost of welding. The necessity for a special machine rests upon economic factors, and the differences between the various types used are those of power, cost of operation, and difference in speed of operation due to the relative stability of the arc.

The question of direct or alternating current raises many interesting points which have never been clearly determined. Good welding can be done with both direct and alternating current. Flux-covered electrodes are essential for certain types of alternating current machines, apparently because the lagging effect of the flux and slag maintains the necessary temperature during the periodical current reversals. Comparative data by independent authorities is missing, and the question of whether direct-current welding is faster or slower, whether flux-covered electrodes enable direct current to take the lead in welding speed, whether the practical losses in motor generator and resistance compare favourably or otherwise with the alternating-current system, etc., etc., are questions which are answered by contradictory claims by both parties to this controversy. However, there are advocates for both systems, and satisfactory equipment can be obtained for arc welding with direct or alternating current.

The successful application of arc welding is largely dependent upon the selection of the proper equipment. There are two systems in general use—(*a*) single operator system, where a separate machine is provided for each operator, each machine receiving its current supply from the supply circuit; (*b*) multiple operator system, where more than one operator receives current direct from the same machine, but each operator is provided with a control panel which enables him to vary the current without interfering with the other operators.

The equipment consists of a motor generator, control panel, and accessories. When using alternating current use is made of a transformer to reduce the distribution voltage to that suitable for the weld. The various types of arc-welding apparatus have been described by Major J. Caldwell in a paper presented to the Institution of Electrical Engineers on December 14, 1922.

Amongst the accessories are protective equipment and electrode holders.

Protective Equipment.

The intense glare emitted in the process of arc welding consists of a combination of invisible infra-red rays, visible light rays, and invisible ultra-violet rays, and special safety devices are required to protect the operator from their harmful effects. For light electric welding it is necessary only to protect the eyes with goggles fitted with suitable coloured glasses. Hand shields are made for medium-weight electric welding work which can be done with one hand. They serve the double purpose of protecting the eyes of the operator and also shielding the face from the heat rays and ultra-violet radiations. For heavy electric welding it is common practice to use a helmet or hood which provides protection for the eyes, head, face, and neck, and leaves the hands free. With regard to the tint of the protective glasses, a reference to the note on goggles in the section on oxy-acetylene welding will be useful. For the protection of the hands and wrists leather gloves are used. These devices are subject to modifications to meet the requirements of special work. Neighbouring workmen and operators should be protected from the dangerous rays of the electric arc.

Precautions in Arc Welding.

The precautions that should be observed in arc welding have been set forth in a memorandum issued by the Factory Department of the Home Office (Form 329, June 1921). These deal with: (*a*) hand-screen; (*b*) helmet or mask; (*c*) gloves; (*d*) aprons; (*e*) protection from hot metal; (*f*) chipping of slag. The memorandum also deals with the comparative dangers of direct and alternating currents, use of direct current, injurious effects of radiations, etc. The memorandum on the Electricity Regulations (Form 928, 1925) should also be consulted.

Automatic Arc Welding.

Depositing metal using an automatic feed for the electrode results in a materially increased rate of deposition. Machines have been developed which are capable of welding steel 0·109 ins. thick at the rate of 22 ins. per minute. This method of depositing metal is particularly advantageous on sections of uniform shape upon which a considerable amount of metal is to be deposited. Automatic welding does not eliminate the human element in welding, but does in certain cases greatly increase the speed of the process, and in other cases obtains results which are beyond the limitations of manual operation. Automatic welding with the bare metallic electrode is in more general use at present than any other method. In one type of machine the electrode is fed to the arc from a reel by means of feed rolls actuated by a 30-volt motor which is shunted across the arc when the arc is struck. Regulation of feed is maintained by two contractors which change the direction of rotation of the feed motor when the arc voltage increases or decreases above or below a certain amount. Research has proved conclusively that a faster, stronger, and more homogeneous weld can be made on material $\frac{1}{2}$ in. or more in thickness by use of a multiple arc automatic welder, depositing the metal in two or more layers, using about 350 amperes in each arc, rather than by depositing in one layer, using an excessively high amperage. A number of welding applications involve all the requirements of automatic welding except that the size or weight of the pieces to be welded prohibits convenient handling, clamping, and traversing. In such cases a semi-automatic welding machine has proved to be of great advantage. One type of machine feeds the welding wire through a flexible conduit to a welding nozzle in which the control switch for the feed motor is located. The control mechanism operates to start and stop the feed motor. The maintenance of a uniform and steady arc depends on the operator.

In the automatic carbon arc-welding machine the welding wire is placed on the work before welding. The heat of the carbon arc fuses both the wire and base metal forming the weld. Very high speeds are thus made possible.

SPEED OF WELDING IN FEET PER HOUR.

Thickness of Metal.	Hand Welding.	Semi-Automatic Welding.	Automatic Welding.
$\frac{1}{16}$	—	25 to 50	50 to 100
$\frac{1}{8}$	7 to 16	15 to 30	30 to 50
$\frac{3}{16}$	6 to 12	12 to 25	20 to 35
$\frac{1}{4}$	5 to 10	8 to 15	10 to 25
$\frac{1}{2}$	3 to 5	5 to 8	5 to 8

Arc Welding Applications.

The application of arc welding to repair and manufacturing is very extensive, but its application should be made with a full knowledge of the possibilities and limitations of the process. In the welding of iron and steel, with their great variety of physical properties, a familiarity with the wide range of conditions is necessary to meet and solve the problems presented. In welding cast iron, copper, brass, aluminium, etc., the application of arc welding should be looked upon as in the development stage where welds with physical, chemical, and mechanical properties similar to the base metal are required.

A complete investigation into the welding of cast iron is at present being carried out, and the results, as far as they have gone, demonstrate that it is possible to weld some grades of cast iron if the proper method and conditions of welding are obtained. The following points have been considered:—(1) Preparation of the parts; (2) prevention of slag inclusions; (3) suitable values of current; (4) method of deposition and its effect on the strength and hardness of the weld; (5) reversed polarity versus straight polarity; (6) effect of long versus short arc; (7) effect of speed on the softness of the weld; (8) the hard zone and its removal; (9) relative weldability of various grades of cast iron; (10) tests of electrodes. There is a great need at the present time for data on these various points.

Cost of Arc Welding.

The cost of electric arc welding with the metal electrode process depends upon several variable factors, such as: (1) the price of labour; (2) the characteristics of the arc, (*a*) arc easy to maintain, (*b*) arc difficult to maintain, (*c*) amount of heat available; (3) the cost of power; (4) the cost of electrodes; (5) supervision required, (*a*) production work, (*b*) work of a varied character; (6) interest charge on equipment.

Welding speed is fundamentally dependent upon the rate of metal deposition. This rate varies with such factors as, energy required for liquefaction of electrode material, arc stability, current density, and electrical resistance of electrode material. It has been shown that high current welding results in an increase of 100 per cent. in the speed of welding a butt joint. Butt joints in $\frac{1}{4}$-inch plate may be welded at a maximum rate of 5·3 ft. per hour when employing 175 amperes; at 10 ft. (or more) per hour when using 400 amperes.

RESISTANCE WELDING.

There is a marked distinction between the joining of metals by the two electric processes, viz., arc welding and resistance welding. In the former the heat is localised through the action of the electric arc and no pressure is applied; in the latter the heat is localised by the resistance to the flow of the current and pressure is used.

The process of resistance welding is based upon the phenomenon that a poor conductor of electric current will heat if current is forced through it, or that a good conductor will also heat if enough current is passed through it, and that the heating effect will be greater if alternating current is used than if direct current is used. Since an imperfect joint, such as the abutting ends of two pieces of metal, or the lapping of two pieces of metal which are to be welded, is a poor conductor and offers great resistance to the passage of the current, it will naturally heat and finally cause the metal to fuse and flow sufficiently to weld. In practice the operation is very rapid because comparatively large amounts of current are used.

For this type of welding a single-phase alternating current of any commercial frequency is used. The transformer in the machine will take the current from an ordinary shop circuit and reduce it to a suitable welding current.

Resistance welding is only suitable for duplicate or repetition work. In general one machine is designed for handling pieces of the same metal and for making joints for similar design. Repair jobs have been done in special cases, but it is only in rare cases that such an adaptation is attempted.

A resistance welding machine is simply a single-phase transformer having a secondary of one or two turns, the voltage required between the terminals being only five to ten volts, and the current being limited only by the size of the pieces to be handled. The transformer is built into a heavy frame which supports the clamping jaws to handle the work and mechanical devices to regulate the heat and pressure. The machine has reached a high degree of perfection, and large savings of time and labour have resulted in production work. The principle involved has been applied in the construction of a variety of machines.

By some one of the resistance welding processes, nearly all metals and alloys can now be welded. Tin is the notable exception. The cross-section of stock that it is possible to weld by the resistance process now seems to be limited only by the electric power available. Special adaptations for heating rods, bars, billets, rivets, etc., and electric brazing and soldering machines are available. Special machines for zinc tube welding, automatic spot welding, rivet heating, forging hearths, welding hollow articles, etc., etc., have been designed, and their main features have been dealt with in a paper read before the Institution of Welding Engineers.*

Butt Welding.

Electric butt welding consists in joining pieces end to end by securing complete fusion of the entire cross-section of the pieces. The pieces to be welded are placed in the clamping jaws, one of which is stationary and the other movable; enough pressure is exerted to bring the ends into contact and the current is then turned on. As soon as the welding temperature is reached the operator increases the pressure, thus forcing the pieces together, and turns off the current. Nearly all metals used commercially have been welded by this process.

Butt welding may be subdivided into three classes, namely, (1) upset welding, (2) flash welding, and (3) contact flash welding or automatic butt welding.

As regards the first subdivision, in which the weld is made by butting the cold ends of the stock to be welded and then applying the electric pressure, it is apparently being superseded for most purposes by flash welding.

Flash welding is made by applying the current before the ends are in actual contact and utilising the flash or minute arcs that play between the ends of the stock. Some advantages of flash over upset welding are (*a*) less power required, (*b*) less extrusion or upsetting, (*c*) burnt metal

* 'Resistance Welding,' by F. E. Saunders, M.I.E.E.

is thrown off, (*d*) increased production, (*e*) stronger welds. The best technique for the flash welding of tungsten steel tips to medium carbon steel shanks in the manufacture of machine cutting tools, and the serviceability of such tools as indicated by bending and service tests, has been determined.

The third subdivision, contact flash welding, is in some respects similar to percussive welding. The weld is made almost instantly by using high continuous contact pressure and heavy current, the current being cut off by automatic methods of control.

Spot Welding.

Electric spot welding consists in pressing the pieces together while passing the current through them, and localising the flow of the current so that the weld is confined to 'spots' between the electrodes, which are used to secure the pressure. The term automatic spot weld is given to a spot weld made on a welder which applies the pressure, makes and breaks the circuit all automatically.

The material to be welded is placed between copper die points supported on the ends of two arms, and the points are brought firmly together on the metal by the use of either foot or motive power. The current is then turned on. The metal, being a poor conductor, becomes heated, and when heated to a sufficient degree, pressure is applied. In the case of automatic control, the current is turned on and off and the necessary welding pressure applied automatically by controlling mechanism usually driven by a variable-speed motor. The majority of commercial metals can be spot welded, but it is essential that the metal to be welded should offer a considerable resistance to the electric current, otherwise sufficient heat cannot be generated. The technique for spot welding galvanised iron has been determined and gives very satisfactory results. The requirements for successful welds are rounded die points and twice the current and half the pressure required for ungalvanised metal of the same thickness. The spot welding of light materials guarantees a successful product and increased production. A commercial spot welder for $\frac{1}{2}$-inch plates is in use.

During the past few years considerable investigation has been carried out with regard to heavy spot welding for ships and constructional work. Large machines capable of supplying a welding current up to 100,000 amperes, and equipped to exert a pressure up to 30,000 lbs. per square inch on each spot, have been constructed. The main difficulties which have been encountered are, briefly, electrode-tip protection and the preparation of the materials to be welded. Two secondary considerations have been the separation of the electrodes and the shape of the head of the spot welder.

The following indicate the variations of spot welding:

Button and Disc-Depression Welding.

Where very thick work is to be spot welded it is often desirable to find means to localise the current and cut down the amount of pressure required. Small metal discs or buttons can be used for this purpose placed between the head of the welder and the metal to be welded. Disc-depression welding differs from button welding in that in the disc-depression method an annular depression is provided in one of the sheets, around the disc. The method makes possible the use of a comparatively light machine for welding heavy steel plate, and also the use of less power and time for making the welds.

Bridge Welding.

This method is used to join thin sheets edge to edge without overlapping and without reducing the dimensions of the pieces. The sheets are brought together in their correct position, and then thin strips or discs are spot welded across the joint.

Multiple Electrode Welding.

Time and power can frequently be saved by making several welds at once, in which case the spot welder is equipped with two or more electrodes. It is advisable to have projections on one of the pieces to be welded to assist in localising the current. Successful multiple welding requires a separate transformer for each weld.

T Spot Welding.

When pieces are welded in the form of a **T** by holding one piece in a hollow electrode and welding it to the other the resulting weld is called a **T** spot weld.

Point or Projection Welding.

In this method the metal to be welded is provided with points or projections. The points are brought in line with each other, and the welding effect is to provide a smaller contact point which increases the resistance and allows the weld to be made with the consumption of less time and power. Ridge welding is the same as point welding, except that, instead of a single point, a ridge is raised in the metals in such a way that the ridges on the two pieces come together in the form of a cross.

Duplex Spot Welding.

In this type of spot welding two transformers are used simultaneously on opposite sides of the sheets to be welded and their currents pass through two secondaries, welding two spots simultaneously.

Combinations of all the above processes have been made for special jobs. Sometimes it is only necessary to make a change in the construction of the electrodes to make a machine do work of a varied character.

Seam or Line Welding

consists in joining pieces along a continuous line or seam, usually by moving the joint in the path of the current, so that fusion is secured continuously. The process combines the features of butt and spot welding. Machinery has been developed very successfully, but is limited to work on light stock and short seams. Standard seam welders are usually equipped with two electrodes, one connected to the work and the other a roller running over the seam, or both electrodes may be converging rollers, with the converging edges resting on opposite parts of the work near the edge to be welded. The work is passed beneath the rollers, which carry the current into the metal, and makes a continuous line of welding. The work must be carefully cleaned and be securely held by the machine to get good results. The width and strength of the weld depend upon the current, pressure, and speed adjustments as well as upon the size and character of the electrodes and the shape, size, and character of the metal being welded.

Considerable development work has been done during the past two years. It has been applied to the manufacture of steel barrels, casks, tanks, ventilators, heating and ventilating pipes, etc. Seams can be made at a rate of 40 ft. per minute on $\frac{1}{16}$ in. sheets, and 20 ft. per minute on $\frac{1}{8}$ in. sheets. The welds may be butt, lap, or bridge, and be made continuously or progressively.

Mash Welding.

Mash welding is a process of welding rods, wires, strips, etc., by crossing or overlapping the pieces and welding between relatively large electrode surfaces under pressure.

Electro-percussive Welding.

This is a process which is chiefly intended for manufacturing applications in which large quantities of duplicate parts are to be produced. The underlying principles utilised in percussive welding were discovered in 1905 by Mr. J. Chubb, of the Westinghouse Company. Following his original experiments, machines were developed for welding metals in wire form of rather small cross-section. Widely different physical properties offered no obstacle, and ductile welds can be made with copper and aluminium, platinum and lead. Electrical devices are used whereby a rapid small separation of the parts to be welded causes an intense arc to melt the surfaces. At the proper moment a forging hammer forges the pieces together. The advantages claimed for the processes are (*a*) power saved; (*b*) time of welding negligible; (*c*) welds of unequal sections are possible; (*d*) welds of unlike metals can be made; (*e*) uniform welds; (*f*) cost of finishing welds reduced. Recent results have shown that percussive welding has many valuable applications, especially in non-ferrous and steel-alloy welding.

Experimental work has been directed toward extension of the process to larger cross-sections. A large impulse transformer has been built capable of storing 20,000 joules. Sections up to $\frac{3}{4}$ in. diameter have been successfully welded and no apparent limitations are anticipated from a process point of view.

ELECTRIC CUTTING.

Although cutting with a blowpipe has many advantages over electric arc cutting, yet there are many places where the electric arc can be used advantageously. The groove is not so narrow as that cut with a blowpipe, nor is the surface cut as clean.

The electric arc will cut any metal, ferrous or non-ferrous, and has been found particularly useful for the cutting of cast iron. The thickness that can be economically cut by the arc varies from 4 to 6 inches, for straight cutting. The current necessary for cutting operations on general and heavy cutting varies from 800 to 1,200 amperes. The voltage of the cutting arc varies between 25 and 45, a good average being 37.

It will be seen that heavy values of current are required, and special apparatus has been designed so that the arc could be controlled with these heavy currents. An important part of these developments is the design of a handle to protect the operator, hold the electrode, and to carry 1,000 amperes. A small item like the use of pure graphite instead of carbon for electrode means the difference between success and failure.

Increase of current means larger electrodes and hence more metal to be cut out. The latest development for this work is a low resistance graphite electrode and the approximate sizes for various current densities are as follows:—200 amperes, $\frac{1}{4}$ to $\frac{3}{8}$ in. electrodes; 300 to 400 amperes, $\frac{3}{8}$ to $\frac{1}{2}$ in. electrodes; 400 to 600 amperes, $\frac{1}{2}$ to $\frac{5}{8}$ in.; 600 to 800 amperes, $\frac{5}{8}$ to $\frac{3}{4}$ in; 800 to 1,200 amperes, $\frac{5}{8}$ to 1 in. electrodes.

Cutting on heavy sections is generally best accomplished from the underneath side or from a vertical face tipped slightly greater than 90 degrees so that the molten metal can flow away, although the action is not entirely simply melting metal. In cutting with the arc a reasonably smooth surface can be obtained by paying attention to one side only, or the cut may be made rough and trimmed up smooth by a second application of the arc.

Recent developments consist of a special electrode for cutting with the arc, and for such work as piercing holes. This special electrode, covered with a coating giving off free oxygen under the temperature of the arc, gasifies the entire metal melted, so that the boring action is uninterrupted after once started. This electrode is used by starting the arc and immediately pushing the electrode into the puddle. After the hole is through the piece it can be widened to any size or shape by drawing the arc around its edges. This type of electrode only takes from 250 to 350 amperes. A development in under-water cutting is an adaptation of the carbon electrode arc cutting process, in which the carbon electrode is pierced by two small brass tubes, through which a special cutting gas is supplied from the surface. The gas oxidises and blows away the metal melted by the arc, and also converts the surrounding water into steam, thus making a gaseous envelope for the arc. The combined action serves to greatly speed up the operation of the cutting electrode, as the metal is blown aside before it has a chance to solidify. This device has been used successfully for cutting metal between three and four inches thick at a depth of about 70 ft.

THERMIT WELDING

Thermit is a trade name for a mixture of finely divided aluminium and iron oxide, which when ignited reacts to produce a superheated liquid steel at 5000° F. The underlying principle of the process is the high chemical affinity of aluminium for oxygen. Up to a temperature of 2800° F. thermit is an inert mixture. At that temperature the aluminium unites with the oxygen of the iron oxide and comes down as liquid steel at about twice the temperature of ordinary molten steel. If steel at this high temperature is poured around the sections to be united, especially if the sections have previously been preheated, it will melt them and amalgamate with them so as to form a fusion weld.

Four varieties of thermit are produced for welding ferrous material, *i.e.* plain, cast iron, railroad and wabbler thermit.

In making a thermit weld, the parts to be united are first lined up with a space between the ends, the extent of which depends upon the size of the sections to be welded. The ends are thoroughly cleaned and a wax pattern is formed around them, the exact shape of the reinforcement of thermit steel which is to be cast at that point to make the weld. A sand box is next rammed around the pattern and inside a sheet iron box, provision being made for pouring gates, heating gates, and risers. The parts to be united are brought to a good red heat by suitable means, such as compressed air liquid fuel. The charge of thermit is placed in a conical shaped crucible supported over the pouring gate of the mould and ignited by means of an ignition powder. In 25 to 35 seconds the reaction is completed and the crucible tapped. The slag does not enter the mould.

The process is extensively employed for locomotive repairs, marine repairs, crankshaft repairs, steel mill repairs, pipe welding, rail welding, and miscellaneous heavy welding. Detailed instructions are available for carrying out thermit welds in the fields mentioned. The process is adapted to all sizes and weights of pipe up to 6 in. diam., and an important feature possessed by the thermit pipe welding process is the ease with which it can be applied to the welding of coils. The joints can be welded either before or after the pipes are bent.

ATOMIC HYDROGEN WELDING.

Equipment has now been placed on the market for atomic hydrogen welding. The process consists in passing a stream of hydrogen gas through the arc formed between two electrodes. The heat of the arc breaks up the hydrogen molecules into atoms, and these combine again a short distance beyond the arc, and in so doing liberate a large amount of heat. Since atomic hydrogen is a powerful reducing agent, it reduces any oxides which may form on the surface of the metal and metals can be melted without the slightest trace of oxidation.

The equipment represents the results of continuous experiment, research, and trials over a considerable period. The outfit consists of a single-phase transformer for converting the voltage of a 60-cycle supply to one suitable for the welding equipment, a specially designed variable reactor for providing the proper welding current and voltage, and a welding blowpipe by means of which the actual work of welding is performed.

The blowpipe consists of a holder supporting two tungsten wire electrodes, the electric conductors connecting these to the reactor, and the tubing for the hydrogen gas. Each electrode is supported inside a nozzle through which the hydrogen is forced out around the electrode. The combination of electrodes and nozzles is set at an angle, and the distance between the electrodes, or arc length, and also the flow of gas, are readily adjustable. In contrast to the usual method of arc welding, there is no current flowing from the electrodes to the work to be welded ; the circuit is completed from one electrode to the other. When welding ceases, the welding circuit is automatically interrupted until the operator is ready to weld again, when the circuit is automatically restored.

In making welds the metal is melted under the heat of the arc, but to add additional metal a welding wire or rod must be used and fed into the arc in much the same way as that followed in oxy-acetylene welding.

The reactor consists of a U-shaped core provided between with pole faces, between which a pivoted armature can move. The legs of the core are provided with coils connected in series with the electrodes of the blowpipe. The amount of welding current and voltage is governed by the movable armature which changes the air gap of the magnetic circuit and therefore the reactance.

The new equipment is so far made for operating from 60-cycle, single-phase circuits only, and for use on ordinary metals less than $\frac{1}{4}$ inch in thickness, or on hitherto unweldable metals of greater thickness. Extremely thin material can be welded. The process is particularly adaptable to the welding of metals and alloys so far not weldable by other methods.

SECTION XLI

EXPLOSIVES

(Contributed by Professor W. R. Hodgkinson, F.R.S. (Edin.), Ph.D., F.I.C., C.B.E.)

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Explosives may be classified into 'Propellants,' which are required to produce a rapid but steady rise in pressure in some kind of firearm; others may be termed 'Detonators,' or the less definite term 'High Explosive.' The latter are practically instantaneous in action and produce a wave or vibration of high velocity. Under certain conditions some substances may behave as belonging to either class.

The first propellant, 'Black Powder,' has since 1770 (about) consisted of nitre 75 per cent., charcoal 15 per cent., and sulphur 10 per cent. Practically all the gases, which may be 700 times the volume of the powder, arise from the nitre, the volume varying according to the density of the powder and to the conditions at burning.

Gunpowders do not detonate, but may give a very rapid rise of pressure if burnt in a closed space. Being porous, though dense, the first formed and very hot gases are driven through the remainder of the charge, igniting it *en masse*.

Cordite.

Cordites and the like are practically the most satisfactory propellants invented; owing to their gelatine-like structure they are non-pervious to gases. All true colloids show this property in some degree; the rate of burning can therefore be well regulated by the area of surface, volume of gas, and temperature. Owing to their composition, these explosives are practically smokeless. The cold-gas volume (i.e. volume at ordinary temperature) is in the region of 1,000 times that of the powder, and the temperature seldom less than 2,000° C., and may be above 3,000° C., according to composition. 'Cordite' proper consists of gelatinised high grade gun-cotton with a certain amount of nitroglycerine and a mineral jelly incorporated while the gelatinising agent is still present, the agent eventually drying off. A number of varieties of these powders are made with lower grades of gun-cotton, their physical properties being much the same. These powders are not easily detonated and are useless for blasting purposes.

Gun-cotton.

Gun-cotton' and 'Cellulose Nitrates' are made by the action of a cool mixture of nitric and sulphuric acids on cleaned cotton waste or the like. Strength of acids, temperature, and time of contact determine the extent and nature of nitration. Real gun-cotton contains about 13·8 per cent. of nitrogen, nearly corresponding to $C_6H_7O_2(NO_3)_3$.

Varieties of nitrated cellulose containing 10 to 11 per cent., or less, nitric-nitrogen than real gun-cotton are also used in some classes of propellants.

Gun-cotton is unaffected by water and does not burn if containing about 10 per cent. of moisture. When dry it ignites at between 160° and 180° C. It burns without smoke and is easily detonated by a sharp blow on a hard surface. When wet it can only be detonated by a primer of dry gun-cotton. When pulped and pressed into slabs, gun-cotton (13·8 per cent. N.) is used for blasting; its action is very local.

Nitroglycerine.

Nitroglycerine is formed by the action of mixed nitric and sulphuric acids on glycerine at a low temperature. It is a colourless oily liquid of sp. gr. 1·6. It freezes easily, and melts at 4° C. It is practically insoluble in, and unaffected by, water. Solid or liquid, it is easily detonated by percussion or by heating to about 150° C., hence the danger of thawing the solid nitroglycerine. As a liquid it is unpractical as an explosive, but when mechanically absorbed into a porous inert material, or incorporated in the substance of a jelly, useful preparations result.

Dynamite.

'Dynamites' which fulfil most of the requirements for blasting, and are reasonably safe, consist of nitroglycerine incorporated in kieselguhr, cork charcoal, and the like non-gritty powders. Generally some metallic nitrate, colouring or binding dope is added. Dynamites can be detonated by fulminate detonators. They are comparatively safe to handle and store for a moderate time in a place of medium temperature. Water may cause the extrusion of nitroglycerine from most forms of dynamite.

Gelignite.

'Gelignites' are mainly a thin jelly of a low grade gun-cotton in nitroglycerine; warm nitroglycerine is usually the gelatinising agent, but others may be employed. They may contain about 90 per cent. nitroglycerine. They are plastic, waterproof, and more powerful and convenient than ordinary dynamites. They should be stored in a place of cool even temperature. Most of the gelignites are doped, for some real or imaginary object.

Permitted Explosives.

'Permitted Explosives' for use in mines are such that comply more or less perfectly to certain tests, such as non-ignition of fire damp or coal dust, not producing a dangerous amount of poisonous fumes, considerable range of safety in storage and use. In many of these explosives, ammonia nitrate is the main oxygen carrier, the combustibles being benzene derivatives such as nitrobenzene, nitronaphthalene, and the like, with or without wood meal or inert powders to cool the flash.

Perchlorate of ammonia is the chief active material in some blasting compositions for civil or military use (cheddites). They are useful in fiery mines, as a quantity of hydrochloric acid gas is produced on explosion which acts as a damper of flame. Almost any kind of organic matters may be used in this class. Paraffin wax is often used, as, amongst other properties, it is waterproof.

Perchlorate compositions are stable and keep well, but all are liable to explode on moderately strong percussion. Generally they simply burn violently on ignition by a flame.

Ordinary chlorate compositions should be completely barred, as they are never safe and are erratic in use.

Detonators.

Detonators are substances employed to start the disruptive explosion or detonation of other compounds which alone may not explode by a flame or a moderately hard blow. Owing to the extreme rapidity of their explosion, detonators initiate a molecular decomposition of the main explosive, or it responds to the wave blow of the detonator.

Mercury fulminate, $HgN_2C_2O_2$, is the oldest and most commonly used detonator. It may be used alone or diluted with nitre, antimony sulphide, potassium chlorate, or even inert substances in some proportion, in order to regulate its sensitiveness, or reduce or modify the manner of exploding.

Cap and igniting compositions contain same proportion of $KNO_3Sb_2S_3$ and $KClO_3$.

Small quantities of fulminate, say 2 grams, may flash off if fired open, but the flimsiest cover will cause it to detonate on firing by a flame contact. A very slight suddenly applied pressure causes detonation. Its function in cap compositions is to respond to the blow of the hammer and ignite the other ingredients.

Lead azide, PbN_6, acts similarly to fulminate, is stronger and quicker in action, but probably not so amenable to regulation as fulminate.

Fuses.

These are, generally, some arrangement for firing an explosive at a desired moment. They consist, as a rule, of finely ground black powder contained in a paper tube protected by tape, machine-wound over it and waterproofed by some resinous or pitchy composition. Rate of burning may be controlled by fineness of powder, and in some cases by its composition, diameter of tube, etc.

In military fuses the powder has to burn along a circuitous route of determinable length in a metal container.

Fuses for blasting are packed in barrels and cases containing 300 or 500 coils of 24 ft. length. The average rate of burning of safety fuses is 75 to 90 secs. per yard. (See also 'Trinitrotoluene.') The fuse end is inserted in the detonator cap, which is then secured in proper contact with the explosive cartridge or charge, which may be tamped in the bore hole or not according to nature of explosive. (See also 'Blasting,' page 2570.)

Lyddite, or Picric Acid.

Lyddite, or picric acid, $C_6H_2OH(NO_2)_3$, is mainly a military explosive. It is somewhat difficult to detonate, otherwise there is no reason against its use for rock blasting. When some quantity is burnt there is a liability for it to pass into the detonation stage. The chief danger in connection with it is the liability to form metallic compounds (picrates), which are extremely sensitive to heat, friction, or percussion. There are several related substances with similar properties and uses, such as dinitrophenol, nitrocresols, etc.

Trinitrotoluene.

Trinitrotoluene (T.N.T.) and trinitroxylene (and other stages of nitration of toluene, xylene, etc.) are mainly military explosives, but T.N.T. has been used for some time in instantaneous fuses for civil work. Under proper conditions all these substances could be used for blasting.

Amatols.

Amatols (of various catagories) are essentially ammonia nitrate compositions with T.N.T. and similar substances. The violence of their explosion is increased by the addition of small quantities of powdered aluminium, magnesium, and other substances.

Amatols have a great future as blasting agents, but some of them are very sensitive and are not quite waterproof.

Blasting Machines.

Dynamo Electrical Blasting Machines are specially built to explode all blasting charges with absolute safety, either in stone quarries, coal mines, or oil shale workings. Being water and damp proof they are always ready for action.

SECTION XLII

WORKSHOP RECIPES, PROCESSES, ETC.

PAINTING — VARNISHES — METAL LACQUERS AND BRONZES — LUBRICANTS AND OILS — CLEANING-COMPOSITIONS — MISCELLANEOUS

SECTION XLII

PAINTING — VARNISHES — METAL LACQUERS AND BRONZES — LUBRICANTS AND OILS — CLEANING-COMPOSITIONS — MISCELLANEOUS.

(All Parts by Weight unless otherwise Specified.)

PAINTING.

Painting Woodwork.

A mixture of linseed oil and white lead is the best preservative of wood. The linseed is the preservative; the white lead gives body and opacity. Spirits of turpentine is added as a solvent, to enable the paint to penetrate into the pores of the material; the solvent should be light and easily evaporated.

Boiled linseed oil dries quicker than raw, but is darker and thicker than the latter.

To Remove Oil Paint.

2 lbs. washing soda, 2 lbs. quicklime, mixed to consistence of cream, spread on, and kept moist for an hour. The paint can then be washed off.

Glazier's Putty.

Whiting and raw linseed oil, well beaten up.

To Remove Old Putty.

Paint it with nitric or hydrochloric acid, and after about an hour it will be soft enough to remove; or a hot iron will soften it at once.

Painting.

In painting woodwork for the first time, kill knots with coating of fresh slaked lime; then in 24 hours scrape off, and paint knots with mixture of red and white lead and linseed oil; or use red-lead powder mixed with strong glue-size, and apply warm—the work can then be gone on with in a few minutes; when dry, smooth with pumice stone. Next put on priming coat. All holes are then stopped with glazier's putty, and the required coats added; each coat in good work is rubbed smooth with glass-paper before adding another.

Painting required to have no gloss has an additional coat, made with turpentine only, and no oil, called a *flatting coat*.

For old work, if much soiled, wash with soap and water and scour; if foul with smoke and grease, wash with lime and water; then commence with *second* coat.

New woodwork should have 4 coats; for periodical repainting 2 are sufficient.

Priming.

This generally consists of a mixture of white lead and red lead, irrespective of the colour to be used in finishing. The lead mixture is diluted with boiled linseed oil and a small quantity of turpentine. A special asbestos priming for painting fibro cement and all classes of asbestos sheeting is supplied by *Messrs. Walter Carson & Sons*, Grove Works, Battersea, London, S.W. 11.

'Muraprime.'

This priming (*Walter Carson & Sons*) is for use on porous plaster walls, for walls with unequal absorption, and for walls stopped with various plasters. Internal walls on which a perfect surface is desired should receive a coat of 'Muraprime' on the bare plaster. It assists to bind loose particles, and stops unequal absorption, which often makes flat painting or distempering patchy and unequal in colour. It is sold in four colours—white, yellow, green, and pink.

'COVERINE.'

This paint (*Walter Carson & Sons*, Grove Works, Battersea, London, S.W. 11) is a white undercoating, which saves time in the preparation of undercoats. It is ready for use in five minutes, and requires to be thinned with turpentine only. One coat is equal to two coats of white lead paint, and is consequently a saving of time and material. It dries hard, and can be coated in a few hours. The finishing coat can be applied and the work completed in one day. It forms a good undercoating for gilding, and will stand washing.

'MURALINE.'

This is a washable water paint (*Walter Carson & Sons*), and is sold in dry powder, in forty artistic shades. Water added to the powder in an equal proportion makes a sanitary washable paint, which forms a highly perfect and durable surface. Compared with paste distempers (which contain about one-third of water), it is claimed to effect a considerable saving, owing to its great covering power. 1 cwt. covers 600 to 700 square yards on non-porous surfaces. It will never deteriorate if stocked in a dry place, unexposed to the air. 1 cwt. of powder with 1 cwt. of water makes 2 cwt. of paint. It can be applied to new lime plaster, if dry, without injury to the colours. It works and flows evenly under the brush, and leaves a hard, smooth surface. Intermediate shades may be produced by mixing colours or by reducing with white. It is non-poisonous and an excellent disinfectant. The colours are fast to light, and do not discolour. It does not rub off, scale, or flake. The white is an excellent covering for ceilings. Unlike whitewash, removal is unnecessary before repainting if in sound condition.

Painting Ironwork.*

For new ironwork, 3 coats Torbay or other oxide of iron paint answers well; 1 lb. mixed with oil will cover from 8 to 12 yards. For periodical painting, 2 coats. For the first, or first and second coats on iron, red lead is very generally used; 1 lb. mixed with oil will cover about 5½ yards.

'FERRI-SILICON.'

This paint (*Walter Carson & Sons*), which can be made in any colour, is a cheap and durable preservative for ironwork, woodwork, and all exposed surfaces. It is a combination of iron and other oxides with silicates, which, when incorporated with a special enamel oil, produces a paint closely resembling enamel, but with a very tough and elastic surface, absolutely impenetrable. The manufacturing process which the enamel oil undergoes is claimed to render it at least twice as durable as the finest linseed oil. The paint is specially suitable for use on gasometers, as the colours are not affected by contact with sulphuretted hydrogen gas, sulphide of ammonia, etc.

'ANTI-CORROSION.'

This paint (*Walter Carson & Sons*) is for out-door work as a preservative for iron, wood, stone, brick, compo, etc. It is employed by many of the leading railways both at home and abroad, and also on life-boat stations. It is well adapted for coating the roofs of corrugated iron buildings, etc., and is especially recommended for buildings exposed to the corrosive action of sea air as it does not blister and wash off under these trying conditions.

SYRONITE ANTI-RUST PAINT.

Syronite is a thin transparent syrup which can be painted upon new ironwork before, during, or after erection, or upon existing structures that are already rusting. If the structure is in a bad state before the Syronite treatment is undertaken, the surface is first well brushed with a stiff wire brush to remove all loose rust. A coat of Syronite is then applied, its action being to penetrate through any remaining rust and cause this to shed off. When shedding has taken place, another coat is applied, and then the treatment is complete.

Pigments can be combined with Syronite when required.

A peculiar feature of the material is its capacity of 'creeping' or spreading. Ordinary paint stays exactly where the brush leaves it, and as the brush cannot always get under and along joints, round rivets, etc., these parts do not get equal protection with the general surface.

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* See also p. 2700.

CARSON'S ENGINEERS' PAINTS

ANTI-CORROSION

The most durable paint for Bridges and all exposed constructional ironwork.

FERRI-SILICON

A specially manufactured preservative for use on Gasometers, etc.,

Unaffected by Sulphuretted Hydrogen Gas and Sulphide of Ammonia.

QUICK-DRYING ENGINEERS'

A good preservative, specially suitable for use in Foundries, Collieries, etc. Dries hard in from two to three hours.

"MURAPRIME"

The best preservative for every kind of stone and brick work. Also for use under "Muraline" and all Distempers and Water Paints.

We are always pleased to answer queries and offer advice P.T.O.

F. 2788

CARSON'S PURE PAINTS

DISTEMPERS, ENAMELS and VARNISHES.

"MURALINE"

THE PERFECT WATER PAINT
Sanitary, Artistic, and Durable.
Requires only the addition of water to make ready for use.

"VITROLITE"

A Decorative White Paint.

Superior to white lead in colour, covering power and durability. Specially suitable for glasshouses.

The Celebrated White Undercoating.

One coat transforms back into white. Ready for use in five minutes. Can be second coated in a few hours.

PURE

LIQUID PAINT

Non-Poisonous. Ready for Use.

Specially manufactured for the finest exterior and interior decoration in over 50 countries.

Patterns and full particulars on application.

WALTER CARSON & SONS,

Grove Works, BATTERSEA, S.W. 11.

And at BACHELOR'S WALK, DUBLIN.

Telephone—BATTERSEA 1630 (2 lines).

Preservative for Ironwork.

(1.)

Coal-tar boiled till the watery vapour and naphtha are expelled, and mixed when cold with ¼ pint of naphtha and the same amount of boiled oil to each gallon of tar.

(2.)

Experiments carried out by the Military Engineering Department at Brest have shown that as an effective preservative for metal work coal tar is rendered far more efficient by the addition of a small quantity of quicklime, in the proportion of one part of lime to two parts of tar. The mixture, after being heated to the boiling point, is brushed upon the ironwork at a temperature of about 120° F. The tar should be used over a coating of red lead.

(3.)

A valuable rust-inhibitive coating for general priming or finishing work may be prepared from sublimed blue lead. Two parts of blue lead and one part of linseed oil containing about 5 per cent. of turpentine drier make a paint of the right consistency. When this paint is used for top-coat work in marine exposures—battleship gray—the addition of 1 per cent. of carbon black to the blue lead aids in the maintenance of the colour.

Rust Proof Coating for Iron or Steel.

Linseed oil, 25 parts; calcium resinate, 36 parts; manganese borate, ½ part; lead acetate, 1 part; naphtha, 37½ parts; artificial graphite, 25 parts. These are mixed and applied to the metal by brushing, or dipping, or any other method. The article is then baked at 300° F. for 1 hour and 40 minutes. The coating is highly lustrous and resistant to corrosion.—*American Machinist.*

Note on Iron-work Painting.

According to experiments published in the *Bulletin de la Société des Ingenieurs Civils de France*, a number of coats of paint form a much less effective rust preventive for metal than a single layer does. Iron plates well cleaned and polished were coated, some with one coat and some with two, three, or more coats of paint, and then exposed to the action of steam for a whole day, after which the paint was removed and the plates were examined. The first was as bright as it was before exposure to steam, the second showed a few rust spots, the third was still more attacked, and the fourth entirely so. This result is stated to be due to the fact that the deeper layers dry badly and tend to dissolve the uppermost coating, increasing its porosity to air and moisture.

Painting Zinc.

Dissolve 1 part chloride of copper, 1 nitrate of copper, and 1 sal ammoniac, in 64 of water, and add 1 part commercial hydrochloric acid. Paint the zinc with this, and leave to dry for 24 hours. Any oil colour will then firmly adhere to it.

To Paint in Imitation of Ground Glass.

White lead, 4 parts; boiled oil, 3 parts; spirits of turpentine, 1 part; add a small quantity of dryers. The colour must be exceedingly thin, and put on the panes of glass with a large brush in as even a manner as possible. Dab the paint over lightly with a pad of cotton-wool covered with an old linen rag.

Hydraulic Cement Paint.

Hydraulic cement mixed with oil forms an incombustible and waterproof paint for roofs of buildings, outhouses, etc.

Outside Whitewash.

Slaked lime, ½ bushel. Add common salt, 1 lb.; sulphate of zinc, ½ lb.; sweet milk, 1 gallon.

Flexible Paint.

Used for painting on canvas. 2½ lbs. good yellow soap dissolved in 1½ gallon boiling water; grind the hot solution with 3½ gallons of good oil paint.

Red Paint, quick drying (8 to 20 Minutes).

(Used for Pillar-boxes.)

Japanner's gold size	40 per cent.
Red lead	60 ,,

When dry, varnish with outside oak varnish.

Waterproof Paints.*

For General Purposes.

(1.)

2 gallons linseed oil, boiled with 11 ozs. each of rosin and litharge, 1½ oz. each of minium and umber; add gradually 8 ozs. of sulphate of zinc and a solution of 12 ozs. of potassium hydrate and a like quantity of alum in 4 gallons of water. For preparing the ground colour, compound 10 lbs. of chalk and 2 lbs. of zinc white with ¾ gallon of water in which 1½ oz. of alum has been previously dissolved, and mix with this a solution of 1½ lb. of glue in ½ gallon of water. This ground paint is mixed with 4 to 5 lbs. of the above composition, and the mixture diluted with petroleum.

(2.)

12 ozs. of melted rosin, thoroughly mixed with 6 gallons of fish oil and 1 lb. of melted sulphur and some ochre or any other colouring substance rubbed up with linseed oil. Apply several coats of the hot composition with a brush. The first coat should be very thin. Suitable for either wood or stone.

For Casks and Waterspouts.

Boiled oil, 1 part; charcoal, finely powdered, 1 part. Mix to consistence of paint.

For Vessels and Submarine Works.

Sulphate of copper, 400 lbs.; grape sugar, 100 lbs.; concentrated solution of potash, 200 lbs. The precipitate of hydrated oxide of copper formed by heating this mixture is filtered, dried, and mixed with 8 lbs. of 75 per cent. carbolic acid. Heat the mass moderately, and add about 12 gallons of crude linseed oil. When the paint is to be used it is reduced with linseed oil, and then applied. This composition is claimed to prevent the deposition of marine animals on the surface to which it is applied.

Paints for Waterproofing Outside Walls.

(1.)

Rosin, 4½ ozs.; litharge, 3 ozs., boiled in 1 pint of clear linseed oil until the wooden spatula used for stirring becomes brown. Give the walls 2 or 3 coats of this, preferably on a hot and dry summer's day.

(2.)

A solution of paraffin wax in heavy coal-tar oil is excellent for painting houses, and especially walls exposed to the action of the weather. Several experiments in painting damp walls with this solution have given very satisfactory results. Wall-paper which formerly became moist and detached from the walls during rainy weather remained perfectly dry after the wall had been painted with this solution, which is prepared by dissolving 1 part of paraffin wax in 2 to 3 parts of coal-tar oil at a moderate heat. A sufficient quantity of oil must be used so that the solution does not entirely congeal on cooling. To heat the paint while applying it, place the vessel containing it in hot water. It is best to apply the solution on a warm day, when the bricks are dry. Generally 1 coat is sufficient, but even if 2 coats are given the cost is considerably less than that of oil paint.

Paint for Wooden Floors.

Soak 2 ozs. good light-coloured glue in cold water for 12 hours, and dissolve it with constant stirring in thick milk of lime (prepared from 1 lb. of caustic lime) heated to the boiling-point. Stir in 8¾ ozs. linseed oil. Mix with any colour not affected by lime, and dilute with water if necessary. For yellow-brown or brown-red colours, boil in the ground colour ⅛th of its volume of a solution of shellac and borax. A coat of varnish produces a bright surface.

Paint for Red Brick Floors.

Wash the bricks with soap-water containing $\frac{1}{20}$th part of carbonate of soda. Dissolve 1 part of glue in 16 of boiling water and 4 parts of red ochre, and stir the mass thoroughly together. Apply 2 coats of this to the bricks, and then give a coat of linseed oil varnish.

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* It has been proved that no paint film, of which linseed oil is one of the chief constituents, can be made *thoroughly* impervious to moisture.

Preservative Solution for Stonework.

1 part white shellac, dissolved in 8 parts wood spirit. Apply to surface by means of a watering pot provided with a rose.

Paint for Roofs.

Pulverised slate (argillaceous schist), 35 parts; pulverised mica slate (mica schist), 30 parts; pulverised rosin, 35 parts; mix with ½ its volume of pure coal-tar, and boil to a fluid mass. This paint gives a very durable and pliant coating, which does not melt in the greatest heat of summer nor crack or break in the greatest cold. It resists moisture, and retains its lustre and smooth surface. It will last for 4 or 5 years.

Paints for Preserving Wooden Posts.

(1.)

50 parts rosin, 40 parts powdered chalk, 4 parts linseed oil; melt together in an iron boiler, add 1 part of natural cupric oxide, and stir very carefully into the mixture 1 part of sulphuric acid. Apply with a stiff brush. When dry the mass forms a coating as hard as stone.

(2.)

1½ part rosin (melted), 48 parts fish oil, 1½ part sulphur. When the mixture is thoroughly combined and liquid, add sufficient ochre rubbed up with linseed oil to give the desired shade of colour. Apply the mass while still warm in as thin a coat as possible, and in a few days, when the first coat is dry, repeat the operation.

Paint for Felt Roofing.

Washed graphite, 2 parts; red ochre, 2 parts; cement, 16 parts; barium sulphate, 16 parts, plumbic oxide, 6 parts. These materials to be ground in an oil varnish prepared as follows: 100 parts of good linseed oil are boiled for 8 hours in a copper boiler with 5 per cent. of pyrolusite. 10 parts of flowers of sulphur and 20 parts of French pitch are then dissolved in the mixture, and the mass filtered before it becomes cold. 25 lbs. of this composition and 1½ gallons of linseed oil varnish or linseed oil, for reducing the paint, are sufficient to give 2 coats to 1,000 square feet of roof surface. The first coat, while still wet, is uniformly covered with fine dry sand by means of a sieve. The sanding should be done during the progress of the painting, so that the workman is not obliged to step on to the wet paint. The free sand is renewed with a broom before the second coat is given, and it is best to apply this 8 days after the first. The second coat need not be sanded, its purpose being to combine with the first to form an insoluble mass hard as stone, and to give to the roof a neat, finished appearance.

Quickly-drying Oil Paint.

Boil for 15 minutes in an earthenware pot 1 part of soft curd soap in 3 parts of water. Pour the mass through a colander, wash it with cold water, and press out the water in a linen cloth. To 1 part of the curd soap add ½ part of unslaked lime and ⅔ part of water. Triturate the fat slime thus formed in oil or water with the necessary pigments. Walls, ceilings, stairs—in short, anything of stone, plaster of Paris, or zinc—can be painted with this. If the paint is to be used on wood, add $\frac{1}{10}$ part of linseed oil. Ochre, chrome yellow, Berlin blue, indigo, lead, and zinc, are best adapted for colouring substances. The mixture dries so quickly that 3 coats can be applied in a day. It is entirely without odour, and is about one-third the cost of ordinary oil paint.

Heat-Proof Paint.

Paint with good heat-proof properties, for smoke boxes, etc., can be made from 3 lbs. lamp black, 2 lbs. black lead, 1 lb. of black manganese oxide; these are mixed together; add ½ gal. of gold size, 1 pint of turpentine, and ½ pint of terebene; this, when thoroughly mixed in, will bring the mixture to the consistency of paint, and if about two coats of this are applied to surfaces exposed to heat, they will be found to resist same very well.

Fire-resisting Paint.

(1.)

20 lbs. finely pulverised glass, 20 lbs. finely pulverised porcelain, 20 lbs. any sort of stone in powder, 10 lbs. calcined lime, and 30 lbs. water glass (silicate of soda). The solid elements, having been powdered as finely as possible and sifted, are moistened and then intimately mixed with the water glass. This yields a syrupy mass that may be employed for painting, either alone or mixed with colour. The coating is applied with a brush, as other paints are, as uniformly as possible over the surface to be protected. The first coat hardens immediately, and a second one may be applied 6 hours or more afterwards; two coats are sufficient. The paint must be used immediately after it is made up.

(2.)

The most practical means so far discovered by the United States Forest Products Laboratory, Madison, Wis., for economically rendering small quantities of wood fire-resistant consists in the

use of fire-retardant paints. Ordinary whitewash or calcimine has proved in tests to be as fire-resistant as any paint covering tried, and it also possesses the advantages of cheapness and ease of application. While it will not prevent the burning of wood continuously exposed to a high temperature, a good coat of calcimine will decrease the likelihood of a blaze spreading from small sources of fire, such as flying sparks and matches. Calcimine is naturally more effective for interior than for exterior use. For work of the latter class the Forest Products Laboratory has developed an effective paint composed of linseed oil, zinc borate, and chrome green, which has maintained its fire-resisting properties through more than three years of exposure to the weather.

Heat-indicating Paint.

A paint for indicating an excessive rise of temperature in machinery bearings is composed essentially of a mixture of the double iodide of silver and mercury and copper mercuric iodide. The former is a pale yellow powder at normal temperatures, but turns to a vivid carmine at 90° to 100° C., while the copper salt, which is normally of a strong scarlet vermilion, changes to a chocolate brown at 60° to 70° C. A mixture of the two in the proportion of 85 per cent. of the copper salt and 15 per cent. of the silver changes promptly from vermilion to nearly black at 60° to 70° C. The paint is made with the aid of white shellac spirit varnish (100 grms. of the mixture to 70 cub. cm. of the spirit), and is applied in the form of a band or bull's-eye to the bearing. After the paint has become dry it is to receive a coat of colourless oil-proof varnish.

See also p. 1040.

Painting Portland Cement.

Portland cement work which is to be painted must be thoroughly hardened and dry. It is advisable to let the work stand for a year before oil paints are applied. The durability of the paint will be assured by, first, brushing over the surface with dilute sulphuric acid—one part of acid to 100 parts water—and allowed to dry before painting. A preparatory coating for oil paint is a solution of common water glass in three or four parts of water. Two applications of this, followed by a washing with water, and then another application of water glass, will be found effective.

Coal-Tar Paint.

(1) Coal-tar, 8 parts; Portland cement, 1 part; kerosene oil, 1 part. (2) Coal-tar 16, Portland cement 4, and kerosene 3 parts. The Portland cement neutralises the action of the tar on iron and steel, while the kerosene acts as dryer. It is suitable for painting ironwork of all kinds, and is a satisfactory coating, it is said, for ships' sides, and may also be used on galvanised iron.

Graphite Paint.

The best and longest records of satisfactory protection against corrosion are said to be held by graphite paints containing silica in intimate admixture with tough crystalline foliated graphite.

An example of this is the 'Foliac' Silica-Graphite Paint manufactured by *Graphite Products, Ltd., Battersea*, which is British manufactured throughout, and has been specified for a large number of steel structures, including Admiralty airship sheds, oil fuel tanks, gas holders, docks, bridges, station roofs, railway wagons, &c.

The relative covering power of foliated silica graphite paint is very high, and owing to the lubricating properties of the pigment the speed of application to the surface is very much more rapid than with other linseed oil paints. Owing to the large adhesion surface between the vehicle and the foliated graphite a very flexible tough paint is obtained which stands wearing action due to dust, for example, much better than paints which become brittle on drying. The resistance of the pigment to the action of the atmosphere found in industrial districts is due, of course, to the fact that it is chemically inert.

Bituminous Paints.

Bituminous paint is a good preventive to rust as it adheres closely to the material to be protected, it is strongly resistant to sulphurous vapours prevalent in the air of industrial centres, and very few of the mineral acids attack it, with the exception of nitric acid. Nitrous fumes have little or no action on the better bituminous paints. A good bituminous paint should dry within four or five hours, and the chances of injury by rain or similar eventualities during the setting are, therefore, correspondingly small. A high-class bituminous paint may be applied at a cost of something like a farthing per square foot with two coats of the paint applied. The life of a well-compounded bituminous paint extends up to twenty years' efficient protection.

Luminous Paint.

Mix 50 parts of lime with 20 parts of flowers of sulphur, heat them together in a closed crucible until all fumes cease to be evolved. When quite cold grind the product up with varnish or paint which is quite free from lead. Luminous paint produced from oyster shells is the most efficient in retaining its luminosity after dark. Take clean shells and, after washing them in warm water, place them in the fire for half an hour, and when cool, after removal, pound them up very small and fine, taking away any grey portions as being of no use, then put this powder in a crucible with alternate layers of flowers of sulphur, place on the lid and cement it round with sand made into a stiff paste with beer; as soon as this is dry, place the crucible in the fire and bake for one hour. Wait until quite cold before opening the lid. The product should be white; any grey portions must be separated as non-luminous. Sift it through fine muslin, and mix with either varnish or gum water. For use with buoys or in places exposed to the weather, varnish of the best quality only must be used.

Foliac Silica-Graphite Paint

Diagram showing relative covering power of Lead Paint and Foliac Silica - Graphite Paint.

1 cwt.
LEAD
PAINT

400 sq. yds.

1 cwt.
Foliac
SILICA-GRAPHITE
PAINT

950 sq. yds.

Diagram showing relative rates at which Lead Paint and Foliac Silica-Graphite Paint can be applied.

AREA
COVERED PER
HOUR WITH
LEAD PAINT

4 sq. yds.

AREA COVERED
PER HOUR WITH
Foliac
SILICA-
GRAPHITE
PAINT

5½ sq. yds.

Diagram showing relative cost of Lead Paint and Foliac Silica-Graphite Paint supplied to plain surface, assuming equal life to both paints

Foliac Silica-Graphite Paint ... LABOUR | Paint

Lead Paint (Admiralty Specification) ... LABOUR | Paint

THE COSTS ARE PROPORTIONATE TO LENGTHS SHOWN

A similar saving will be found over Iron Oxide Paints

In addition to the above advantages, consideration should be given to the proven greater life of Foliac Silica-Graphite Paint

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VARNISHES.

Incombustible Varnish for Wood.

An application of a solution of equal parts of alum and isinglass to the place exposed to the flame prevents ignition, but not the transmission of heat. By coating wooden vessels with this varnish fluids may be boiled in them over an ordinary fire.

Varnish for Wood not acted upon by Boiling Water.

Boil in an untinned copper boiler 750 parts of linseed oil. Suspend in this, in a bag which must not touch the bottom, 150 parts of litharge and 90 parts of pulverised minium. Let the oil boil until it has assumed a dark brown colour; then remove the bag, and replace it by one containing 7 to 8 bulbs of garlic. Now melt 500 parts of pulverised amber in 60 parts of linseed oil over a strong fire; add it while boiling to the prepared linseed oil, and let it boil for 2 to 3 minutes longer, stirring it vigorously. Then take it from the fire, allow it to settle, pour off the clear liquid, and when cold put it in bottles, which should be hermetically closed.

Quick-drying Varnish.

A quick-drying varnish that is less liable to crack than that made from kauri gum is made in the United States from the nuts of the Chinese wood oil tree (*Aleurites fordii*). The tung (or wood) oil has also been found of special value for waterproofing cement.

Varnish to prevent India-rubber Gas-tubing from Leaking.

Treacle, 1¼ part; gum arabic, 2 parts; white wine, 7 parts; strong alcohol, 3¼ parts.

Waterproofing Material.

A new French material for waterproofing leather, cloth, paper, and other materials, consists of a mixture of eight parts of amylacetate and four of castor oil, with one part of sulphur chloride stirred into it. This forms a jelly, giving off hydrochloric acid; it liquefies after being kept tightly covered a few days, and, the acid being then neutralised with barium carbonate, gives a colourless solution on filtering. To make a varnish, nitrocellulose is dissolved in the liquid after the addition of alcohol or benzine.

Cellulose Lacquers and Varnishes.

Cellulose lacquers and varnishes are extensively used for motor-cars and other purposes where a brilliant finish coupled with great resistance to weather is desired. They are made by dissolving nitrocellulose or cellulose acetate in amyl nitrate or acetate, castor-oil, or other suitable solvent, and may be applied with a spray or a brush, according to the nature of the lacquer and the surface to be decorated.

Cellulose lacquers have been used for twenty-five years or more, but their great popularity is of recent growth. In many instances they have replaced oil enamels, but in numerous other cases the reverse has occurred. For motor-cars, the American cellulose lacquer finish is superior to the American oil-varnish finish, but inferior to the English oil-varnish. English cellulose lacquer finish is superior to the American product and approaches, but is not quite equal to, English oil-varnish. In appearance the cellulose lacquer finish and the oil-varnish finish are almost equal, and it is a question of workmanship rather than material which gives the advantage, sometimes to one and sometimes to the other. The relative durability remains to be proved, short time tests being unreliable. Cellulose lacquer is more liable to crack under vibration, but is more resistant to changes in temperature, and whilst it is harder than oil-varnish it is more brittle and more liable to peel.

The cost of cellulose lacquer is greater than that of oil-varnish, but in large quantities it is cheaper to apply, so that the cost of covering a given area is less with cellulose than with oil-varnish. Although the use of cellulose lacquers is increasing rapidly, these materials have not superseded oil-paints, water-paints, and stove-enamels. They are limited in scope, cannot be repaired so readily when damaged, and many of them are inflammable and produce vapours injurious to the health of those applying them. These are temporary disadvantages which will probably disappear as still further improvements are made in cellulose lacquers. In selecting such lacquers care should be taken to avoid those of poor quality, of which there are too many available.

METAL LACQUERS AND BRONZES.

Lacquer for Iron and Steel.

Mastic, 10 parts; camphor, 5 parts; sandarach, 15 parts; elemi, 5 parts. Dissolve in alcohol and apply without heat.

A Rustless Coating for Steel.

A solution of white wax in benzine applied with a camel-hair brush. When the film of wax hardens, the bulk of it is wiped off with a chamois leather, just sufficient remaining to prevent rust, but not to be noticeable.

Angus Smith's Coating for Pipes.

Coal Tar 1 cwt., Tallow 7 lbs., Quick Lime (slaked) 10 lbs., Pine Resin 4 lbs., Coal Naphtha sufficient to thin the composition to a degree suitable for proper coating. Heat mixture, and immerse pipes, and allow to remain until the same temperature is diffused through the mass; then withdraw pipes. This treatment leaves a very firm and hard coating of pitch. It is very essential that the mixture be heated to a proper degree, viz., 350° to 450° F. If heated too much the pitch will not adhere properly, but will scale off.

Bronzing Liquids.

(1.)

Sulphate of copper, 1 oz.; sweet spirits of nitre, 1 oz.; water, 1 pint.

(2.)

Solution of chloride of platinum, laid on surface with a feather. When dry, blacklead over with an ordinary blacklead brush, and then lacquer.

(3.)

Boil 1 oz. of ammonium carbonate and a like quantity of blue vitriol in 1½ pint of vinegar until the latter is nearly evaporated. Then add 1½ pint of vinegar in which has been dissolved ½ drachm of oxalic acid and a like quantity of sal ammoniac. Place the mixture (known as Walker's Chemical Bronze) over the fire until it commences to boil, then allow it to cool; filter and put by in well-closed bottles.

If a medal, etc., is to be bronzed, it is first thoroughly cleansed, then heated, and the liquid applied by means of a badger-hair brush. In a short time boiling water is poured over the medal, and when dry it is rubbed with a cotton rag dipped in oil, and then with dry cotton.

Browning for Gun Barrels.

Tincture of muriate of iron, 1 oz.; nitric ether, 1 oz.; sulphate of copper, 4 scruples; rain water, 1 pint. When the barrel is finished let it remain in lime-water for a short time; then scratchbrush and apply bronzing.

Lacquer for Gun Barrels after Browning.

Shellac, 1 oz.; dragon's blood, ½ oz.; rectified spirit, 1 quart. Dissolve and filter.

To Chemically Blacken Brass.

Dissolve copper in nitric acid (out of doors) until all action ceases; when cold decant into another jar.

Sand-blast work, or clean in hot lye and soda; dry in sawdust; heat to 212° F.; immerse in the (cold) nitrate solution; remove and heat again sufficiently to dry off solution and burn off green colour; repeat if necessary; cool and free from oxide by brushing; dip in ammonia; rub dry with soft cloth or in sawdust—work is then brown. To make it dead black, heat just enough not to burn hands, and rub with soft leather and fine olive oil; heat, to dry oil.

Highly-polished work, if well cleaned and dipped in commercial ammonia before applying nitrate, will take a permanent black.

Sand-blasted work takes a black that cannot be removed by ordinary wear.

Black-bronzing Aluminium.

(1) Immerse the articles, after being thoroughly cleaned, in a hot solution containing 8 oz. of white arsenic, 8 oz. of iron sulphate, ¼ gallon of hydrochloric acid, and ¼ gallon of water. When sufficiently blackened the articles are removed, washed and lacquered. A more adhesive deposit may be obtained by adding to the solution a small quantity of ammonium molybdate and yellow prussiate of potash. (2) Paint the articles with a solution made by dissolving 60 grammes of copper chloride in 300 c.c. of water and add ammonia in excess to re-dissolve the precipitate first formed. Then heat the articles, care being taken not to melt the aluminium. A deeper black may be got by repeating the process, or by dipping the articles in a solution of sodium sulphide.

Black Finish on Steel Shears, etc.

Prepare a saturated solution of caustic soda and add about ¼ lb. of saltpetre to a five-gallon solution. Boil the solution for a short time, and allow it to cool. The clear liquid should only be used, and this should be brought to the boiling point in an iron kettle. The articles should be wired as for plating and immersed in the solution. The articles will take on a grey colour at once with black underneath, and should be left in the solution until the grey finish disappears and a beautiful black remains. Rinse the articles in cold water, dry in sawdust, oil with linseed oil and wipe clean. The resulting finish will be a fine blue-black that wears well.

LUBRICANTS AND OILS.*

Greases for Railway Axles.

(1.)

Water, 1 gallon; palm oil, 6 lbs.; clean tallow, 3 lbs.: common soda, ½ lb.

(2.)

Tallow, 8 lbs.; palm oil, 10 lbs. Heat to 212° F., and well stir.

Antifriction Grease.

(1.)

Tallow, 100 lbs.; palm oil, 70 lbs. Boil together, and when cooled to 80° F. strain through a sieve and mix with 28 lbs. common soda and 1½ gallon of water.

(2.)

Blacklead, 1 part; lard, 4 parts.

Rosin-Oil Soap.

90 lbs. powdered slaked lime, stirred into 100 lbs. rosin oil. Heat the mixture, constantly stirring it well until a uniform paste of the consistence of syrup is obtained. This rosin oil is a component of all the patent wagon greases.

Blue Patent Grease.

2 lbs. powdered slaked lime, heated in 550 lbs. of crude rosin oil for 1 hour, and then allowed to cool. Skim the oil, and stir in 10 to 12 lbs. of rosin-oil soap, until the compound is of a butter consistency and of a blue colour.

Yellow Patent Grease.

1 part turpentine, 20 parts caustic lye. Add to 350 parts of blue grease.

Black Patent Grease.

2 parts lampblack, 110 parts blue grease.

Patent Palm-Oil Wagon Grease.

Melt 10 lbs. rosin-oil soap in 10 lbs. palm oil: add 550 lbs. rosin oil, with as much rosin-oil soap as will give the whole the consistence of butter; finally, add 7¾ to 10 lbs. of caustic soda lye.

Adhesive Grease for Machine Belts.

Lubricate the belts with fish oil to which 10 per cent. of tallow has been added. This will make them flexible, and augment their friction on the pulleys.

Grease for Waterproofing Leather.

Oleic acid, 24 parts; crude stearic acid, 6 parts; ammoniacal soap, 18 parts; extract of tannin, 6 parts; water, 24 parts. Melt the oleic acid together with the stearic acid; then add gradually the ammoniacal soap, the extract of tannin, and finally the water. The ammoniacal soap is obtained by adding to heated oleic acid caustic ammonia until, after continued stirring, the odour of ammonia remains apparent and the whole congeals to a jelly-like mass.

Cooling Compound for Hot Bearings.

(1.)

Mercurial ointment mixed with black cylinder oil and applied every quarter of an hour, or as often as expedient. The following is also recommended as a good cooling compound for heavy bearings:—Tallow, 2 lbs.; plumbago, 6 ozs.; sugar of lead, 4 ozs. Melt the tallow with gentle heat, and add the other ingredients, stirring until cold. For lubricating gearing, wooden cogs, etc., nothing better need be used than a thin mixture of soft soap and black lead.

(2.)

For cooling a hot bearing Professor Lecocq, of the Charleroi Higher Industrial School, recommends that the oil usually employed for lubrication be dissolved in an equal quantity of petroleum spirit, the evaporation of which latter will, he says, afford the cooling desired.

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* See also pages 1055–1069.

Watchmaker's Oil.

Expose the best olive oil to a temperature a few degrees below the freezing point, which will cause all foreign substances to separate. Pour off carefully the supernatant clear oil, and filter through a cup of linden wood or pith of elder wood. By this process an oil is obtained which will remain liquid for several years, and does not attack the delicate machinery.

Neat's-foot oil treated in the above manner furnishes a less useful oil, since it loses much fatty matter by exposure to cold.

A very useful oil is obtained by dissolving 1 part of pure neat's-foot oil in 3 of pure benzine. Allow the compound to remain for several days in a closed vessel; then filter, and expose the solution to a temperature of 40° F., at which it is again filtered, and the benzine distilled off. The oil should be kept in small, dark vials protected from the air.

A very fine lubricant for clocks and watches is, according to Artemus, obtained by mixing 2 parts of solar oil with 1 of rape-seed oil.

To test the fitness of Oils for Lubricating Watches and Clocks.

Pour a drop of the oil to be tested upon different metal plates, as iron, brass, tin, lead, etc.; keep them in a place free from dust, and examine the drops during 8 to 14 days in regard to their liquidity. Oil remaining liquid after the lapse of this time can be safely used.

Viscosity of Various Standard Oils.

Description.	Viscosity.	
	At 70° F.	At 120° F.
Sperm oil	100	45
Whale oil	190	70
Olive oil	213	75
Lard oil	225	78
Neatsfoot oil	247	80
Rape-seed oil	250	88
Axle oil	600	120
Valve oil	—	550
Cylinder oil	—	700

In the above table sperm oil is taken as the standard for viscosity at 70° F.

The viscosity of thick oils can be greatly reduced by adding 8 per cent. of naphthalene to the oil.

An objectionable characteristic in an oil is its tendency to become resinous with use, due to the oil undergoing the process of oxidation. This change in the oil indicates, to some extent, the degree of refining process the oil has undergone. A simple test can be made in the following way :—Place a small quantity of oil in a glass beaker and put in a nearly equal amount of nitric acid. Should the oil have no tendency to gum, the acid and oil will combine and get very thick, while should there be any objectionable characteristic the oil will remain thin.

CLEANING AND PRESERVATIVE COMPOSITIONS.

To clean Brass.

Oxalic acid, 1 oz. Rotten stone, 6 oz.; powdered gum arabic, ½ oz.; sweet oil, 1 oz. Rub on with piece of rag.

Soap for cleaning Metal-work.

The soaps used for cleaning metal-work usually consist of mixtures of vaseline, oleic acid, and fat, mixed with a small quantity of rouge. When freshly prepared they leave nothing to be desired; but, unfortunately, such mixtures soon turn rancid and become unfit for use. A newer soap for metal-work, which is stated to be free from this objection, is made from cocoanut butter in the following way :—2·5 kilogrammes of the butter are melted in an iron vessel, together with a little water, and to the mixture is added, with constant stirring, 180 grammes of chalk, 87·5 grammes of alum, 87·5 grammes of cream of tartar, and 87·5 grammes of white lead. This mixture is then poured into moulds and allowed to solidify. The soap so obtained is made into a paste with water, rubbed over the metal to be cleaned, and finally removed by a dry rag or chamois leather.

To clean Grease from Paper.

(1.)

Warm the spotted part, and press blotting-paper upon it until all the grease is extracted that is practicable by this method; then with a brush apply very hot turpentine, and wash off with alcohol.

(2.)

Apply benzine collas freely to the spot.

To clean Marble.

Powdered chalk, 1 part; powdered pumice stone, 1 part; soda, 2 parts. Mix with water. Paint over marble; then clean, and wash off with soap and water.

To clean Grease from Stone or Marble.

Soft soap, 1 part; fuller's earth, 2 parts; potash, 1 part. Mix with boiling water. Lay it on the spots, and let it remain for a few hours.

A Solvent for Rust.

It is often very difficult, and sometimes impossible, to remove rust from articles made of iron. Those which are very thickly coated are most easily cleaned by being immersed in a solution (nearly saturated) of chloride of tin. The length of time they remain in this bath is determined by the thickness of the coating of rust. Generally twelve to twenty-four hours is long enough.

To cleanse Paint Brushes from Dried-in Paint.

Suspend the brush in a tumbler containing a solution of 1 part of crystallised sodium carbonate in 3 of water, in such a manner that it hangs several inches from the bottom of the tumbler. Let it stand from 12 to 24 hours in a moderately warm place (140° to 150° F.). The dried paint will be softened so much that it can be easily washed out with soap and water. Brushes which have become as hard as stone can be restored by this process.

To Remove Rust from Iron.

(1.)

Freely apply turpentine or paraffin oil, leave for twelve hours, and then rub with the finest emery cloth.

(2.)

Dip in strong hot potash bath, for about ½ hour. Then immerse in a cold muriatic acid pickling solution—2 parts water, 1 acid. This removes rust in a few minutes, the metal being attacked but very little. Without the potash it will take about 65 minutes against 4 when both baths are used. The appearance of the rust when treated is black and soft and it can almost be entirely rubbed off with the hands. The metal so treated has a smooth, glossy finish.

(3.)

A dip of 40 parts of muriatic acid and 60 parts of water is effective for removing rust. After the rust has been removed, it is necessary to dip the steel in a strong alkaline bath to remove every trace of acid. The alkaline solution usually employed for this purpose is composed of 2 oz. each of soda ash, sodium cyanide, and caustic lime.

To Remove Rust from Iron Electrically.

A very simple and effective way of cleaning rusted iron articles, no matter how badly they are rusted, consists in attaching a piece of ordinary zinc to the articles, and then letting them lie in water to which a little sulphuric acid is added. They should be left immersed for several days, or a week, until the rust has entirely disappeared, the time depending on how deeply they were rusted. If there is much rust, a little sulphuric acid should be added occasionally. The essential part of the process is that the zinc must be in good electrical contact with the iron; a good way is to twist an iron wire tightly around the object, and connect this with the zinc, for which a remnant of a battery zinc is suitable, as it has a binding post. Besides the simplicity of this process, it has the great advantage that the iron itself is not attacked in the least as long as the zinc is in good electrical contact with it. When there is only a little rust, a galvanised iron wire wrapped around the object will take the place of the zinc, provided the acid is not too strong. The articles will come out a dark grey or black colour, and should then be washed thoroughly and oiled. The method is specially applicable to objects with sharp corners or edges, or to files and other articles on which buffing wheels ought not to be used. The rusted iron and the zinc make a short-circuited battery, the action of which reduces the rust back to iron, this action continuing as long as any rust is left.

To keep Machinery from Rusting.

Take 1 oz. of camphor, dissolve it in 1 lb. of melted lard; mix with it (after removing the scum) as much fine blacklead as will give it an iron colour. Clean the machinery, and smear it with this mixture. After 24 hours rub clean with soft linen cloth. It is stated that this mixture will keep machinery clean for months under ordinary circumstances.

To protect Iron and Steel from Rust.

The following method is but little known, although it deserves preference over many others: Add 1¾ pints of cold water to 7 ozs. of quicklime. Let the mixture stand until the supernatant fluid is entirely clear. Then pour this off, and mix it with enough olive oil to form a thick cream, or rather to the consistency of melted and recongealed butter. Grease the articles of iron or steel with this compound, and then wrap them up in paper; or, if this cannot be done, apply the mixture somewhat more thickly.

To keep Tools from Rusting.

Half-ounce camphor dissolved in 1 lb. melted lard: skim and mix in as much black-lead as will give it an iron colour. Smear tools, and after 24 hours rub clean with soft linen cloth.

Or, 6 oz. lard to 1 oz. rosin. When semi-fluid it is ready for use.

Or, use vaseline, to which, when warm, a little powdered camphor has been added.

To remove Rust from Tools.

Tools which have become very rusty should be treated with a chemical solution, instead of trying to scour the rust off by means of emery cloth. A good solution for removing rust may be made as follows. Into one quart of distilled water dissolve, little by little, sufficient chloride of tin to obtain a saturated solution, that is, until the water will not dissolve any more of the salt. Put the tool into a receptacle containing the solution and let it stand over night. In the morning rinse the solution off in running water and dry thoroughly with a piece of chamois or cloth.

Blueing Steel.

Outfit.

The outfit consists of a cast-iron kettle, one tank for boiling water, and one tank for oil (aquiline). The mixture consists of nine parts of saltpetre, by weight, and one part pyrolusite. The articles are hung in perforated baskets. A scraper is necessary for the melting kettle to stir the solution and to scrape the sediment from the bottom.

Method.

The desired temperature for treatment is obtained when all the mixture has melted and begun to boil, and when a pinch of fine sawdust thrown in bursts into flame the moment it reaches the surface. The temperature must be kept constant to give good results. In operation, the full basket may be hung on the chain at one end of a lever and lowered into the solution. The articles are left in for three minutes, then are slowly lifted out to allow the surplus solution to drain off; they are then dipped into hot water to clean off the solution; after the water has drained off, the articles are dipped into the oil and taken out as quickly as possible and allowed to drain. It is essential to note that there be no rust on the work, and that red-hot cast iron is attacked by these chemicals.

Blueing Small Screws.

Use a boiling bath composed of:

Water	1 gallon.
Hyposulphite of soda	2 ozs.
Acetate of lead	2 „

The hyposulphite of soda and the acetate of lead are first dissolved in the water and the whole is then brought up to boiling point. The work, which must be absolutely clean and free of grease, and preferably polished, is immersed in the bath for a few seconds, and then withdrawn. At first the work will be a kind of yellow, changing to red and then to blue almost immediately. The work is rinsed in water and quickly dried. Changing the length of time during which the work is immersed in the bath will give varying depths of colour. When the desired tint is obtained, note the time immersed, and give subsequent dippings the same period in the bath.

The brilliancy of the blues obtained by the above method is greatly enhanced if the work is copper plated before immersion in the colouring bath. The plating may be accomplished by the dipping process. To a quantity of distilled water add all the copper sulphate it will dissolve, then for every four ounces of distilled water add from 10 to 14 drops of sulphuric acid. Start with 10 drops in the first instance and add more sulphuric acid if required. Before coppering it is absolutely essential that the work be free from grease. It should be noted that in all colouring processes the higher the initial polish on the work the greater the brilliance of the finished work.

(*'Machinery.'*)

Blueing Small Hardened Steel Springs Without Heating.

Thoroughly clean the springs in boiling lime water and afterwards remove any remaining lime by means of a brush. Dip the springs in a nitric acid bath; wipe clean and oil; linseed oil is generally used for this purpose. (*W. R., 'Machinery.'*)

Waterproof and Fireresisting Boards.

The boards are first laid in a waterglass solution of 5° to 10° Bé., where they are left 10 to 12 hours, when they are taken out and allowed to drip off. After drying, they are placed in a solution (gravity 2° to 3° Bé.) of calcium chloride, magnesium chloride, and ammonium chloride. In this they are left four to six hours, and after dripping off and drying again, they are ready for use.

MISCELLANEOUS.

To Prevent Rusting-in of Screws.

In machines exposed to heat or moist air the screws soon rust in, even with the use of oil, which later on renders it difficult to take the machines apart. By dipping the screws before use in a thin paste of graphite and oil they can be readily taken out, even after years.

Drilling Glass.

To drill holes in glass a common steel drill, well made and well tempered, is the best tool. Whilst drilling, the hole should be moistened with turpentine in which some camphor has been dissolved.

To drill a large hole in thin glass, make in a piece of wood a hole of the size required, and fasten the wood with beeswax upon the glass so as to act as a guide. A piece of brass or copper tubing, of the size of the hole required, is placed in the hole in the wood, supplied with emery powder and water, and is twirled round between the fingers or by means of a bow-string. This will cut a hole in a few minutes.

To Divide Glass Bottles.

Breaking glass tubes or vessels with a clean edge by the aid of a string dipped in an inflammable oil is a well-known method, but the latter is not suitable for large vessels, such as a carboy; to break such vessels, fill to point required with cold water, then pour boiling oil over surface of water: before oil has time to cool, dash cold water on outside of vessel, when a clean break is said to result.

A still better method is to make a small mark, with a triangular file, at the point where the break or division is required. A tiny gas flame, not larger than $\frac{1}{8}$ in. diameter, is then applied to the file-mark. If a crack does not start quickly the hot glass is wetted with a drop of water. When a crack has started the flame is held in contact with the glass, just in front of the crack; the crack will then extend to the flame and by causing the flame to travel, step by step around the vessel, complete severence will be effected with accuracy and certainty.

To Cut Glass Tubing of Large Diameter.

Nick the glass tube with a file or a cutter at the point where the fracture is desired. Wrap three or four thicknesses of blotting paper around the tube about $\frac{1}{4}$ in. from each side of the mark, the blotting paper being held in place by copper wires. Soak the blotters with water, and expose the narrow section of tube between the two wet blotters to the heat of a bunsen burner. The flame will cause a fracture starting at the file nick and extending in almost a straight line around the tube. The method describes for glass bottles (above) may also be used.

Cutting Glass under Water.

Cutting a glass sheet with a pair of scissors may seem difficult, but it is not, although the job must be done under water and both the glass and scissors must be submerged. A good way is to first cut a paper the size or shape of the glass desired; place it on the under side of the glass for a pattern. It is not expected that it is possible to cut through the centre of a large piece of glass, but by trimming a little at a time a good job can be done. The cutting sensation is a good deal the same as that of cutting cardboard.

To make Ivory and Bone Permanently White.

Hydrated oxide of zinc is dissolved in ammonia and the articles laid in it. To remove the yellow tint, a few drops of an aqueous solution of blue vitriol is added; after impregnation the articles are repeatedly washed with cold water, dried in the air and polished. The zinc-oxide of ammonia solution is prepared as follows:—40 parts by weight water mixed with 25 parts of pure zinc, with (after a quarter of an hour) 50 parts concentrated hydrochloric acid added. To the zinc solution 150 parts hot water is added, then (gradually stirring the while) caustic ammonia until the precipitated white hydrated oxide of zinc is dissolved.

Hard Rubber.

The finest grade of hard rubber, such as is found in a good comb or fountain pen, may contain 75 per cent. rubber and 25 per cent. sulphur, and may have been vulcanised ten hours. The specific gravity of pure hard rubber ranges from 1·12 to 1·25. The tensile strength in the finest and purest grades may be over three tons, and the dielectric strength is specified by the United States Navy for sheets at 10,000 volts per $\frac{3}{32}$ in. of thickness.

Fibre.

There are three kinds of fibre in general use—viz., two kinds of vulcanised fibre, known as hard and flexible, and horn fibre.

The flexible is restricted to such uses as pump valves, washers and gaskets. The tensile strength of vulcanised fibre varies from 10,000 lbs. to 20,000 lbs. per sq. in. (as compared with 3,000 lbs. to 6,000 lbs. for leather). Its resistance to compression varies from 40,000 lbs. to 60,000 lbs. per sq. in. (for wood it varies from 3,000 lbs. to 11,000 lbs.). Its resistance to shearing varies from 9,000 lbs. to 13,000 lbs. per sq. in. (compared to wood, with the grain, 225 lbs. to 906 lbs.; to aluminium casting, 12,000 lbs.; and to aluminium forgings, 16,000 lbs.). There is no clearly defined elastic limit, but it approximates 4,000 lbs., and there is no permanent set even at rupture point. The specific gravity is about 1·3, varying from 1·2 to 1·5 (sp. gr. of pure aluminium in a cast state is 2·58; of cork, 0·24; of wood, 0·35 to 1·33). It possesses the strength and density of a metal, yet is elastic and nearly as light as hardwood. A square foot of $\frac{1}{8}$ in. fibre weighs about $\frac{7}{8}$ lb. and the same area of 1 in. stock about 7 lbs.—i.e., about 20 cub. ins. to the pound.

Vulcanised fibre is insoluble in all the ordinary solvents, and is not affected by immersion in alcohol, ammonia, benzine, or any of the animal, vegetable, or mineral oils. It absorbs water freely, and swells when wet, but is not otherwise injured. When heated this fibre does not melt or soften, but at a high temperature it chars and loses its elasticity. Vulcanised fibre is not brittle, and will stand a great amount of pounding and rough usage. It can be machined, and will take a fine polish, but cannot be moulded.

One of the purposes to which vulcanised fibre is being applied is the thrust bearings in light sensitive, drilling machines. Ball bearings cause endless trouble in this position if one of the balls fractures or chips, and it has been found that a fibre disc answers the purpose admirably. The permeability of the fibre to oil renders it self-lubricating, and its life under these conditions is remarkable.

To Face Oilstones.

On a sheet or plate of iron with an accurately even or straight face (it ought to be planed) scatter a little emery or fine sand, add a little water, and rub the face of the stone on the sheet, renewing the emery or sand and water as requisite, finishing with an addition of water without emery or sand.

Etching and Etching Fluids.

The nearest approach to a perfect protective for general purposes is beeswax of the proper consistency, which can be easily applied in any desired thickness. Before applying the wax it is important that the surface be thoroughly clean and absolutely dry, and the difference in temperature between the wax and the article to be etched should be slight. If it is necessary to dip the piece into melted wax, the article should be kept immersed for a few moments until it acquires the same temperature as the molten wax. The design is cut in the wax and through to the metal, after which the etching liquid is applied.

The following fluids have been found to work satisfactorily:

Iron and Steel.—Hydrochloric acid (full strength) should be used. Nitric acid, however, must not be used.

Brass.—Nitric acid.

Copper.—A mixture containing 2 parts of nitric acid and 1 part of sulphuric acid.

Silver.—Nitric acid, 3 parts; water, 1 part.

Gold.—A mixture containing 1 part of nitric acid and 3 parts of hydrochloric acid. The mixture should be prepared just before being applied, and should be used warm, under a hood or fume closet.

Platinum.—The same mixture as that used for gold.

Lead.—Nitric acid.

Aluminium.—A 10 per cent. solution of caustic soda or potash.

Zinc.—A mixture containing equal parts of hydrochloric acid and water, used warm.

Glass.—Hydrofluoric acid. The article may be immersed in the liquid acid for a few minutes or it may be exposed to the fumes for five to fifteen minutes. Extreme caution should be used in handling this acid, using rubber gloves for the hands and a lead or hard rubber container for the acid. Contact with the skin will cause severe burns, and the action seems to be continuous, producing burns far more severe than those caused by the mineral acids.

All the acids may be used full strength, but if the etching is to be of considerable depth most of them may be diluted with water before applying. This will require more time, but will produce a cleaner cut. The exception to this is the mixture of gold and platinum, which must always be used full strength and applied as warm as the melting point of the wax will permit.

Bending Small Metal Tubes.

Put a cork or plug into one end and fill with slightly damp sand well rammed in, then close with another cork; heat the tube until it is just uncomfortably hot to the hand, and then bend round a bit of board sawn to the required curve.

In making coils and spirals of small tubing, the Bureau of Standards at Washington has adopted the plan of filling the tubes with ice. This has the advantage of being very easily got rid of after the completion of the operation, and has proved very effective. To produce the ice filling, the tube, after charging with water, is immersed in a bath of ice and salt.

To Drill Hard Steel.

Use turpentine instead of oil; it will drill readily even when the drill lubricated with oil will not touch the metal.

Turning and Cutting Aluminium.

One of the best lubricants for cutting aluminium in the lathe is paraffin; this prevents tearing, and enables a better finish to be obtained.

To Remove a Stubborn Nut.

Heat the spanner end and place on nut for a moment or two or apply a red hot bar to the nut; this will expand the nut only, whereas using a blow-lamp, etc., heats both nut and bolt. If the above method fails, the nut should be split.

Silvering a Mirror.

(Up to 14 square inches area.)

Well scrub glass with brush, soap, and hot water; rinse repeatedly in cold water; soak in nitric acid for few minutes; rinse in distilled water. Do not touch surface after soap stage.

Solutions.

(*a*)		(*b*)		(*c*)	
Silver nitrate .	50 grs.	Grape sugar .	50 grs.	Caustic potash .	50 grs
Distilled water .	1 oz.	Distilled water .	1 oz.	Distilled water .	1 oz.

Add strong ammonia drop by drop to (*a*), when a yellowish precipitate will form, and later liquid will clear. No more ammonia must then be added; swirl after each drop. Add (*c*), when black precipitate will form; add ammonia drop by drop until solution clears; add 2½ ozs. distilled water and mix in sugar solution (*b*). *Immediately* put into dish and carefully insert glass with face (downwards) just below the surface. When sugar is added solution becomes cloudy, so it should only be added when quite ready for use. Leave glass undisturbed for 30 minutes. Remove glass and again wash in distilled water. Drain for few minutes and swish off any drops of water. If cloudy, polish with a pad of cotton wool covered with soft chamois leather and jewellers' rouge, by light circular strokes. Lacquer with No. 2 cold colourless lacquer from Messrs. Gedge, 90 St. John's Street, Clerkenwell. Back with Brunswick black. Absolute cleanliness in vessels and liquids is essential to success. It is usually cheaper and more satisfactory to send the glass to a mirror-maker.

Size of Clock Dials.

Allow 1 ft. diameter for every 10 ft. from the ground, and then add 6 ins. to this; thus, if the dial is to be 40 ft. from the ground, the diameter should be 4 ft. 6 ins.

Wire Drawing.

Wire may be reduced in diameter or *drawn* by forcing it through holes in a piece of steel or other substance. A steel die is used where practicable but for some purposes diamond dies are preferable. The diamonds used are either natural stones or chips from large stones used in jewellery. For a hole ·055 in. in diameter a 5-carat stone is needed, whilst stones weighing half-a-carat suffice for dies with holes from ·014 in. down to ·009 in. in diameter and under. In copper wire the smallest size made commercially is 0·002 in. in diameter. Thirteen diamonds are needed to reduce the wire from ·010 in. in diameter to 0·003 in. in diameter. Wires thinner than ·002 in. in diameter are exceedingly expensive to make. A lot drawn for exhibition purposes from ·0022 in. in diameter down to ·001 in. in diameter took 7 drafts. The life of the diamonds when drawing copper wire is six months to a year, provided the stones are of good size, hard, smooth, and well drilled. The weight produced per operator per day falls very rapidly as the size of the wire is reduced. Thus, whilst one man will produce 1,100 lbs. per day of No. 22 (B. and S. gauge), he can only draw 45 lbs. of No. 40 (B. and S.). Diamonds are also used for drawing steel, though they are not economical, nor do they produce a better quality of wire than steel die-plates; but if fine steel wire is wanted very round and true to size, the diamond dies seem necessary. A steel die will not keep to size for more than one coil of No. 33 wire or finer. The life of a diamond is much shorter on steel than on copper, averaging only about three days when it must be polished out for the next larger size. The surface produced on steel wire is not so smooth when diamonds are used as it is with steel. The speed at which the wire is drawn appears to have little effect on the life of the diamond die, which depends solely on the length passed through. About 200 lbs. weight of steel wire can be drawn through a No. 32 (B. and S.) diamond die-plate before it is off size, 15 lbs. through holes ·005 in. to ·003 in. in diameter, and less than 1 lb. through holes smaller than ·002 in. in diameter. The smallest commercial size is ·0025 in. steel brush wire, drawn from low or medium carbon steel. Difficulty was at one time experienced in drawing hard music wire smaller than ·012 in. in diameter without breaking the diamond; but nowadays it can be drawn as small as ·005 in. in diameter, using 2 to 2½-carat diamonds for the dies. Below about ·009 in. or ·008 in. diameter, however, music wire becomes very curly, and no method of keeping it straight has yet been discovered.

Cracks in Metal.

A crack in a piece of metal is prevented from extending further by the well-known means of drilling a hole where the rent ends; but when the hole is not bored on just that spot the crack is apt to continue beyond the hole. To facilitate the search for the exact point, moisten the cracked surface with petroleum, then wipe it, and immediately rub it with chalk. The oil that has penetrated into the crack exudes, and thus indicates with precision where the crack stops. The best method of healing cracks is by electric or acetylene welding.

Rendering Celluloid Incombustible.

In order to overcome the undesirable quality of celluloid to ignite, it may be dissolved in a mixture of ether and alcohol and added to an ether-alcohol solution of ferric perchloride. The clear syrupy liquid is poured into a suitable vessel and is left for spontaneous evaporation. The resulting substance of shell-colour is, after washing and drying, a celluloid of great pliability and transparency, and is incombustible.

See also "Celluloid," by Dr. Beckmann: Fr. London, Scott, Greenwood & Son, 8 Broadway Ludgate Hill, London, E.C. 4. Price 8*s.* 6*d.*

Wood-Worms in Oak.

It is stated that the most effective means of treating oak work when attacked with wood worm is to give it several coats of paraffin, well soaked into the wood. This should be done by a careful workman, making quite sure that every hole has been well soaked with the paraffin; the paraffin does not damage the oak, but has a tendency to improve the colour.

The extermination of the *Xestobium tessellatum* in the oak roofing of Westminster Hall has been effected by spraying the timber with a mixture of 50 per cent. tetrachlorethane, 6 per cent. cedarwood oil, 2 per cent. solvent soap, 2 per cent. paraffin wax, and 40 per cent. trichlorethylene. The tetrachlorethane is a perfect insecticide, but it is so dangerous that those who handle it must use gas masks.

Thermostatic Metal.

Thermostatic metal, manufactured by the *British Thomson-Houston Company, Ltd.*, has appearance a homogeneous metal, is formed of two metal strips having widely different coefficients of expansion. The two metals are welded together along their entire length, and are quite inseparable under normal working conditions. When the duplex strip is subjected to change of temperature, one half will expand more quickly than the other, causing the strip to bend. A change of one degree of temperature is said to affect its curvature to a measurable extent and practically instantaneously. In bending, it exerts a force sufficient for the direct operation of levers, the opening and closing of ventilators, etc. The metal can be cut, stamped, or machined; it is supplied in various thicknesses from 0·015 in. to 0·25 in.

Setting a Spirit-Level Glass.

A simple method of setting a spirit level glass is to use a small piece of putty to support each end temporarily. The plastic putty can be made to hold the glass in the required position, it being an easy matter to depress either end so that it will be parallel or level with the working surface of the levelling bar. When properly levelled up in this way plaster of Paris is poured around the supporting ends of the glass and allowed to set. The glass will then be held permanently in place. (J. H. B., *Machinery*).

Supporting Power of Ice.

Ice 1½ inches thick will support a man.		Ice 10 inches thick will support a crowd.	
„ 4 „ „ „	cavalry and light guns.	„ 18 „ „ „	a railway train.
„ 5 „ „ „	an 84-pound cannon.		

Removing Enamel.

The ordinary paint-removers, designed to remove air-dried paint and varnishes, are not adapted, or intended to be used, for the removal of baked enamel from metallic surfaces such as those of automobiles. It is customary in the removal of baked enamel, particularly enamel which is baked under high temperatures, to laboriously chip it off. D. F. Clark, of Harrisburg, Pa., has compounded a body (U.S. Patent No. 1,495,547) which may be applied with a brush, and which will adhere to the enamelled surface, and on allowing it to remain for from 15 mins. to 2 hours, depending upon the temperature at which the enamel was baked, the enamel may be easily brushed off. The best results are obtained from a mixture of the following ingredients in the proportions mentioned; 20 parts of methyl acetone; 20 parts of denatured alcohol; 10 parts of aqua ammonia (of 26° to 32°); 10 parts ammonia carbonate; 15 parts benzol; 10 parts xylol; 5 parts paraffin wax; 5 parts celluloid chips; 5 parts soap. The benzol, xylol, and methyl acetone are boiled, and the wax and celluloid are stirred in until thoroughly incorporated. The mixture thus far made is then permitted to cool. After cooling, the denatured alcohol is added. Finally, the ammonia is added. The purpose of the celluloid and the wax is to impart a viscous consistency to the mass and prevent evaporation of the volatile constituents. Some enamelled metals have so adhesive an enamel that this treatment will not remove it.

Flow of Sand.

The velocity of flow of sand and other fine materials through openings of various shapes and in different circumstances, is determined mainly by the size of the particles and of the opening, but is slightly diminished by angularity of the particles or by moisture on them. The specific gravity of the particles, the height of the material above the opening, and the shape of the upper contour of the material have little effect. If D is the diameter of the opening, d that of the particles, both in inches, the mean velocity of flow V in feet per second is given with sufficient accuracy for most practical purposes by the equation, $V = (D - 2d)/\sqrt{D}$.

(*Hersam: Journal of the Franklin Institute.*)

SECTION XLIII

LENGTHS — SURFACES — WEIGHTS — CAPACITIES — WIRE GAUGES — FOREIGN WEIGHTS, MEASURES, AND MONEY, WITH THEIR ENGLISH EQUIVALENTS—SIZES OF PAPER

(pages 2807-2825)

(Revised by S. W. Attwell, of the National Physical Laboratory)

SECTION XLIII

LENGTHS—SURFACES—WEIGHTS—CAPACITIES—FOREIGN MEASURES—WIRE-GAUGES—SIZES OF PAPER, etc.

(Revised by S. W. Attwell, of the National Physical Laboratory.)

The accepted relations of English Imperial to International Metric Measures are thus given by the Standards Office of the Board of Trade :

1 inch = 25·399978 mm.; 1 metre = 39·370113 inches; 1 gallon = 4·5459631 litres; 1 litre = 1·75980 pint; 1 pound = 0·45359243 kilogram; 1 kilogram = 2·2046223 pounds.

In 1893 the United States of America recognised the metre as the fundamental standard of length, and adopted the conversion value of 1 metre = 39·37 inches.

10 penny diameters = 1 ft.; halfpenny = 1 inch; 5-shilling piece = 1½ inch. Weight of 3 pennies, 1 five-shilling piece, or 5 shillings, each = 1 oz.

LENGTHS.

English.

The length of the standard yard of 36 inches is such that a pendulum vibrating seconds of mean time, temperature 62° F., at the level of the sea and latitude of Greenwich, has a length of 39·1393 inches.

Miles.	Furlongs.	Chains.	Rods.	Yards.	Feet.	Inches.
1	8	80	320	1,760	5,280	63,360
·125	1	10	40	220	660	7,920
·0125	·1	1	4	22	66	792
·003125	·025	·25	1	5·5	16·5	198
·00056818	·0045454	·045454	·181818	1	3	36
·00018939	·00151515	·01515151	·060606	·33333	1	12
·000015783	·000126262	·001262626	·0050505	·0277777	·083333	1

GUNTER'S SURVEYING CHAIN.

7·92 inches = 1 link. 100 links = 1 chain 4 rods, or 22 yards. 80 chains = 1 mile.

ROPES AND CABLES.

1 cable-length = 120 fathoms = 720 feet. 1 fathom = 6 feet.

GEOGRAPHICAL AND NAUTICAL MEASURES.

1 degree of a great circle of the earth round the equator = 69·174 statute miles = 365,239 feet. 1 nautical mile (knot) = 6,080 feet. 1 telegraph mile = 6,087 feet.

LOG-LINE.

The log-line should be about 150 fathoms long, and 10 fathoms from the log to the first knot on the line. If half-a-minute glass is used, it will be 50·66 feet between each succeeding knot. For 28-seconds glass it will be 47·29 feet = 7·88 fathoms per knot. This is the length of knot by calculation, but practically it is shortened to 7·5 fathoms per knot for 28-seconds glass.

Metric System.

Name.	Ins.	Feet.	Yards.	Miles.
Millimetre† . .	·03937	·003281		
Centimetre‡ . .	·39370113	·032808		
Decimetre . .	3·9370113	·3280843	·10936	
Metre§ . .	39·370113	3·280843	1·0936143	
Decametre . }	393·70113	32·80843	10·936143	
Hectometre . }	Road	328·0843	109·36143	·06213718
Kilometre . }	measures.	3280·843	1093·6143	·6213718
Myriametre . }		32808·43	10936·143	6·213718

† Nearly the $\frac{1}{39\frac{3}{8}}$th part of an inch. ‡ Full $\frac{3}{8}$ inch.
§ Very nearly 3 ft. $3\frac{3}{8}$ ins., which is too long by only 1 part in 8,056.

Conversion of English Inches into Centimetres.

Ins.	0	1	2	3	4	5	6	7	8	9
	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.	Cms.
0	·00	2·54	5·08	7·62	10·16	12·70	15·24	17·78	20·32	22·86
10	25·40	27·94	30·48	33·02	35·56	38·10	40·64	43·18	45·72	48·26
20	50·80	53·34	55·88	58·42	60·96	63·50	66·04	68·58	71·12	72·66
30	76·20	78·74	81·28	83·82	86·36	88·90	91·44	93·98	96·52	99·06
40	101·60	104·14	106·68	109·22	111·76	114·30	116·84	119·38	121·92	124·46
50	127·00	129·54	132·08	134·62	137·16	139·70	142·24	144·78	147·32	149·86
60	152·40	154·94	157·48	160·02	162·56	165·10	167·64	170·18	172·72	175·26
70	177·80	180·34	182·88	185·42	187·96	190·50	193·04	195·58	198·12	200·66
80	203·20	205·74	208·28	210·82	213·36	215·90	218·44	220·98	223·52	226·06
90	228·60	231·14	233·68	236·22	238·76	241·30	243·84	246·38	248·92	251·46
100	254·00	256·54	259·08	261·62	264·16	266·70	269·24	271·78	274·32	276·86

The above table is correct throughout to within 1 part in 1,000,000.

Conversion of Centimetres into English Inches.

Cms.	0	1	2	3	4	5	6	7	8	9
	Ins	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
0	·0000	·3937	·7874	1·1811	1·5748	1·9685	2·3622	2·7559	3·1496	3·5433
10	3·9370	4·3307	4·7244	5·1181	5·5118	5·9055	6·2992	6·6929	7·0866	7·4803
20	7·8740	8·2677	8·6614	9·0551	9·4488	9·8425	10·236	10·630	11·024	11·417
30	11·811	12·205	12·598	12·992	13·386	13·780	14·173	14·567	14·961	15·354
40	15·748	16·142	16·535	16·929	17·323	17·717	18·110	18·504	18·898	19·291
50	19·685	20·079	20·472	20·866	21·260	21·654	22·047	22·441	22·835	23·228
60	23·622	24·016	24·409	24·803	25·197	25·591	25·984	26·378	26·772	27·165
70	27·559	27·953	28·346	28·740	29·134	29·528	29·921	30·315	30·709	31·102
80	31·496	31·890	32·283	32·677	33·071	33·465	33·858	34·252	34·646	35·039
90	35·433	35·827	36·221	36·614	37·008	37·402	37·795	38·189	38·583	38·976
100	39·370	39·764	40·158	40·551	40·945	41·339	41·732	42·126	42·520	42·913

Conversion of English Feet into Metres.

Ft.	0	1	2	3	4	5	6	7	8	9
	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.	Metres.
0	·0000	·3048	·6096	·9144	1·2192	1·5240	1·8288	2·1336	2·4384	2·7432
10	3·0480	3·3528	3·6576	3·9624	4·2672	4·5720	4·8768	5·1816	5·4864	5·7912
20	6·0960	6·4008	6·7056	7·0104	7·3152	7·6200	7·9248	8·2296	8·5344	8·8392
30	9·1440	9·4488	9·7536	10·058	10·363	10·668	10·973	11·278	11·582	11·887
40	12·192	12·497	12·802	13·106	13·411	13·716	14·021	14·326	14·630	14·935
50	15·240	15·545	15·850	16·154	16·459	16·764	17·069	17·374	17·678	17·983
60	18·288	18·593	18·898	19·202	19·507	19·812	20·117	20·422	20·726	21·031
70	21·336	21·641	21·946	22·250	22·555	22·860	23·165	23·470	23·774	24·079
80	24·384	24·689	24·994	25·298	25·603	25·908	26·213	26·518	26·822	27·127
90	27·432	27·737	28·042	28·346	28·651	28·956	29·261	29·566	29·870	30·175
100	30·480	30·785	31·090	31·394	31·699	32·004	32·309	32·614	32·918	33·223

INCHES	MILLIMETERS
$\frac{1}{64}$	$\frac{1}{2}$
$\frac{1}{32}$	1
$\frac{3}{64}$	$1\frac{1}{2}$
$\frac{1}{16}$	2
$\frac{5}{64}$	$2\frac{1}{2}$
$\frac{3}{32}$	3
$\frac{7}{64}$	$3\frac{1}{2}$
$\frac{1}{8}$	4
$\frac{9}{64}$	$4\frac{1}{2}$
$\frac{5}{32}$	5
$\frac{11}{64}$	$5\frac{1}{2}$
$\frac{3}{16}$	6
$\frac{13}{64}$	$6\frac{1}{2}$
$\frac{7}{32}$	7
$\frac{15}{64}$	$7\frac{1}{2}$
$\frac{1}{4}$	8
$\frac{17}{64}$	$8\frac{1}{2}$
$\frac{9}{32}$	9
$\frac{19}{64}$	$9\frac{1}{2}$
$\frac{5}{16}$	10
$\frac{21}{64}$	$10\frac{1}{2}$
$\frac{11}{32}$	11
$\frac{23}{64}$	$11\frac{1}{2}$
$\frac{3}{8}$	12
$\frac{25}{64}$	$12\frac{1}{2}$
$\frac{13}{32}$	13
$\frac{27}{64}$	$13\frac{1}{2}$
$\frac{7}{16}$	14
$\frac{29}{64}$	$14\frac{1}{2}$
$\frac{15}{32}$	15
$\frac{31}{64}$	$15\frac{1}{2}$
$\frac{1}{2}$	16
$\frac{33}{64}$	$16\frac{1}{2}$
$\frac{17}{32}$	17
$\frac{35}{64}$	$17\frac{1}{2}$
$\frac{9}{16}$	18
$\frac{37}{64}$	$18\frac{1}{2}$
$\frac{19}{32}$	19
$\frac{39}{64}$	$19\frac{1}{2}$
$\frac{5}{8}$	20
$\frac{41}{64}$	$20\frac{1}{2}$
$\frac{21}{32}$	21
$\frac{43}{64}$	$21\frac{1}{2}$
$\frac{11}{16}$	22
$\frac{45}{64}$	$22\frac{1}{2}$
$\frac{23}{32}$	23
$\frac{47}{64}$	$23\frac{1}{2}$
$\frac{3}{4}$	24
$\frac{49}{64}$	$24\frac{1}{2}$
$\frac{25}{32}$	25
$\frac{51}{64}$	$25\frac{1}{2}$
$\frac{13}{16}$	26
$\frac{53}{64}$	$26\frac{1}{2}$
$\frac{27}{32}$	27
$\frac{55}{64}$	$27\frac{1}{2}$
$\frac{7}{8}$	28
$\frac{57}{64}$	$28\frac{1}{2}$
$\frac{29}{32}$	29
$\frac{59}{64}$	$29\frac{1}{2}$
$\frac{15}{16}$	30
$\frac{61}{64}$	$30\frac{1}{2}$
$\frac{31}{32}$	31
$\frac{63}{64}$	$31\frac{1}{2}$
1	32
$1\frac{1}{64}$	$32\frac{1}{2}$
$1\frac{1}{32}$	33
$1\frac{3}{64}$	$33\frac{1}{2}$
$1\frac{1}{16}$	34
$1\frac{5}{64}$	$34\frac{1}{2}$
$1\frac{3}{32}$	35
$1\frac{7}{64}$	$35\frac{1}{2}$
$1\frac{1}{8}$	36
$1\frac{9}{64}$	$36\frac{1}{2}$
$1\frac{5}{32}$	37
$1\frac{11}{64}$	$37\frac{1}{2}$
$1\frac{3}{16}$	38
$1\frac{13}{64}$	$38\frac{1}{2}$
$1\frac{7}{32}$	39
$1\frac{15}{64}$	$39\frac{1}{2}$
$1\frac{1}{4}$	40
$1\frac{17}{64}$	$40\frac{1}{2}$
$1\frac{9}{32}$	41
$1\frac{19}{64}$	$41\frac{1}{2}$
$1\frac{5}{16}$	42
$1\frac{21}{64}$	$42\frac{1}{2}$
$1\frac{11}{32}$	43
$1\frac{23}{64}$	$43\frac{1}{2}$
$1\frac{3}{8}$	44
$1\frac{25}{64}$	$44\frac{1}{2}$
$1\frac{13}{32}$	45
$1\frac{27}{64}$	$45\frac{1}{2}$
$1\frac{7}{16}$	46
$1\frac{29}{64}$	$46\frac{1}{2}$
$1\frac{15}{32}$	47
$1\frac{31}{64}$	$47\frac{1}{2}$
$1\frac{1}{2}$	48
$1\frac{33}{64}$	$48\frac{1}{2}$
$1\frac{17}{32}$	49
$1\frac{35}{64}$	$49\frac{1}{2}$
$1\frac{9}{16}$	50
$1\frac{37}{64}$	$50\frac{1}{2}$
$1\frac{19}{32}$	51
$1\frac{39}{64}$	
$1\frac{5}{8}$	
$1\frac{41}{64}$	
$1\frac{21}{32}$	
$1\frac{43}{64}$	
$1\frac{11}{16}$	
$1\frac{45}{64}$	
$1\frac{23}{32}$	
$1\frac{47}{64}$	
$1\frac{3}{4}$	
$1\frac{49}{64}$	
$1\frac{25}{32}$	
$1\frac{51}{64}$	
$1\frac{13}{16}$	
$1\frac{53}{64}$	
$1\frac{27}{32}$	
$1\frac{55}{64}$	
$1\frac{7}{8}$	
$1\frac{57}{64}$	
$1\frac{29}{32}$	
$1\frac{59}{64}$	
$1\frac{15}{16}$	
$1\frac{61}{64}$	
$1\frac{31}{32}$	
$1\frac{63}{64}$	
2	

$\frac{31}{32}$ inch is shown to be equal to 25 millimetres; carried to three decimal places the correct value would be 23·019 millimetres. (*C. H. W.*, '*Machinery*,' *June* 26, 1919.)

Inches reduced to Decimals of a Foot.

Ins.	Foot.	Ins.	Foot.	Ins.	Foot.	Ins.	Foot.	Ins.	Foot.	Ins.	Foot.
0	·0000	2	·1667	4	·3333	6	·5000	8	·6667	10	·8333
1/32	·0026	1/32	·1693	1/32	·3359	1/32	·5026	1/32	·6693	1/32	·8359
1/16	·0052	1/16	·1719	1/16	·3385	1/16	·5052	1/16	·6719	1/16	·8385
3/32	·0078	3/32	·1745	3/32	·3411	3/32	·5078	3/32	·6745	3/32	·8411
1/8	·0104	1/8	·1771	1/8	·3438	1/8	·5104	1/8	·6771	1/8	·8438
5/32	·0130	5/32	·1797	5/32	·3464	5/32	·5130	5/32	·6797	5/32	·8464
3/16	·0156	3/16	·1823	3/16	·3490	3/16	·5156	3/16	·6823	3/16	·8490
7/32	·0182	7/32	·1849	7/32	·3516	7/32	·5182	7/32	·6849	7/32	·8516
1/4	·0208	1/4	·1875	1/2	·3542	1/4	·5208	1/4	·6875	1/4	·8542
9/32	·0234	9/32	·1901	9/32	·3568	9/32	·5234	9/32	·6901	9/32	·8568
5/16	·0260	5/16	·1927	5/16	·3594	5/16	·5260	5/16	·6927	5/16	·8594
11/32	·0286	11/32	·1953	11/32	·3620	11/32	·5286	11/32	·6953	11/32	·8620
3/8	·0313	3/8	·1979	3/8	·3646	3/8	·5313	3/8	·6979	3/8	·8646
13/32	·0339	13/32	·2005	13/32	·3672	13/32	·5339	13/32	·7005	13/32	·8672
7/16	·0365	7/16	·2031	7/16	·3698	7/16	·5365	7/16	·7031	7/16	·8698
15/32	·0391	15/32	·2057	15/32	·3724	15/32	·5391	15/32	·7057	15/32	·8724
1/2	·0417	1/2	·2083	1/2	·3750	1/2	·5417	1/2	·7083	1/2	·8750
17/32	·0443	17/32	·2109	17/32	·3776	17/32	·5443	17/32	·7109	17/32	·8776
9/16	·0469	9/16	·2135	9/16	·3802	9/16	·5469	9/16	·7135	9/16	·8802
19/32	·0495	19/32	·2161	19/32	·3828	19/32	·5495	19/32	·7161	19/32	·8828
5/8	·0521	5/8	·2188	5/8	·3854	5/8	·5521	5/8	·7188	5/8	·8854
21/32	·0547	21/32	·2214	21/32	·3880	21/32	·5547	21/32	·7214	21/32	·8880
11/16	·0573	11/16	·2240	11/16	·3906	11/16	·5573	11/16	·7240	11/16	·8906
23/32	·0599	23/32	·2266	23/32	·3932	23/32	·5599	23/32	·7266	23/32	·8932
3/4	·0625	3/4	·2292	3/4	·3958	3/4	·5625	3/4	·7292	3/4	·8958
25/32	·0651	25/32	·2318	25/32	·3984	25/32	·5651	25/32	·7318	25/32	·8984
13/16	·0677	13/16	·2344	13/16	·4010	13/16	·5677	13/16	·7344	13/16	·9010
27/32	·0703	27/32	·2370	27/32	·4036	27/32	·5703	27/32	·7370	27/32	·9036
7/8	·0729	7/8	·2396	7/8	·4063	7/8	·5729	7/8	·7396	7/8	·9063
29/32	·0755	29/32	·2422	29/32	·4089	29/32	·5755	29/32	·7422	29/32	·9089
15/16	·0781	15/16	·2448	15/16	·4115	15/16	·5781	15/16	·7448	15/16	·9115
31/32	·0807	31/32	·2474	31/32	·4141	31/32	·5807	31/32	·7474	31/32	·9141
1	·0833	3	·2500	5	·4167	7	·5833	9	·7500	11	·9167
1/32	·0859	1/32	·2526	1/32	·4193	1/32	·5859	1/32	·7526	1/32	·9193
1/16	·0885	1/16	·2552	1/16	·4219	1/16	·5885	1/16	·7552	1/16	·9219
3/32	·0911	3/32	·2578	3/32	·4245	3/32	·5911	3/32	·7578	3/32	·9245
1/8	·0938	1/8	·2604	1/8	·4271	1/8	·5938	1/8	·7604	1/8	·9271
5/32	·0964	5/32	·2630	5/32	·4297	5/32	·5964	5/32	·7630	5/32	·9297
3/16	·0990	3/16	·2656	3/16	·4323	3/16	·5990	3/16	·7656	3/16	·9323
7/32	·1016	7/32	·2682	7/32	·4349	7/32	·6016	7/32	·7682	7/32	·9349
1/4	·1042	1/4	·2708	1/4	·4375	1/4	·6042	1/4	·7708	1/4	·9375
9/32	·1068	9/32	·2734	9/32	·4401	9/32	·6068	9/32	·7734	9/32	·9401
5/16	·1094	5/16	·2760	5/16	·4427	5/16	·6094	5/16	·7760	5/16	·9427
11/32	·1120	11/32	·2786	11/32	·4453	11/32	·6120	11/32	·7786	11/32	·9453
3/8	·1146	3/8	·2813	3/8	·4479	3/8	·6146	3/8	·7813	3/8	·9479
13/32	·1172	13/32	·2839	13/32	·4505	13/32	·6172	13/32	·7839	13/32	·9505
7/16	·1198	7/16	·2865	7/16	·4531	7/16	·6198	7/16	·7865	7/16	·9531
15/32	·1224	15/32	·2891	15/32	·4557	15/32	·6224	15/32	·7891	15/32	·9557
1/2	·1250	1/2	·2917	1/2	·4583	1/2	·6250	1/2	·7917	1/2	·9583
17/32	·1276	17/32	·2943	17/32	·4609	17/32	·6276	17/32	·7943	17/32	·9609
9/16	·1302	9/16	·2969	9/16	·4635	9/16	·6302	9/16	·7969	9/16	·9635
19/32	·1328	19/32	·2995	19/32	·4661	19/32	·6328	19/32	·7995	19/32	·9661
5/8	·1354	5/8	·3021	5/8	·4688	5/8	·6354	5/8	·8021	5/8	·9688
21/32	·1380	21/32	·3047	21/32	·4714	21/32	·6380	21/32	·8047	21/32	·9714
11/16	·1406	11/16	·3073	11/16	·4740	11/16	·6406	11/16	·8073	11/16	·9740
23/32	·1432	23/32	·3099	23/32	·4766	23/32	·6432	23/32	·8099	23/32	·9766
3/4	·1458	3/4	·3125	3/4	·4792	3/4	·6458	3/4	·8125	3/4	·9792
25/32	·1484	25/32	·3151	25/32	·4818	25/32	·6484	25/32	·8151	25/32	·9818
13/16	·1510	13/16	·3177	13/16	·4844	13/16	·6510	13/16	·8177	13/16	·9844
27/32	·1536	27/32	·3203	27/32	·4870	27/32	·6536	27/32	·8203	27/32	·9870
7/8	·1563	7/8	·3229	7/8	·4896	7/8	·6563	7/8	·8229	7/8	·9896
29/32	·1589	29/32	·3255	29/32	·4922	29/32	·6589	29/32	·8255	29/32	·9922
15/16	·1615	15/16	·3281	15/16	·4948	15/16	·6615	15/16	·8281	15/16	·9948
31/32	·1641	31/32	·3307	31/32	·4974	31/32	·6641	31/32	·8307	31/32	·9974

To reduce Inches to Decimals of an Inch use the Table, page 121.

Conversion of Metres into English Feet.

Metres.	0	1	2	3	4	5	6	7	8	9
	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0	·0000	3·2808	6·5617	9·8425	13·123	16·404	19·685	22·966	26·247	29·528
10	32·808	36·089	39·370	42·651	45·932	49·213	52·493	55·774	59·055	62·336
20	65·617	68·898	72·179	75·459	78·740	82·021	85·302	88·583	91·864	95·144
30	98·425	101·71	104·99	108·27	111·55	114·83	118·11	121·39	124·67	127·95
40	131·23	134·51	137·80	141·08	144·36	147·64	150·92	154·20	157·48	160·76
50	164·04	167·32	170·60	173·88	177·17	180·45	183·73	187·01	190·29	193·57
60	196·85	200·13	203·41	206·69	209·97	213·25	216·54	219·82	223·10	226·38
70	229·66	232·94	236·22	239·50	242·78	246·06	249·34	252·62	255·91	259·19
80	262·47	265·75	269·03	272·31	275·59	278·87	282·15	285·43	288·71	292·00
90	295·28	298·56	301·84	305·12	308·40	311·68	314·96	318·24	321·52	324·80
100	328·08	331·37	334·65	337·93	341·21	344·49	347·77	351·05	354·33	337·61

Conversion of English Statute Miles into Kilometres.

Miles.	0	1	2	3	4	5	6	7	8	9
	Kiloms.	Kiloms.	Kiloms.	Kiloms.	Kiloms.	Kiloms.	Kiloms.	Kiloms.	Kilom.	Kilom.
0	·0000	1·6093	3·2187	4·8280	6·4374	8·0467	9·6561	11·265	12·875	14·484
10	16·093	17·703	19·312	20·921	22·531	24·140	25·749	27·359	28·968	30·578
20	32·187	33·796	35·406	37·015	38·624	40·234	41·843	43·452	45·062	46·671
30	48·280	49·890	51·499	53·108	54·718	56·327	57·936	59·546	61·155	62·764
40	64·374	65·983	67·592	69·202	70·811	72·420	74·030	75·639	77·248	78·858
50	80·467	82·076	83·686	85·295	86·905	88·514	90·123	91·733	93·342	94·951
60	96·561	98·170	99·779	101·39	103·00	104·61	106·22	107·83	109·44	111·04
70	112·65	114·26	115·87	117·48	119·09	120·70	122·31	123·92	125·53	127·14
80	128·75	130·36	131·97	133·58	135·18	136·79	138·40	140·01	141·62	143·23
90	144·84	146·45	148·06	149·67	151·28	152·89	154·50	156·11	157·72	159·32
100	160·93	162·54	164·15	165·76	167·37	168·98	170·59	172·20	173·81	175·42

Conversion of Kilometres into English Statute Miles.

Kiloms.	0	1	2	3	4	5	6	7	8	9
	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	Miles
0	·0000	·6214	1·2427	1·8641	2·4855	3·1069	3·7282	4·3496	4·9710	5·5923
10	6·2137	6·8351	7·4565	8·0778	8·6992	9·3206	9·9419	10·563	11·185	11·806
20	12·427	13·049	13·670	14·292	14·913	15·534	16·156	16·777	17·398	18·020
30	18·641	19·263	19·884	20·505	21·127	21·748	22·369	22·991	23·612	24·234
40	24·855	25·476	26·098	26·719	27·340	27·962	28·583	29·204	29·826	30·447
50	31·069	31·690	32·311	32·933	33·554	34·175	34·797	35·418	36·040	36·661
60	37·282	37·904	38·525	39·146	39·768	40·389	41·011	41·632	42·253	42·875
70	43·496	44·117	44·739	45·360	45·982	46·603	47·224	47·846	48·467	49·088
80	49·710	50·331	50·952	51·574	52·195	52·817	53·438	54·059	54·681	55·302
90	55·923	56·545	57·166	57·788	58·409	59·030	59·652	60·273	60·894	61·516
100	62·137	62·759	63·380	64·001	64·623	65·244	65·865	66·487	67·108	67·730

SURFACES.

English.

Sq. Miles.	Acres.	Sq. Chains.	Sq. Rods.	Sq. Yards.	Sq. Feet.	Sq. Inches.
1	640	6,400	102,400	3,097,600	27,878,400	4,014,489,600
·001562	1	10	160	4,840	43,560	6,272,640
·0001562	·1	1	16	484	4,356	627,264
·000009766	·00625	·0625	1	30·25	272·25	39,204
·000000323	·0002066	·002066	·033	1	9	1,296
·0000000359	·00002296	·0002296	·00367	·1111111	1	144
·00000000025	·000000159	·00000159	·00002551	·0007716	·006945	1

Metrical.

Name.	Sq. Ins.	Sq. Ft.	Sq. Yards.	Acres.
Sq. Millimetre . .	·00155	·00001076	·0000012	
Sq. Centimetre. .	·1550	·0010764	·0001196	
Sq. Decimetre . .	15·50006	·1076393	·0119599	
Sq. Metre, or Centiare	1550·006	10·76393	1·195992	·000247
Sq. Decametre, or Are	1550006	1076·393	119·5992	·024711
Sq. Hectometre or Hectare . .	—	107639·3	11959·92	2·471058
Sq. Kilometre . .	·3861029 sq.	—	1195992	247·1058
Sq. Myriametre .	38·61029 miles	—	—	24710·58

WEIGHTS.

English.

One cubic inch of distilled water (weighed in air against brass weights) at temperature 62° F., the barometer being at 30 ins., weighs 252·326 grains, of which 7,000 go to the pound avoirdupois, and 5,760 to the pound troy.

AVOIRDUPOIS.

Ton.	Cwts.	Pounds.	Ounces.	Drams.
1	20	2240	35840	573440
·05	1	112	1792	28672
·00044643	·0089286	1	16	256
·0000279	·000558	·0625	1	16
·000001744	·00003488	·003906	·0625	1

TROY.

Pound.	Ounces.	Dwts.	Grains.	Pound Avoir.
1	12	240	5760	·822857
·083333	1	20	480	·068571
·004166	·05	1	24	·00342857
·0001736	·002083333	·0416666	1	·000142857
1·215278	14·58333	291·6666	7000	1

APOTHECARIES'.

Pound.	Ounces.	Drams.	Scruples.	Grains.
1	12	96	288	5760
·08333	1	8	24	480
·01041666	·125	1	3	60
·0034722	·0416666	·3333	1	20
·00017361	·0020833	·016666	·05	1

Metrical.

1 gramme=15·432356 grains, and is the weight of a cubic centimetre of distilled water in vacuo at 4° Centigrade, or 39·2° Fahr.

Weight.	Grammes.	Avoirdupois Ounces.	Avoirdupois Lbs.	Cwts.	Ton	Grains.
Milligramme .	·001	—	—	—	—	·015
Centigramme .	·01	—	—	—	—	·154
Decigramme .	·1	—	—	—	—	1·543
Gramme . .	1	·035	·0022	—	—	15·432356
Decagramme .	10	·35	·022			
Hectogramme	100	3·527	·22046			
Kilogramme .	1000	35·2739	2·204622	·019	·00098	
Myriagramme	10000	—	22·04622	·1968	·00984	
Quintal . .	100000	—	220·4622	1·9684	·0984	
Millier or Bar	1000000	—	2204·622	19·68413	·984206	

CONVERSION OF METRICAL TO ENGLISH WEIGHTS.

Grammes to Grains		Kilogrammes to Ounces. (Avoir.)		Kilogrammes to Pounds. (Avoir.)	
1=15·432356	6=92·594138	1=35·27396	6=211·64374	1=2·204622	6=13·227734
2=30·864713	7=108·02649	2=70·54791	7=246·91770	2=4·409245	7=15·432356
3=46·297069	8=123·45885	3=105·82187	8=282·19166	3=6·613867	8=17·636978
4=61·729426	9=138·89121	4=141·09583	9=317·46561	4=8·818489	9=19·841601
5=77·161782		5=176·36978		5=11·023111	

A milligramme is about $\frac{1}{65}$ grain.

CONVERSION OF ENGLISH TO METRICAL WEIGHTS.

Grains to Grammes.	Ounces (Avoir.) to Grammes.	Pounds (Avoir.) to Kilogrammes.	Hundredweights to Kilogrammes.
1=·0647989	1= 28·34953	1= ·4535924	1= 50·80235
2=·1295978	2= 56·69905	2= ·9071849	2=101·6047
3=·1943968	3= 85·04858	3=1·360777	3=152·4071
4=·2591957	4=113·3981	4=1·814370	4=203·2094
5=·3239946	5=141·7476	5=2·267962	5=254·0118
6=·3887935	6=170·0972	6=2·721555	6=304·8141
7=·4535924	7=198·4467	7=3·175147	7=355·6165
8=·5183914	8=226·7962	8=3·628739	8=406·4188
9=·5831903	9=255·1457	9=4·082332	9=457·2212

The Metric Carat.

By decision of the Standards Department of the Board of Trade, the metric carat of 200 milligrams, and its necessary multiples and sub-multiples, are standard weights in the United Kingdom.

CAPACITIES.

English.

Gallon.—The standard gallon (*International Bureau of Standards, Paris*, 1921) measures 277·420 cubic inches, and contains 10 lbs. (avoir.) weight of distilled water (weighed in air against brass weights) at the temperature of 62° F., the barometer being at 30 ins.

DRY MEASURE.

Cu. Yard.	Bushels.	Cu. Feet.	Pecks.	Gallons.	Cu. Ins.
1	21·0223	27	84·089	168·179	46656
·047568	1	1·28435	4	8	2219·35
·037037	·7786	1	3·1141	6·22884	1728
·011892	·25	·32109	1	2	554·838
	·125	·16054	·5	1	277·420
		·00579	·001802	·0036047	1

LIQUID MEASURE.

Gallon.	Quarts.	Pints.	Gills.	Cub. Ins.
1	4	8	32	277·420
·25	1	2	8	69·355
·125	·5	1	4	34·677
·03125	·125	·25	1	8·6693
·0036047	·014419	·028837	·11535	1

APOTHECARIES' MEASURES.

Gallon (C) = 8 pints (O) : 1 pint = 20 fluid ounces (oz. weight of water).
Ounce (f℥) = 8 drachms (f℈) = 480 minims (♏) = 720 drops (gtt).
One wine-glass = 4 tablespoonfuls = 16 teaspoonfuls = 2 ounces.
Symbols.—f. or fl., fluid ; ss., one half ; aa., for each. Thus, f℥ss. means ½ a fluid ounce.

Conversion of Metrical to English Capacities.

Cub. Centimetres to Cub. Ins.	Litres to Fluid Ounces.	Litres to Pints.	Litres to Gallons.
1=·061024	1= 35·1961	1= 1·75980	1= ·219975
2=·122048	2= 70·3921	2= 3·51961	2= ·439951
3=·183072	3=105·5882	3= 5·27941	3= ·659926
4=·244096	4=140·7842	4= 7·03921	4= ·879902
5=·305120	5=175·9803	5= 8·79902	5=1·099877
6=·366143	6=211·1764	6=10·55882	6=1·319852
7=·427167	7=246·3724	7=12·31862	7=1·539828
8=·488191	8=281·5685	8=14·07842	8=1·759803
9=·549215	9=316·7646	9=15·83823	9=1·979779

The capacity of a litre is approximately that of a cube each side of which is a decimetre. One litre equals 1000·027 cubic centimetres.

Conversion of English to Metrical Capacities.

Cub. Ins. to Cub. Centimetres.	Fluid Ounces to Cubic Centimetres.	Pints to Litres.	Gallons to Litres.
1= 16·3870	1= 28·413	1= ·568245	1= 4·54596
2= 32·7740	2= 56·826	2=1·136491	2= 9·09193
3= 49·1611	3= 85·239	3=1·704736	3=13·63789
4= 65·5481	4=113·652	4=2·272982	4=18·18385
5= 81·9351	5=142·065	5=2·841227	5=22·72982
6= 98·3221	6=170·478	6=3·409472	6=27·27578
7=114·7091	7=198·891	7=3·977718	7=31·82174
8=131·0962	8=227·304	8=4·545963	8=36·36770
9=147·4832	9=255·717	9=5·114209	9=40·91367

Angle Measurement by the Opening of a Two-foot Rule.

Opening Rule.	Fractions of an Inch.															
	0		1/8		1/4		3/8		1/2		5/8		3/4		7/8	
Ins.	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′
0		0		36	1	12	1	47	2	23	2	59	3	35	4	11
1	4	47	5	22	5	58	6	34	7	10	7	46	8	22	8	58
2	9	34	10	10	10	46	11	22	11	57	12	34	13	10	13	46
3	14	22	14	58	15	34	16	10	16	46	17	22	17	59	18	35
4	19	11	19	48	20	24	21	0	21	37	22	13	22	50	23	26
5	24	3	24	39	25	16	25	53	26	30	27	7	27	43	28	20
6	28	57	29	34	30	11	30	48	31	26	32	3	32	40	33	18
7	33	55	34	32	35	10	35	48	36	25	37	3	37	41	38	19
8	38	57	39	35	40	13	40	51	41	29	42	7	42	46	43	24
9	44	3	44	42	45	20	45	59	46	38	47	17	47	56	48	36
10	49	15	49	54	50	34	51	14	51	53	52	33	53	13	53	53
11	54	34	55	14	55	54	56	35	57	16	57	57	58	38	59	19
12	60	0	60	41	61	23	62	5	62	47	63	29	64	11	64	53
13	65	35	66	18	67	1	67	44	68	27	69	11	69	54	70	38
14	71	22	72	6	72	51	73	35	74	20	75	5	75	51	76	36
15	77	22	78	8	78	54	79	41	80	27	81	14	82	2	82	49
16	83	37	84	25	85	14	86	3	86	52	87	41	88	31	89	21
17	90	12	91	3	91	54	92	46	93	38	94	31	95	24	96	17
81	97	11	98	5	99	0	99	56	100	51	101	48	102	45	103	43
19	104	41	105	40	106	40	107	40	108	41	109	43	110	45	111	49
20	112	53	113	58	115	5	116	12	117	20	118	30	119	40	120	52

PRESSURES

Conversion of Kilogrammes per Square Centimetre to Pounds per Square Inch.

Kilos. per Sq. Cm.	0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Pounds per Square Inch.									
0	0·000	1·4223	2·8447	4·2670	5·6893	7·1117	8·5340	9·9563	11·379	12·801
1	14·223	15·646	17·068	18·490	19·913	21·335	22·757	24·180	25·602	27·024
2	28·447	29·869	31·291	32·714	34·136	35·558	36·981	38·403	39·825	41·248
3	42·670	44·092	45·515	46·937	48·359	49·782	51·204	52·626	54·049	55·471
4	56·893	58·316	59·738	61·160	62·583	64·005	65·427	66·850	68·272	69·694
5	71·117	72·539	73·961	75·384	76·806	78·228	79 651	81·073	82·495	83·918
6	85·340	86·762	88·185	89·607	91·029	92·452	93·874	95·296	96·719	98 141
7	99·563	100·99	102·41	103·83	105·25	106·67	108·10	109·52	110·94	112·36
8	113·79	115·21	116·63	118·05	119·48	120·90	122·32	123·74	125·17	126·59
9	128·01	129·43	130·85	132·28	133·70	135·12	136·54	137·97	139·39	140·81
10	142·23	143·66	145·08	146·50	147·92	149·34	150·77	152·19	153·61	155·03

Conversion of Pounds per Square Inch to Kilogrammes per Square Centimetre.

Lbs. per Sq. In.	0	1	2	3	4	5	6	7	8	9
	Kilogrammes per Square Centimetre.									
0	0·0000	0·07031	0·14061	0·21092	0·28123	0·35154	0·42184	0·49215	0·56246	0·63276
10	0·70307	0·77338	0·84369	0·91399	0·98430	1·0546	1·1249	1·1952	1·2655	1·3358
20	1·4061	1·4764	1·5468	1·6171	1·6874	1·7577	1·8280	1·8983	1·9686	2·0389
30	2·1092	2·1795	2·2498	2·3201	2·3904	2·4607	2·5311	2·6014	2·6717	2·7420
40	2·8123	2·8826	2·9529	3·0232	3·0935	3·1638	3·2341	3·3044	3·3747	3·4450
50	3·5154	3·5857	3·6560	3·7263	3·7966	3·8669	3·9372	4·0075	4·0778	4·1481
60	4·2184	4·2887	4·3590	4·4293	4·4997	4·5700	4·6403	4·7106	4·7809	4·8512
70	4·9215	4·9918	5·0621	5·1324	5·2027	5·2730	5·3433	5·4136	5·4840	5·5543
80	5·6246	5·6949	5·7652	5 8355	5·9058	5·9761	6·0464	6·1167	6·1870	6·2573
90	6·3276	6·3979	6·4683	6·5386	6·6089	6·6792	6·7495	6·8198	6·8901	6·9604
100	7·0307	7·1010	7·1713	7·2416	7·3119	7·3822	7·4526	7·5229	7·5932	7·6635

1 kilogramme per sq. centimetre = 0·91 tons per sq. ft.
1 ton per sq. ft. = 1·10 kilogrammes per sq. centimetre.
1 ton per sq. ft. = 15·6 lbs. per sq. in., nearly.

Conversion of Pounds to Tons.

Tons = Pounds × 0·00044643.

Pounds.	Tons.	Pounds.	Tons.	Pounds.	Tons.	Pounds.	Tons.
1,000	0·446	24,000	10·714	47,000	20·982	88,000	39·286
2,000	0·893	25,000	11·161	48,000	21·429	90,000	40·179
3,000	1·339	26,000	11·607	49,000	21·875	92,000	41·072
4,000	1·786	27,000	12·053	50,000	22·321	94,000	41·964
5,000	2·232	28,000	12·500	51,000	22·768	96,000	42·857
6,000	2·679	29,000	12·946	52,000	23·214	98,000	43·750
7,000	3·125	30,000	13·393	54,000	24·107	100,000	44·643
8,000	3·571	31,000	13·839	56,000	25·000	110,000	49·107
9,000	4·018	32,000	14·286	58,000	25·893	120,000	53·572
10,000	4·464	33,000	14·732	60,000	26·786	130,000	58·036
11,000	4·911	34,000	15·179	62,000	27·679	140,000	62·500
12,000	5·357	35,000	15·625	64,000	28·572	150,000	66·965
13,000	5·804	36,000	16·071	66,000	29·464	160,000	71·429
14,000	6·250	37,000	16·518	68,000	30·357	170,000	75·893
15,000	6·696	38,000	16·964	70,000	31·250	180,000	80·357
16,000	7·143	39,000	17·411	72,000	32·143	190,000	84·822
17,000	7·589	40,000	17·857	74,000	33·036	200,000	89·286
18,000	8·036	41,000	18·304	76,000	33·929	210,000	93·750
19,000	8·482	42,000	18·750	78,000	34·822	220,000	98·215
20,000	8·929	43,000	19·196	80,000	35·714	230,000	102·680
21,000	9·375	44,000	19·643	82,000	36·607	240,000	107·140
22,000	9·821	45,000	20·089	84,000	37·500	250,000	111·610
23,000	10·268	46,000	20·536	86,000	38·393	260,000	116·072

Corresponding Heights of Barometer in Millimetres and English Inches.

Millimetres.	English Inches.	Millimetres.	English Inches.	Millimetres.	English Inches.
720	28·347	739	29·095	758	29·843
721	28·386	740	29·134	759	29·882
722	28·425	741	29·174	760	29·922
723	28·465	742	29·213	761	29·961
724	28·504	743	29·252	762	30·000
725	28·543	744	29·292	763	30·039
726	28·583	745	29·331	764	30·079
727	28·622	746	29·370	765	30·118
728	28·662	747	29·410	766	30·158
729	28·701	748	29·449	767	30·197
730	28·740	749	29·488	768	30·236
731	28·780	750	29·528	769	30·276
732	28·819	751	29·567	770	30·315
733	28·858	752	29·606	771	30·355
734	28·898	753	29·645	772	30·394
735	28·937	754	29·685	773	30·433
736	28·976	755	29·724	774	30·473
737	29·016	756	29·764	775	30·512
738	29·055	757	29·803		

COMPARISON OF VARIOUS FOREIGN AND ENGLISH MEASURES.

Country.	Measure.	English Value.	Country.	Measure.	English Value.
America	Bushel	2150·4 cu. ins.	Germany	Morgen	27,484 sq. feet
,,	Gallon (dry)	268·80 cu. ins.	,,	Pfund	1·01 to 1·23 lbs.
,,	,, (fluid)	231 cu. ins.	India	Seer	32·914 oz.
,,	Peck	537·605 cu. ins.	,,	Tola	180 grains
,,	Pint	28·875 cu. ins.	Netherlands	Myle	3,281 feet
,,	Quart	57·750 cu. ins.	Norway	Centner	110·231 lbs.
Austria	Joch	1·422 acres	,,	Mile	4·6803 miles
,,	Klafter	6·2213 feet	,,	Morgen	27,484 sq. feet
Bengal	Maund	74·667 lbs.	Russia	Archine	28 inches
Canada	Mino	2,339 cu. ins.	,,	Dessatine	2·69977 acres
China	Catty or Gin	1·3333 lbs.	,,	Dola	·68573 grains
,,	Li	608·5 yds.	,,	Pud or Pood	36·112 lbs.
,,	Picul	133·33 lbs.	,,	Sagene	7 feet
,,	Tael	583 grains	,,	Verst	3,500 feet
Denmark	Centner	110·231 lbs.	Spain	Arroba	25·35 lbs.
,,	Mile	4·6803 miles	,,	,,	2·77 gallons
,,	Morgen	27,484 sq. feet	Sweden	Mile	6·64 miles
France	Aune	47·245 inches	,,	Tunnland	1·2198 acres
,,	Brasse	5·328 feet	Turkey	Archin	26·9 inches
,,	Lieu	6,077 yds.	,,	Oke	2·829 lbs.
Germany	Centner	110·231 lbs.	,,	Pie	25·69 inches
,,	Mile	4·6803 miles	Vienna	Centner	123·46 lbs.

WIRE GAUGES.

BIRMINGHAM WIRE-GAUGE.

Number.	Dimensions.	Number.	Dimensions.	Number.	Dimensions.	Number.	Dimensions.
	Mils.		Mils.		Mils.		Mils.
0000	454	7	180	17	58	27	16
000	425	8	165	18	49	28	14
00	380	9	148	19	42	29	13
0	340	10	134	20	35	30	12
1	300	11	120	21	32	31	10
2	284	12	109	22	28	32	9
3	259	13	95	23	25	33	8
4	238	14	83	24	22	34	7
5	220	15	72	25	20	35	5
6	203	16	65	26	18	36	4

BIRMINGHAM WIRE-GAUGE FOR SILVER AND GOLD.

No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.
1	·004	6	·013	11	·029	16	·051	21	·072	25	·095	29	·120	33	·145
2	·005	7	·015	12	·034	17	·057	22	·074	26	·103	30	·126	34	·148
3	·008	8	·016	13	·036	18	·061	23	·077	27	·113	31	·133	35	·158
4	·010	9	·019	14	·041	19	·064	24	·082	28	·120	32	·143	36	·167
5	·013	10	·024	15	·047	20	·067								

SHEET ZINC TRADE GAUGE.

No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.	No.	Ins.
1	·00395	5	·0097	9	·0177	12	·0260	15	·0375	18	·0526	21	·0699	24	·0915
2	·00554	6	·0114	10	·0196	13	·0292	16	·0426	19	·0577	22	·0768	25	·0980
3	·0067	7	·0132	11	·0228	14	·0323	17	·0478	20	·0632	23	·0843	26	·1052
4	·0082	8	·0149												

(See also page 249.)

Standard Wire-Gauge.*

No.	Diameters.			No.	Diameters.			No.	Diameters.		
	Mils.†	Differences.	Millimètres.		Mils.	Differences.	Millimètres.		Mils.	Differences.	Millimètres.
0,000,000	500	..	12·70	13	92	12	2·34	32	10·8	·8	·274
000,000	464	36	11·78	14	80	12	2·03	33	10·0	·8	·254
00,000	432	32	10·97	15	72	8	1·83	34	9·2	·8	·234
0,000	400	32	10·16	16	64	8	1·63	35	8·4	·8	·213
000	372	28	9·45	17	56	8	1·42	36	7·6	·8	·193
00	348	24	8·84	18	48	8	1·22	37	6·8	·8	·173
0	324	24	8·23	19	40	8	1·016	38	6·0	·8	·152
1	300	24	7·62	20	36	4	·914	39	5·2	·8	·132
2	276	24	7·01	21	32	4	·813	40	4·8	·4	·122
3	252	24	6·40	22	28	4	·711	41	4·4	·4	·112
4	232	20	5·89	23	24	4	·610	42	4·0	·4	·102
5	212	20	5·38	24	22	2	·559	43	3·6	·4	·0914
6	192	20	4·88	25	20	2	·508	44	3·2	·4	·0813
7	176	16	4·47	26	18	2	·457	45	2·8	·4	·0711
8	160	16	4·06	27	16·4	1·6	·417	46	2·4	·4	·0610
9	144	16	3·66	28	14·8	1·6	·376	47	2·0	·4	·0508
10	128	16	3·25	29	13·6	1·2	·345	48	1·6	·4	·0406
11	116	12	2·95	30	12·4	1·2	·315	49	1·2	·4	·0305
12	104	12	2·64	31	11·6	·8	·295	50	1·0	·2	·0254

* This gauge is the only legal standard wire-gauge for the United Kingdom.

† 1 Mil. = $\frac{1}{1000}$th of an inch.

Warrington Wire-Gauge.

Mark.	Size.	Mark.	Size.	Mark.	Size.	Mark.	Size.
No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.
7/0	$\frac{1}{2}$	2	·274	10	·133	16	·0625, or $\frac{1}{16}$
6/0	$\frac{15}{32}$	3	·25, or $\frac{1}{4}$	10½	·125, or $\frac{1}{8}$	17	·053
5/0	$\frac{7}{16}$	4	·229	11	·117	18	·047
4/0	$\frac{13}{32}$	5	·209	12	·10, or $\frac{1}{10}$	19	·041
3/0	$\frac{3}{8}$	6	·191	13	·090	20	·036
2/0	$\frac{11}{32}$	7	·174	14	·079	21	·0315, or $\frac{1}{32}$
0	·326	8	·159	15	·069	22	·028
1	·300	9	·146				

Whitworth's Wire-Gauge, in Decimals of an Inch.

Mark.	Size.	Mark.	Size.	Mark.	Size.	Mark.	Size.	Mark.	Size.
1	·001	14	·014	34	·034	85	·085	240	·240
2	·002	15	·015	36	·036	90	·090	260	·260
3	·003	16	·016	38	·038	95	·095	280	·280
4	·004	17	·017	40	·048	100	·100	300	·300
5	·005	18	·018	45	·045	110	·110	325	·325
6	·006	19	·019	50	·050	120	·120	350	·350
7	·007	20	·020	55	·055	135	·135	375	·375
8	·008	22	·022	60	·060	150	·150	400	·400
9	·009	24	·024	65	·065	165	·165	425	·425
10	·910	26	·026	70	·070	180	·180	450	·450
11	·011	28	·028	75	·075	200	·200	475	·475
12	·012	30	·030	80	·080	220	·220	500	·500
13	·013	32	·032						

Birmingham Gauge ('B.G.') for Sheets and Hoops.

(Legalised by the Board of Trade Nov. 1, 1914.)

Descriptive Number.	Equivalents in parts of an Inch.	Descriptive Number.	Equivalents in parts of an Inch.
No.	Inch.	No.	Inch
15/0 B.G.	1·000	20 B.G.	·0392
14/0 B.G.	·9583	21 B.G.	·0349
13/0 B.G.	·9167	22 B.G.	·03125
12/0 B.G.	·8750	23 B.G.	·02782
11/0 B.G.	·8333	24 B G	·02476
10/0 B.G.	·7917	25 B.G.	·02204
9/0 B.G.	·750	26 B.G.	·01961
8/0 B.G.	·7083	27 B.G.	·01745
7/0 B.G.	·6666	28 B.G.	·015625
6/0 B.G.	·625	29 B.G.	·0139
5/0 B.G.	·5883	30 B.G.	·0123
4/0 B.G.	·5416	31 B.G.	·0110
3/0 B.G.	·500	32 B.G.	·0098
2/0 B.G.	·4452	33 B.G.	·0087
1/0 B.G.	·3964	34 B.G.	·0077
1 B.G.	·3532	35 B.G	·0069
2 B.G.	·3147	36 B.G.	·0061
3 B.G.	·2804	37 B.G.	·0054
4 B.G.	·250	38 B.G.	·0048
5 B.G.	·2225	39 B.G	·0043
6 B.G.	·1981	40 B.G.	·00386
7 B.G.	·1764	41 B.G.	·00343
8 B.G.	·1570	42 B.G.	·00306
9 B.G.	·1398	43 B.G.	·00272
10 B.G.	·1250	44 B.G.	·00242
11 B.G	·1113	45 B.G.	·00215
12 B.G.	·0991	46 B.G.	·00192
13 B.G.	·0882	47 B.G.	·00170
14 B.G.	·0785	48 B.G.	·00152
15 B.G.	·0699	49 B.G.	·00135
16 B.G.	·0625	50 B.G.	·00120
17 B.G.	·0556	51 B.G.	·00107
18 B.G.	·0495	52 B.G.	·00095
19 B.G.	·0440		

STUBS' STEEL WIRE GAUGE (DIMENSIONS IN MILS.).

No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.	No.	Mils.
Z	413	Q	332	H	266	1	227	9	194	17	172	25	148	33	112	41	95	49	72	57	42	65	33	73	23
Y	404	P	323	G	261	2	219	10	191	18	168	26	146	34	110	42	92	50	69	58	41	66	32	74	22
X	397	O	316	F	257	3	212	11	188	19	164	27	143	35	108	43	88	51	66	59	40	67	31	75	20
W	386	N	302	E	250	4	207	12	185	20	161	28	139	36	106	44	85	52	63	60	39	68	30	76	18
V	377	M	295	D	246	5	204	13	182	21	157	29	134	37	103	45	81	53	58	61	38	69	29	77	16
U	368	L	290	C	242	6	201	14	180	22	155	30	127	38	101	46	79	54	55	62	37	70	27	78	15
T	358	K	281	B	238	7	199	15	178	23	153	31	120	39	99	47	77	55	50	63	36	71	26	79	14
S	348	J	277	A	234	8	197	16	175	24	151	32	115	40	97	48	75	56	45	64	35	72	24	80	13
R	339	I	272																						

TABLE SHOWING RELATIVE VALUES OF STANDARD, BIRMINGHAM, AND AMERICAN (BROWN AND SHARPE) WIRE GAUGES.

S.W.G.	B.W.G.	A.W.G.	Equivalent in Mils.	Equivalent in Mms.	S.W.G.	B.W.G.	A.W.G.	Equivalent in Mils.	Equivalent in Mms.	S.W.G.	B.W.G.	A.W.G.	Equivalent in Mils.	Equivalent in Mms.	S.W.G.	B.W.G.	A.W.G.	Equivalent in Mils.	Equivalent in Mms.
7/0			500	12·699	5			212	5·384	15	15	13	072	1·828	28	28	27	014	3555
6/0			464	11·785			4	204	5·181		16		065	1·650	29	29		013	3300
		0000	460	11·683		6		203	5·156	16		14	064	1·625			28	0122	3100
	0000		454	11·531	6			192	4·876		17		058	1·472	30	30		012	3046
5/0			432	10·972			5	182	4·622			15	057	1·447	31		29	011	2800
	000		425	10·794		7		180	4·571	17			056	1·421	32			0108	2743
		000	409	10·388	7			176	4·470			16	050	1·270	33	31	30	010	2539
0000			400	10·159		8		165	4·191		18		049	1·244	34	32	31	009	2300
	00		380	9·651			6	162	4·114	18			048	1·218	35	33	32	008	2031
000			372	9·448	8			160	4·064			17	045	1·142	36	34	33	007	1777
		00	365	9·271		9		148	3·759		19		042	1·066	37			0068	1727
00			348	8·839	9		7	144	3·657	19		18	040	1·016	38		34	006	1523
	0		340	8·635		10		134	3·403	20		19	036	9140			35	0056	1422
		0	325	8·254	10		8	128	3·251		20		035	8886	39	35	36	005	1269
0			324	8·229		11		120	3·047	21	21	20	032	8124	40			0048	1219
1	1		300	7·620	11			116	2·946		22		030	7617	41		37	0044	1118
		1	289	7·340			9	114	2·895			21	0284	7213	42	36	38	004	1015
	2		284	7·213		12		109	2·768	22			028	7109	43		39	0036	0914
2			276	7·010	12			104	2·641			22	0253	6126	44		40	0032	0813
	3		259	6·578			10	102	2·590		23		025	6347	45			0028	0713
		2	257	6·527		13		095	2·412	23			024	6093	46			0024	0610
3			252	6·400	13			092	2·336	24	24	23	022	5585	47			002	0507
	4		238	6·045			11	090	2·286	25	25	24	020	5078	48			0016	0406
4			232	5·892		14		083	2·108	26	26	25	018	4570	49			0012	0305
		3	229	5·816	14		12	080	2·032	27	27	26	016	4062	50			001	0253
	5		220	5·588															

American Wire Gauges.

Different Standards for Wire Gauges in use in the United States.

Dimensions of Sizes in Decimal Parts of an Inch.

Number of Wire Gauge.	American or Brown and Sharpe.	Birmingham or Stubs' Wire.	Washburn and Moen Mfg. Co., Worcester, Mass.	Imperial Wire Gauge.	Stubs' Steel Wire.	U.S. Standard for Plate.	Number of Wire Gauge.
000000	—	—	—	·464	—	·46875	000000
00000	—	—	—	·432	—	·4375	00000
0000	·46	·454	·3938	·400	—	·40625	0000
000	·40964	·425	·3625	·372	—	·375	000
00	·3648	·38	·3310	·348	—	·34375	00
0	·32486	·34	·3065	·324	—	·3125	0
1	·2893	·3	·2830	·300	·227	·28125	1
2	·25763	·284	·2625	·276	·219	·265625	2
3	·22942	·259	·2437	·252	·212	·25	3
4	·20431	·238	·2253	·232	·207	·234375	4
5	·18194	·22	·2070	·212	·204	·21875	5
6	·16202	·203	·1920	·192	·201	·203125	6
7	·14428	·18	·1770	·176	·199	·1875	7
8	·12849	·165	·1620	·160	·197	·171875	8
9	·11443	·148	·1483	·144	·194	·15625	9
10	·10189	·134	·1350	·128	·191	·140625	10
11	·090742	·12	·1205	·116	·188	·125	11
12	·080808	·109	·1055	·104	·185	·109375	12
13	·071961	·095	·0915	·092	·182	·09375	13
14	·064084	·083	·0800	·080	·180	·078125	14
15	·057068	·072	·0720	·072	·178	·0703125	15
16	·05082	·065	·0625	·064	·175	·0625	16
17	·045257	·058	·0540	·056	·172	·05625	17
18	·040303	·049	·0475	·048	·168	·05	18
19	·03589	·042	·0410	·040	·164	·04375	19
20	·031961	·035	·0348	·036	·161	·0375	20
21	·028462	·032	·03175	·032	·157	·034375	21
22	·025347	·028	·0286	·028	·155	·03125	22
23	·022571	·025	·0258	·024	·153	·028125	23
24	·0201	·022	·0230	·022	·151	·025	24
25	·0179	·02	·0204	·020	·148	·021875	25
26	·01594	·018	·0181	·018	·146	·01875	26
27	·014195	·016	·0173	·0164	·143	·0171875	27
28	·012641	·014	·0162	·0149	·139	·015625	28
29	·011257	·013	·0150	·0136	·134	·0140625	29
30	·010025	·012	·0140	·0124	·127	·0125	30
31	·008928	·01	·0132	·0116	·120	·0109375	31
32	·00795	·009	·0128	·0108	·115	·01015625	32
33	·00708	·008	·0118	·0100	·112	·009375	33
34	·006304	·007	·0104	·0092	·110	·00859375	34
35	·005614	·005	·0095	·0084	·108	·0078125	35
36	·005	·004	·0090	·0076	·106	·00703125	36
37	·004453	—	—	·0068	·103	·006640625	37
38	·003965	—	—	·0060	·101	·00625	38
39	·003531	—	—	·0052	·099	—	39
40	·003144	—	—	·0048	·097	—	40

Care should be taken to distinguish the difference between Stubs' Iron Wire Gauge and Stubs' Steel Wire Gauge. The former is commonly known as the English Standard Wire or Birmingham Wire Gauge, and designates the Stubs' *Soft* wire sizes.

The Stubs' Steel Wire Gauge is the one employed in measuring drawn steel wire or drill rod, of Stubs' make, and is also used by some makers of American drill rods.

(*Brown and Sharpe.*)

VARIOUS FOREIGN WE[illegible]D MEASURES WITH THEIR APPROX[illegible]BRITISH EQUIVALENTS.

(Compiled by the Boa[illegible]de (July 1923) from information published by the respective Governments.)

[NOTE.—In the case of fractional equivalents the last figure shown is uncertain.]

Country.	Length.	Area.	Weight.	Capacity.	Approximate British Equivalent.
1. United States of America	—	—	Barrel (flour)	—	196 lbs. avoir.
	—	—	Short Ton	—	2,000 lbs. avoir.
	—	—	Long „	—	2,240 „ „
	—	—	—	Bushel (Winchester)—dry	0·96897 imperial bushel.
	—	—	—	Gallon (Old English)—wet	0·83268 „ gallon.
	Metre	—	—	—	1·09361 yards.
	Kilometre	—	—	—	0·62137 mile.
	—	Sq. Kilometre = 100 Hectares	—	—	0·38610 square mile.
	—	Are	—	—	0·024711 acre.
	—	Hectare	—	—	2·4711 acres.
2. Austria	—	—	Kilogramme	—	2·20462 lbs. avoir.
	—	—	Quintal métrique (Centner) = 100 kilogs	—	220·462 lbs. avoir.
	—	—	Tonne	—	2204·62 lbs. avoir.
	—	—	—	Cubic metre	1·30795 cubic yards.
	—	—	—	Hectolitre (liquid)	21·9975 imperial gallons.
	—	—	—	„ (cereals)	2·74969 „ bushels.
3. Belgium	—	As No. 2	—	—	—
4. Bulgaria	—	„ „	—	—	—
5. China	Ch'ih (= 10 Ts'un)	—	—	—	*14·1 inches.
	Chang (= 10 Ch'ih)	—	—	—	*11·75 feet.
	—	—	Tael (Liang)	—	*1⅓ ozs. avoir.
	—	—	Catty	—	*1⅓ lbs. avoir.
	—	—	Picul	—	*133⅓ lbs. avoir.
6. Czechoslovakia	—	As No. 2	—	—	—
7. Denmark	Weights and measures as No. 2 have been compulsory since April 1922.				
	Pic for textiles (0·58 metres) (Diraa Baladi)	—	—	—	22·83466 inches.
	—	Feddan (land)	—	—	1·038050 acres.
8. Egypt	—	—	Oke (400 Dirhems) = 1·248 kilogs.	—	2·751367 lbs. avoir.
	—	—	Kantar (36 Oke) = 44·928 kilogs.	—	99·049272 „
	—	—	—	Ardeb (198 litres)—dry	5·444391 bushels
9. Esthonia	—	As No. 2	Russian weights and measures as No. 24 also in use.		
10. Finland	—	„ „	—	—	—
11. France	—	„ „	—	—	—
12. Germany	—	—	—	—	—

14. Holland	—	As No. 2	—	—	—
15. Hungary	—	,, ,,	—	—	—
16. Italy	—	,, ,,	—	—	—
	Ri	—	—	—	2·4403 miles.
	Cho	—	—	—	5·423 chains.
	Ken	—	—	—	1·9834 yards.
	—	Square Ri	—	—	5·95505 square miles.
	—	Cho (land)	—	—	2·4507 acres.
	—	Tsubo	—	—	3·9538 square yards.
17. Japan	—	—	Kwan	—	8·26733 lbs. avoir.
	—	—	Kin	—	1·32277 ,,
	—	—	—	Koku (wet)	39·7033 gallons.
	—	—	—	(dry)	4·9629 bushels.
	—	—	—	,, (capacity of vessel)	$\frac{1}{10}$ of a measurement ton.
	—	—	—	Sho (wet)	1·5881 quarts.
	—	—	—	,, (dry)	0·1985 peck.
18. Latvia	As No. 2.				
19. Lithuania	Russian system as No. 24, but at same time metric system is in use. Arrangements are being made for making latter compulsory.				
20. Norway	—	As No. 2	—	—	—
	Lokieć	—	—	—	0·62992 yard.
	—	Square lokieć (lokieć kwadretowe)	—	—	0·39680 square yard.
	—	Morg	—	—	1·3835 acres.
21. Poland	—	—	Funt	—	0·893983 lb. avoir.
	—	—	Center = 100 funt	—	89·3983 lbs.
	—	—	—	Cubic lokieć (lokieć szescienne)	0·24995 cubic yard.
	—	—	—	Kwarta (wet and dry) = 1 litre	0·21998 gallon.
22. Portugal	—	As No. 2	—	—	—
23. Roumania	—	,, ,,	—	—	—
	Verst	—	—	—	0·6629 mile.
	—	Square verst	—	—	0·4394 square mile.
	—	Dessiatine	—	—	2·6997 acres.
24. Russia	—	—	Pood	—	36·113 lbs. avoir.
	—	—	Berkovets (= 10 pood)	—	361·13 ,,
	—	—	—	Tchetvert (dry)	5·7717 imperial bushels.
	—	—	—	Vedro (wet)	2·705 ,, gallons.
25. Serb-Croat-Slovene State	As No. 2	—	—	—	—
26. Spain	,, ,,	—	—	—	—
27. Sweden	,, ,,	—	—	—	—
28. Switzerland	,, ,,	—	—	—	—

* As fixed for foreign trade by treaty between Great Britain and China in 1902. Customary weights and measures of the same name vary in every province and trade in China.

Various Foreign Standard Monetary Units with their Nominal Gold Parity.

(Compiled by the Board of Trade (July 1923) from information published by the Economic Section of the League of Nations.)

Country.	Unit of Currency.	Approximate Gold Parity.	Country.	Unit of Currency.	Approximate Gold Parity.
1. United States of America	Dollar	0·20549	15. Hungary	Korona	0·04163
2. Austria	Krone	0·04163	16. Italy	Lira	0·03965
3. Belgium	Franc	0·03965	17. Japan	Yen	0·10242
4. Bulgaria	Lev	0·03965	18. Latvia	Lat	0·03965
5. China	Haikwan Tael	—	19. Lithuania	Litas	0·020549
6. Czechoslovakia	Koruna	0·04163	20. Norway	Krone	0·05507
7. Denmark	Krone	0·05507	21. Poland	Marka p.	0·04895
8. Egypt	£ Egyptian	1·02564	22. Portugal	Milreis	0·22222
9. Esthonia	Esth. Mark	—	23. Roumania	Leu	0·03965
10. Finland	Markka	0·03965	24. Russia	Rouble	0·10574 *
11. France	Franc	0·03965	25. Serb-Croat-Slovene State	Dinar	0·03965
12. Germany	Mark	0·04895	26. Spain	Peseta	0·03965
13. Greece	Drachma	0·03965	27. Sweden	Krone	0·05507
14. Holland	Guilder	0·08260	28. Switzerland	Franc	0·39605

* Russian Agricultural Year Book.

Foreign Measures into English Equivalents.

Country.	Foreign Measure.	British Measure.	Country.	Foreign Weight.	British Weight.
China	1 Ts'un	1·41 in.	China	1 Liang or Tael	1·3 oz.
	1 Ch'ih	14·1 in.		1 Chin or Catty	1·3 lb.
	1 Chang	11·75 ft.		1 Picul	133 lb.
	1 Li	586 yds. 2 ft.			
Egypt	1 Feddan	1·08808 acres	Egypt	1 Okis	1·3207 oz.
Greece	1 Pike	27 in.		1 Roti	·99049 lb.
Japan	1 Ken	5·965 ft.		1 Oke	2·7513 lb.
	1 Cho	117 yds. 1 ft.		1 Quantar	99·049 lb.
	1 Ri	2·44 miles.	Greece	1 Livre	1·05 lb.
Russia	1 Vershok	1·75 in.		1 Oke	2·80 lb.
	1 Arshin	28 in.		1 Stator	123·20 lb.
	1 Sajene	7 ft.	Russia	1 Pound	·9 lb.
	1 Verst	0·663 mile.		1 Pood	26 lb.
	1 Sq. Verst	0·4394 sq. mile	Turkey	1 Oke	2·83 lb.
	1 Dessiatine	2·70 acres.		1 Cantar	1·25 lb.
Turkey	1 Donum	1096·76 sq. yds.			

Siamese Weights and Measures.

$$1 \text{ rai} = \frac{4}{25} = 0{\cdot}16 \text{ hectare} = \frac{79}{200} = 0{\cdot}395 \text{ acre}$$

$$1 \text{ hectare} = 6{\cdot}25 \text{ rai}; \quad 1 \text{ acre} = 2{\cdot}43 \text{ rai}$$

$$1 \text{ picul} = \frac{10}{168} \text{ ton} = \frac{100}{84} \text{ cwt.} = 133\tfrac{1}{3} \text{ lbs.}$$

$$1 \text{ ton} = 16{\cdot}8 \text{ piculs}; \quad 1 \text{ cwt} = 0{\cdot}84 \text{ piculs}$$

$$1 \text{ picul per rai} = 0{\cdot}1506 \text{ tons per acre} = 3{\cdot}012 \text{ cwt per acre}$$

Sizes of Paper and Books.

Sizes of Paper used for Printing Books, etc.

	Ins. Ins.		Ins. Ins.		Ins. Ins.
Foolscap . .	$13\frac{1}{2} \times 17$	Medium . .	18×23	Super royal . .	20×27
Crown . . .	15×20	Royal . . .	$20 \times 25\frac{1}{2}$	Imperial . . .	$22\frac{1}{2} \times 31$
Demy . . .	$17\frac{1}{2} \times 22\frac{1}{2}$				

Most of these papers are also made double size.

Sizes of Books.

Broadside, folio, quarto (4to), octavo (8vo), 12mo, 16mo, 18mo, 32mo, 48mo.
These names indicate the number of pages in the half-sheet; for instance, an octavo has 8 pages in the half-sheet. A crown octavo is about 5 ins. × 8 ins.

A ream of paper contains 20 quires of 24 sheets each. A bale is 10 reams. A roll of parchment is 60 skins.

Sizes and Descriptions of Type.

The following descriptions of type have been used in the printing of this book :—

LONG PRIMER SMALL CAPITALS.
BOURGEOIS CAPITALS.
Bourgeois Roman.
Bourgeois Italic.
MINION CAPITALS.
MINION SMALL CAPITALS.
NONPAREIL ANTIQUE CAPS.

Nonpareil Antique.
NONPAREIL CAPITALS.
NONPAREIL SMALL CAPITALS.
Nonpareil Roman.
Nonpareil Italic.
PEARL ANTIQUE CAPITALS
Pearl Roman.
Pearl Italic.
Diamond Italic.

SECTION XLIV

PATENTS, TRADE MARKS, AND DESIGNS

(Contributed by a Chartered Patent Agent.)

SECTION XLIV

PATENTS, TRADE MARKS, AND DESIGNS.

(Contributed by a Chartered Patent Agent.)

PATENTS.

Application for a patent must be made by the inventor or inventors either alone or in conjunction with one or more co-applicants or a limited company. By inventor is understood either the actual inventor or a person who first introduces an invention from abroad or to whom an invention is communicated from abroad.

When an application is made it is accompanied by either a 'provisional' or a 'complete' specification. In the former case the specification must describe the nature of the invention, but need not particularly describe the same, and the applicant has the right to use and publish the invention during nine months from the date of application, which time may be employed in perfecting the invention and in applying for foreign patents. This protection against the consequences of use and publication is known as Provisional Protection. Should a complete specification not to be filed within the prescribed period of nine months, the application is deemed to be abandoned, and no official publication of the provisional specification takes place. When the application is accompanied by a complete specification, full protection is obtained from the date of the acceptance, and between this date and that of the sealing of the patent the applicant has all the privileges and rights accorded by the patent, except that he will not be entitled to institute any proceeding for infringement, unless and until a patent for the invention has been granted.

When a provisional specification has been filed and it is not desired to abandon the application, a complete specification must be filed within nine months from the date of filing the provisional specification; one month's extension of this time, however, can be obtained on payment of a fee. In such a case the complete specification must describe substantially the same invention as that the nature of which is disclosed in the provisional specification; if not, the Comptroller may require the complete specification to be amended to avoid any disconformity between the two specifications.

A complete specification—whether filed with the application or after a provisional specification—must fully describe (if necessary with the assistance of drawings) the manner of carrying out the invention in practice, and at the same time clearly and correctly point out the features of novelty by a distinct statement of the invention claimed. The complete specification on being filed is submitted to an examiner who makes an investigation to ascertain whether the invention described therein has been wholly or in part claimed or described in any specification (other than a provisional specification not followed by a complete specification) published before the date of the application, and deposited pursuant to any application for a patent made in the United Kingdom within fifty years next before the date of the application, or in the complete specification of any prior application, although such complete specification may not have been filed when the application was made. If any anticipating specifications are found, the applicant will have the opportunity of amending the specification, and, if the amendment is not effected to the satisfaction of the Comptroller, the Comptroller may insert a reference to any of the prior specifications in the specification by way of notice to the public. Where the Comptroller is satisfied that the invention has been wholly and specifically claimed, he may refuse to grant a patent.

When an applicant has two or more provisional applications running concurrently and the subject-matter of such applications is of such a nature as to constitute a single invention which may properly be covered by one patent, the Comptroller may accept one complete specification in respect of the whole of such applications and grant a single patent thereon bearing the date of the earliest of such applications; in case of legal proceedings, however, the respective dates of the several applications may be considered.

Patents of addition for improvements in, or modifications of, an invention already patented may be applied for for any unexpired term of the original patent, and no renewal fees, other than those payable in respect of such original patent, will be payable.

Great Britain is a party to the International Convention for the protection of industrial property, under which an applicant for a patent in any one of the States being parties to the Convention may obtain priority in any of the other States—that is to say, an application may be made in any such States, notwithstanding that publication of the invention may have been made therein, providing that such application be filed within twelve months from the date of the original application.

When a complete specification has been accepted such acceptance is advertised, and the specification will be open to public inspection. Notice of opposition to the grant of a patent may be given at any time within two months from the date of such advertisement, but on the following grounds only, viz.:—

(*a*) That the invention was obtained from the opponent or from a person of whom he is the legal representative.

(*b*) That the invention has been published in the complete specification of a British patent filed in the United Kingdom within fifty years before the date of application for the patent, the grant of which is being opposed, or has been made available to the public by publication in any document (other than a British specification) published in the United Kingdom prior to the application.

(*bb*) That the invention has been claimed in the complete specification of a British patent which, though not published at the date of the application for a patent, the grant of which is opposed, was deposited pursuant to an application for a patent which is, or will be, of prior date to such patent.

(*c*) That the nature of the invention or the manner in which it is to be performed is not sufficiently or fairly described in the complete specification.

(*d*) That the complete specification includes matter not in the provisional specification, and forms the subject of an application made by the opponent in the interval between the leaving of the provisional and complete specifications.

(*e*) That, in case of an application under the International Convention, the specification describes or claims an invention other than that for which protection has been applied for in a foreign state or British possession, and that such other invention forms the subject of an application made by the opponent in the interval between the leaving of the application in the foreign state or British possession and the leaving of the application in the United Kingdom.

If there is no opposition, or, in case of opposition, if the determination is in favour of the grant of a patent, the Comptroller causes a patent to be sealed.

The decision of the Comptroller in most cases is subject to appeal to the Law Officer.

Letters patent extend to Great Britain, Ireland, and the Isle of Man, and are granted for sixteen years, subject to the payment of renewal fees commencing at 5*l.* in respect of the fifth year, and increasing 1*l.* for each succeeding year during the term of the patent, the last payment being 16*l.* These renewal fees are payable before the commencement of the year in respect of which the payment is made, but extensions of time for making these payments up to three months can be obtained, with the addition of a fine, and in the event of a patent lapsing through the non-payment of a fee, the Comptroller is empowered to revive the patent on certain conditions.

At any time after the sealing of a patent the Comptroller may, if requested by the patentee, cause the patent to be endorsed with the words 'licences of right' and any person shall then be entitled, as of right, to a licence under the patent upon such terms as, in default of agreement, may be settled by the Comptroller.

Furthermore, any person interested may apply to the Comptroller alleging that there has been an abuse of the monopoly rights under a patent and asking for relief. Such rights will be deemed to have been abused, if, after four years from the date of the patent, the invention—being capable of being worked in the United Kingdom—is not being worked on a commercial scale; or if such working is being prevented or hindered by the importation from abroad of the patented article; or if the demand for the patented article is not being met to an adequate extent and on reasonable terms; or if trade or industry is being prejudiced by refusal to grant licences, or by conditions attached by the patentee to the purchase, or use of the patented article or to the working of the patented process. If the Comptroller is satisfied that an abuse of the monopoly rights has been proved, he may order the patent to be indorsed with the words 'licences of right' and grant a licence to the applicant on such terms as he may think expedient; or he may order the patent to be revoked.

For 'PATENT SPECIFICATION DRAWINGS,' see page 200.

TRADE MARKS.

Trade marks are registered under the Trade Marks Act of 1905 as amended by the Act of 1919, which provides that a registrable Trade Mark must contain, or consist of, at least one of the following essential particulars:—

1. The name of a company, individual, or firm represented in a special or particular manner.

2. The signature of the applicant for registration or some predecessor in his business.

3. An invented word or invented words.

4. A word or words having no direct reference to the character or quality of the goods, and not being, according to its ordinary signification, a geographical name or a surname.

5. Any other distinctive mark; but a name, signature or word or words, other than such as fall within the descriptions in the above paragraphs 1, 2, 3, and 4, shall not be registrable under the provisions of this paragraph except upon evidence of its distinctiveness.

Provision is also made for the registration of any special or distinctive word or words, letter, numeral, or combination of letters or numerals used as a Trade Mark by the applicant or his predecessors in business before the 13th August, 1875, and which has continued to be used down to the date of the application for registration.

The Trade Marks Act of 1905 as amended by the Act of 1919 provides for a new kind of registration of Trade Marks whereby certain marks, not registrable under the principal Act, can now be registered, provided they have been in *bona-fide* use in the United Kingdom for not less than two years. For this purpose the Register is divided into two parts called Part A and Part B, the new kind of marks being registered in Part B.

An application for registration is made on a form bearing the necessary stamp and should be accompanied by four additional representations of the mark properly mounted. The application is then examined and the mark compared with other marks on record in the Trade Marks Office (this provision may be dispensed with in the case of application to register in Part B), and if, in the opinion of the registrar, any mark or marks be found having such resemblance to the mark sought to be registered as to be calculated to deceive, the applicant will be notified of the conflicting mark or marks, and if, within one month from the date of issuing such notice, no action is taken by the applicant the application will be deemed to be abandoned. Should, however, the applicant so desire, the registrar will appoint a hearing in order that the applicant may attend before him, when the registrar will decide whether the application can proceed. Appeal can be taken from the decision of the registrar to the Board of Trade.

When an application is allowed the mark is advertised in the Official Journal of the Trade Marks Office. The application is then open to opposition for one month from the date of the Journal in which the advertisement appears, and should no opposition be entered the registrar will, upon payment of the registration fee, issue his certificate of registration.

The term of registration of a Trade Mark is fourteen years and may be renewed.

DESIGNS.

For articles which do not form the subject of a patent, protection may in some cases be obtained by design registration where the novelty consists of shape, pattern or ornamentation. Copyright is granted for five years and is renewable for a further similar term, and it is within the discretion of the Comptroller of Patents and Designs to extend the term of a copyright for a third period of five years.

SECTION XLV

COST OF ENGINEERING WORKS

(Contributed by John T. Rea, Author of 'How to Estimate.')

SECTION XLV

COST OF ENGINEERING WORKS.*

(Contributed by John T. Rea, Author of 'How to Estimate.')

AERIAL ROPEWAYS.

Two broad types—Single-rope or Monocable, and Double-rope or Bi-cable. In the former the load carriers hang from and move with an endless hauling wire rope, for gradients up to 1 in 4; in the latter the load carriers hang from a fixed wire rope (double line), and are drawn along with an endless hauling rope, for any gradient.

Aerial ropeways fixed complete, including wire ropes, pulleys, carriers, wooden supports, engine, driving gear, machinery, labour, etc., to carry 10 or 20 tons per hour, in loads not exceeding 5 cwts. per carrier, and gradients as above, pre-war costs :—

	Per Mile.
	£ £
Running single-rope system, to carry 10 tons per hour	900 to 1,200
" " " 20 "	1,400 „ 1,700
Fixed-rope system (double line), to carry 10 tons per hour	1,500 „ 2,500
" " " 20 "	2,200 „ 3,200

Prime Cost of Plant with Steel Structures.—The following table, by Mr. John H. Huntley, M.I.E.S., shows the pre-war standard amounts for aerial ropeways with no peculiar complications, using spiral construction ropes up to 20 tons capacity and locked coil ropes for 40 to 80 tons capacity, and represents the total cost of the plant erected. For lengths over 5 miles costs in proportion.

Capacity in Tons per Hour.	Length of Line in Miles.			
	½ Mile.	1 Mile.	2 Miles.	5 Miles.
Tons.	£	£	£	£
5 per hour	1,900	2,000	3,300	6,900
10 "	2,100	2,300	3,650	7,400
20 "	2,350	2,600	3,900	8,000
40 "	2,500	2,870	5,000	10,500
60 "	2,850	3,200	5,700	11,900
80 "	3,100	3,500	6,300	13,100

Working Costs per Day.—The following pre-war costs, by Mr. John H. Huntley, M.I.E.S., include depreciation, but exclude cost of driving, which varies extremely owing to the difference of height between stations, etc., and cannot be standardised.

Length in Miles.	Capacity per Day in Tons.					
	50 Tons.	100 Tons.	200 Tons.	400 Tons.	800 Tons.	1,000 Tons.
	s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
½ mile	17 6	21 0	25 0	32 0	42 4	48 0
1 "	19 5	24 0	28 10	37 7	52 0	58 5
2 "	26 6	31 6	36 4	49 7	68 10	76 10
5 "	45 7	51 0	61 0	83 3	126 0	156 10

* All prices mentioned are pre-war figures unless otherwise stated; present rates (1928) about double.

Aerial Ropeway at Loch Leven, Argyllshire (1906).—Erected for the construction of a dar for water-power purposes. Length of line about 4¼ miles. Arranged on the single-rope systen and has a mean gradient of 1 in 22·8, or a difference in altitude of 1,100 ft. against the load Three bends in the line, with a station at each bend, and including the power station and bot terminals, there are six stations for loading and unloading. Eighty-six trestles, averaging 24 f high. Trestles, terminals, angle, and power stations of pitch pine. Driving power is from Pelton wheel of 250 brake horse-power. Speed of line, 300 ft. per minute. Capacity, 700 t 1,000 tons per day, with 580 steel buckets, each having an individual load of 6 cwt., an spaced about 90 ft. apart. Twenty men are engaged in working the line. Total cost, includin carriage, erection, and foundations, etc., complete, about 12,500*l.* or 2,600*l.* per mile.

Cost of operating per ton-mile, allowing for redemption in 3 years, labour and 10 per cen on the labour account for supervision, was estimated at 2*d.*

Plant for Single-rope Fixed-grip System.—Prices vary greatly according to the ground passe over and the material transported, so the following figures are merely approximate. They are th rates for articles at manufacturers' works to which must be added the cost of packing and markin for export, about 4 per cent. overall, carriage, loading and unloading, and erection with concret foundations, etc., as well as of motive power, which always differs. The value of timber structure would be about 15 per cent. less than that of corresponding structures in steel. From quotation received in August, 1922.

Description of Parts.	10 tons per 10 hrs'. line. £	25 tons per 10 hrs'. line. £	50 tons per 10 hrs line. £
1. Steel wire rope, trestle mountings, grips and carriers for a length not exceeding 1 mile—per mile	400	600	825
Ditto over 1 mile but not exceeding 3 miles in length—per mile	440	660	910
2. Driving and tension gears for a line not exceeding 1 mile	140	160	175
Ditto over 1 mile but not exceeding 3 miles in length	250	300	330
3. Mountings for each angle station giving any degree of deviation	70	80	90
4. Steel trestle structures, average about 16 per mile, height 20 ft., per trestle	18	22	20
5. Steel structures for terminal gears for a line not exceeding 1 mile	100	120	135
Ditto, ditto, for a line over 1 mile, but not exceeding 3 miles in length	160	180	200
6. Steel structures for angle stations, each	50	65	75

Example of Approximate Estimate.—To illustrate the method of estimating from the fore going particulars the following example is given. The cost of a ropeway ¾ mile long to carr 25 tons per 10 hours with one angle station: steel trestles, and timber structures for termina and angle stations. From quotations received in August, 1922:

	£	*s.*	*d*
Steel wire rope, trestle mountings, grips, carriers, as No. 1—¾ of 600*l.* per mile	450	0	0
Driving and tension gears as per No. 2	160	0	0
Mountings for angle station as per No. 3	80	0	0
Steel structures for 12 trestles as per No. 4—22*l.* × 12	264	0	0
Timber structures for terminal gears as per No. 5—120*l.*, less 15 per cent. (18*l.*)	102	0	0
Timber structures for angle stations as per No. 6—65*l.*, less 15 per cent. (9*l.* 15*s.*)	55	5	0
	1,111	5	0
Packing and marking for shipment, 4 per cent.	44	9	0
Total cost of ropeway materials for ¾ mile	1,155	14	0

Add to the foregoing carriage, unloading, erection, foundations, and motive power.

ARTESIAN WELLS.

Artesian bored tube wells, including boring by the percussion, percussion hydraulic, or rotary methods, according to the sub-strata, supplying steel-socketed lining tubes with butt ends flush-screwed, and special solid steel cutting shoe, and providing all materials, plant and labour, up to 100 ft. in depth; add 10 per cent. for every additional 10 ft. Telescoping the lining tubes

is obsolete, as they should be one continuous tier. Special sizes run up to 4 ft. and 6 ft. diameter. See also 'Tube Wells' p. 2877.

Soil.	Tubes.	Per ft. deep.
In easy soils, such as earth and sand .	3 in. to 4 in. external diameter . .	8*s.* to 10*s.*
	6 in. „ 9 in. „ „ . .	13*s.* „ 18*s.*
In soft rocks, such as chalk or shale .	3 in. „ 4 in. „ „ . .	11*s.* „ 13*s.*
	6 in. „ 9 in. „ „ . .	17*s.* „ 23*s.*
In hard rocks, such as basalt or sandstone	3 in. „ 4 in. „ „ . .	17*s.* „ 20*s.*
	6 in. „ 9 in. „ „ . .	25*s.* „ 32*s.*

London.—The charges of the Metropolitan Water Board for domestic supply are based upon 5 per cent. of the rateable value of property, and in the case of a large building, such as business premises or a bank, are out of all proportion to the water used. Charges of 200*l.* to 600*l.* per annum are common, and even 4,000*l.* has been paid. Roughly speaking, any building owner in London paying more than £120 a year for water will find it better to sink an artesian well. Boreholes over 1,000 ft. deep have been sunk in the London basin, and yield 100,000 gallons per hour. The flow is reliable, the water is of a low temperature, pure and soft (generally about 5° of hardness compared with 16° of the Water Board supply), leaves no deposit on pipes and boilers, and the cost is very small.

The capital outlay for many important buildings in London for an independent water supply, including sinking an artesian well and providing the pumping plant, where the quantity runs from 1,000 to 4,000 gallons per hour, varies from 1,500*l.* to 4,000*l.*

The cost of pumping artesian wells depends on the lift and power required, and may be as low as ¼*d.* per 1,000 gallons on a lift up to 400 ft., and is commonly 1½*d.* per 1,000 gallons for manufacturing purposes. Pumping by electric motors, with current at 1½*d.* per unit, will work out to about 2½*d.* per 1,000 gallons when the water is raised some 300 ft. from the borehole to the storage tanks above. The capital invested in a separate installation would thus be repaid in three to six years, leaving only the pumping costs to be considered as an annual expense, so that the value of artesian wells is apparent.

BORING.

Percussion boring by the ordinary 'English' method to depths of 500 ft. costs 10*s.* to 20*s.* per foot, advancing 2 to 6 ft. per 24 hours.

Rope boring for oil, salt, etc., holes 6 to 15 ins. diameter, 20 to 60 ft. per day, costs 2*s.* to 8*s.* per foot. Plant for a hole 2,000 ft. deep weighs 80 tons, and costs about 2,000*l.*

Diamond boring in hard rock, 5 ins. diameter, costs in this country 8*s.* per foot down to 500 ft., and 12*s.* to 18*s.* down to 1,500 ft. Advance 5 to 10 ft. per day. Bort 'diamonds' are 2*l.* to 3*l.* per carat for the softer rocks, and carbon 6*l.* to 12*l.* per carat for the harder ones. Boreholes above 6 ins. diameter are thus almost prohibitive for expense.

Chilled shot method for relatively large boreholes, 6 in. diameter, in hard ground, costs 10*s.* to 12*s.* per foot. It is slower but cheaper than diamond boring, and consists of chilled steel shot fed into a thick steel pipe notched at the lower end and rotated upon the rock to be pierced, with water forced down.

Actual Costs—The following are from practical pre-war experience :—

	Per ft. *s.* *d.*
Rope boring at Middlesbrough, 8 ins. diameter, to depths of 1,000 ft., at rate of 60 ft. per day	8 0
Ditto. in Pennsylvania and Ohio, 6 to 15 ins. diameter, at rate of 20 ft. per day, average contract price	6 0
Diamond boring in Scotland, 5 ins. diameter, to depth of 1,800 ft., advancing about 6 ft. per day	6 4
Ditto. in British Columbia, 2,200 ft. deep, at rate of 10 ft. per day	8 6
Ditto. in Nova Scotia, 2 ins. diameter, sunk by the Government in fairly hard ground to depths of 200 to 400 ft. in 1913, averaged	9 0
Ditto. in Victoria, also sunk by the Government, averaged in the coal measures in 1912	9 3
Ditto. ditto. in the harder rocks	14 0
Chilled shot 6 in. Government boreholes in Nova Scotia in 1913, averaged . . .	10 6
Some important boreholes of the world—	
Bezuidenville, Transvaal, 5,800 ft.	42 0
Czachow, Rybnik, Upper Silesia, 7,350 ft.	43 4
Paruschowitz, Silesia, 6,572 ft. (12 in. bore decreasing to 2¾ in.)	11 6
Schladebach, Prussia, 5,737 ft.	21 2

BREAKWATERS.

Breakwaters formed of large rough blocks of stone as a foundation with heavy masonry walls above, forming a harbour. Average width 300 ft., and average depth 50 ft. below low-water mark. 150*l.* to 300*l.* per foot run complete.

Alderney.—Composite type of rubble mound and upright wall above. Mound terminate 12 to 15 ft. below low water. 338 ft. wide at base and 36 ft. at top. 90 ft. mean depth of wate 259*l.* per foot run.

Algiers.—Mound type, with large random concrete blocks surrounding the rubble. 50 f mean depth of water. 122*l.* per foot run.

Bizerta.—Composite type, with wall built on caisson system. 58 ft. mean depth of wate 60*l.* per foot run.

Colombo.—South-west breakwater, 1874–85, is 4,212 ft. long, built of concrete blocks weighin 18 to 30 tons, on the sloping bond system, and cost 705,200*l.*, or 167*l.* per foot run. Extension t ditto as a further protective arm, 1907–12, is 1,800 ft. long, also of concrete blocks, and cos 380,000*l.*, or 211*l.* per foot run.

North-east breakwater, 1894–7, is 1,100 ft. long, and constructed as a rubble embankment the north-west or island breakwater, 1900–6, is 2,657 ft. long, and made of concrete; the tw together cost 500,000*l.*, or 133*l.* per foot run.

Total length of the four breakwaters about 9,770 ft., with five lighthouses on them, and tota cost 1,585,200*l.*, or an average of 162*l.* per foot run. Depth of sea, 30 to 36 ft. at low water. Ris of tide at Ceylon is only 2 ft. Engineers, Sir John Coode, Son, and Mathews.

Dover.—Wall type, composed of concrete blocks weighing 26 to 40 tons, 82 ft. wide at base an 40 ft. at top. Depth of water, 61 ft. high; 42 ft. low. 415*l.* per foot run.

Holyhead.—Composite type, with very predominant mound of rough rubble stone, 400 f average width at base and 40 ft. at top. Sea and harbour walls built upon the mound. 54 f mean depth of water. 163*l.* per foot run.

Marseilles.—Mound type. Outer casing of concrete blocks, 25 tons each, and average thickne 14 to 20 ft. Inner casing of rubble stone, 2 to 5 tons weight, about 12 ft. thick. Rubble hear ing, ½ to 2 tons stones, and 6 ft. thick. 35 ft. mean depth of water. Joliette section, 72*l.* per fo run, and new section, 109*l.* per foot run.

Naples.—Composite type. 93 ft. mean depth of water. 186*l.* per foot run.

Plymouth (1811–48).—Rubble mound with walls on top, nearly a mile long. Slope of 5 to seawards. 360 ft. wide at base and 43 ft. at top. Average depth, 45 ft. below low-water mar Absorbed 3,670,440 tons of rubble and 22,150 cubic yards of masonry. Engineer, Sir Joh Rennie. 250*l.* per foot run.

Portland.—Mound type with large rubble blocks and heavy masonry wall above, 270 ft. wi at base. The largest of its kind in England and in two portions—inner about 2,000 ft. long ar outer over 6,000 ft., with 400 ft. opening between them. Depth of water, 58 ft. high; 51 f low. 6 million tons of stone used. Convict labour. Total cost, 1,250,000*l.* 140*l.* per foot ru

Maintenance.—This is less for walls than for rubble mounds, as the latter are greatly affect by wave action, and need constant repair. Cost varies according to situation and exposur and rarely exceeded 1*l.* per foot run per annum, pre-war. For some time it averaged 1*s.* 3 at Holyhead, 7*s.* at Geneva, and 13*s.* at Naples.

(See Section XXVIII, p. 1519.)

BRIDGES.

Types.—(1) Arched, (2) Cantilever, (3) Girder or lattice, (4) Movable (bascule or liftin rolling, swing, and transporter), (5) Pontoon (with barrels, boats, planks, etc.), (6) Suspensio (7) Trestle (with very high steel or wood framework piers), and (8) Viaducts or "land" bridges.

Costs include foundations, piers, abutments, approaches, footpaths, machinery, etc., complet

Description.	Span.	Number of Spans.	Cost per ft. sup.
	ft. ft.		
Brick or masonry	50 to 100	Single	£1 to £2
	50 „ 100	Multiple	£2 „ £4
Ordinary concrete	30 „ 50	Single	15*s.* „ £1
	30 „ 50	Multiple	£2 „ £3
Reinforced concrete	50 „ 100	Single	10*s.* „ £1
	50 „ 100	Multiple	£1 „ £2
Steel bascule or lifting	50 „ 100	Single	£3 „ £5
	100 „ 200	Multiple	£5 „ £8
Steel girder or lattice	50 „ 100	Single	£1 „ £3
	50 „ 100	Multiple	£2 „ £5
Steel suspension	50 „ 100	Single	£1 „ £2
	100 „ 200	Multiple	£2 „ £4
Steel swing	50 „ 100	Single	£2 „ £3
	100 „ 200	Multiple	£3 „ £5

Brooklyn Bridge (1870–83).—Wire cable suspension bridge over the East River, connecting New York with Brooklyn. 5,990 ft. total length, including 1,596 ft. central span from tower to tower, two spans of 930 ft. from the towers to anchorage on either side, and the approaches of ironwork and masonry, 1,563 ft. on New York side and 971 ft. on Brooklyn side. Width 85 ft., divided into five passage ways for vehicles, trams, and foot passengers. Clear height above high water 135 ft. in centre and 118 ft. at towers, giving a free passage to shipping. Towers 277 ft. above high water, upon rock foundation 80 ft. below surface of river and 40 ft. beneath its bed. Supporting the spans are four cables nearly 16 ins. diameter, and 3,758 ft. long, with anchorages of solid stone masonry weighing 60,000 tons each, and rising 90 ft. above river's edge. Each cable contains 5,282 galvanised steel wires in 19 separate strands, of 278 lengths, and each strand has over 200 miles of continuous wire. Wires laid parallel, not twisted, with spiral wire wrapping. Deflection of cables between towers is 128 ft. Engineer, John A. Roebling. Total cost, including approaches, 3,100,000*l.*, or 518*l.* per ft. run, or 6*l.* per ft. sup.

Forth Bridge, Scotland (1883–90).—At South Queensferry, near Edinburgh. Steel latticework, with two main cantilever spans 1,710 ft. each, and 24 land spans, 42 to 688 ft. each. Each cantilever 690 ft. long, united by a girder 250 ft. span. The steel towers supporting the cantilevers are 361 ft. high, and the steel tubes of both are 12 ft. diameter at base, tapering to extremities. 50,960 tons of steel employed and 6½ millions of rivets. Complete length, 8,100 ft., and with approaches, 8,300 ft.; width, 30 ft.; 145 acres of surface to be painted. Double line railway. Height of railroad, 152 ft. above high water. Main piers of masonry, and concrete foundations in rock, 70 ft. below high water. Central pier of granite standing on the islet of Inchgarvie. Engineers, Sir John Fowler and Sir Benjamin Baker. Contractors, Sir Wm. Arrol & Co. Total cost, including approaches, 1,700,000*l.*, or 25*l.* per ft. run, or 7*l.* per ft. sup.

Gôkteik Viaduct (1901).—In the Shan States, Upper Burmah, the viaduct forming part of the railway where it crosses a deep wide valley about 80 miles from Mandalay, and runs on to Kunlon at the Chinese frontier. The second most lofty steel trestle bridge in the world, but for combination of height, length, and weight of material easily the first. It is straight for 1,638 ft. at the centre, with terminal curves of 800 ft. radius, 341 ft. and 281 ft. long respectively. Total length between abutments, 2,260 ft. There are 15 trestles or skeleton towers, varying from 250 ft. to 320 ft. in height, 10 spans of 120 ft., and 7 spans of 60 ft., or 17 spans altogether, formed with lattice or plate girders. 5,000 tons of metal, and 200,000 rivets. All the metal parts, some 230,000 pieces, were prepared in the United States, shipped 10,600 miles, and transported 460 miles up country by the Burmah railway, where they were re-assembled and put up without a hitch. A single track was first laid, but space was left for a second when the traffic required it. Total cost, 61,000*l.*, or 27*l.* per ft. run, or 3*l.* 10*s.* per ft. sup.

Holyhead, Britannia Tubular Bridge (1845–50).—Across the Menai Straits. Continuous double tube of wrought-iron plates, each tube 15 ft. wide by 23 ft. high at ends, and 30 ft. at centre, with one railway line in each. Two main spans of 460 ft. each, two smaller spans of 230 ft., and two shore spans of 65 ft., or a total length of 1,510 ft. Each tube weighs 4,680 tons, and is fixed 100 ft. above high water. Two abutments, and three masonry piers or towers, the highest of which is 230 ft. Complete distance, with approaches, 1,560 ft. Engineers, Robert Stephenson, assisted by Sir Wm. Fairbairn and Professor E. Hodgkinson. Total cost, including approaches, 608,000*l.*, or 390*l.* per ft. run, or 13*l.* per ft. sup.

Kingston Bridge, Surrey (1825–8).—Brick and stone. Five elliptical arches: middle arch 60 ft. span, other arches 56 ft. and 52 ft. span. Ratio of piers to spans, 1: 6. Bridge, 382 ft. long and 25 ft. wide. Bridge itself, 26,800*l.*; approaches and other works, 13,200*l.* Total cost, 40,000*l.*, or 105*l.* per ft. run, or 4*l.* per ft. sup.

London Bridge (1824–31).—Stone bridge of five elliptical arches over the Thames and of handsome design, connecting the City of London with the borough of Southwark, and replacing the 12th century stone bridge. Centre span 152 ft., rising 30 ft. above Trinity high-water mark, arches on each side 140 ft. spans, and abutment arches 130 ft. Total length 1,005 ft., and 56 ft. outside width. Two centre piers 24 ft. thick, exterior stones of granite and interior half Bramley Fall and half Painshaw, Derbyshire; granite voussoirs. General depth of foundations 30 ft. below low water. Engineer, John Rennie, and completed by his son Sir John Rennie. Contractor's tender for the bridge alone was 425,081*l.*, but actual cost was 1,458,310*l.*, or 1,451*l.* per ft. run, or 26*l.* per ft. sup.

Newcastle High-level Bridge (opened 1849).—Example of a true bowstring arch in which there is no cross bracing, with six spans of 125 ft. each. Total length 1,373 ft., and 37 ft. external width. Superstructure is supported on five intermediate piers and eight land piers, four at each side, latter with arched abutments. Height of soffit above high-water, 83 ft. Arched ribs of cast iron and ties of wrought iron. 4,728 tons of cast iron and 321 tons of wrought iron were employed. A carriage roadway passes underneath the railway, the bridge supporting both. Engineer, Robert Stephenson. Total cost, 243,000*l.*, or 177*l.* per ft. run, or 5*l.* per ft. sup.

Newport Bridge, Mon. (1924-27).—Over the river Usk. Reinforced concrete and stone, five spans, length 356 ft., and overall width between parapets 60 ft. Two footways. Total cost, 140,300*l.*, or 6*l.* 11*s.* per ft. sup. of deck area.

Niagara Suspension Bridge (1852–5).—Connects the United States with Canada. A wire-rop suspension bridge for road and railway, with a single span of 821 ft., centre to centre of pier and 245 ft. above the water. Superstructure is a hollow rectangular box, 24 ft. wide × 18 ft deep, on the top of which the railway is laid, while the bottom forms a roadway for public traffic both floors being constructed of timber beams, etc. Railway floor is suspended from two wir cables, 10 ins. diameter, at intervals of 5 ft., and the lower floor by two similar cables. 120 stays Two masonry towers at each end of the bridge, 60 ft. high, 15 ft. square at base, tapering t 8 ft. square at top, and pierced by an arch. Anchor chains embedded in masonry 7 ft. × 3 ft. and 25 to 35 ft. deep. Engineer, John A. Roebling. Total cost, 80,000*l.*, or 97*l.* per ft. run or 4*l.* per ft. sup. This suspension bridge was replaced by a steel arch bridge in 1897.

Tower Bridge, London (1890–4).—Steel, with two fixed shore suspension spans 270 ft. each, an a lifting central span of 200 ft. Two large steel towers encased with stone, with two bascules o drawbridges in the centre and connected at top by a high-level footbridge, 140 ft. above high wate Bascules weigh 1,000 tons each, and are raised and lowered by hydraulic machinery which i contained in the chambers of the piers supporting the towers, each pier being 180 ft. long × 70 ft wide. Staircases and hydraulic lifts are provided in the towers for foot passengers crossing the high level bridge when the bascules are raised for the passage of shipping. Complete length, wit approaches, 2,980 ft. Width of fixed spans between parapets, 60 ft., and breadth across centr span 50 ft. Engineer, Sir John Wolfe Barry. Sir Horace Jones, the City Architect, designe the architectural details. Contractors: Sir John Jackson for foundations; Sir Wm. Arrol & Co for steelwork; and Sir W. G. Armstrong & Co. for hydraulic machinery. Total cost, includin machinery and approaches, 903,000*l.*, or 303*l.* per ft. run, or 5*l.* per ft. sup.

Westminster Bridge, London (1853–62).—Road bridge over the Thames, with cast and wrough iron arches of 120 ft. span and 20 ft. high. 1,160 ft. long and 83 ft. wide. Engineer, Thoma Page. Contractors, Messrs. Marc. Total cost, 235,000*l.*, or 203*l.* per ft. run, or 2*l.* per ft. sup.

Suspension Bridges.

Estimated costs by a well-known firm of steel manufacturers of strong steel wire rope suspensio bridges of large power, designed to carry 15-ton traction engines with wagons in line on th bridge floor, the prices being for the whole of the iron and steel work, including lattice pie surmounted by cast-iron saddles for the ropes to run over, all bolts and nuts, holding down bolt steel rod suspenders, open-steel parapets, high tension steel cables, steel cross girders to suppo decking, steel wind ties under floor, etc., ungalvanised but painted two coats before despatch delivered f.o.b., London or Liverpool, or to railway stations in England; supplied only, an exclusive of timber floor, foundation work, and erection. Pre-war rates. If a concrete asphalt floor is required the prices will be subject to an increase, owing to the additional strengt necessary and the greater weight put on the structure. The span is centre to centre of pier and the feet super. for area unit price, have been reckoned accordingly.

Span.	Width.	Area.	Total Price.	Price per Foot Super.	Weight of Steelwork.
Ft.	Ft.	Ft. Sup.	£	*s.* *d.*	Tons.
50	19	950	565	11 11	31
75	19	1,425	785	11 0	44
100	19	1,900	945	9 11	53
125	19	2,375	1,115	9 5	60
150	19	2,850	1,275	8 11	66
175	19	3,325	1,430	8 7	75
200	19	3,800	1,575	8 3	81
225	19	4,275	1,740	8 2	91
250	19	4,750	1,880	7 11	100
275	19	5,225	2,065	7 10	110
300	19	5,700	2,230	7 10	118

The prices may therefore vary from about 8*s.* to 12*s.* per ft. sup. If erected complete, includir timber floor and concrete, stone, or brick foundations or abutments, and anchorages, the cos would be at least double the foregoing. Narrower bridges, down to 3 ft. wide, for lighter load such as foot traffic, cattle, mules, horses and carts, would be of reduced construction an correspondingly cheaper.

Actual costs of steel wire-rope suspension bridges, delivered and erected, including steel pier wire ropes, suspension bands, and timber for floor, but exclusive of any foundation work

anchorages. Pre-war rates. The span is centre to centre of piers, and the feet super. for area unit cost have been reckoned accordingly as before.

Locality.	Load.	Span.	Width.	Area.	Total Cost.	Cost per F.S.
		Ft.	Ft.	Ft. Sup.	£	s. d.
Bournemouth, across Alum Chine	Donkey carts and bath chairs	230	6	1,380	590	8 7
Derby sewage works	Foot traffic	86	3	258	165	12 9
Dryburgh, across the Tweed, near Melrose Abbey	Foot traffic	260	6	1,560	540	6 11
Linley, over the Severn. Two approach spans in addition, making a total span of 390 ft.	A row of 10-ton carts	213	12	2,556	1,700	13 3
Llandilo	Foot traffic	144	5	720	220	6 1
Llangollen	Foot traffic	146	3	438	190	8 8
Rhayader, for the Birmingham Corporation Waterworks	Cart traffic	110	10	1,100	450	8 2
Shrewsbury. Two approach spans of 30 ft. each in addition, making a total span of 210 ft.	Light vehicular traffic	150	8	1,200	950	15 10
Swalwell, over the Derwent	Foot traffic	125	4½	562	285	10 2
Warrington	Foot traffic	183	6	1,098	430	7 10
Wrexham, across the Dee.	Row of loaded haycarts	130	10	1,300	670	10 4

The average rate was therefore about 10*s.* per ft. sup. If erected complete, including foundation work and anchorages, the costs would be at least double foregoing.

Bridges of Concrete.

Coulouvrenière Bridge, Geneva (1895–6).—Across the Rhone, 351 ft. wide, and total length of bridge over the abutments 492 ft. Width between parapets 61 ft. 4 ins., two footways 12 ft. 6 ins. each, with a carriageway 36 ft. 4 ins. between the kerbs. Two large arches with spans 131 ft. 3 ins., and rise of 17 ft. 6 ins. Arches 3 ft. 3 ins. thick at both springings and centre, about 4 ft. 6 ins. at the haunches, and steel pivoted. Two smaller arches, 35 ft. 5 ins., and 39 ft. 4 ins., but are not pivoted, being elliptical. Very handsome bridge. Arches, spandrels, 9 spandrel walls, 2 ft. thick, 12 in. top table, and filling, all of concrete, 1 to 4¼, 6, 7, and 8. Piled abutments. Facing of spandrel walls, columns, cornice, and parapet of stone. Wooden centres were used, with sand boxes for adjusting and striking. Total cost, 68,000*l.*, or 138*l.* per ft. run, or 2*l.* 5*s.* per ft. sup. of roadway and footpaths. Cost per cubic yard, including centering and scaffolding, was 3*l.* 2*s.* 3*d.*

Eyach Bridge, Hohenzollern (1895).—Designed by Herr Max Leibbrand, of Sigmaringen. A single span of 98 ft. 5 ins., with a rise of 9 ft. 10 ins. Concrete arch and table, 1 to 7½, and foundations to abutments, 1 to 9, which are piled. Pivots or joints made of granite instead of iron or lead. Bridge is 143 ft. long, 12 ft. 6 ins. total width, with roadway 7 ft. 6 ins. wide, and each footpath 2 ft. 6 ins. The footpaths overhang the arch on either side and were formed of old iron rails. Plain iron railing as parapet. Cost, 900*l.*, or 6*l.* per ft. run, or 10*s.* per ft. sup.

Kirchheim Bridge, Württemburg (1897).—Over the Neckar, which is 361 ft. wide at this point, with 230 ft. of foreshore, or a total of 591 ft. Designed by President von Leibbrand, chief engineer to the State of Württemburg. Length of bridge from outside to outside of abutments, 592 ft., and space between parapets 17 ft. 8 ins., including road, 12 ft. 8 ins., and two footways, 2 ft. 6 ins. each ; open iron parapets. Four spans of concrete arches, 124 ft. 8 ins. each, with a rise at the centre of 18 ft. Thickness of arch at crown, 2 ft. 8 ins., increasing to 3 ft. at springing. Concrete piers 7 ft. 6 ins. thick at springing level, faced with stone at water level ; cutwaters also faced with stone. Concrete in arches and abutments, 1 to 7½, spandrel walls, tables, etc., 1 to 9, and foundations for piers, 1 to 4. Concrete on face was tooled and coloured, and concrete in piers rendered 2 ins. thick with 1 Portland cement and 2 sand. Lead joints in the centres and springings of arches 6 to 7 ins. wide, bedded and recessed in stone. Screw jacks were used for striking the centres in place of folding wedges or sand boxes. Cost, 7,000*l.*, or 12*l.* per ft. run, or 13*s* .5*d.* per ft. sup. of bridge table. Approaches, 2,250*l.* in addition.

Munderkingen Bridge, *Württemburg* (1893).—Over the Danube. Designed by President von Leibbrand. One span only of 164 ft., and rise 16 ft. 5 ins. Thickness of arch at centre 3·28 ft., at springing 3·61 ft., and at haunches 4·26 ft. The first concrete bridge where steel pivots on bearing boxes were used, one set at each abutment and one set at the crown. Internal and external spandrel walls, abutments, horizontal and intermediate tables, cornice, and arch itself, were of concrete, 1 to $7\frac{1}{2}$, and tinted. Spandrel face of limestone, and ornamental open iron parapet. Cost of bridge, including piled abutments, 3,600*l.*, or 21*l.* per ft. run, or 13*s.* 6*d.* per ft. sup. of road and footway surface. Approaches, 1,000*l.* in addition.

Neckarhausen Bridge, *Hohenzollern* (1900).—Over the Neckar. Designed by Herr Max Leibbrand, of Sigmaringen. The handsomest concrete bridge in Germany, the concrete being coloured, and no stone used. A single concrete arch of 164 ft. clear span, with a rise of 15 ft. Arch ring 2 ft. 10 ins. thick at the centre, 3 ft. at the springing, and 4 ft. at the haunches. The arch is tapered on plan, being 1 ft. 8 ins. wider at the springing than at the centre. Concrete spandrel columns and arches over, instead of solid spandrel walls and haunches, thus reducing both material and dead load. Arches pivoted with steel pins and cast-iron brackets or bearings, and those carrying roadway were strengthened with iron rails built into the top and abutments. Concrete in arch 1 to $7\frac{1}{2}$, faced with $\frac{3}{8}$-in. spalls of limestone. Voussoirs, cornice, etc., were coloured. Width of macadam roadway 13 ft., and overhanging footpaths 2 ft. 6 ins., which is a cheap method. Centering was supported on temporary piles, with screw jacks for striking. Cost, 3,000*l.*, or 17*l.* per ft. run, or 19*s.* 5*d.* per ft. sup. Long approaches, 5,000*l.* in addition.

Bridges of Reinforced Concrete.

Spans, 50, 75, or 100 ft. External width, including parapets, 25 ft. Height, from mean water level to underside of elliptical arch, 13 ft. 15*s.* to 30*s.* per ft. sup.

Items.	Cost.		
	50 ft. Span.	75 ft. Span.	100 ft. Span.
	£	£	£
Excavations	70	111	184
Concrete	251	462	667
Centering	129	240	341
Reinforcing Steel	104	194	277
Preliminaries 10 per cent.	55	100	147
Contractors' Profit, etc., 15 per cent.	91	166	242
Total Cost	700	1,273	1,858

Alexandra Bridge, *Pietermaritzburg* (1914–15).—Reinforced concrete on the Kahn system 170 ft. long × 30 ft. wide between the parapets, with two 5-ft. footpaths cantilevered over a 20-ft. roadway. Central arch 75 ft. span, and a half arch 38 ft. span at each end. Cost, including 5 per cent. for designs and supervision, 5,906*l.* for the bridge and 4,008*l.* for the approaches = 9,914*l.* total. 52*l.* per ft. run, or 2*l.* per ft. sup.

Brivio Bridge, *Italy* (1913–17).—Over the river Adda, and gives access to the railway station of Cisano Bergamasco. Entirely constructed of reinforced concrete, 444 ft. long and 30 ft. wide, with a 24 ft. roadway flanked by two raised footpaths, each 2 ft. 7 ins. wide, with edges of L irons. The roadway is about 26 ft. above the average level of the river, and suspended from three reinforced concrete arches overhead. Span of centre arch 177 ft., and of side arches 144 ft., all being supported on two massive concrete pillars and shoulders, each 43 ft. × 13 ft., built on a group of 48 steel-shod concrete piles made on the Considère system, 14 ins. square, and driven 43 to 53 ft. through the bed of the river by a steam hammer weighing 4 tons. Normal load on each pile averages 35 tons, uniformly distributed by a superimposed concrete slab 3 ft. thick. Foundations protected by pitch pine shuttering 5 ins. thick. Sole of roadway 5 ins. thick, covered with asphalt and a layer of concrete and gravel on top, with 12 in. × 30 in. transverse beams underneath attached to 11 in. × 24 in. vertical bars and to 18 in. × 40 in. longitudinal external beams. Cast steel rollers for expansion. Parapet is of cast ironwork. Bridge designed to carry a double-track electric tramway, a steam roller of 22 tons, and a dense crowd of people calculated at 10 cwt. per square yard. Total cost, 20,000*l.*, or 45*l.* per ft. run, or 30*s.* per ft. sup.

Chatellerault Bridge, *France* (1900).—Across the river Vienne, and is formed entirely of ferro-concrete on the Hennebique system. Centre span 164 ft. and two side spans 135 ft. each, with rises of respectively 16 ft. and 13 ft., and a width between the parapets of 26 ft. 3 ins., excluding two cantilevered footways which overhang 3 ft. 5 ins. Spans of four arched concrete ribs, 35 ins. deep × 19 ins. wide at springings, tapering to 9 ins. square at the soffit, and extrados connected together by an arched table. Roadway and footpaths supported by spandrel pillars, 8 ins. square, and longitudinal concrete beams, the top table being 10 ins. thick at the centre, tapering to 5 ins. at kerb. The bridge only weighs 250 lbs. per ft. sup. Cost, 8,000*l.*, or 18*l.* per ft. run, or 12*s.* 6*d.* per ft. sup.

Loughor Bridge, Glamorganshire (1920–23).—Spans the tidal estuary of the river Loughor, and replaces the old timber trestle structure. The new bridge is of reinforced concrete, from a design by Messrs. L. G. Mouchel and Partners, carried out by the Yorkshire Hennebique Contracting Co., Ltd. Length, 720 ft. between the abutments, divided into 18 spans of 40 ft. each. Width, 36 ft. between the parapets, providing two footways, 5 ft. wide, and a carriage-way of 26 ft. between the kerbs. Piers rest on reinforced concrete piles, 15 ins. square, driven into the bed of the river to various depths of 5 ft. to 37 ft. Four piles to each pier, each pile being encased in a reinforced concrete cylinder, 1 ft. 9 ins. diameter, cross-braced with reinforced concrete tie-beams, 10 ins. × 14 ins. Main longitudinal beams, 12 ins. wide × 2 ft. 8 ins. deep in the centre; secondary beams, 7 ins. × 18 ins. Four main or longitudinal beams and 12 secondary or cross beams to each span. 5½ ins. reinforced concrete decking, covered with 2 ins. cushion of sand and finished with 4 ins. of 'Tarmac' roadway. Ducts, 18 ins. × 9 ins., left under footpath concrete flagging to accommodate electric cables. Parapet of pierced concrete panels, with moulded handrail. Abutments have reinforced concrete wall supporting the ground behind. Steel reinforcement was of plain round steel bars, ⅜ in. to 1⅛ in. diameter, and the bridge was built in half-widths, so as not to interrupt the traffic. It was designed to carry a normal working super. load of 120 lbs. per square ft., and a rolling load of 48 tons. Total cost, excluding approaches, 56,700*l.*, or 79*l.* per ft. run, or 2*l.* 2*s.* 7*d.* per ft. super.

Pontypridd Bridge (1908).—Over the river Toll. Reinforced concrete on the Hennebique system, with the two piers on reinforced concrete piles. Total length 170 ft., and width 30 ft. Central river span 117 ft. Total, 3,600*l.* 21*l.* per ft. run, or 14*s.* per ft. sup.

Terralba Bridge, Italy (1916).—Part of a scheme for enlarging the Genova Brignole Station. It replaces about 600 ft. of the Terralba highway connecting St. Martino with St. Fruttuoso. Total length of bridge, including approaches, is 750 ft.; width 45 ft., including two footways each 5 ft. wide. Constructed of reinforced concrete and has six spans, four of 61 ft. and two of 58 ft., each span being built in three bays across. Part of the inclined approach was also formed in six spans, each of 35 ft. and three bays across, the remainder of the plane being constructed of massed work between supporting walls. Subsoil was a deep bed of soft, marshy clay, which prohibited piling and required a specially light foundation formed by 1 per cent. reinforced concrete rafts, the reinforcement being carried up into the pillars of the bridge. The rafts were supported on two pinewood piles per square yard, each 20 ft. long by 10 ins. wide, and tops coated with cement. Volume-ratio of reinforcement in superstructure was 1·8 per cent. to the gravel concrete. Total cost, 18,000*l.*, or 24*l.* per ft. run, including approaches, or 12*s.* 5*d.* per ft. sup. of concrete, including the foundation, and 6*s.* 8*d.* per ft. sup. of road and footpath.

Warrington Bridge (1913).—Over the river Mersey. Largest single-span reinforced concrete bridge in England, on the Considère system. River walls and abutments also of reinforced concrete. Clear span 134 ft., width 80 ft. between parapet walls, and ten parabolic ribs supporting upright and cross beams on which rest 6½ in. floor slabs. Roadway has wood-block paving, and footpaths have concrete slabs. Total cost, including approaches, 24,000*l.* or 34*s.* per ft. sup. ditto.

CANALS.

The total length of canals for inland navigation in the United Kingdom is 4,673 miles (3,641 in England and Wales, 184 in Scotland, and 848 in Ireland). 1,144 miles are owned by the railway companies, and 219 controlled by them. An ordinary inland canal in this country is 25–30 ft. wide at bottom, 40–45 ft. wide at water level, and 4–5 ft. deep. Canal boats are 70–75 ft. long and 7–8 ft. wide; barges are about the same length, but double the width, *i.e.* 14–15 ft. For maps and towns, etc., see the *Handbook on Canals*, with map, issued by the Canal Control Committee (Board of Trade), and obtainable from H.M. Stationery Office, Kingsway, London, W.C. 2, price 6*d.* net, or 8*d.* post paid. (November, 1918.) Total paid-up capital was 47,550,000*l.*, and the cost varied from about 5,000*l.* to 20,000*l.* per mile.

In 1905 the constructional cost of new canals in Great Britain, 40–45 ft. wide at bottom, 80–85 ft. wide at water level, and 8 ft. deep in centre, with locks 230 ft. × 22 ft. and 6½ ft. draught of water over sills, suitable for two lighters of 250 tons carrying capacity, was estimated at 30,000*l.* per mile. The cost of improving existing routes to reach the same standard was similarly reckoned at 15,000*l.* per mile.

In France, in 1870, there were 3,000 miles of canals and 2,000 miles of canalised rivers. The average cost of the French canals up till then was 11,600*l.* per mile, and of the canalised rivers, 4,800*l.* per mile. Present length, 7,500 miles.

BARGE OR BOAT CANALS.

Basingstoke Canal (1794–96).—From Basingstoke, Hampshire, to the river Wey Junction Canal, Surrey. Length, 37 miles, including 29 locks. Total cost, constructional works only, 170,000*l.* or 4,600*l.* per mile.

Bridgewater Canal (1759–61).—In Lancashire; originated by the Duke of Bridgewater to bring coal from his mines on the Worsley estate to Manchester, but it was later extended to the Mersey. First length was only 10 miles, but complete length 38 miles. 50 ft. wide and 5½ ft. deep, with vertical stone walls instead of banks. The Barton aqueduct carried the canal over the river Irwell, at a height of 39 ft. Engineer, James Brindley. (The Bridgewater Canal was purchased by the Manchester Ship Canal Co. in 1887.) Total cost, constructional works only, 235,000*l.*, or 6,180*l.* per mile.

Dortmund and Ems Canal (1890–1900).—From Dortmund to the North Sea at Emden. Part of the 157 miles total length includes canalisation of the river Ems. Bottom width, 59 ft., 98 ft. at water level, and depth, 8 ft. Works include 1 canal lift, 3 masonry aqueducts, 185 bridges, and 20 masonry locks, 220 ft. long each. Artificial canal portion cost 29,000*l.* per mile, and river canalisation portion, 14,000*l.* per mile. The locks were 15,000*l.* each, and the weirs 8,500*l.* each. Total cost, 3,970,000*l.*, including 400,000*l.* for land.

Cost per mile of total length, including land	25,286*l.*
,, ,, ,, ,, constructional works only	22,740*l.*

Elbing Canal.—In Holland. Length, 28 miles. Total cost about 212,200*l.*, or 7,580*l.* per mile.

Grand Junction (begun, 1790).—From the Oxford Canal at Bramston, Northamptonshire, to the Thames at Brentford, Middlesex. Width at bottom, 24 ft., and 36 ft. at water level. The main line is 93 miles long, but the total length, with branches, is 140½ miles (189 by Whitaker). Cost per mile, including land, etc., 19,500*l.*

Ulster Canal (1826–41)—Unites Lough Neagh with the upper Lough Erne, and extends from Charlemont, Co. Armagh, on the river Blackwater (which is navigable from Charlemont to Lough Neagh), passes Caledon, Monaghan, and Clones, and joins Upper Lough Erne, Co. Fermanagh, near Belturbet. Length, 47 miles. Total cost, constructional works only, 200,000*l.*, or 4,255*l.* per mile.

Worcester and Birmingham Canal (1791).—Connects these towns, and joins the Severn at the former. Runs through a tunnel 500 yards long, and three shorter tunnels. All are 18½ ft. wide, 7 ft. deep, and 18 ft. high. Length, 30 miles. Original cost per mile, 20,000*l.*

Irrigation Canals.

For irrigating large tracts of land for growing cotton, rice, sugar, wheat, etc., especially in America, Australia, Egypt, and India. The cost varies according to geographical features, nature of ground, available water supply, size of main canal, number of branches, distributing channels, and subsidiary works. In India the costs are approximately—

5,000*l.* to 10,000*l.* per mile of canal and main branches.
2*l.* to 3*l.* per acre of land irrigated.

Agra Canal (opened 1874).—In India, and draws its water supply from the Jumna at Okhla, ten miles below Delhi, irrigating 380,000 acres. The main and branch canals total 110 miles, and the distributing channels 600 miles. Total cost, including all works, 800,000*l.*

7,270*l.* per mile of canal and main branches.
2*l.* 2*s.* per acre of land irrigated.

Cavour Canal (begun 1862).—In Italy, and starts from the river Po, not far from Turin, and terminates in a junction with the river Tessin above Novara. Length, 51 miles, with a total fall of 71 ft. The summer discharge of the Po being found insufficient, a branch canal was constructed for bringing a supplementary supply from the Dora Baltea, which rises from the glaciers of the Alps and possesses a large discharge in the summer when the Po is low. Total cost, 4,104,000*l.*, or 80,470*l.* per mile of main canal.

Ganges Canal (opened 1854).—The largest irrigation work in India, and waters the district between the Ganges and the Jumna. Designed by Sir Proby Cautley. The canal with its main branches is about 650 miles long, and can irrigate an area of 1,205,000 acres. It was remodelled about twelve years later. Total cost up to 1878 was 3,055,000*l.*

4,700*l.* per mile of canal and main branches.
2*l.* 11*s.* per acre of land irrigated.

Lower Ganges Canal (1870–90 approximately).—An extension to supplement the original foregoing canal. Designed for a total length of 582 miles. Irrigates 2,500,000 acres. Total cost about 4,500,000*l.*

7,730*l.* per mile of canal and main branches.
1*l.* 16*s.* per acre of land irrigated.

Upper Swat Canal.—In India, along mountainous country at the Malakand hills. Length, 150 miles, and irrigates 450,000 acres. Works include a tunnel, 11,235 ft. long by 18 ft. wide and 13 ft. high, seven shorter tunnels totalling one mile, 167 aqueducts across ravines, 20 to 100 ft. deep, a weir 700 ft. long, stop-dam, pitched channel, etc. Total cost about 1,300,000*l.*

8,670*l.* per mile of canal and main branches.
2*l.* 18*s.* per acre of land irrigated.

Ship Canals.

Large waterways as formed for ocean-going shipping, complete with channels, locks, docks, machinery, entrance breakwaters, etc.; construction works only, and excluding promotion, purchase of land, compensation, or legal charges:

100,000*l.* to 500,000*l.* per mile of actual canal.

Amsterdam Canal (1865–76).—Connects Amsterdam and the Zuyder Zee with the North Sea *via* Lake Y and Wyker Meer, and across a narrow neck of sand-hills in a westerly direction. Works comprise a dam 4,462 ft. long, with maximum bottom width 147 ft. and top width 13 ft., shutting off Lake Y from the Zuyder Zee. There are five large locks, six sluiceways, three swing-bridges (two railway and one roadway), and a harbour of 260 acres at the North Sea entrance, protected by two rubble stone breakwaters, 5,070 ft. long each, with pier on top formed of concrete blocks, 6 to 12 tons each. Canal is 16½ miles long, 88½ ft wide at bottom, 186 ft. at water level, and 23 ft. deep (now increased to 30 ft.). 21,000,000 cubic yards of soil and mud were excavated and dredged and 13,000 acres of land reclaimed. The sale of the latter realised about 70*l.* an acre, or a total of some 910,000*l.*, which mitigated the engineering cost. The largest type of dredger used could deposit 1,300 cubic yards of material on the banks in twelve hours, at 2*d.* per cubic yard. Permanent pumping machinery was installed for draining the adjacent lands into the canal and out again into the sea. Engineers, Sir John C. Hawkshaw and Mr. Dirke. Contractors for the whole of the works, Messrs. Henry Lea and Son. For full details see paper by Mr. Harrison Hayter read at the Institution of Civil Engineers in 1880, and printed in the *Proceedings*, vol. lxii. p. 1.

	Total.	Per Mile.
Constructional works only . . .	2,600,000*l.*	157,580*l.*
Other expenditure and charges . .	400,000*l.*	24,240*l.*
Whole cost	3,000,000*l.*	181,820*l.*

Caledonian Canal (1803–23).—From Inverness to Fort William, along the Great Glen of Scotland, and connects Inverness Firth with Loch Eil, having Lochs Ness (22 miles), Oich (6 miles), and Lochy (10 miles) in between. The summit level of 102 ft. is overcome by 28 locks, 14 on either side, each about 170 ft. long × 40 ft. wide; 23 miles of artificial or canal navigation in four stages, and 38 miles of natural lake navigation through the foregoing three lochs, the total distance between extremities being thus 61 miles. Canal is 50 ft. wide at bottom, 120 ft. at water level, and 17 to 20 ft. deep, for vessels up to 600 tons burden. Engineer, Thomas Telford. Total cost, including land, 1,311,270*l.*, or 57,010*l.* per mile of actual canal length of 23 miles.

Corinth Canal (1882–93).—Across the isthmus of Corinth, between Gulf of Corinth and Gulf of Aegina, in Greece, and mostly through solid rock with very deep cutting. The neck of land rises in the centre to 286 ft. above the bottom of the canal. Bottom width, 72 ft., and average depth, 26 ft. No locks. Length, 4 miles. Entrances at each end protected by solid jetties built out into the sea. Greek engineer, Matsos. Total cost, 1,400,000*l.*, or 350,000*l.* per mile.

Cronstadt and St. Petersburg Canal (1877–90).—Starts from the Neva and goes south-west for about 2 miles, when it curves and proceeds in a straight line to Cronstadt. Average width, 240 ft., and depth, 20 ft. No locks. Total length, 16 miles, including 10 miles bay channel and 5 miles canal proper. Costs per mile are based on the total length of 16 miles.

	Total.	Per Mile.
Constructional works only . . .	1,240,000*l.*	77,500*l.*
Other expenditure and charges . .	760,000*l.*	47,500*l.*
Whole cost	2,000,000*l.*	125,000*l.*

Elbe and Trave Canal (opened 1900).—In Germany. Width at bottom, 72 ft., and depth, 10 ft. Length, 41 miles. Total cost, 1,170,000*l.*, or 28,540*l.* per mile.

Kiel Canal (1888–95).—Also known as the Kaiser Wilhelm Canal, or the Baltic and North Sea Canal, connecting Kiel in the Baltic to Elbe in the North Sea. Mostly through marshes or shallow lakes and river valleys, with tidal waterway throughout. Original dimensions: bottom width, 72–85 ft., surface width, 190–226 ft., and depth, 28–30 ft. (since increased to 150 ft., 335 ft.,

and 45 ft., respectively). Total excavation, 106,000,000 cubic yards. Two entrance locks, originally 492 ft. long × 82 ft. wide × 32 ft. deep over sill (now enlarged to 1,083 ft. × 148 ft. × 45 ft., and constructed in concrete, each lock having three pairs of caissons dividing the chambers into lengths of 725 ft. and 330 ft.). The original canal was completed in 1895, and the works for broadening and deepening in 1914. Breakwaters at each end. Length, 61 miles.

	Total.	Per Mile.
Original cost up to 1895, including land purchase	7,800,000*l.*	127,870*l.*
Enlargements and reconstructions up to 1914	11,200,000*l.*	183,605*l.*
Whole cost	19,000,000*l.*	311,475*l.*

Manchester Canal (1887–94).—Connects Manchester with Eastham, the Mersey port of Liverpool. Fifteen miles of canal proper, and 21 miles tidal waterway, or 36 miles total. Canal averages 120 ft. wide at bottom, 170 ft. at water level, and 26 ft. minimum depth (now increased to 28 ft.). Four sets of locks, with an average lift of 15 ft. each, thus raising the water level of the canal at Manchester to 60 ft. above mean sea-level at Liverpool. Capacity for 9,000 ton vessels, and it takes seven hours to pass through the whole distance and locks. The latter vary from 600 ft. × 80 ft. to 150 ft. × 30 ft., and sills 16–28 ft. deep below normal water-level of canal, the gates being moved by hydraulic machinery. The works include 160 acres of docks, with warehouses, machinery, and 95 miles of railway sidings, 6 high-level bridges, 7 swing-bridges, and the Barton swing aqueduct, 234 ft. long, for the Bridgewater Canal over the Irwell (to replace Brindley's fixed aqueduct), which latter canal had to be bought. 52,000,000 cubic yards of excavation and removal. Plant cost 980,000*l.*, and comprised engines, locomotives, steam pumps, cranes, piling machines, horses, wagons, temporary railway, etc. Principal engineer, Sir E. Leader Williams, assisted by W. Henry Hunter and others. Contractors, T. A. Walker (who died on November 25, 1889, during the progress of the work), and his executors, T. J. Reeves, L. P. Nott, and C. H. Walker, who continued. For full particulars see *History of the Manchester Ship Canal*, 2 vols., published by Sherratt & Hughes, 34 Cross Street, Manchester. Price 25*s.* Details of cost below are based on the total length of 36 miles:—

	Total.	Per Mile.
Purchase of Bridgewater Canal	1,783,000*l.*	111,438*l.*
Land and compensation	1,167,000*l.*	72,937*l.*
Constructing the canal and docks	9,000,000*l.*	562,500*l.*
Interest on capital during construction	1,050,000*l.*	65,625*l.*
Law charges, Parliamentary expenses, etc.	500,000*l.*	31,250*l.*
Whole cost	13,500,000*l.*	843,750*l.*

Average annual maintenance per mile of canal	2,000*l.*
Do. do. per acre of docks	400*l.*

Panama Canal (1904–15).—From Colon, on the Atlantic, to Panama on the Pacific. A concession was granted in 1876 to a French syndicate, which made surveys for two years and reported to an international congress at Paris in May, 1879. The Panama Canal Company was then floated, with Ferdinand de Lesseps as president, and preparatory work undertaken in 1881, the first excavation being made in January, 1882. The French scheme, however, was finally abandoned in 1904 owing to fever and bad administration, after the failure of both the first and a second company, and after only 12 miles had been cut out of the 54 originally proposed, and 50,000,000*l.* spent. On May 4, 1904, the United States Government bought the effects of the French company in Panama for 8,000,000*l.*, and started the American project as now completed. A strip of territory extending five miles on each side of the route of the canal was also purchased from Colombia for 2,000,000*l.* Colonel (now General) George W. Goethals, U.S.A. Engineers, was chairman of the Canal Commission which worked out the type and salient features.

Total length along axis, 50½ miles, but only 41½ miles within the coastlines. Rise of tide at Limon Bay in the Atlantic varies from 7 to 19 in., and from 8 to 21 ft. at Panama. The opening channel at sea-level, from Limon Bay to Gatun, is 7 miles long by 500 ft. wide and 41 ft. deep. At Gatun are three twin locks to raise vessels to the summit canal level, 85 ft. above sea, also an earthen dam, 8,000 ft. long, 1,500 to 2,000 ft. thick at the base, 100 ft. wide at top, and 115 ft. high, damming the Chagres River and forming the artificial Gatun Lake, 164 square miles area, with surface 85 ft. above sea-level, through which ships pass in a channel 500 to 1,000 ft. wide and 45 ft. deep. After 23¼ miles of Gatun Lake the Gaillard Cut (formerly Culebra Cut) extends for 8 miles and 280 ft. maximum depth, with a channel 300 ft. wide and 45 ft. deep. Then a single twin lock, with 30 ft. drop, at Pedro Miguel to the small Miraflores Lake, where a channel, 1½ miles long by 500 ft. wide and 45 ft. deep, leads to Miraflores itself. Here two twin locks lower vessels, 31 ft. each lock, to the Pacific sea-level, and a channel 8 miles long, likewise 500 ft. wide and 45 ft. deep, conducts them to deep water in Panama Bay. In addition there are nearly 3 miles in locks and alongside approach walls. About 26 miles are artificial canal work, out of the total distance of 50½ miles.

Width of channel varies from 300 to 1,000 ft. at bottom, and depth 40 to 45 ft. The six pairs of locks are 1,000 ft. long × 110 ft. wide, with intermediate gates to divide them into two sections of 600 ft. and 400 ft., and 6 pairs of lock gates with steel frames and plates. There are 46 pairs of lock gates altogether, 46 to 82 ft. high, and the largest weighs 730 tons. Least depth of water over sills of locks when lake is at normal level is 41 ft.

The total excavation for the whole canal amounted to 220,000,000 cubic yards (130,000,000 in the dry, and 90,000,000 by dredges), of which about 112,000,000 yards was in the Culebra Cut, the most extensive excavation ever made. Concrete in the locks came to 4,500,000 cubic yards. Maximum number of employees at one time was 50,000 (6,000 Americans, 5,000 Europeans, and 39,000 negroes).

In addition to General Goethals, other engineers were Messrs. S. B. Williamson, chief of the Pacific Division, Gaillard, Sibert, Hodges, Goldwork, Schildhauer, Cornish, Zinn, Nichols, Alfred Noble, and others.

The canal was opened for traffic on August 15, 1914, the steamer passage being 10 hours each way. Ships are towed by electric cars or 'mules' running on rails alongside the waterway. Several landslides subsequently occurred necessitating temporary suspension of traffic till well into 1915.

Total cost was approximately as follows, the cost per mile being based on the total length of 50½ miles:—

	Total.	Per Mile.
Spent by the original French Canal Co. up to 1904 before abandonment	50,000,000*l.*	990,100*l.*
Purchase money paid to the French Canal Company	8,000,000*l.*	158,416*l.*
Sum paid to the Republic of Colombia or Panama for concession	2,000,000*l.*	39,604*l.*
Constructional cost of American scheme, including terminal facilities	65,000,000*l.*	1,287,130*l.*
Whole cost	125,000,000*l.*	2,475,250*l.*

Saulte Ste. Marie Canal (opened 1895).—In Canada, connecting Lakes Superior and Huron, Known as the 'Soo,' and passes 20,000 vessels a year round the Saulte Ste. Marie Falls. Length, 1½ miles. Width at bottom 142 ft., and depth 20 ft. It has the longest lock in the world, with gates operated by electric power. Total cost, 560,000*l.*, or 509,090*l.* per mile.

Suez Canal (1859–69).—Between Port Said on the Mediterranean and Suez on the Red Sea. M. Ferdinand de Lesseps, engineer and promoter. Total length all but 100 miles, including 60 miles through the shallow lakes of Menzaleh, Ballah, Timsah, and the Bitter Lakes, with and without dredging, and the rest actual canal formed by cutting. Sandy soil and a little rock. Sixty dredging machines were employed, and about 100,000,000 cubic yards of material excavated and dredged. Over 25,000 labourers were employed during the earlier period. Canal was originally 72 ft. wide at bottom, 196 to 328 ft. at water-level, and 16 ft. average depth (now increased to 147 ft., 420 ft., and 39 ft., respectively). No locks, as the canal is level throughout. Rise of tide is only about 1 ft. in the Mediterranean, and 6 ft. in the Red Sea. A slight current of 3 ft. per second keeps the canal clear. Passage takes 16 hours.

An auxiliary freshwater canal was constructed at the same time from the Nile, near Cairo, to Lake Timsah, and thence nearly parallel to the main canal as far as Suez, to supply fresh water and to convey provisions and materials, and afterwards to irrigate. It was 26 ft. wide at bottom, 56 ft. at surface, and 6½ ft. deep.

At Port Said the harbour encloses 450 acres, with an eastern breakwater 6,233 ft. long and a western breakwater 9,800 ft., composed of random concrete blocks weighing 20 tons. At Suez the outlet of the canal is protected on the south-west by a mole 2,900 ft. long, and on the north-west by a sold earthwork embankment.

Costs per mile are based on the total length of 100 miles.

	Total.	Per Mile.
Cost of promotion and preliminaries	5,300,000*l.*	53,000*l.*
Constructional works only	10,700,000*l.*	107,000*l.*
Enlargement, widening, and deepening since 1869.	4,000,000*l.*	40,000*l.*
Whole cost	20,000,000*l.*	200,000*l.*
Less indemnity granted in 1864 for loss of forced labour, about	4,000,000*l.*	40,000*l.*
Net cost	16,000,000*l.*	160,000*l.*

Welland Canal (opened 1833).—Constructed to avoid the break in communication between Lakes Erie and Ontario, Canada, caused by the falls in the Niagara River, and runs parallel to the latter on the west. Length, 26 miles. Twenty-seven locks, with total lift of 330 ft. Enlarged in 1867 to accommodate vessels of 400 tons. Again enlarged, 1874–87, to take vessels of 1,000 to 1,500 tons, so that the bottom width of canal would be 100 ft., and depth 14 ft. Locks increased to 270 ft. long by 45 ft. wide, and 14 ft. depth of water on the sills.

	Total.	Per Mile.
Cost of original canal opened in 1833	2,700,000*l.*	100,935*l.*
Cost of enlargement from 1874–87	2,300,000*l.*	86,019*l.*
Whole cost	5,000,000*l.*	186,954*l.*

(See p. 1578.)

Concrete.

(*London Prices, July*, 1927.)

The following prices are based on best British Portland cement at 64*s.* per ton to contractor delivered on site, including use of bags and returning empties. Clean pit sand 13*s.* per yard cube, Thames ballast 10*s.* 6*d.*, gravel 13*s.*, and 1½ in. broken stone 14*s.*, ditto. Wages, labourer, 1*s.* 4½*d.* per hour.

The rates for measured work include materials, measuring and mixing by hand, wheeling up to 20 yds., laying and ramming, and 17 per cent. establishment charges and profit. Machine-mixed concrete would be about 4*s.* to 6*s.* per cubic yard cheaper.

Plain Concrete.

		s.	*d.*
Portland cement concrete, 1 to 6, with unscreened Thames ballast in foundations, walls, and masses exceeding 12 ins. thick	per yd. cube	39	0
Ditto, 1 : 3 : 6, with 1 cement, 3 sand, and 6 clean pit gravel, ditto	,,	41	0
Ditto, 1 : 3 : 6, with 1 cement, 3 sand, and 6 local broken stone, 1½ in. gauge graded down to ¼ in., in foundations, walls, and masses	,,	45	0
Add if in foundations and walls not exceeding 12 ins. thick	,,	3	0
Add if in underpinning in short lengths up to 5 ft.	,,	7	0
Add if executed between high and low water mark, including covering with canvas to protect against tides	,,	8	0
Deduct from the foregoing 1 : 3 : 6 proportions if the proportion is 1 : 4 : 8	,,	3	0
Portland cement concrete, 1 : 3 : 6, with 1 cement, 3 sand, and 6 clean pit gravel, spade finish, spread and levelled in beds, pavings, or ground floors, 6 ins. thick	per yd. sup.	7	6
Add for floated or trowelled surface with 1 cement and 2 sand, ¾ in. thick	,,	2	2
Granitic surface layer of 1 cement to 2 granite chippings, 1 in. thick, floated and trowelled to a smooth face whilst concrete is unset	,,	4	6
Hard dry filling under concrete, of clean broken brick, hard core, mason's spalls, etc., spread and levelled 6 ins. thick	,,	2	9
Portland cement concrete, 1 : 3 : 6, with clean pit gravel, ballast, or crushed aggregate, graded ¾ in. to ¼ in. gauge, cast *in situ* complete, with exposed faces left clean and perfect, including use of casings, for kerbs and channels to footpaths, roads, pavements, etc.	per ft. cube	2	3
Ditto pre-cast solid building blocks, exceeding 4 ins. thick, and set in 1 to 3 cement mortar	,,	3	0
Ditto pre-cast hollow blocks (measured as solid), ditto, ditto	,,	2	6
Ditto pre-cast lintels, door and window heads, window sills, steps, copings, cornices, quoins, and setting and jointing in 1 to 3 cement mortar	,,	4	0

Reinforced Concrete.

Reinforcement varies from ½ to 5 per cent. sectional area of the steel compared with the sectional area of the concrete, according to position.

1 per cent. volume of steel = 132 lbs. reinforcement per yard cube of concrete.

General economy of reinforced concrete construction for large structures, and over steel-framed buildings of equal strength, is 10–20 per cent., and over brick buildings and in heavy foundations 20–30 per cent.

Reinforced concrete factories, offices, stores, warehouses, etc., cost 10*d.* to 1*s.* 2*d.* per ft. cube.

Proportionate costs vary : ⅛ concrete, ⅓ steel, ⅓ formwork, to ½, ½, ¼, respectively.

General proportions—1 : 1½ : 3 and 1 : 2 : 4. Cement should equal British Standard Specification (B.S.S. No. 12). Ferrocrete, Super-Cement, and Ciment Fondu harden much more quickly and are stronger, but more expensive.

Sand graded $\frac{3}{16}$ in. to $\frac{1}{16}$ in. (75 per cent. to pass ¼ in.), and aggregate ¾ in. to $\frac{3}{16}$ in. Concrete to be quickly deposited in layers not exceeding 6 ins. thick and 3 ins. next reinforcing bars, and in quantities not more than 2 ft. cube, closely punned round the steel.

Each class of work and story to be given separately, and heights stated. The space occupied by the steel is not to be deducted. Prices for mass concrete include forming chamfers, splays, rounded angles, etc., but the use of moulds for these should be taken under formwork.

The concrete, the steel, and the formwork are first priced separately, then combined into a condensed table of complete work.

Concrete Piles—

		s.	d.
Pre-cast reinforced Portland cement concrete, 1 : 1½ : 3, with 1 cement, 1½ washed sand, and 3 local broken stone, ¾ in. or ⅝ in. gauge graded down to $\frac{3}{16}$ in., in bearing or sheet piles, including all moulds, and planted in position ready for driving (exclusive of steel reinforcement and pile shoes)	per ft. cube	6	0
Steel reinforcement and shoes for ditto, and fixing	,,	4	0
Placing and driving ditto not less than 144 sq. ins. section, including all working apparatus, such as pile engine, etc., in ordinary ground (portion in soil only to be measured)	,,	4	0
Ditto ditto ditto in tide work	,,	6	0
Ditto ditto if driven from barges or floating stages, including use of same	,,	3	0
Simplex reinforced concrete piles, 16 ins. diameter, cast in place and driven complete (8 or 10 piles, of 25 ft. average length and reinforcement provided, can be driven per 8-hr. day)	per ft. run	12	0
Allowance for bringing, erecting, and removing pile engine and tackle for driving, etc.	per job	10*l.* to 20*l.*	

Concrete Foundations, Walls, etc.—

		s.	d.
Reinforced Portland cement concrete (only), 1 : 2 : 4, with 1 cement, 2 washed sand, and 4 local broken stone, ¾ in. gauge graded down to $\frac{3}{16}$ in., in foundations and masses	per yd. cube	52	0
Ditto in walls exceeding 12 ins. total thickness	,,	56	0
Ditto beams, not exceeding 72 ins. sectional area, to floors or roofs	per ft. cube	2	3
Ditto large beams, exceeding 72 ins. but not exceeding 144 ins., ditto	,,	2	1
Ditto independent piers, columns, struts, or pilasters	,,	2	6
Ditto steps, stairs, winders, strings, carriages, etc., any section	,,	2	9
Ditto floor slabs or flat roofs, 4 ins. thick, and hoisting 30 ft.	per yd. sup.	6	9
Ditto ditto ditto 6 ins. thick, ditto	,,	10	2
Ditto walls, 6 ins. thick, measured between piers or projections	,,	1	8

Steel Reinforcement—

		s.	d.
Mild high-tension steel in accordance with B.S.S. No. 15, British Standard Specification for Structural Steel, Class A, in plain reinforcement (round, square, or flat bars), including cutting, bending, hoisting, 30 ft., assembling or putting into position, stout binding wire, and fixing complete in foundations, walls, columns, floors, etc., in			
¾ in. to 1½ in. bars	per cwt.	20	6
⅞ in. to ⅝ in. ,,	,,	21	6
¼ in. to ⅜ in. ,,	,,	23	0
Steel in proprietory systems of trussed or stirrup bars, and fixed	,,	27	0
Ditto ditto indented, twisted, or studded bars, ditto	,,	30	0
Fixing only sheet reinforcement, such as expanded metal, fabric, and mesh systems, 4–16 lbs. per yd. sup., including cutting, bending, or wiring (measured net, with no allowance for laps)	per yd. sup.	0	6

Formwork—

		s.	d.
Use and waste of 1½ in. simple flat centring, machine-planed one side, edges shot, to flat concrete floors and roofs, including about 14 ft. cube rough timber supports, ties and braces, and wedges, cleats, clamps, dog-irons, straps, etc., erection, cutting, maintenance, striking, and removal, average 12 ft. high	per square	50	0
Ditto ditto if to curved ceilings or roofs	,,	60	0

		s.	d.
Use and waste of 1 in. to 1½ in. strong shuttering to concrete walls, vertical or battering, including all supports, struts, etc., erection, cutting, maintenance, and removal (both sides measured)	per square	55	0
Ditto ditto if curved	,,	65	0
Add if boarding is machine-planed one side, thicknessed, and edges shot	,,	5	0
Limewashing internal surfaces of formwork, or treating with soft soap or mould oil, to prevent the concrete adhering	per yd. s.	0	3
Use and waste of fir in rough timber supports, shoring, etc.	per ft. cube	3	0
Use and waste of casing, planed one side and edges shot, to concrete beams, average 12 ins. × 6 ins., including sides and soffits	per ft. sup.	1	0
Ditto to concrete pillars or columns, square, including supports	,,	0	10
Ditto ditto ditto circular, ditto	,,	1	0
Use and waste of casing in narrow widths, under 12 ins., to openings in concrete walls, floors, roofs, etc	per ft. run	0	8
Extra for fillets to internal angles of casing or shuttering to form chamfers, splays, rebates, rounded angles, etc., not exceeding 9 ins. girth	,,	0	4
Labour forming small splays, grooves, rounded edges, etc., not exceeding 2 ins. girth	,,	0	2
Raking, cutting, and waste to shuttering, not exceeding 1½ ins. thick	,,	0	3

Complete Work.—The following may give a general idea of the whole cost, including concrete, steel reinforcement, and formwork, but there are so many systems that it is impossible to be more definite, and the range of values must be great :—

			s.	d.
Reinforced concrete	12 ins. × 12 ins. piles, including driving, etc., complete	per ft. run	12 to	18
,, ,,	12 ins. pillars or columns, square or circular	,,	6 ,,	12
,, ,,	steps, stairs, and sills, average 12 ins. × 6 ins.	,,	4 ,,	8
,, ,,	floors, 4 ins. to 6 ins. thick, including beams	per yd. sup.	15 ,,	30
,, ,,	flat roofs, 4 ins. to 6 ins. thick, including beams	,,	15 ,,	30
,, ,,	walls, 4 ins. to 6 ins. thick, vertical or battering	,,	12 ,,	24
,, ,,	partitions, 2 ins. to 4 ins. thick, smooth on both sides	,,	10 ,,	16
,, ,,	foundations, thick walls, and masses	per yd. cube	80 ,,	120

Reinforced Granite Concrete Tubes.

Manufactured by John Ellis & Sons, Ltd., 16 Pocklington's Walk, Leicester, of best Portland cement and Mountsorrel granite, 1 to 3, crushed, washed, and passed through ¼-in. mesh, and with sufficient sand to fill up all interstices. The tubes are made both with and without steel ribs, the latter being ¼ in. welded steel rings placed in the centre of the material, 12 ins. apart. The concrete is cast in vertical steel moulds, filled in thin layers, and rammed with a heavy machine-driven hammer. The pipes are left in the moulds for three days, after which they are put in the open air to mature for six months.

Prices of reinforced circular sewer tubes free on rail at works, Barrow-on-Soar, L.M.S. Railway (July, 1927) :—

Internal Diameter.	Thickness in inches.	Stock Lengths.	Weight per ft. run.	Feet per ton.	Price of Tube per ft. run.
ins.	ins.	ft.	lbs.	ft.	s. d.
12	1¼	3	56	40	2 6
15	1½	2 and 3	86	26	3 0
18	1½	2 ,, 3	97	23	3 6
21	1¾	2½ ,, 3	132	17	4 6
24	2	2 ,, 3	176	12⅝	6 0
27	2	2 ,, 3	199	11¼	7 0
27	2¼	2 ,, 3	219	10¼	8 0
30	2¼	2 ,, 3	276	8⅛	9 3
33	2½	3	289	7¾	10 0
36	2½	3	326	6¾	11 0
36	2¾	2 and 3	345	6½	12 0
39	3	3	415	5⅔	14 0
42	3	2 and 3	472	4⅝	16 0
45	3¼	3	541	4⅛	18 0
48	3½	2 and 3	640	3½	20 0
57	4½	3	943	2⅜	31 6
60	5	3	1120	2	37 6

Laying.—Cost of laying and jointing in addition. The tubes are usually laid on a square concrete bed raised half-way up the outside, and 6 ins. thick. The ogee joints are sealed with cement mortar, 1 to 1.

Connections.—Bends, junctions, circular manholes, well tubes, etc., are also supplied of granite concrete.

Other Tubes.—Socket and spigot sewer tubes, 15 ins. to 24 ins. diameter, and egg-shaped tubes, with internal measurements 18 ins. × 12 ins. to 60 ins. × 40 ins., are similarly made.

Stanton-Hume Reinforced Concrete Pipes.

The Stanton-Hume Reinforced Concrete Pipe is manufactured by the Stanton Ironworks Co., Ltd., near Nottingham, under sole licence from the Hume Pipe and Concrete Construction Co., Ltd., London. A hard, dense pipe is produced, owing to the centrifugal action of the moulding machinery, and the concrete mixture spreads itself evenly over the inner surface, while the circular motion expels excess air and water, so that there are no voids. All materials are mechanically tested in laboratories, then carefully graded and mixed by special apparatus, and the sand automatically washed. The pipe is particularly suitable for drainage and sewage work, as it is very strong, the internal surface is abnormally smooth, owing to the longer lengths fewer joints are required, and cost is low. The reinforcement is a spirally wound steel wire cage of great tensile strength, kept in a central position by centrifugal tendency.

The pipes are made 4 ins. to 60 ins. diameter, and in classes A, B, C, D, E, for working pressures of 10, 25, 50, 75, 100 lbs. per sq. in. respectively. Proportions, 1 : 2 and 1 : 3 graded granite, finely crushed.

Prices delivered 50 miles from Stanton Gate at Ilkeston, near Nottingham (July, 1927) :—

Internal Diameter.	Thickness in inches.	External Diameter.	Stock Lengths.	Weight of Pipe for Class A.	Weight of Collar A.	Price of Pipe per ft. run.
ins.	ins.	ins.	ft.	lbs.	lbs.	*s.* *d.*
4	1	6	6	104	13½	0 9
6	1	8	6	146	17	1 1
9	1⅛	11¼	6	237	26	1 9
12	1⅜	14⅝	6	380	40	2 9
15	1½	18	6	513	56	3 8
18	1⅝	21⅛	8	887	75	4 8
21	1¾	24½	8	1,111	92	5 9
24	1⅞	27¾	8	1,350	118	7 6
27	2	31	8	1,612	132	8 9
30	2⅛	34¼	8	1,906	175	10 6
33	2¼	37½	8	2,220	202	12 3
36	2⅜	40¾	8	2,540	240	15 0
42	2½	47	8	3,110	302	20 0
48	2¾	53½	8	3,900	415	25 0
54	3	60	8	4,790	560	32 6
60	3	66	8	5,310	620	38 6

Joints.—The above prices include one collar for each length of pipe. Pipes with ogee joints 5 per cent. less. Jointing requires skilled labour, but experienced men can be sent ; 1 cement to 2 sand.

Laying.—Cost of laying and jointing extra to rates in table. Reinforced bends, tees, angle branches, etc., are also made.

Deep-water Quays.

The structural conditions of deep-water quays are so variable that the assumption of a unit of cost is misleading. For ocean-going shipping in the Thames, however, the rates between 1919–22 (post-war) varied from 50*l.* to 200*l.* per ft. run.

Deep-water Quay, Greenhithe (1919–21).—On the south bank of the river Thames, and was an extension of the existing wharves of the Empire Paper Mills. Tidal range over 18 ft., with 17 ft. depth at low-water ordinary spring tides. Length of new section of the approach 455 ft.,

with minimum width of 8 ft., and new deep-water berthage at end 303 ft. by 52 ft. width throughout, and three splays at corners. Total deck area of new works approximately 24,600 sq. ft. Quay carried out in creosoted Oregon and pitch pine, with steel superstructure. Engineers, Messrs. Carey and Latham.

Total cost, 70,783*l.*, or 2*l.* 17*s.* 7*d.* per ft. sup. of new wharf accommodation obtained. About 93*l.* per ft. run, including approaches.

Deep-water Quay, Shellhaven (1920–21).—On the Essex side of the river Thames, and consisted of the extension of a deep-water berthage for an oil storage depot. Tidal range 18 ft., with 29 ft. depth at low-water ordinary spring tides. Length of new quay approach 560 ft. by 18 ft. wide, and new deep-water berthage at end 420 ft. long by 40 ft. deck width, the two forming a T shape. Total deck area approximately 31,000 sq. ft. All of reinforced concrete on the Coignet system. Engineers, Messrs. Carey and Latham, and contractors Messrs. Mowlem & Co.

Total cost 80,000*l.*, or 2*l.* 11*s.* 7*d.* per ft. sup. of new wharf accommodation obtained. About 82*l.* per ft. run, including approaches.

Docks.

Cardiff, Liverpool, and London wet docks, including wharves, gates, locks, machinery, etc.: 20,000*l.* to 35,000*l.* per acre of water area.

Aberdeen, Glasgow, and Portsmouth, dry or graving docks for repairs, including equipment: 2*l.* to 4*l.* per yard cube of internal capacity.

Steel floating docks for repairs, in terms of lifting power	10*l.* to 15*l.* per ton.
Dock gates of greenheart, 70 to 90 ft. wide and 40 to 50 ft. high, including hydraulic machinery	40*s.* to 50*s.* per ft. sup.
Ditto of steel, ditto, ditto	30*s.* to 40*s.* ,,
Caissons, traversing or floating, 60 to 90 ft. wide, and 30 to 40 ft. high, including hydraulic machinery	50*s.* to 100*s.* per ft. sup. of waterway.
Dock walls, of concrete, stone or granite, with concrete backing, including digging	25*s.* to 45*s.* per yd. cube.

Actual Costs of wet docks, including dock walls, gates, locks, machinery, etc.:—

	Per acre of Water Area. £
Avonmouth Docks, near Bristol (1868–77)	22,600
Barry Docks, near Cardiff (1889). Water area, 114 acres. Total cost, 3,072,000*l.*	26,947
Cardiff. Water area, 50 acres. Total cost, 1,500,000*l.*	30,000
,, Bute Dock Extension. Water area, 35 acres	22,000
,, West Bute Dock (1839). Water area, 22 acres. Total cost, 400,000*l.*	18,180
,, Roath Dock (1887). Water area, 33 acres. Total cost, 500,000*l.*	15,150
Glasgow, Queen's Dock	24,500
Hull, Alexandra Dock	28,900
Immingham, near Grimsby (1912). Water area, 56 acres. Total cost, including land, railway sidings, dock sheds, coal hoists, etc., 2,600,000*l.*	46,430
Liverpool, Alexandra Dock	23,300
,, North Extension. Water area, 83 acres. Total cost, 2,640,000*l.*	31,810
London, King George V Dock (opened 1921). Concrete walls 7 reinforced concrete jetties, entrance lock, &c. Water area, 64 acres. Total cost, with equipment, £4,130,000	64,531
London, St. Katherine's Docks	36,000
Newport, S. Alexandra Docks (1893). Water area, 20 acres. Total cost, 500,000*l.*	25,000
Swansea, Prince of Wales' Docks (1879). Water area, 28 acres	18,600

Actual Costs of dry or graving docks for repairs, including equipment :—

	Per yard cube of internal capacity. £ s. d
Aberdeen. Internal size, 524 ft. × 73 ft. at surface level. Total 46,000*l.*	1 15 0
Belfast (1905–12). Length over all, 901 ft. Total cost, 350,000*l.*	2 1 0
Glasgow. Internal capacity, 81,555 yds. cube. Stone and concrete	2 9 0
Hartlepool. Brick and concrete, 570 ft. × 75 ft. × 17 ft. deep	1 8 0
Liverpool. Gladstone Dock (1910–13). Total cost, 500,000*l.*	1 13 0
Otago, New Zealand. Internal capacity, 37,000 yds. cube. Total 75,000*l.*	2 0 0
Portsmouth. Granite with brick and concrete backing ; 42 ft. deep	2 0 0

See pp. 1523, 1528, 1537.)

DRAINAGE.

4-in. and 6-in. stoneware drains, jointed in cement, including trenches 3 ft. deep and concrete bed, 6 ins. thick	2*s.* to 3*s.* per ft. run.
Ditto ditto with manholes, ventilating pipes, etc.	5*s.* to 6*s.* per ft. run.
Manholes and inspection chambers, 3 ft. × 2 ft. 6 ins. × 3 ft. 6 ins. deep, complete, including digging, concrete, brick sides, iron cover, etc.	8*l.* to 10*l.* each.
Add extra for every additional foot in depth	16*s.* to 18*s.* per ft. deep.
Drains and sewers for estate development and town planning schemes	200*l.* to 400*l.* per acre.
Drainage and sewage disposal works for cities and towns	3*l.* to 6*l.* per inhabitant, 20*l.* to 30*l.* per house.

Reconstruction of Drainage, Stanhope Lines, Aldershot (1893).—Combined water carriage system with 4 in., 6 in., 9 in., and 12 in. glazed stoneware pipes (total, 54,670 yds. run), 2 to 6 ft. deep, 500 Jennings' latrines, 500 urinal stalls, 80 w.c.'s, with 3 gal. flushing cisterns, 200 gal. galvanised iron automatic cisterns, and 16 100-gal. brick automatic flushing tanks, with disposal of sewage by irrigation on War Department land. Occupation of barracks, 8,000 adults, 200 children, and 200 horses. Total cost, exclusive of sewage disposal works, 20,500*l.*, or 2*l.* 10*s.* per head of occupation exclusive of horses; 7*s.* 6*d.* per yd. run of excavation.

DRAINAGE OF LAND.

Agricultural, or subsoil, unglazed earthenware drain pipes laid dry in 12 in. or 15 in. lengths, without jointing material and ends simply abutting. Depths and distances apart vary according to nature of soil. Cost includes digging, filling, pipes, and laying.

	Cost per acre.
In compact or heavy soils, drains 5 to 8 yds. apart, and 2 ft. 6 ins. to 3 ft. deep	6*l.* to 10*l.*
In medium soils, drains 9 to 10 yds. apart, and 3 ft. to 3 ft. 6 ins. deep	5*l.* to 6*l.*
In porous or light soils, drains 11 to 22 yds. apart, and 3 ft. 6 ins. to 4 ft. 6 ins. deep	4*l.* to 5*l.*

DREDGING.

Dredging Plant.—Modern dredging appliances are of two main classes, with subdivisions and pre-war costs as follows :—

Class I.—Digging dredgers, comprising :

(*a*) Bucket dredger, or ladder (single or double), or elevator dredger, with a continuous band of buckets.

	£
With 5 ft. cube bucket, single ladder, raising 40 ft.	7,000
,, 15 ,, ,, ,, ,, 45 ,,	27,000
,, 27 ,, ,, ,, ,, 55 ,,	43,000

(*b*) Dipper dredger, with a single bucket at the extremity of a long arm or lever. Almost purely an American type.

With 1 to 2 yds. cube dipper, hull of timber, 1,600*l.* to 2,400*l.*
With 3½ to 4 yds. cube dipper, dredging to depth of 35 ft., 16,000*l.* to 18,000*l.*
With 10 yds. cube dipper, dredging to depth of 35 ft., 26,000*l.* to 28,000*l.*

(*c*) Grab or grapple dredger, with a drop bucket suspended at the end of a chain.
A twin-screw hopper dredger, with hopper capacity of 12,000 tons, fitted with five hydraulic grab cranes each of 5 tons bucket capacity, working to a depth of 47 ft., has cost 35,000*l.*

(*d*) Hand or bag and spoon dredger, which consists of a bag attached to a steel rim at the end of a long pole, and is suitable only for mud in ponds and canals.

Class II.—Suction or hydraulic dredgers, comprising:

(*a*) Sand pump dredger, with centrifugal pump.
A 2,000-ton suction hopper dredger would cost 50,000*l.*

(*b*) Suction cutter dredger, with water jets and rotary cutters.
A suction hopper dredger with hopper capacity of 70,000 cub. ft., capable of raising 4,000 tons of sand per hour from a depth of 70 ft., has cost 75,000*l.*

(*c*) Compound dredger, fitted with both the suction or suction cutter and a bucket ladder.
A sea-going hopper dredger, fitted with both ladder buckets (18 cub. ft.) and suction pumps, capable of dredging 400 to 650 yds. cube per hour from a depth of 50 ft., has cost 53,000*l.*
Rock cutters are not dredgers, but an auxiliary class.

Cost of Work.—Costs include use of plant, dredging, and removing and depositing excavated material at sea. Steam dredgers cost 10,000*l.* to 70,000*l.* each; steam hopper barges in attendance, of 800 tons or 800 yds. cube capacity, with a speed of 11 knots per hour, cost 18,000*l.* to 20,000*l.*; ordinary hopper and dredger barges, 300*l.* to 1,000*l.* Pre-war.

Description.	Material.	Per yd. cube.	Per ton.
Bucket dredging, or ladder dredging	Mud, sand, or soft clay Gravel or stiff clay	1*s.* to 2*s.* 2*s.* ,, 4*s.*	9*d.* to 1*s.* 1*s.* ,, 2*s.*
Grab dredging, or grapple dredging	Mud, sand, or soft clay Gravel or stiff clay	2*s.* ,, 4*s.* 3*s.* ,, 5*s.*	1*s.* ,, 2*s.* 2*s.* ,, 3*s.*
Hand dredging, or 'bag and spoon dredging'	Mud, sand, or soft clay Gravel or stiff clay	3*s.* ,, 4*s.* 4*s.* ,, 6*s.*	2*s.* ,, 3*s.* 3*s.* ,, 4*s.*
Pump dredging, 'suction or hydraulic dredging'	Mud, sand, or peat	6*d.* ,, 1*s.*	4*d.* ,, 9*d.*

Grab dredging can be done for as little as 2*d.* to 6*d.* per yd. cube, and sand pump dredging for 1*d.* ditto, but a great deal depends on the kind of spoil and distance to be carried.

Alluvial Mining.—Dredging for alluvial mining costs anything from 1*d.* to 1*s.* per yd. cube (pre-war), depending upon character of ground, depth, quantity treated, climate, transport, power, labour, management, types of dredges capacity of buckets, operating time, etc.

Mersey.—At the bar and in the entrance channels of the Mersey nearly fifteen million cubic yards of sand were removed annually at a pre-war cost of 6*d.* per yd. cube, exclusive of interest and depreciation on the plant.

Mississippi River (1907).—Three pipe-line suction-cutter dredges got up 1,279,000 cu. yds. including cost of idle time, for 4¼*d.* per yd. cube. In 1908 the same dredges lifted 989,000 cu. yds., ditto, for 5¼*d.* per yd. cube.

Newry.—After blasting the bottom in a depth of 6 to 8 ft. at low water, the material was removed by dredging at 4*s.* to 5*s.* per yd. cube.

New York Harbour (1909).—Four sea-going suction dredgers removed 10,786,638 cu. yds., including dredging, surveys, contingencies, and supervision, for 2*d.* per yd. cube. Another dredger disposed of 1,675,562 cu. yds. at 2½*d.* per yd. cube.

Panama Canal (1910).—Costs of removal of various quantities by different kinds of dredgers worked out at:

Removal of	6,083,902 cu. yds.	by	two sea-going suction dredgers	3¾*d.* per yd. cube
,,	1,372,665 ,,	,,	one ladder dredger	8*d.* ,,
,,	560,622 ,,	,,	,, ,,	1*s.* 1¾*d.* ,,
,,	1,013,485 ,,	,,	two small dipper dredgers	2*s.* 4*d.* ,,
,,	2,472,822 ,,	,,	two 20-in. pipe-line suction dredgers	1*s.* 2*d.* ,,
,,	5,800,000 ,,	,,	two dipper dredgers	2¼*d.* to 5¼*d.* ,,

Port Natal, Durban (1903–14).—Cost of pump dredging in sea, including all charges for working, maintenance, insurance, depreciation, and interest on capital, with coal at only 8*s.* per ton, 2¼*d.* to 7*d.* per ton of material handled.

Severn.—Blasting and dredging the marl beds, 4*s.* per yd. cube.

Siam (1920).—Dredging heavy clay from irrigation canal in Siam, 85 ft. wide by 8 ft. deep, by a Lobnitz dipper dredge with buckets of 2½ yds. cube capacity, working at a speed of 30 to 40 seconds per dip. Total quantity raised was 312,130 cu. yds. in one place, running 9 hours per day, or an average of 26,010 cu. yds. per month. Average cost for year was 3*d.* per yd. cube, including labour, oil fuel, supplies, repairs, and every expense except interest and depreciation. Repairs, 4·3 per cent. of total cost.

Tees.—Blasting and dredging. In 1875 holes were drilled in the bed of the river Tees 7 to 9 ft. deep and 10 ft. apart, from a dredger; then dynamite blasting in 2 lb. charges. Average depth of rock blasted 4 ft. 6 in., oolite shale. 110,000 yds. cube were blasted at 3*s.* 1*d.* per yd. cube, so as to be lifted by the dredger.

Ladder dredging in the Tees, mostly in hard boulder clay, and lifting stones and tree trunks, cost 1*s.* 6¾*d.* per yd. cube.

Thames.—Contract cost of lifting ballast and clay, by ladder or bucket dredgers from the Thames below London Bridge has varied from 1*s.* 4*d.* to 2*s.* 6*d.* per yd. cube, depending on distance material had to be conveyed.

(See also p. 1546.)

Rock-cutting and Dredging.

Rock-cutting Plant.—The sub-aqueous Lobnitz Patent Rock-breaker or Rock-cutter, made by Lobnitz & Co., Ltd., shipbuilders and engineers, Renfrew, Scotland, is usually employed. The rock-breaker chisel, or rock-cutter itself, consists of a compressed steel cone-shaped point fitted to a solid steel shaft, 15 to 18 in. diameter and 40 to 50 ft. long, depending on depth of water, and weighing from 6 to 25 tons. This drops 6 to 10 ft. on the same place, from a frame mounted on a barge fitted with steam winch, hoisting gear, steel wire ropes, mooring chains, etc. No explosives are used. The striking points are marked on a chart, and the holes are spaced about a yard apart. After a penetration of 3 ft. on one spot the rock is cut, and then dredged away in horizontal layers. The general result is 2 cu. ft. of rock broken per blow, suitable for bucket dredging afterwards to remove the pulverised stone. And 2 cu. ft. × 150 blows per hour on an average = 300 cu. ft. ÷ 27 = 11 yds. cube per hour for a single-cutter machine, or say 100 yds. cube per working day of 9 hours. Output of a double-cutter machine is about one-half more. A crew of four men is required on a barge with one cutter, and six men with two cutters, the barge being shifted after a hole has been made to the next position. Skilled labour is unnecessary. 1 ton of coal is consumed per working day by a single 10-ton cutter, and ½ tons by a double 10-ton cutter. The cost of oil, stores, and repairs does not exceed the outlay for coal and wages.

Blyth Harbour, Northumberland (1906).—Rock-cutting in friable to very hard sandstone by the Lobnitz Rock-breaker steel ram weighing 15 tons, falling 8 ft. to a depth of 3 ft. in the rock in 8 or 9 blows, to allow of being dredged to a depth of 2 ft. 6 ins. Average quantity was 908 cu. yds. of rock broken by one machine per week, night and day, allowing for all stoppages, and based on six months' working. Details per week for 908 cu. yds. was:

	£	*s.*	*d.*
Wages for men on dredger	16	1	6
Coal, stores, and water	6	10	7
Estimated cost of repairs, renewals of rams, ropes, etc.	22	0	0
Insurance at 30*s.* per cent. = 120*l.* per annum	1	19	2
908)	46	11	3
Rate per yard cube	0	1	0¼
Add 4 per cent. interest on cost of one Rock-breaker at 6,800*l.*, and 2½ per cent. for depreciation, making a further	0	0	2¼
Total cost per yard cube	0	1	2¼

As compared with blasting, the rock-cutting disintegrates and breaks the rock into smalle pieces, so that the quantity lifted by the dredgers in a given time is about 15 per cent. more tha that of blasted rock. The comparative cost of removal under the two systems of blasting an rock-cutting is as follows:—

	s.	*d.*
Blasting:—		
Drilling and blasting rock in position	3	0
Dredging and removing débris, 2*s.* 6*d.*+ 8*d.* for interest and depreciation on the dredger	3	2
Cost per yard cube	6	2
Rock-cutting:—		
Cutting rock by rock-breaker as already detailed	1	2½
Dredging and removing débris, 2*s.* 2*d.*+ 7*d.* for interest and depreciation on the dredger	2	9
Cost per yard cube	3	11½

Difference in cost per yard cube in favour of the removal of rock by means of the rock-breake was thus 6*s.* 2*d.* *less* 3*s.* 11½*d.*= 2*s.* 2½*d.* Saving on 500,000 cu. yds. executed was accordingl 55,200*l.*, after the drilling and blasting had been tried and abandoned.

Manchester (1905–6).—Deepening a length of 14 miles of the Manchester Ship Canal fro 26 ft. to 28 ft. by a Lobnitz Rock-cutter No. 1, designed to work in sandstone of varying degre of hardness, the average quantity broken per month (over a period of 10 months) being 6,4 cu. yds. at an average cost of 9*d.* per yd. cube.

The cost of rock-breaking and dredging on the same canal in April 1907, by the Lobnitz dredg was as below. The price of one Rock-cutter was 6,800*l.*, and if 4 per cent. is allowed for interes and 2½ per cent. for depreciation, the additional cost per yard cube is 2¼d., as added. 17,0 cu. yds. were broken, the rock being sandstone of different hardness, with some stiff marl.

	s.	*d.*
Breaking, excluding cost of plant, but including maintenance and repairs	0	5½
Dredging the broken rock	0	5½
Barging and tipping	0	6¾
Towage	0	2½
	1	8¼
Add interest and depreciation on cost of plant	0	2¼
Total cost per yard cube	1	10½

Suez Canal.—Deepened in 1884 by a Lobnitz dredger, with cutting rams of 3½ tons, ro removed in layers 20 in. thick, and the breaking up cost was 7*s.* 3½*d.* per yd. cube.

The canal was further deepened to 31 ft. in 1897 by a Lobnitz Rock-cutter with cutting ra of 13 tons, the average thickness of rock shattered was 31 in., and the average cost, includi repairs and depreciation, was 1*s.* 4*d.* per yd. cube. Cost of raising the rock by dredgers a carrying it away in addition.

ELECTRIC POWER STATIONS.

Town.	Total Cost.	Cost of Land and Buildings.	Kilowatts Housed.	Cost of Buildings per Kilowatt.	Total Cost per Kilowa
	£	£	No.	£	£
Brighton	717,738	149,431	5,400	28	133
Bristol	671,616	53,550	9,050	6	74
Chichester	20,000	{ 600 not land }	200	3	100
Glasgow	1,368,134	211,172	10,993	19	124
Hackney	280,982	42,394	3,372	13	83
Metropolitan	1,802,383	435,777	18,500	24	97
Newcastle	1,192,442	169,675	20,000	8	55
Tonbridge	22,420	7,228	120	6	187
Tunbridge Wells	81,134	13,207	1,170	11	69

	£	£	
Electric light installations for cities and towns, with buildings, plant, and mains complete	80 to 130		per kilowatt.
	3 ,, 5		per c.p. lamp.
Steam plant power stations		24	per kilowatt.
Oil plant power stations	23 ,, 25		,,
Capital cost of generating stations		20	,,
Power and electric stations generally, brick, exclusive of plant and machinery. 10*l.* to 25*l.* per kilowatt			6*d.* to 8*d.* per f.c.
Aldershot electric lighting station (1902). Brick walls and slated roof			6½*d.* ,,
Curragh electric light generating station (1913–14). For three 100-h.p. Diesel oil engines, 66 kilowatts per engine, with a 750 ampere hour battery and accessory machinery. Contains a basement for engine beds, silencer chamber, and oil-fuel store, and above, on ground level, an engine-room, battery-room, store-room, two offices, and lavatory. Brick walls in cement mortar, 1 to 3, concrete foundations, engine beds and floors, steel sashes, steel roof, boarded and covered with asbestos slates. 99,700 feet cube. Building only, exclusive of plant and machinery. Total, 2,080*l.*			5*d.* ,,
Building, including plant and machinery. Total, 7,456*l.*			1*s.* 6*d.* ,,
Cost of foregoing per kilowatt housed, 10*l.* to 38*l.*			
Extension to Curragh electric light station (1920–21). For one additional 100-h.p. Diesel oil engine and plant, 66 kw., the extension of engine-room and exhaust pit being 12 ft. long, and same width and height as existing building. Construction also similar. A corrugated iron workshop, 18 ft. × 12 ft., is attached to the end of the brick extension, and included in total cost and cubing. Lump sum tender for both together. 17,600 ft. cube total. 17*l.* external services in addition. Building only, exclusive of plant and machinery. Total, 2,188*l.*			2*s.* 5¾*d.* ,,
Building, including plant and machinery. Total, 5,188*l.*			5*s.* 10¾*d.* ,,
Cost of foregoing per kilowatt housed, 33*l.* to 79*l.*			
East Ham electric power station, including tramway sheds and offices. Built by direct labour under the borough engineer. Total, 26,020*l.*			5½*d.* ,,
Salisbury engine-room and boiler-house (1904). Brick walls and slated roof, concrete floors			6½*d.* ,,
Usual charges for current for electric lighting			2*d.* to 3*d.* per unit.
Ditto for heating and power purposes			1*d.* to 2*d.* ,,

Engineering Factories.

Engineering factories, brick, exclusive of machinery		4*d.* to 7*d.* per f.c.
Material	52	per cent.
Labour	37	,,
Power	5	,,
Other costs	6	,,
	100	,,

Esplanades.

Marine Drive, Scarborough (1905).—Road 40 ft. wide, parade 20 ft. wide, and sea-wall 20 to 40 ft. high. Of concrete, on deep filling at base of cliff. Length, 1,400 yds. Total, 102,400*l.*, or 73*l.* per yd. run.

Excavating (Mechanical).

Methods.—Mechanical excavating greatly saves in labour, time, and cost over hand digging by pick and shovel, and may be classed under ten heads:

1. Steam shovels.
2. Trench-diggers.
3. Grab buckets.
4. Chain bucket excavators.
5. Drag-line excavators.
6. Scrapers.
7. Derricks and cranes.
8. Radial loaders.
9. Paving breakers.
10. Soil Transport.

1. *Steam Shovels.*—Steam shovel or steam navvy excavating for large masses of earth or rock in canals, docks, railway cuttings, etc., including filling wagons for removal. The buckets scoop

upwards with a general capacity of 1 to 3 cubic yards. Average output and pre-war costs o a 1½ cubic yard bucket steam excavator :—

	Yds. Cube
Ordinary soft soils	60–90 per hour, at 3*d.* to 4*d.* per yd. cube
Stiff clay or gravel	40–50 „ „ 4*d.* „ 6*d.* „
Strong ground or soft rock	30–40 „ „ 7*d.* „ 9*d.* „

Manchester Ship Canal (1887–94).—Forty-two million cubic yards of excavating in sand clay, gravel, etc., and 10 million cubic yards in sandstone rock. Average quantity for each steam navvy was 700 yds. per 10-hour day, or 70 yds. per hour, and cost 2d. per yd. cube, exclusive o cost of plant, depreciation, repairs, superintendence, etc.

Pre-war costs excavating and loading into wagons, 2*d.* to 6*d.* per yd. cube ; the harder th material the greater the saving. In easy soil as low as 1*d.* per yd. cube, including interest, depre ciation, and repairs, but this is exceptional ; in stiff clay 2*d.* or 3*d.* ditto. Costs per yard cube ar higher for small machines owing to the comparatively small output, and less for larger machine with big output.

Analysis of Costs.—Assuming a steam-driven crane navvy with 20 ft. jib centre and ¾ cu. yd bucket capacity is getting out clay at the rate of 30 yds. cube per hour, the costs (August 1922 would work out to approximately as follows, including excavating and dumping into clients wagons :

Output per day = 30 yds. cube per hour × 8 hrs. per day = 240 yds. cube.

	s.	*d.*
Working costs per day—		
One driver upon the machine	12	0
One boy as fireman	5	0
Two men assisting on ground at 8s. each	16	0
8 cwt. coal at 35s. per ton	14	0
Oil waste and stores	3	0
	50	0
240 yds. cube.		
Rate per yd. cube	0	2½

	s.	*d.*
Add capitalised cost, including depreciation at 10 per cent. per annum, interest 5 per cent. per annum, and maintenance 2½ per cent. per annum, making a further	0	1½
Total capitalised cost per yd. cube.	0	4

With an output of 80 yds. cube per hour for loose material the cost would be 2*d.* to 3*d.* per yd. cube

On bigger productions the cost per yard cube comes down owing to the working rates bein practically the same with the exception of a slight increase in coal consumption, so that on th larger machines the value would be well below the figure given. Fewer men are needed with electric power, or if caterpillar tracks are fitted.

Removing earth cover with a No. 6 ' Ruston ' crane navvy for the United Brick Co., Peter borough, came to 3¾*d.* per yd. cube. This previously cost 1s. 6d. per yd. cube by hand labour.

A 45-ton Wilson's steam-crane ' Jubilee ' excavator will work a clear 22-ft. face, and drive gullet 45 ft. wide, and can travel forward in 30 seconds as each advance is made.

Weight of Machine.	Capacity of Bucket.	Lift of Crane.	Depth of Cut.	Output per Hour based on 10-hour day.
tons.	cub. yd.	tons.	ft.	yds. cub.
17	¾	3	16	25–45
20	¾	4	16	30–50
25	1	5	18	40–70
30	1½	8	20	60–100
45	2½	15	22	100–140

Pre-war cost was 1*d.* to 6*d.* per yd. cube delivered into wagons.

The ' Erie ' revolving steam shovels are built in two sizes, and can be fitted with broa traction wheels, rail wheels, or caterpillar tread, and will climb 25 per cent. grades under thei own power.

Type ' A ' is used for stiff clay, gravel, or lighter shales, and Type ' B ' for stiffer clay, gravel, heavy rock shales, or blasted rock. The following rates of output are conservative and have often been exceeded. The yield depends upon plant management, and to keep the shovel busy ample hauling equipment is essential. To dig and load by pick and shovel costs seven times as much as the same amount with an ' Erie.'

Standard Type.	Capacity of Bucket.	Working Weight.	Approx. Price, August 1922.	Output per hour, ordinary conditions.
	cu. yd.	tons.		cu. yds.
A	½	13	£1,800	15–25 shallow cuts (10 in. to 24 in.) 30–40 deep cuts (3 ft. or over)
B	¾	19	£2,070	25–35 shallow cuts (10 in. to 24 in.) 50–60 deep cuts (3 ft. or over)

Two hundred to 300 yds. cube per day is good going in a trench cut, which may be 19 ft. deep. One ' Erie ' ditcher does as much as a 50-man gang in clearing sides and keeping cuts ditched.

Analysis of Costs.—The following approximate working costs per day (August 1922) are based on 200 working days per annum of digging and filling wagons or trucks with a Type 'A' ' Erie ' revolving shovel. The figures do not include any team or truck time.

	£	*s.*	*d.*
One driver or operator	0	15	0
One fireman	0	10	0
Two groundmen at 12*s.* 6*d.* each	1	5	0
Oil and fuel	1	0	0
Daily interest on capital invested, cost of machine £1,800 at 6 per cent.	0	10	10
Daily depreciation, say 10 per cent.	0	18	0
Total capitalised cost per working day	4	18	10

And £4 18*s.* 10*d.* per day ÷ 200 yds. cube output per day . . . 6*d.* per yd. cube.

(Output variable according to soil, shallow or deep cuts, wagon service, etc.) 300 " " " . . . 4*d.* "
400 " " " . . . 3*d.* "

For a Type ' B ' shovel the approximate working costs per day would similarly be :

	£	*s.*	*d.*
One driver or operator	0	15	0
One fireman	0	10	0
Two groundmen at 12*s.* 6*d.* each	1	5	0
Oil and fuel	1	1	0
Daily interest on capital invested, cost of machine £2,070, at 6 per cent.	0	12	6
Daily depreciation, say 10 per cent.	1	2	0
Total capitalised cost per working day	5	5	6

And £5 5*s.* 6*d.* per day ÷ 300 yds. cube output per day . . . 4½*d.* per yd. cube.

(Output variable according to soil, shallow or deep cuts, wagon service, etc.) 400 " " " . . . 3½*d.* "
500 " " " . . . 2½*d.* "
600 " " " . . . 2*d.* "

The ' B ' ' Erie ' with 4-men crew (driver, fireman, and two groundmen) is equal on deep cuts to 50 or more labourers, and on rock loading to 20 or 30 men. Assuming a labourer gets 3*s.* 3*d.* per hour, and can dig and throw into wagons ½-yd. cube per hour, this is equivalent to 3*s.* 6*d.* per yd. cube for hand labour. That is, 50 labourers × 4 or 5 yds. cube each per day = 200 to 250 yds. cube per day for the gang, whereas the Shovel will excavate 500 to 600 yds. cube per day and lift into wagons at a cost of about 2½*d.* per yd. cube.

Two loads of a ' B ' ' Erie ' dipper or bucket will completely fill an ordinary 1½ cub. yd. wagon and three ditto a 2 cub. yd. wagon.

Wagon Service.—There is no waiting with steam shovels, as the buckets or dippers lift ½ to 5 or even up to 6 cu. yds. in one bite, and the spoil is at once tipped into trucks or wagons an removed on rails with a minimum loss of time. One steam excavator requires at least one loco motive to look after it, with a speed not exceeding 8 to 10 miles per hour for sets of 30 to 40 wagon and stops of 15 to 20 minutes not more than 4 miles apart for 'fatting.' Allow ½ hr. at one end an ½ hr. at the other for running round the wagons, getting coal and water, and shunting out cripple ones. Steam-driven end-tipping wagons hold 2½ cu. yds. and side-tipping wagons 3 cu. yds measured in the solid. Maintaining them in good running order costs, pre-war, ½*d.* to 1*d.* p yd. cube per mile.

Generally, it takes 45 side wagons to keep a steam excavator going, if the haul is not mo than 1½ miles, and gradients are such that a 12- or 13-in. locomotive can handle 20 wagons in a s

Expenses of operating a locomotive depend on water (mostly), gradients, and coal. T pre-war labour cost of driving and repairing a locomotive is £1 per shift, including fitters and smith To this add foreman, boy turning points, general expenses 30 per cent., interest and depreciatio 1 ton of coal, repair accounts, water, oil, and stores, or £2 10*s.*, making a total cost per shift of £3 10 Washing and repairing engine while in shed adds 20 per cent. to wages paid for actual driving.

2. *Trench-diggers.*—The advantages compared with hand labour are economy, speed, ease control, and ready supervision. The cost is less than half that of hand labour, and the deep the trench the greater the saving. If a labourer can excavate and throw out by hand ½ yd. cu per hour in trench work it will take 120 men to yield a total output equal to one No. 36 machin which can dig 1 yd. cube per minute or 60 yds. cube per hour.

A 'Parsons' trench excavator, operated by petrol or steam, can dig a trench as detailed belo The prefix numbers indicate the maximum width in inches to which that particular machine w cut, and it will excavate any depth up to that mentioned.

Machine.	Working Weight.	Width of Trench.	Depth.	Rate per Minute.
	tons.	ins.	ft.	
No. 24	8	15, 18, 24	10	8 ins. to 10 ft.
No. 36	14	20 to 36	15	6 ins. to 10 ft.
No. 78	24	28 to 78	20	1½ ins. to 4 ft.

3. *Grab Buckets.*—Grab buckets are employed when it is impracticable to use a steam sho or trench-digger, and they can be operated by a special crane, or by attaching to an ordina steam crane or derrick. The common type is known as the clam-shell grab, which has jaws ope ing in and out. Capacity varies from ¼ to 3 cu. yds., and 20 to 30 cycles per hour of grabbin raising and swinging round, and discharging can be performed. The cost is about half that hand labour, and the saving is greater when under water. When dredging Limerick harbour wi a Priestman's grab the average pre-war cost of dredging and discharging was 1¾*d.* per ton.

4. *Chain Bucket Excavators.*—This excavator consists of a bucket ladder which scoops material and discharges it into wagons either above or below the engine. The machine is be for a definite profile, such as a railway cutting or reservoir, but the ground must be free of ro or boulders. A good size weighs 40 tons, and digs to 20 ft. deep or more at theoretically 1 cu. yds. per hour, but the actual output is about 66 per cent. of this rate.

5. *Drag-line Excavators.*—Generally speaking, drag-line and cable-line excavators are used f cuttings of large size for drainage purposes, for canals, handling sand and gravel, and in soi instances for preliminary road work over rough ground. These excavators can proceed in a direction, from railway station to works or from one job to another.

Bucket capacity 1 cu. yd., weight of machine 26 tons.
" 2 " " " 62 "
" 3 " " " 75 "

The cableway drag-line excavator has two masts, known as the head tower and tail tow with track cable between, along the line of which the bucket runs. Buckets, 1½ cu. yds. Wi an average haul of 225 ft. cost was 5*d.* per yd. cube, including maintenance, repairs, fuel, supe vision, and depreciation.

6. *Scrapers.*—Two types, 'drag scrapers' and 'wheel scrapers.' These are widely used in America for shallow excavation and grading work, and are drawn by one horse and one man, or by two horses and two men. The surface is first cut up with an ordinary plough, and the scraper then dragged over the ground to remove the loosened soil. Capacity of a drag scraper is about $\frac{1}{8}$ cu. yd.—wheel scraper much greater, about $\frac{1}{2}$ cu. yd.

7. *Derricks and Cranes.*—Contractors' locomotive or 'loco' steam cranes may weigh from 10 to 60 tons, and lift loads up to 25 tons, with a jib radius of 16 to 25 ft. The cranes have 'all motions,' *i.e.* lifting, lowering, revolving, jib adjusting, and travelling on rails with a gauge of 4 ft. $8\frac{1}{2}$ ins. to 12 ft.

Stationary or travelling steam cranes may be employed to work iron or flat-bottom wooden skips, which are like large buckets or open boxes respectively, and hold $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1 cu. yd., or more, made to discharge from the crane over a wagon. Woodford's patent steel bucket skips are excellent, self-righting, and with safety catch.

8. *Radial Loaders.*—These are used for raising loose soil from the bottom of an excavation to the surface level, and have a chain of buckets attached to an inclined arm or boom, and a shoot, and are driven by an electric motor or a petrol engine. The usual capacity is 1 cu. yd. per minute, and the machine can load a 7-ton wagon in 7 mins. Cost of handling soil by this method is 1*d.* to 6*d.* per yd. cube.

The Haiss wagon-loader is a labour-saving device for dealing with loose materials, supplied by Millar's Machinery Co., Ltd., Pinners' Hall, London. It is a self-propelled petrol-driven machine fitted with a bucket elevator, operated by one man, and can load 5 cu. yds. into a truck in five minutes.

The saving in loading cost will enable a contractor to quickly regain the expenditure on these appliances.

9. *Paving Breakers.*—Breaking up old macadam, concrete, or paving was formerly done by steel wedges, sledge hammers, and crowbars by hand labour, but these are tedious and expensive compared with mechanical means.

Pneumatic paving-breakers show a cost saving of as much as 65 per cent., and a time saving of 75 per cent., over hand methods. These percussion tools are operated by compressed air from a portable compressor, driven either by petrol or electricity, which will work two to five large picks.

Weight.	Length overall.	Size of Steel.	Hose.	Air pressure.
lbs.	ins.	in. hex.	in.	
60	$24\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	Over 80 lbs.
69	$26\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	Under 80 lbs.

The steel cutters are of two kinds—one with a chisel edge, and the other with a moil point. An ordinary gang consists of three men—one compressor man and two breaker operatives. Each operative can break up an average of 245 yds. sup. of 9-in. concrete per day. Cost of running plant in oil and fuel is about 2*s.* per hour. Breaking up concrete surfaces, 8 to 20 ft. wide and 9 ins. to 12 ins. thick, in London streets, was 2*s.* 6*d.* per yd. cube, based on one portable compressor working four or five large picks.

One man with one paving breaker can smash up as much old tarmac on concrete roads for cutting trenches, etc., as nine men handling wedges and sledge hammers. Removing the top layer of a road came to 6*d.* per yd. sup. against 2*s.* per yd. sup. for burning and picking off.

10. *Soil Transport.*—It is impossible to maintain a big output with excavating equipment unless the surplus soil can be removed as quickly as the digging is done. Speed obviates the large number of trucks or wagons caused by slowness. Careful planning is required for rails, wagons, dumps, etc., and good organisation.

The types of transport may be classified as—

(*a*) Hand labour small receptacles, such as wheelbarrows or buggies.
(*b*) Horse-drawn vehicles, wagons or carts.
(*c*) Steam-driven wagons.
(*d*) Petrol-driven wagons.
(*e*) Narrow-gauge track with wagons.
(*f*) Standard-gauge track with trucks.
(*g*) Electrically driven trucks and vehicles.

(*a*) *Hand Labour.*—Net unit cost per ton-mile about 7*s.* 6*d.* (February 1922), for remova including loading up, wheeling, levelling, and return of empty, reckoning interest on initial outla depreciation, and maintenance.

Assume one man will do the equivalent to 10 ton-miles per week of 44 hrs. Output low an unit cost high, as many journeys are needed to transport a ton.

(*b*) *Horse-drawn Vehicles.*—1*s.* 6*d.* per ton-mile under ordinary average conditions, so this very economical compared with hand labour, or only one-fifth cost. It is also a flexible systen as horses and vehicles can be hired, but is not sufficient for extensive excavation schemes. Ti carts or tip-wagons are necessary, and the tipping can be done by a lever at the seat of the drive

(*c*) *Steam-driven Wagons.*—The haulage costs of these may be divided into standing charge which are constant, and running costs, which are governed by mileage. The costs per mi (July 1921) work out as below, including standing charges of insurance, rent, interest on fir cost, licence, registration, and wages; and running costs of fuel (coal, coke, or petrol), lubricant tyres, repairs, maintenance, depreciation on 'life,' etc., based on 200 miles per week, althoug 400 miles or more may be accomplished. The fuel-consumption basis, plus 20 per cent. f wastage, is 55*s.* per ton for coal or coke, and 2*s.* 8*d.* per gallon for petrol.

Unit.	4-ton Steam.	4-ton Petrol.	6-ton Steam.	6-ton Petrol.	10-ton Steam and Trailer Combination
Cost per ton-mile	4¾*d.*	6*d.*	3½*d.*	4¾*d.*	2½*d.*
Fuel mileage	20 miles per cwt.	7 miles per gal.	15 miles per cwt.	5 miles per gal.	13 miles per cwt.

Life of a steam wagon without trailer is taken as 12,000 miles.
,, petrol lorries is 25 per cent. less, say . 9,000 ,,
,, wagon tyres with trailer . . . 7,000 ,,
,, trailer tyres . . . . . 12,000 ,,

In calculating the depreciation allowance—

Life for a steam wagon without trailer is taken as 150,000 miles.
,, steam wagon with trailer . . . 120,000 ,,
,, petrol lorries . . . . . 100,000 ,,

The cost shows considerable saving over horse-drawn vehicles at 1*s.* 6*d.* per ton-mile. In fac the expense of transporting 4 tons 1 mile by steam wagon, 4¾*d.* × 4 = 1*s.* 7*d.*, is practical equal to that of 1 ton only the same distance by horse wagons.

The output of a 4-ton steam wagon with a speed of 8 to 10 miles per hour will run to 800 t miles per week, equivalent to 80 men by hand labour. To justify the initial outlay of an end- side-tipping wagon at £1,200 over a horse and cart, it should go 24,000 ton-miles to make t necessary saving, which is easy considering that its estimated life is 300,000 ton-miles of work be performed. With several steam wagons the gain is enormous, and the economy of employi them on large works amply justified.

(*d*) *Petrol-driven Wagons.*—A steam wagon is best for transporting a maximum tonnage o a maximum distance in a minimum time at a minimum cost; but for maximum mobility w lighter loads and for special suitability for intermittent work, the petrol vehicle has undisput claims, though its working costs are necessarily higher.

An investigation into the actual working records of 100 steam wagons by five different make and of 100 petrol vehicles by nine leading makers, showed that the average cost (1920) for hauli 5 tons per mile worked out at:—

For steam wagons, 1*s.* 5½*d.*, or 3½*d.* per ton-mile.
For petrol vehicles, 2*s.* 10½*d.*, or 7*d.* per ton-mile.

These rates included all overhead charges, 12½ per cent. depreciation, interest, fuel, wages, repa etc., over 15 million ton-miles. The annual saving of each steam wagon compared with pet was over £1,000. Steam wagons gave steadily consistent figures, whereas petrol lorries var widely.

Usual capacities of tipping petrol wagons are 1½, 2, 3, 4, and 5 tons, but 2 tons is the m useful. Cost per ton-mile, 6¾*d.*, based on 300 miles per week, including depreciation, interest capital, wages, tyres, renewals, fuel, etc.

(*e*) *Narrow-gauge Track with Wagons.*—Transporting surplus soil in side-tipping wagons on a narrow-gauge track is, under general conditions, more economical and far superior to ordinary manual labour with small receptacles or to horse-drawn carts. The track is commonly known as 'Jubilee,' industrial, or contractors' track, and the wagons as 'Jubilee' wagons. It is a portable railway with steel rails (10 to 20 lbs. per yd.) and corrugated steel sleepers, and the lay-out should be well planned. The tip wagons (½ to 7 cu. yds.) can be managed by hand labour, horses, or light locomotives.

Cost for hand-operated wagons on a level railway is 1*s.* 3*d.* per ton-mile.
„ horse-drawn „ „ „ 0*s.* 3*d.* „

Comparative costs for the different methods of transport:—

	s.	*d.*	
(*a*) Hand labour with wheelbarrow	7	6	per ton-mile
(*b*) Horse and cart	1	6	„
(*c*) Steam wagons, average	0	3½	„
(*d*) Petrol vehicles, average	0	7	„
(*e*) Hand-operated wagons on industrial track	1	3	„
(*f*) Horse-drawn „ „ „	0	3	„

Steam wagons are, therefore, cheapest for large quantities over considerable distances, and the industrial track (with horse labour) for small or large quantities over short distances.

(*f*) *Standard-gauge Track with Trucks.*—This system is restricted, as the first outlay is expensive, and the method is not so flexible as light railways. Large tipping wagons will be necessary, and no cost figures can be given, as the mode of transportation is for special circumstances.

(*g*) *Electrically-driven Trucks and Vehicles.*—These have not been extensively developed up to the present, but they are useful for short haulages and when continual stopping and restarting are unavoidable.

Taking a standard make of 5-ton electric vehicle, the 'fuel' cost at 2*d.* per unit works out at 2⅝*d.* per mile, with loads from 4 to 5 tons. Running costs, including interest at 6 per cent., depreciation at 10 per cent., tax, insurance, wages, charging current, rubber tyres, oil, grease, batteries at 5 years' life, etc.:—

Weekly mileage.	Load carried.	Annual Cost.	Running Cost.
	tons.	£	per ton-mile.
100	2	482	11½*d.*
100	3	482	7½*d.*
140	4	515	4½*d.*
140	6	515	3*d.*

Electrical traction on industrial or light railways, running costs 1½*d.* per mile.

Electric locomotives (costing about £450 per vehicle, complete with battery) will haul a load of 10 tons on a level track, and one charge of battery will give a normal run of 20 miles. One charge takes 14 units of electricity at 2*d.* per unit, which works out to 1½*d.* per mile run.

An electric locomotive can economically pull wagons on a narrow-gauge track in lieu of manual or animal labour, with great saving of time. The comparatively small capital will soon be recovered. The advantages are—reduced first cost, easy control, efficiency, flexibility, and low expenses of operation, upkeep, maintenance, and depreciation.

GAS WORKS.

Gasworks.—Gasworks complete, including buildings, plant, and distributing mains:

	Small Towns.	Large Towns. or Cities.
Per head of population	30*s.* to 40*s.*	40*s.* to 50*s.*
Per ton of coal carbonised per annum	5*l.* to 6*l.*	6*l.* to 7*l.*
Per million cubic feet of gas produced per annum	500*l.* to 600*l.*	600*l.* to 700*l.*

Land.—Area of land for the erection of works at least 2 acres per million cubic feet of gas per maximum diem.

Proportionate Capital Expenditure.—Including works, distribution plant, etc.:—

On buildings and works	38	per cent.
On district mains	55	„
On Parliamentary, promotion and engineer's expenses	7	„
	100	

Proportionate Cost of Parts.—Including buildings and plant :—

Retort house, including benches, fireclay retorts, etc.	25 per cent.
Purification buildings, with purifiers, gas scrubbers, etc.	30 ,,
Gasholders, iron or steel, with guide framing, brick-lined tanks, concrete bottoms, and excavation	40 ,,
Station meter-house, meter, and miscellaneous	5 ,,
	100

Retort-houses.—Including foundations and brickwork to benches, etc. :—

Exclusive of plant or machinery	5*d.* to 6*d.* per f.c.
Including retorts, ironwork, and fittings	1*s.* to 2*s.* ,,

Glover-West's system for vertical gas retorts, Belfast (1913) :—

70,950*l.* for a plant to carbonise 480 tons of coal per 24 hours,
=148*l.* ,, ,, ,, 1 ton ,, ,,

Gasholders.—Steel or iron telescopic holders, including guide framing, etc. :—

	Per 1,000 cub. ft. of capacity. £ £
Single-lift holders, up to about 50,000 cub. ft.	25 to 28
If of the spiral type, 25 per cent. less	20 ,, 22
Two-lift holders, about 250,000 cub. ft. capacity	16 ,, 20
If spirally guided, about 50 per cent. less	8 ,, 10
Large holders, from 2 to 3 million cub. ft. capacity	9 ,, 12
The 10½-million holder at Manchester cost	5
The 12-million holder at East Greenwich Works cost	5 guineas

(See pp. 2460, 2465.)

GROYNES.

There are four types of groyne construction in this country—timber, concrete bloc reinforced concrete, and chain cable. Cost of timber groynes for the seashore, comprisi creosoted fir piles with horizontal sheeting bolted thereto, and stiffened with ties and strut Piles well driven into sand or shingle, and executed as tide-work. Pre-war costs :

Light timber groynes, 1*l.* to 3*l.* per yard run.
Heavy ,, ,, 3*l.* ,, 6*l.* ,, ,,

The following particulars have been condensed from *Marine Works*, by E. Latham, M.I.C. (1922. 16*s.* Crosby Lockwood & Son, London), and the other books mentioned in each cas The first five examples are pre-war, and the last post-war.

	Cost per yd. ru £ *s.*
Bridlington.—Low timber case groynes, constructed of pitch pine piles, shod with 18-lb. pile-shoes, driven 8 ft. into the boulder clay in pairs, at 7 ft. 6 in. centres. 11 in. × 4 in. pitch pine planking inserted between the piles, so that a depth not exceeding two planks projects beyond the sand level. Timber all creosoted. Groynes spaced at a distance apart not exceeding their length, which was about 200 ft. First four groynes cost	2 14
Most of the others cost	1 16
For details see *Coast Erosion and Protection*, pp. 114–115, by E. R. Matthews, A.M.I.C.E. (1918. Charles Griffin & Co., London.)	
Eastbourne.—Timber groynes erected about 1886–96, some 70 yards apart, at right angles to the foreshore. Constructed of 9 in. × 9 in. pitch pine and oak piles, 6 to 16 ft. long, driven to an average depth of 9 ft., set 4 ft. 6 ins. apart, centre to centre, with walings 8 ins. × 6 ins. and 6 ins. × 6 ins. Planks, 9 ins. × 2 ins., are spiked to the piles in lengths of 20 ft. and over, to span four bays and break joint. Large oak land-ties fixed at right angles to the piles, and fastened to a smaller pile at back. The majority are high groynes, and were originally 8 to 10 ft. in height at shore end, and about 4 ft. at low end, and did not extend to low-water mark. The more recently constructed groynes vary from 4 ft. high at the land end to 2 ft. at low-water mark. Average length 100 yards, and cost 375*l.* each, or	3 15
Seven case groynes erected to the east of the pier in 1897. Pairs of 9 in. × 3 in. pitch pine piles, spaced 7 ft. 6 in. centres, with 9 in. × 3 in. planks inserted between. Average length 100 yards, and cost 68*l.* 15*s.* each, or	0 13
For details see *Coast Erosion and Protection*, pp. 104–106, by E. R. Matthews, A.M.I.C.E. (1918. Charles Griffin & Co., London.)	
Lowestoft (1901–1903).—North Denes. Four timber main groynes, three having a length of 290 ft., and the fourth 340 ft., spaced 1,500 ft. apart. Shoreward ends 4 ft. above high-water level, and seaward ends 3 ft. below the same level. For details see *Proceedings of the Institution of Civil Engineers*, vol. clxxxv. p. 106	22 1

	£	s.	d.
Southwold.—Timber groynes. For details see *The Protection of Sea Shores from Erosion*, p. 23, by A. E. Carey, M.I.C.E.	4	4	0
Withernsea (1873).—Six timber groynes consisting of 13 in. piles, 22 ft. long, 5 ft. apart, driven down 12 ft., with 11 in. × 4 in. planks, 13 in. × 6½ in. struts, and foot piles. Four are 300 ft. in length, and two 350 ft. Only three planks project above sand-level. For details see *Proceedings of the Institution of Civil Engineers*, vol. clix. p. 73	3	7	6
Blue Anchor (1921).—On the Bristol Channel, and in front of the Minehead to Watchet Road, north Somerset. Groyne 600 ft. long and two timber stockades, each 1,500 ft., parallel to existing sea-wall. Stockades consisted of 10 in. × 10 in. main piles of pitch pine, with 9 in. × 4 in. intermediate piles bolted to continuous walings. Half of total length of stockades had to be constructed by bedding the piles in mass concrete, necessitating trenching in rock. Engineer, E. Latham, M.I.C.E. Contractors, Messrs. John Cochrane & Sons, Westminster. Total about 30,000*l.* Cost per yd. run includes stockades	£25	0	0

Harbours.

Artificial harbours complete, including reclamation of land, dredging, enclosure walls, breakwaters, landing stages, lighting, buoys, cranes, etc.:

5,000*l.* to 10,000*l.* per water acre enclosed.

Colombo Harbour (1874–1914).—On the west coast of Ceylon and entirely artificial. It ranks twelfth among the greatest seaports, and there is ample space for 50 steamers besides smaller craft. The enclosed area is 650 acres (over a square mile), and depth 30 to 36 ft. at low water. Rise of tide at Ceylon is only 2 ft.

South-west breakwater, 1874–85, is 4,212 ft. long, built of concrete blocks weighing 18 to 30 tons on the sloping bond system, and cost 705,200*l.*, or 167*l.* per ft. run. Extension to ditto as a further protective arm, 1907–12, is 1,800 ft. long, also of concrete blocks, and cost 380,000*l.*, or 211*l.* per ft. run. North-east breakwater, 1894–7, is 1,100 ft. long, and constructed as a rubble embankment; the north-west or island breakwater, 1900–6, is 2,657 ft. long, and made of concrete; the two together cost 500,000*l.*, or 133*l.* per ft. run. Total length of the four breakwaters about 9,770 ft., with 5 lighthouses on them, and total cost 1,585,200*l.* Graving dock, 1900–4, is 700 ft. long, 85 ft. wide, and cost 400,000*l.*; patent slip, 1900–3, is 800 ft. long, and cost 43,000*l.*; coaling depot, on 24 acres of reclaimed land, has a frontage of 2,200 ft. with 18 jetties, and cost 163,000*l.* Other services, 821,900*l.* Total expenditure from 1874 to 1914 (forty years) was 3,013,100*l.* The small Fishery Harbour immediately to the northward has a rubble arm 800 ft. long, and cost 12,000*l.* The engineers were Sir John Coode, Son, and Mathews; and the resident engineers, Sir John Kyle, M.I.C.E., Mr. J. H. Bostock, M.I.C.E., Mr. John Kyle, M.I.C.E. (son of Sir John), and Mr. A. D. Prouse, M.I.C.E.

4,636*l.* per water acre enclosed; 162*l.* per ft. run, average of breakwaters.

Dover Harbour (1898–1909).—Original Admiralty Pier, 1,000 ft. long, was built in 1847–71. Dover Harbour Board then constructed a small commercial harbour of their own in 1890, between the existing Admiralty Pier and a new east pier, of 56 acres net area, afterwards increased to 75 acres by reclaiming the foreshore. The National Harbour was proceeded with in 1898–1909, and comprised the extension of the western breakwater, or old Admiralty Pier, from 1,000 to 3,000 ft., an eastern arm, 3,320 ft., and an isolated breakwater in the middle, 4,200 ft. Total sheltering works, 9,520 ft., or nearly 2 miles long, with two entrances 740 ft. and 650 ft. wide and 42 ft. deep at low water, enclosing 610 acres, exclusive of the 75 acres in the Commercial Harbour. Height of breakwaters from bottom of foundation to parapet top 60 to 120 ft. or an average of 90 ft., with 50 ft. average depth below low-water level, and 50 ft. average thickness, built of concrete blocks, weighing 10 to 40 tons each and faced with granite above low-water level. Works include a sea-wall, 3,850 ft. long, to protect base of cliffs, a lesser sea-wall, 700 ft., and reclaiming about 20 acres of land. Engineers, Sir John Coode, Son & Mathews. Contractors, Messrs. S. Pearson & Son, Ltd. National Harbour, 610 acres, cost 4,000,000*l.*, and inside Commercial Harbour, 75 acres, 1,250,000*l.*, or a total of 685 acres and 5,250,000*l.*

National Harbour:	6,557*l.* per water acre enclosed;	420*l.* per ft. run of breakwater.
Commercial Harbour:	16,666*l.* " " " ;	131*l.* " " "
The two combined:	7,664*l.* " " " ;	551*l.* " " "

(See also p. 1520.)

Heating.

The fewer the radiators, and the longer the run, the higher the cost per radiator. 15 ft. sup. of radiator should be supplied for every 1,000 cubic feet of space to be heated. Cost includes fittings complete, but is exclusive of boiler-house and buildings.

Heating buildings with boilers, pipes, and radiators	1*l.* to 4*l.* per 1,000 f.c.
Low-pressure hot-water heating	8*l.* " 10*l.* per radiator.
Hot-water work inside a building	1*s.* 6*d.* per ft. run.

(See also pp. 2488, 2499, 2500, 2501.)

Landing Slips.

Landing Slips, Milford Haven (1894).—Formed of Portland cement concrete, with shingl supplied by contractor, and 8 ft. wide × 3 ft. high, on 18-in. foundations. In tidework, and no exceeding 40 yards from shore. Excavation in boulders and shingle on beach. 30*s.* per foot run

Lighthouses.

Lighthouses. (All of Granite.)	Date.	Height of Focal Plane above High Water.	Engineer.	Total Cost.	Cubical Contents.	Cost per Ft. Cub. of Masonry.
		Ft.		£	f.c.	£ *s.* *d.*
Ar'men, Finistère, France	1867–81	94	L. Reynand	37,692	32 400	1 3 3
Bell or Inchcape Rock, Forfarshire	1808–11	117	R. Stevenson	55,620	28,530	1 19 0
Bishop Rock, Scilly Isles	1851–58	110	J. Walker	34,560	35,209	0 19 8
Bishop Rock, strengthening and part reconstruction	1883–87	146	Sir J. N. Douglass	64,889	45,080	1 8 9
Dhu Heartach, West of Scotland	1866–72	145	D. & T. Stevenson	72,584	42,050	1 14 6
Eddystone (third lighthouse), off Plymouth	1756–59	72	J. Smeaton	40,000	13,343	3 0 0
Eddystone (fourth lighthouse)	1878–82	133	Sir J. N. Douglass	59,255	65,198	0 18 2
Fastnet, S.W. Ireland	1899–1904	158	W. Douglass	79,000	62,600	1 5 6
Great Basses, Ceylon	1870–73	108	Sir J. N. Douglass	63,560	47,808	1 6 7
Hanois, Alderney	1862	100	J. Walker, Burges, and Cooper	25,296	24,542	1 0 7
Longships, Land's End	1872	110	Sir J. N. Douglass	43,870	47,610	0 18 5
Minot's Ledge, Boston, Mass.	1855–60	89	General Barnard	62,500	36,322	1 17 2
Skerryvore, Argyllshire	1838–44	158	A. Stevenson	72,200	58,580	1 4 8
Smalls, Bristol Channel	1856–61	114	J. Walker	50,125	46,386	1 1 7
Spectacle Reef, Lake Huron	1870–74	93	General Poe	78,125	42,742	1 16 2
Wolf Rock, Land's End	1862–69	110	J. Walker and Sir J. N. Douglass	62,726	59,070	1 1 3

Lighthouse, Northern Point, Northern Province, Ceylon (1914–16).—Tower is supported on reinforced concrete platform over hardwood piles, and built of dressed coral stone in lime mortar, cement rendered externally. Walls 2 ft. 7½ ins. thick above plinth, carried up with a uniform thickness at a batter of 1 in 48. Internal diameter of tower 8 ft. 3 ins., and height from top of foundation to reinforced concrete cap 91 ft. Fourth order light visible for 16 miles, and focal plane 97½ ft. above mean sea level. Cost, exclusive of lantern and ironwork above the cap 1,730*l.*, or 1*s.* 6*d.* per foot cube.

Lighting.—A complete gasworks plant for a lighthouse costs about 800*l.*
Annual expenditure for gas lighting, where works are installed . . . 72*l.* per light
" " " " where gas is supplied from elsewhere . 32*l.* "

A first-class electric lighthouse installation, including optical apparatus, lantern, dynamos, engines, air compressor, siren, etc., but not buildings, costs about 6,000*l.*

Maintenance.—Average annual cost of maintenance of an English shore lighthouse, with two keepers, is 280*l.*

Average annual cost of maintenance of an English shore lighthouse, with three keepers and a siren fog signal, is 450*l.*

Annual maintenance of a rock lighthouse, with four keepers and an explosive fog signal, is about 800*l.*; and of an electric light station, 1,100*l.*

Lightships.—Steel lightships, of average size, with power driven compressed air siren, cost about 16,000*l.*

Annual maintenance of ditto, including periodical overhaul, 1,320*l.*

Usual limits.—Length . . . . . 80 to 114 ft.
Beam . . . . . 20 " 24 "
Depth moulded . . . . . 13 " 16 "
Tonnage . . . . . 155 " 280 "

LIGHTING.

Buildings.—Cost of gas and electric lighting inside buildings, including service pipes, stop-cocks, ordinary brackets, pendants, switches, wiring, and other articles, fixed complete, but excluding meters, external gas mains, generators, etc.

	s.	*s.*	
Acetylene	20 to	40	per light.
Coal gas	30 „	50	„
Electric	25 „	50	„

Wiring, including all necessary wire, switches, fuses, lamps, holders, casings, etc., but not electroliers or shades, 15*s.* to 40*s.* per lamp.

Installing artificial lighting per 100 points, including oil-engine, dynamo, wires, lamps, etc. but excluding buildings:

Acetylene.	Petrol Gas.	Electric Light.
100*l.* to 200*l.*	150*l.* to 200*l.*	200*l.* to 300*l.*

Acetylene.—Cost of upkeep consists mainly in the purchase of carbide with occasional renewa of burners. A 25 c.p. burner of ordinary type consumes about 1 f.c. of gas per hour, which demands ½ lb. carbide. With calcium carbide at 15*s.* per cwt. the cost of such a burner works out at ½*d.* per hour. Total upkeep of a 100-light installation is between 20*l.* and 30*l.*, according to number of hours lights are used.

Gas Lighting of the Castle, Carlisle (1896).—Supply from City of Carlisle Gas Company's mains through a 600-light dry meter supplied by Company. 4 in., 3 in., and 2 in. cast-iron mains and 1½ in. to ¼ in. galvanised wrought-iron service pipes, underground pipes 3 to 3½ ft. deep. Fittings include 19 governors, 10 valves, 20 stopcocks, 10 dry meters, 572 burners, 10 Wenham lights, 12 Schulke lights, 20 Deimel lights, 18 Welsbach incandescent lights, 12 Sugg's lights, etc. Occupation of barracks, 731 adults and 72 married quarters.

Total, 1,144*l.* 36*s.* per light or point. 28*s.* per head.

Gas Lighting of Strensall Camp, near York.—Completed 1915, in extension of the York Gas Co.'s mains. Cost includes 3-in. external steel mains, 2 in. to ¼ in. wrought-iron branches, brick meter-house and meters, siphons, stopcocks, burners, excavation, fixing, etc., complete, in huts and 40 married quarters for about 1,260, total of officers, N.C.O.'s, and men. 376 incandescent burners and 584 flat-flame burners, or 960 lights altogether.

Total, 1,780*l.* 37*s.* per light or point. 28*s.* per head.

Electric Lighting, Army Pay Offices, York.—Feb. 1915. 84 electric lights, mostly of 100 c.p. each, including opal glass shades, wiring, cords, switches, fuses, etc., but not cable into building or any plant, as taken from the Corporation electric main in road. 18 officers and 300 clerks.

Total, 91*l.* 22*s.* per light or point. 6*s.* per head.

Electric Lighting, Army Pay Offices Extension, York.—Aug. 1916. One-storey corrugated iron building, lined with plaster slabs. 136 electric lights, mostly of 100 c.p. and 50 c.p. metal filament lamps, including pendants, opal and holophane glass shades, wiring, cords, 109 switches, fuses, distribution boards, etc. Direct-current supply on the three-wire system taken from the Corporation electric main in adjacent road. 24 officers and 400 clerks.

Total, 137*l.* 20*s.* per light or point. 6*s.* 6*d.* per head.

Railway Coaches.—

	£
Cost of fitting a railway coach with electric light	130
„ „ „ „ incandescent gas	34
Annual maintenance of an electric lit railway coach	13
„ „ a gas „ „	7

STREET LIGHTING AT CROYDON.

(1910.)

Type of Lamp.	Number of Lamps.	Distance Apart.	Total Cost.	Average c.p. per Mile.	Cost per c.p. per Annum.
	No.	Yds.	£	c.p.	*d.*
Incandescent gas	2,137	80	7,062	839	15·86
Incandescent electric	90	66	288	1,373	13·71
Electric arcs	428	65	7,212	10,537	11·32

Locks.

Including foundations, invert, walls, gates, sills, machinery, lock-keeper's cottage, etc.

Brick and concrete	Per yd. cu. of internal capacity 30*s.* to 50*s.*
Stone and concrete	,, ,, 40*s.* ,, 60*s.*
Canal locks	each 5,000*l.* to 15,000*l.*
River locks	,, 15,000*l.* ,, 30,000*l.*

Marine Piers.

Timber and iron piers for seaside places, with creosoted fir or iron screw piles, averaging 40 ft long and driven up to 15 ft. in sand or shingle, including braces, ties, timber decking, railings tarring, gates, seats, etc.

Gangway or promenade portion	8*s.* to 12*s.* per ft. sup.
Landing stage or head to pier	10*s.* ,, 16*s.* ,,

Military Pier, Tilbury (1896).—450 ft. long by 16 ft. wide, or 7,200 ft. sup. Height above h.w.o.s.t. level, 4 ft., and above l.w.o.s.t. level, 20 ft. Foundation, 3 ft. of mud over 20 ft. of chalk, the distance bored. Substructure of wrought-iron piles, 10 ft. apart, with rod iron braces on which are fixed wrought-iron girders with intermediate joists supporting timber decking 18-in. gauge tramway rails, 24 lbs. per yard, and steam crane to lift 10 tons. Total cost, including 500*l.* for hoisting machinery, 3,200*l.*, or 8*s.* 11*d.* per ft. sup.

Batticaloa Jetty, Eastern Province, Ceylon (1900).—Timber pier, 50 ft. long, with return portion 22 ft. long, and 10 ft. wide. Cost, 5*s.* 6*d.* per ft. sup.

Galle Jetty, Southern Province, Ceylon (1916).—Jetty is 162 ft. long × 20 ft. wide, carried on concrete cylinders 6 ft. diameter, spaced 20 ft. centre to centre longitudinally and 14 ft. transversely, end pair being taken down to a depth of 20 ft. Special cylinders, 8 ft. diameter, form seats for two 3-ton cranes. Jetty is roofed for a length of 137 ft. Cost, 4,923*l.*, or 1*l.* 10*s.* per ft. sup. Cost of cylinders sunk, 6 ft. diameter, 3*l.* 19*s.*, and 8 ft. diameter, 5*l.* 3*s.*, per ft. run.

Kalkudah Jetty, Eastern Province, Ceylon (1901).—Jetty of iron, with wooden joists and planking, 165 ft. long × 28 ft. wide, and landings. Piles of H-iron section, 9 ins. × 7 ins. carried through a stratum of sand about 8 ft. into the coral bed of 1 to 2 ft. thick. Cross bracing, walings, fenders, etc. Corrugated iron roof over 122 ft. of length, supported on iron principals carried by H-iron standards, 8 ins. × 6 ins. Water 8 ft. deep at end of pier. Cost, including crane seat, 2,516*l.*, or 11*s.* per ft. sup. of platform area.

Paddiruppu Jetty, Eastern Province, Ceylon (1900).—70 ft. long with a tee head 30 ft. × 6 ft. wide, constructed of Palu timber with brick abutment. Cost, 8*s.* per ft. sup.

Mining.

(See pp. 2573, 2575, 2581, 2587, 2590, 2592, 2599, 2622, 2633, 2635, 2638, 2641.)

Pile Driving.

(See p. 610.)

Railways.

Average cost of railways, main lines, 4 ft. 8½ in. gauge, double track, total capital expenditure including land and all charges :—

	£	£	
In England	35,000	to 45,000	per mile.
,, Scotland	25,000	,, 35,000	,,
,, Ireland (5 ft. 3 in. gauge)	20,000	,, 25,000	,,
,, Europe	15,000	,, 25,000	,,
,, India (5 ft. 6 in. and metre gauge)	12,000	,, 25,000	,,
,, Norway, light railways, 3 ft. 6 in. gauge	5,000	,, 10,000	,,
,, Queensland	7,000	,, 15,000	,,
,, United States	8,000	,, 12,000	,,
Single line railways in poor districts of Scotland and Ireland	5,000	,, 7,000	,,

(See also pp. 643, 652, 653, 751, 752.)

PROPORTIONATE COST OF PARTS.

Earthworks	24 per cent.
Tunnels	10 ,,
Permanent way, including ballast	12 ,,
Sidings	3 ,,
Junctions and signals	1 ,,
Bridges and viaducts	9 ,,
Culverts and drainage	5 ,,
Stations and buildings	6 ,,
Construction only	70 ,,
Land and compensation	15 ,,
Rolling stock	10 ,,
Legal expenses	5 ,,
	100

	£	£	
Main lines, construction work and stations only	10,000 to	20,000	per mile.
Light railways ,, ,, ,, ,,	1,000 ,,	3,000	,,
Permanent way, single line, light construction, 4 ft. 8½ in. gauge, in flat country, cuttings and banks averaging 3 ft., rails 55 lbs. per yard, ballast 15 ins. deep, including stations and permanent works, but excluding land and rolling stock	5,000 ,,	6,000	,,
Ditto, heavy construction, 75-lb. rails, and 24 ins. ballast	6,000 ,,	8,000	,,
Yearly maintenance of permanent way	200 ,,	250	,,
Rolling stock, single line, depends on kind of traffic	700 ,,	1,000	,,
Permanent way, double line, in excess of above figures	50 ,,	75	per cent.
Rolling stock ,, ,, ,, ,,	10 ,,	30	,,

Working expenses in England average 50 per cent. of the gross receipts.
,, ,, Scotland ,, 45 ,, ,, ,,
,, ,, Ireland ,, 40 ,, ,, ,,
Average gross receipts, 4*s.* to 6*s.* per train mile.

Railway Footbridges.—Of iron or steel, including foundations, supports, girders, floor, staircases, lattice sides, etc., erected complete, 5 ft. wide.
250*l.* to 350*l.* each, 30 to 40 ft. span, or 15*s.* to 20*s.* per ft. sup.

Railway Viaducts.—On the Great Western Railway there are a great many viaducts, especially in Cornwall, commencing at 50 to 60 ft. deep, and being as much as 90 or 100 ft., and even up to 150 ft., in the centre of the gorge. They are, as a rule, about 60 ft. spans between the piers, which is found to be the economical width. Segmental arches nearly, but not quite, semi-circular, 3 ft. thick at centre, and 3 ft. 9 ins. at the springing. Piers, 7 ft. 6 ins. wide at the top, tapering on every side at 1 in 32. This gives a pressure of about 8 tons per square foot on the masonry. The cost comes out for such a structure, carrying two lines of way, at 1*l.* per yard forward per foot high, measured from ground to rail. That is, for example, a viaduct 200 yards long, and averaging 70 ft. in depth, will cost 14,000*l.*

Avon Viaduct.—On the Midland Railway, and of brick. 720 ft. long, 51 ft. high, and 11 arches of 50 ft. span. Cost, 14,000*l.*, or 19*l.* per ft. run.

Congleton Viaduct.—On the Manchester and Birmingham Railway, and of stone. 3,080 ft. long, or over ½ mile, and 106 ft. high. Cost, 113,000*l.*, or 37*l.* per ft. run.

Dove Viaduct.—On the same line, and of brick. 1,716 ft. long, 88 ft. high, and 23 arches of 63 ft. span. Cost, 54,000*l.*, or 32*l.* per ft. run.

Viaduct over the River Eye, Berwickshire (1889).—Six openings of 50 ft. clear span, 55 ft. 3 ins. between centres of piers, and extreme height above bed of stream 60 ft. Total length of bridge 331 ft. and 15 ft. wide; single track. Abutments of 1 to 7 concrete. Five piers, 45 ft. high and 12 ft. wide at top, with 9-in. and 18-in. brick face and concrete hearting, and 9-in. brick wall up the centre. Superstructure of lattice main girders 8 ft. apart, with cross girders of 10-in. × 5-in. rolled iron joists, 40 lbs. per ft. run. Flooring of 4-in. planking, and the rails carried by longitudinal beams, 14 ins. × 12 ins. Cost, 3,700*l.*, or 11*l.* per ft. run, or 15*s.* per ft. sup.

Viaduct on the Gifford Light Railway, Haddingtonshire (1900).—Four spans of 42 ft. 8 ins., centre to centre of three piers, with 1 to 6 concrete foundations. Height to rail level above the bed of stream is 50 ft., and length over all 194 ft. by 18 ft. wide; single track. Masonry piers, haunches, and abutments, and brick arches over openings. Cost, 2,013*l.*, or 11*l.* per ft. run, or 12*s.* per ft. sup.

New York Elevated Railroad (1872–80).—Steam traction. Two lines of way supported on square wrought-iron lattice-work columns, let into cast-iron base blocks founded on brickwork and concrete, at distances of 37 to 44 ft. apart. Rails of Vignoles or flange pattern, of Bessemer steel, weighing 50 lbs. per yd. run, spiked to cross timber sleepers and guarded by longitudinal timbers. Sharpest curve is 90-ft. radius. Steepest gradient. 1 in 50 for a length of 800 yds. Stations about ½ mile apart, with platforms 200 ft. long and 13 ft. wide. No payment was made for way-leave along the streets, nor for compensation to frontages. Length, 35 miles. Total cost, 2,870,000*l.* Cost per mile of double track :—

	£
Foundations, columns, girders, superstructure, and permanent way	57,696
Railway stations and platforms	12,000
Rolling stock, 5 locomotives and 12 cars	11,680
Per mile of double track	81,376

Tube or Underground Railways.—Electric traction, as constructed in London. Two tracks, 4 ft. 8½ in. gauge, each laid in a separate tunnel, 11 to 12 ft. diameter. 300,000*l.* to 600,000*l.* per mile of double track.

	£	
London (Central), 1891–1900, 6 miles, 13 stations	580,000	per mile of double track.
London (Waterloo and City), opened 1898, 1½ miles	340,000	,, ,, ,,

Steam Traction.—Two tracks, 4 ft. 8½ in. gauge, laid in elliptical tunnel, 29 ft. wide and 17 ft. high, of 27 in. brickwork on concrete foundations.

	£	
London (Metropolitan), 1863–84	600,000	per mile of double track.
London (Metropolitan District), 1864–84	250,000	,, ,, ,,

Both the foregoing have since been converted to electric traction, completed in 1905. The Metropolitan has 32 electric miles, and the "District" 28 electric miles.

Cost of electrification only, exclusive of power stations, sub-stations, rolling stock, etc., 5,000*l.* to 10,000*l.* per mile of double track.

Cost of Indian Railways.—For the year 1895 the capital cost (rupee at 1*s.* 3¼*d.*) of Indian railways was :—

	£	
Standard gauge, 5 ft. 6 ins.	10,095	average cost per mile.
Metre gauge, 3 ft. 3⅜ ins.	4,519	,, ,,
Special gauges, 2 ft. 6 ins. and 2 ft.	2,093	,, ,,

London Railway Stations.

Particulars.	Cannon Street, London, South-Eastern Railway.		Charing Cross, London, South-Eastern Railway.	
	Total.	Per F.S.	Total.	Per F.S.
		£ *s.* *d.*		£ *s.* *d.*
Area, exclusive of forecourt	F.S. 152,632	—	F.S. 103,672	—
Cost of substructure	£ 74,962	0 9 10	£ 41,422	0 8 0
Cost of superstructure	£157,262	1 0 7	£111,604	1 1 6
Total costs	£232,224	1 10 5	£153,026	1 9 6
Cost of land	£572,370	3 15 7	£302,808	2 18 5

Charing Cross Station roof has since been rebuilt with a different type (1906).

Light Railways.

Narrow-gauge Railways.—Approximate cost, including works and rolling stock, cuttings and embankments 2 ft. deep, and ballast 6 ins. to 14 ins. deep.

Gauge.	Weight of Engines exclusive of Tender.	Max. Load per Wheel.	Weight per Yard of each Rail.	Cost per Mile.
Ft. Ins.	Tons.	Tons.	Lbs.	£ £
2 0	6	1	20	1,500 to 2,000
2 6	9	1½	25	2,500 „ 3,000
3 0	12	2	30	3,000 „ 3,500
3 3½	17	3	40	3,500 „ 4,500
3 6	20	3½	50	4,000 „ 5,000

Belgium.—Over 1,000 miles of minor lines have been constructed at a cost, including rolling stock and all outlay, of rather less than 3,000*l.* a mile. These are generally on the metre gauge (3 ft. 3⅜ ins.), and as many of them appear to be laid on the roads the cost of land is very small. They earn about 6*l.* per mile per week, and working expenses are 66 per cent., or 4*l.* per mile per week. Net earnings of 2*l.* per mile per week give a return for over 3 per cent. per annum on the capital.

England.—In England a line on the standard gauge, with no heavy work, would cost twice as much as the Belgian metre gauge railways, or say 6,000*l.* per mile. As regards land, a light railway can seldom do with less than an average width of 1 chain (66 ft.) or 8 acres per mile, and this at 100*l.* per acre comes to 800*l.* per mile. Hence to run the line on a strip of green alongside a road would save a good deal of expense, but this might involve bad gradients and sharp curves and the maximum speed would be reduced. The following are some actual costs :—

Clogher Valley Railway, Ireland (1885–87).—Length 37 miles, 3 ft. gauge, 45-lb. rail, and runs for the most part on the side of the road. Cost, 3,300*l.* per mile. It earns about 4*l.* per mile per week, but this is mostly absorbed in working expenses.

Listowel and Ballybunion Railway, Ireland (1888).—Length 9 miles, mono-rail supported on steel trestles, fastened to steel sleepers resting on wooden sleepers, with gradients up to 1 in 45, and worked by locomotives. Cost, including rolling stock, 3,666*l.* per mile.

Wisbech and Upwell Light Railway, Cambridgeshire.—Length 5¾ miles, with 2 miles of sidings, standard gauge, 50-lb. rail, and runs mostly on the edge of the road. Cost, excluding sidings, 7,000*l.* per mile of line. The earnings are about 9*l.*, and the expenses 7*l.* per mile per week.

Agrails.—The Decauville tracks of the new light railways, or ' agrails ' as they are called, did admirable service at the front, both in France and Belgium. They can be laid at a cost of 2,500*l.* per mile, and are now being put forward as a rival or as an adjunct to motor lorry traffic, to save the costly wear and tear of roads and to relieve congestion. They can be run on the edge of existing roads, with sidings on the various farms, but are only suitable for comparatively flat districts. The old narrow-gauge railways were too solidly and expensively built, but the agrails are of very light construction and should prove most useful.

River Canalisation, see Section XXIX, p. 1575.

River Regulation, see Section XXIX, p. 1567.

Roads.

	£	£	
Main roads, 30 to 40 ft. wide, for heavy traffic, constructed complete, including bottoming, metalling, gravelling, watering, and steam rolling	3,000 to	5,000	per mile.
By-roads, 20 to 30 ft. wide, for light traffic, and ditto	ditto	ditto	1,000 „ 3,000 „

Maintenance of Roads.

	£	£	
City roads	300 to	400	per mile per annum.
Urban main roads	200 „	300	„ „
County main roads	100 „	200	„ „
County by-roads	50 „	100	„ „
English rural public roads	30 „	40	„ „
Scotch „ „	20 „	30	„ „
Irish „ „	10 „	20	„ „
Inferior country roads	7 „	15	„ „

	s. d.	s. d.	
Asphalt paving in London	0 6 to	1 0	per y.s. per annum
Granite sett ,, ,,	1 0 ,,	1 4	,, ,,
Wood-block ,, ,,	1 0 ,,	1 6	,, ,,
Ordinary macadam ,,	1 0 ,,	2 0	,, ,,
Tarred macadam ,,	0 4 ,,	0 9	,, ,,

Cost per Head.—Cost per head of population for maintenance, repair, and improvements to roads, 6*s.* to 7*s.* per annum.

Damages.—Cost of maintenance has increased about 30 per cent. within recent years owing to traction engine and motor traffic. Damage through traction engines, steam lorries or carts is often assessed at 1*d.* to 2*d.* per ton per mile conveyed over the road. Damage by 'extraordinary traffic' sometimes 2*l.* to 3*l.* per mile.

Supervision.—Cost of supervision, including county surveyor's and clerk's salaries, office expenses, audit of urban accounts, etc., 3 to 6 per cent. on cost of maintenance.

(See also 'Roads,' Section XV, pp. 808, 844, 845, 849, 851, 855.)

Roofs.

	£	£	
Roofs, light, corrugated iron, 18 to 22 gauge, exclusive of iron or steel trusses	2 to	3	per square.
Roofs for light cheap sheds and buildings, including trusses, corrugated sheeting, gutters, etc., fixed complete	5 ,,	8	,,
Roofs, ordinary steel and iron, including purlins, boarding, gutters, etc.	5 ,,	10	,,
Roofs, railway station platform, with glass	10 ,,	20	,,
,, ,, termini, over 150 ft. span, fixed complete	30 ,,	45	,,
Roof trusses, delivered only, for galv. iron	4*s.* per foot of span		
,, ,, ,, ,, for slates	8*s.*		,,

Railway Station Roofs.

Railway and Station. (Old titles of Railways.)	Span of Roof.	Covered Area.	Cost per Square of 100 F. S.	Additional for one Gable.
	Feet.	Sq. Yds.	£ s. d.	£ s. d.
London, Brighton and South Coast Railway, Victoria Station (1860)	120	—	27 13 4	with gable
London & North-Western Railway, New Lime Street Station	212	—	30 0 0	—
Midland Railway, St. Pancras Station (1868)	240	18,822	31 11 0	4 7 0
South-Eastern Railway, Cannon Street Station (1867)	190	13,875	43 10 0	6 0 0
South-Eastern Raily., Charing Cross Station (1864)	166	8,888	34 0 0	6 0 0

Victoria Station and Charing Cross Station have since been entirely rebuilt.

Seaside Resorts.

Estimated costs, based on actual costs, 1927.

Bathing Pools, open, including accommodation for spectators, require a capital outlay of about 1*l.* per head of population, or 20*l.* to 30*l.* per square foot of water area.

Bathing châlets, with gas and water laid on, frequently fetch a rental of 35*l.* to 50*l.* a year.

Foreshore Lay-out is commonly 2*l.* per head of population, and in one case was 17*l.* per head.

Groyning, to form and maintain beaches, may cost 15,000*l.* per mile of beach.

Hard Tennis Courts, red or green, 6*s.* to 7*s.* per square yard of surface.

Sea-Walls.

Sea-walls to protect coast line, formed of 1 to 6 Portland cement concrete, 10 ft. high from base to top, 4 ft. average thickness, including foundations and excavating in clay, in tide-work, pre-war average cost—

6*l.* per yd. run, or 2*l.* per ft. run.

Pre-war actual costs from *Marine Works*, by E. Latham, M.I.C.E. (1922. 16*s.* Crosby Lockwood & Son, London.)

	Cost per yd. run. £ *s.* *d.*
Bridlington.—Alexandra sea-walls (1879). 340 yards long, of mass concrete 5 ft. thick at base and 3 ft. at top, curved on face. Concrete apron 9 ft. wide, and 2 to 2½ ft. thick, the toe-piece being 6 ft. deep and 18 ins. thick. Back of wall is battered 1½ in. per foot. Counterforts at 20 ft. centres. Wall is 20 ft. high, with projecting cornice, coping, and handrail. Chains embedded to act as bonds for the concrete. For details see *Coast Erosion and Protection*, pp. 49–50, by E. R. Matthews, A.M.I.C.E. (1918. Charles Griffin & Co., London); and *Proceedings of the Institution of Civil Engineers*, vol. clix. p. 65. Total, £5,657 .	16 12 9
Bridlington.—Beconsfield sea-wall (1888). 340 yards long, with Bramley Fall rock-faced stone and concrete backing. 1¾ in. wrought-iron tie-rods at intervals. 12 ft. 3 ins. thick at base, and 4 ft. at top, stepped and curved on face. Total height, 25 ft. 7 ins., with projectng cornice, coping, and handrail. Counterforts, 3 ft. 6 ins. by 3 ft. 6 ins, and 20 ft. apart, centre to centre. For details see *Coast Erosion and Protection*, pp. 47-48, by E. R. Matthews, A.M.I.C.E. (1918. Charles Griffin & Co., London.) Total, £10,000	29 8 3
Bridlington.—Sewerby sea-defence (1896). 305 yards long. Combination of rubble and timber, with two rows of 12 in. × 12 in. pitch-pine piles, 10 ft. apart. Front piles are 15 ft. long driven 9 ft. into the clay, and back piles 23 ft., driven 10 ft., with tie piece, 9 ins. × 4 ins. Face of 11 in. × 3 in. planking, and back planking 11 ins. × 4 ins., with 9 in. × 6 in. bearers and 11 in. × 4 in. ribs. Puddle clay backing, 2 ft. 6 ins. thick. Block chalk filling between the timber work. Foot-path on top. For details see *Coast Erosion and Protection*, pp. 86–88, by E. R. Matthews, A.M.I.C.E. (1918. Charles Griffin & Co., London); and *Proceedings of the Institution of Civil Engineers*, vol. clix. p. 65. Total, £3,000 . . .	9 16 8
Extension of ditto in 1899, by 82 yards, £788	9 12 2
Chatham (1913).—Reinforced concrete revetment on the De Muralt system on the banks of the Medway. Protects a length of 90 yds. of bank between two wharves	7 15 5
Frinton (1912–13).—Reinforced concrete apron 200 yds. long, to protect a stone pitched sea-wall at Frinton in Essex, which was being undermined by the waves. Apron 12 ft. wide, sloping 1 in 12, and 4 ins. thick, reinforced with Clinton fabric and ½ in. steel bars. Front toe wall, 9 ins. thick and 2 ft. high, with ½ in. steel bar reinforcement. 6 in. × 3 in. reinforced concrete ribs, with ½ in. steel bars .	2 5 0
Hornsea.—Reinforced concrete sea-wall. For details see *Proceedings of the Institution of Civil Engineers*, vol. cxxxv. p. 151	39 0 0
Lowestoft (1901–1903).—North Denes. Mass concrete sea-wall on steel piles, including steps, filling, and excavation. Total length with returns, 5,744 ft. run. Cost per yd. cube, 21*s.* 2*d.* For details see *Proceedings of the Institution of Civil Engineers*, vol. clxxxv. p. 106	5 11 6
Maintenance.—Maintenance of earthen embankments along river fronts or sea shores, about 18 ft. high to top of wall and protected by stone pitching or light reinforced concrete revetment; average cost of maintenance per annum (1910–13) when in normal repair	4*d.* to 4½*d.*

Sewage Works.

Sewage disposal works for cities and towns . . .	3*l.* to 6*l.* per inhabitant.
Bacteria filter-beds with earth embankments and floors, completed with clay puddle, and filled in with clinker or coke breeze 3 ft. deep	5*s.* to 10*s.* per yd. sup.
Ditto with concrete walls, and clinker or coke breeze 4 ft. deep	20*s.* to 30*s.* ,,

Precipitation and sludge tanks in the north-west of England, to treat a million gallons of sewage daily, built in 1910. From actual tenders received.

	£
Scheme with cast-iron tank plates	7,000
,, ,, brickwork in cement	6,000
,, ,, reinforced concrete	4,500

Bio-aëration System.—Complete works on the bio-aëration system, including aëration or circulating tanks, settling tanks of the Dortmund type, gauging chambers, sludge wells, motor houses, pump houses, etc., cost from 25,000*l.* to 30,000*l.* per million gallons, d.w.f., according to size and local circumstances (1924).

Activated Sludge Process.—The estimated cost for a complete activated sludge scheme, dealing with all storm water and treating all the sludge, is 1*l.* per head (1924).

Reading.—Activated sludge plant on the diffused air method, completed in 1924, designed to treat the whole flow of the city, amounting to 3½ million gallons d.w.f. per 24 hours, from an estimated future population of 120,000, cost 72,813*l.*, or 12*s.* 1½*d.* per head.

Strensall Camp Sewage Works, near York (1914–16).—For 1,000 nominal number of troops at 20 gals. per head per day, or 20,000 gals. sewage per day. Lift system, ground being low and sandy. Drainage connections comprised replacing 86 e.c.'s by w.c.'s, 18 additional w.c.'s, or 104 total w.c.'s, 234 gullies, and 80 manholes, with 4-in. and 6-in. stoneware drains gravitating to the ejectors. Brick engine shed, 15 ft. by 14 ft., for air compressor plant with 2 gas engines, and 4 ejector pits, with 12-in. concrete walls lined with ⅝-in. cast-iron plates, and concrete floors with expanded metal; pits octagonal in plan, 12 ft. internal diameter and 12 ft. average depth, containing 5 pneumatic ejectors, 25 gallons each, 1 pit holding 2 ejectors. 2½ in. steel compressed air mains from engine-house to ejectors, which raise sewage to the 5-in. and 6-in. cast-iron rising main drains and thence 1,700 yards (about a mile) to the outfall works. Total lift for sewage, 19 feet. Outfall works include two reinforced 6-in. concrete tanks, 20 ft. × 10 ft. × 6 ft. each, containing 7,500 gallons, or 15,000 gallons altogether; two brick sludge beds, 20 ft. × 10 ft. × 3 ft. each, with 10-in. screened ashes at bottom and 4-in. agricultural drains on 6-in. concrete floor; two circular filter beds, 46 ft. diameter, with rubble sides and reinforced concrete floors filled with 5-ft. furnace clinker, ½-in. to 4-in. gauge, the liquid sewage being distributed by a revolving sprinkler delivering 84,000 gallons per day. Special filter tiles on floor for aeration, concrete surface channel all round, and effluent then taken by waterways for land irrigation prior to discharging into existing ditch. Cost under five separate contracts:—

	£
Drainage connections, w.c.'s, stoneware drains, and manholes	2,710
Brick engine shed, and four concrete and iron ejector pits	775
Five ejectors, compressors, two gas engines, 2½-in. steel air mains, and 5-in. and 6-in. cast-iron main drains	1,837
Outfall works, including tool house, wire fence, and entrance road	2,035
Preparation of 13 acres of land, waterways and ditches for effluent	493
Total cost	7,850

Cost per head, 7*l.* 17*s.*, or 392*l.* 10*s.* per 1,000 gals. per day treated.

STANDS.

Permanent stands for athletic or race meetings, displays, processions, reviews, etc., constructed of brick, concrete, or reinforced concrete, with refreshment rooms, kitchens, offices, weighing and saddling rooms, lavatories, drainage, water supply, electric light, seats, etc., roofed or partly roofed—

2*l.* to 3*l.* per spectator, or head of accommodation.

Imperial Stadium, Wembley, near London (1920–1923).—Major axis, overall length, 900 ft. and maximum overall width 650 ft. Oblong of grass for football and sports in centre 492 ft. × 260 ft., with cinder running tracks, encircled by a wide stepped slope for spectators beyond which begins the structural work with terraces of concrete steps, roofed in for 650 ft. on each side of the stadium and provided with seats. Total accommodation, including seated grand stands, ring seats, standing enclosures and terraces, 125,200 spectators. A space of 16 ins. is allotted per ring seat, and 17½ ins. for a grand stand seat. Royal box, banqueting hall, 215 ft. × 70 ft., for 1,000 people, dressing-rooms, shower baths, lavatories, board-room, box office, gymnasium with seats for 250 spectators, recreation room with billiard tables and reading tables, buffets, cloak-rooms, tea-rooms for 600 people at a time, observation gallery, offices, press gallery, special heating, 96 turnstiles, telephones, electric lighting and cooking, wireless, good water supply and drainage, etc. The whole structure is of reinforced concrete on a steel skeleton, and there are 25,000 tons of concrete, 1,400 tons of structural steelwork, 31 terraces of concrete steps on steel joists, girders, and stanchions, and steel-framed roofs covered with corrugated asbestos sheets. Height from ground to roof eaves of stand is 50 ft. Two towers 160 ft. high, flank the royal entrance, and high walls on main frontage, with arched openings with an average span of 50 ft. The whole structure is larger than the Coliseum, Rome, which held 80,000 people. Architects, Sir John W. Simpson, F.R.I.B.A., and Mr. Maxwell Ayrton, F.R.I.B.A. Engineer, Sir Evan O. Williams, B.Sc., A.M.I.C.E. General contractors, Sir Robert McAlpine & Sons, and numerous sub-contractors. Total cost, 300,000*l.*, or 2*l.* 8*s.* per spectator.

TANKS.

Tanks, cast-iron, 5,000 to 10,000 gals., supplied only	1*s.* 6*d.* to 2*s.* per f.c., 3*d.* to 4*d.* per gal.
„ wrot.-iron „ „ „	2*s.* to 2*s.* 6*d.* „ 4*d.* „ 5*d.* „
Galvanised wrot.-iron square cisterns, 14 W.G., 50 to 500 gals. capacity, exclusive of fixing	2*s.* 6*d.* to 4*s.* „ 5*d.* „ 8*d.* „
Add if covered in at top	6*d.* to 1*s.* „ 1*d.* „ 2*d.* „

TELEPHONES.

Providing and fixing complete, including copper line weighing 150 lbs. per mile, with poles, brackets, insulators, etc.

25*l.* for ¼ mile ; 30*l.* for ½ mile ; 38*l.* for 1 mile ; and beyond, 30*l.* per mile.

TRAMWAYS.

Approximate Cost per Mile.	Single Track. £ £	Double Track. £ £
Electric tramways, overhead trolley system, with span wires, including buildings and equipment, but exclusive of generating station for electricity	9,000 to 12,000	15,000 to 20,000
Ditto, ditto, with side brackets or centre poles	7,000 „ 10,000	14,000 „ 18,000
Overhead equipment, including supports :—		
Span wire construction	1,200 „ 1,500	1,600 „ 2,000
Bracket arm construction	900 „ 1,200	1,300 „ 1,700
Permanent way, granite setts :—		
3 ft. 6 in. gauge, 100 lb. rails	4,000 „ 5,000	8,000 „ 9,000
4 ft. 8½ in. gauge, 100 lb. rails	5,000 „ 6,000	9,000 „ 10,000
Conduit system, centre slot, with underground wires, including special work	12,000 „ 15,000	23,000 „ 28,000
Cable tramways, mechanical, with underground cables, etc.	15 000 „ 20,000	25,000 „ 30,000
Horse tramways, with stables, cars, etc.	6,000 „ 9,000	12,000 „ 15,000
Steam tramways, with locomotives and cars	7,000 „ 10,000	13,000 „ 16,000

The cost of line per mile varies according to power station, plant, number of cars, cables, class of paving for permanent way, gauge and weight of tram-rails, etc.

PROPORTIONATE COST OF PARTS.

	Per cent.
Permanent-way construction	50
Overhead construction	10
Street alterations, etc.	5
Cables, feeder pillars, etc.	10
Power stations, buildings, plant, etc.	8
Tramcars	7
Supervision and incidental expenses	5
Compensation and legal charges	5
	100

Cars per mile of single line	3 to 6
Motor terminal voltage	500 to 550

Trolley vehicle system of electric railless traction :—	£ £
Capital cost per mile of route, double wire	2,000 to 3,000
Good overhead work, per mile	1,200 „ 1,500
Vehicles, cost of each	700 „ 800
Obtaining Parliamentary powers	1,000 „ 5,000
Cost of working per car mile	5*d.* „ 6*d.*
Traffic receipts per car mile	6*d.* „ 11*d.*

ACTUAL COSTS OF TRAMWAYS PER MILE.

Parts of Construction.	Edinburgh Cable Conduit.	South London (1903). Electric Conduit.	Electrical Overhead Trolley System. Glasgow.	Huddersfield.	Leeds.	Sunderland.
	£	£	£	£	£	£
Permanent-way construction	14,431	13,460	5,849	5,589	5,600	6,810
Overhead construction	—	—	776	928	1,173	720
Street alterations, etc.	890	134	—	245	—	522
Cables, feeder pillars, etc.	221	2,301	3,068	904	1,000	312
Power stations, buildings, plant, etc.	7,994	3,933	7,188	1,440	3,477	1,543
Tramcars	1,780	4,363	2,573	1,125	1,875	2,240
Supervision and incidental expenses	1,000	915	348	50	—	380
Total cost per mile of single track	26,316	25,106	19,802	10,281	13,125	12,527
Cars per mile of single track	4·1	6·1	5·25	2	2·91	3·4
Length of single track in miles	35	16	130	35	81	21
Motor terminal voltage	—	550	500	500	500	500

Aberdeen, overhead trolley system, 4 ft. 8½ in. gauge, exclusive of generating station, cost per mile of double track . . . . . £ 13,400

Darwen, overhead trolley system, 4 ft. gauge, exclusive of power station, total 35,000*l.*, per mile of double track 13,000

Dover, overhead trolley system, 3 ft. 6 in. gauge, exclusive of power station, total 28,000*l.*, per mile of single track 7,000

Manchester (1905), overhead trolley system, current provided by the lighting station, cost per mile of track 12,500
Permanent way, cables, and electrical equipment only, per mile of track . . . 6,575

Portsmouth, overhead trolley system, 4 ft. 7¾ in. 'Scotch' gauge, exclusive of power station, but including taking up old tram lines and concrete foundations and new ditto, cost per mile of double track 21,000
Ditto, including power station and machinery, ditto 23,900

Staffordshire, Bristol, and Coventry, capital expenditure on electric tramways per mile of single track, average 12,000

Wolverhampton, permanent way, electrical equipment, and cables, on the Lorain surface contact system, per mile 8,600

WORKING EXPENSES.	Per car mile. d.
Aberdeen, electric overhead trolley system, including interest on sinking fund	9·00
Birmingham, 1890–1, electric accumulator	9·90
" " cable traction	6·33
" " horse traction	9·79
" " steam traction	10·99
Dover, overhead trolley system, including interest on sinking fund	8·75
London County Council conduit tramways worked on purchased current, in 1905–6	8·02
Staffordshire, Bristol, and Coventry electric trams	6·30
Modern electric trolley lines generating their own current work	5*d.* to 6*d.*
" " " where current is purchased	6*d.* to 7½*d.*

The Peak Cable Tramway, Hong-Kong (1888).—Rises 1,207 ft. in a total length of 4,690 ft. Maximum gradient 1 in 2, and minimum 1 in 25. Three intermediate stations, and top and bottom termini. Single track 5 ft. gauge of two 30-lb. rails, and steel sleepers 24 lbs. per yard. Midway crossing place 130 ft. in the clear, above which the track is formed of three rails. Power-house at summit, with two engines, boilers, etc. Steel haulage cable, 3½ in. circumference, weighing 2 lbs. per ft. run. Rolling stock consists of two cars, each holding 45 passengers, and one ascends while the other descends, 9 minutes per trip. Total cost, 20,000*l.*, or at the rate of 22,516*l.* per mile.

(See p. 776.)

Tube Wells.

Driven tube wells sunk in ordinary ground, including use of tackle, well driver's time, and wrought-iron lap-welded tubes, approximate costs as detailed below; add pumps. The quantity of water obtainable depends on the water-bearing strata, and can be increased by connecting two or more wells together. See also 'Artesian Wells.'

Depth of Tubes, etc.

		Internal Diameter.		
		1¼ in.	2 in.	3 in.
Not exceeding 15 ft. deep	each	4*l.*	7*l.*	11*l.*
15 ft. to 20 ft. deep	,,	5*l.*	8*l.*	13*l.*
20 ft. ,, 25 ft. ,,	,,	6*l.*	10*l.*	16*l.*
25 ft. ,, 30 ft. ,,	,,	7*l.*	12*l.*	20*l.*
30 ft. ,, 35 ft. ,,	,,	8*l.*	13*l.*	22*l.*
35 ft. ,, 40 ft. ,,	,,	9*l.*	14*l.*	24*l.*
If beyond this depth, per foot deep		4*s.*	7*s.*	12*s.*
Sand strainers	each	20*s.*	30*s.*	40*s.*
Galvanised perforated driving points in 3 ft. lengths	,,	1*l.*	2*l.*	3*l.*
Special point of tough yellow metal for waters impregnated with iron	,,	2*l.*	3*l.*	5*l.*
Average quantity of water obtained, gallons per hour:		150 to 900;	300 to 1,500;	450 to 3,000.

Description of Pump.

	Size of barrel.		
	3 in.	3½ in.	4 in.
Standard pump, with valve door, supplied only, each	3*l.*	4*l.*	5*l.*

Tunnels.

Estimated Costs, 1924.

Cost of all tunnelling varies considerably according to locality, nature of excavations, pumping, size and depth of shaft, lining, distance to remove spoil, etc.

Adits.—Headings or tunnels at bottom of shafts, including excavating, removing, and raising material from a depth not exceeding 100 ft., and length of tunnel not exceeding 50 yds. from mouth of shaft, timbering, etc., complete, but exclusive of pumping:—

4 ft. × 6 ft. in clay, gravel, or soft chalk	per ft. run	2*l.* to 3*l.*
do. in hard rock requiring blasting	do.	4*l.* ,, 5*l.*

Aqueduct Tunnels.—As constructed in connection with large waterworks:—

Tunnels lined with concrete, 10 ft. diameter	per yard run	70*l.* to 100*l.*

Canal Tunnels.—As for inland navigation by ordinary canal boats, 72 ft. long × 7 ft. wide, average dimensions of tunnels being 16 ft. × 18 ft.:—

Excavation in clay, and lining with brickwork and concrete	per yd. run	50*l.* to 80*l.*
Excavation in rock, and lining with masonry and concrete	do.	80*l.* ,, 120*l.*

Irrigation Canal Tunnels.—As constructed in India to convey water from the mountainous districts to the lowlands, the average dimensions being 18 ft. wide by 12 ft. high. The longest is the Swat Canal Tunnel, 11,235 ft., and the next, the Pariyar Tunnel, 5,704 ft.

Irrigation canal tunnels in hard rock	per yd. cube	2*l.* to 3*l.*
,, ,, ,,	per yd. run	40*l.* ,, 60*l.*

Railway Tunnels.—Cost depends upon nature of excavations, lining required, etc. :—

For narrow-gauge or metre railways (3 ft. 3⅜ ins.), single track	per yd. run	50*l.* to	100*l.*
For standard-gauge railways (4 ft. 8½ ins.), single track	,,	80*l.* ,,	150*l.*
,, ,, ,, ,, double track	,,	150*l.* ,,	300*l.*

Ordinary Tunnels.—Ordinary tunnelling, cubic rate. It is generally cheaper to tunnel than to make a cutting over 50 ft. deep, but a good deal depends upon whether earth is required for embankments, and upon the kind of ground.

	Per yd. cube.
	s. *s.*
Tunnelling or driving headings, 20–50 ft. sup. sectional area, not exceeding 50 ft. below surface of ground or 50 yds. from shaft or adit, including use and waste of timbering, and drawing spoil to foot of shaft ready for removal :	
in ordinary ground, sand, or gravel	9 to 11
in stiff clay or shingle	12 ,, 14
in hard, solid chalk and flints	17 ,, 20
in soft rock not requiring blasting	45 ,, 50
in hard rock requiring blasting	55 ,, 60
Hoisting spoil from foot of shaft to ground surface, for any depth not exceeding 25 ft.	2 ,, 3
Extra only for every additional 25 ft. in height	1 ,, 2
Removing not exceeding ½ mile, and depositing	4 ,, 5
Excavating in large tunnels not less than 18 ft. wide × 20 ft. high, including fixing and removing temporary timbering and shoring, and removal of spoil not exceeding 1 mile :	
in ordinary ground, clay, or gravel	20 ,, 30
in soft rock not requiring blasting	30 ,, 40
in hard rock requiring blasting	40 ,, 70

Open Shield Tunnelling.—For subways or tunnels under rivers, with open headings and ordinary atmospheric conditions. Cost includes providing, fixing, and removal of timbering, shield, hydraulic jacks, pumping machinery, electric light, lifting excavated material to surface of ground, etc., but *exclusive* of concrete, masonry, or iron lining to tunnel ; for quantities not less than 3,000 yds. cube.

	Per yd. cube.
	s. *s.*
Open shield tunnelling, 100–200 ft. sup. sectional area, not exceeding 50 ft. below surface of ground nor 300 yds. from mouth of tunnel :	
in ordinary ground or sand	50 to 70
in stiff clay or gravel	60 ,, 80
Open shield tunnelling, 200–400 ft. sup. sectional area :	
in ordinary ground or sand	70 ,, 90
in stiff clay or gravel	80 ,, 100
Add for every additional 25 yds. in length	1 ,, 2

Pneumatic (or Closed Shield) Tunnelling.—For excavations in water-logged ground under air pressure, the closed shield having bulk-heads and air-locks, to admit and remove materials, workmen, etc. Cost includes providing, fixing, and removal of timbering, shield, hydraulic jacks, pumping machinery, air-compressing plant, electric light, raising excavated material to surface of ground, etc., but *exclusive* of concrete, masonry, or iron lining to tunnel ; for quantities not less than 3,000 yds. cube.

	Per yd. cube.
	s. *s.*
Pneumatic shield tunnelling, 100–200 ft. sup. sectional area, not exceeding 50 ft. below surface of water or ground nor 300 yds. from mouth of tunnel :	
in ordinary ground or sand	100 to 120
in stiff clay or gravel	110 ,, 130
Pneumatic shield tunnelling, 200–400 ft. sup. sectional area :	
in ordinary ground or sand	120 ,, 140
in stiff clay or gravel	130 ,, 150
Add for every additional 25 yds. in length	2 ,, 3

Tunnel Shields.—The cast-iron lining of a shield-driven tunnel is equivalent to about one-third total cost of tunnelling. The shield was first used by Brunel at the Rotherhithe tunnel in 1825, then by Mr. Greathead at the Tower subway in 1869, and the improved 'Greathead' shield in

1884 on the City and South London Railway. It consists of a steel ring with cutting edge, which is pushed forward by hydraulic jacks about 3 ft. apart. Tube railways and subways vary from 11 to 30ft. diameter, with 8–28 jacks per shield, and the tunnelling progresses at the rate of 30–60 ft. per week.

Costs complete with bolts, nuts, hydraulic jacks, etc., but *exclusive* of hydraulic machinery, piping, etc.:

Steel open tunnelling shields complete, 10–20 ft. external diameter, 40*l.*–50*l.* per ton
each 1,000*l.* to 4,000*l.*

Steel closed tunnelling shields complete, 12–25 ft. external diameter, 50*l.*–70*l.* per ton
each 4,000*l.* to 12,000*l.*

Tunnel Maintenance.—Cost of reinstating 3- to 6-ring double-track railway tunnels, in sand, clay, or chalk, including cutting out the inner ring and replacing by a brindle ring in cement, sometimes an additional ring, or part of the tunnel inverted, toe wall built to the footings, parts of the wall relined, or spaces behind walls and over arches filled with concrete, etc., the work being carried out day and night during traffic by contract or departmentally, a single line run at night, and taking various periods of from three to eight years to complete.

20*l.* to 40*l.* per lineal yard:

Other tunnels requiring more extensive repairs, such as shoring, bad portions cut out, and completely rebuilt, use of cement gun, etc.:

60*l.* to 500*l.* per lineal yard.

TUNNELS. Actual Costs.	Date. Years.	Length. Yds. Run.	Ft. Per Day.	Total in thousands	Per Y.R.
				£	£
Arlberg (6½ miles), Austria. 2 tracks in single tunnel, 25 ft. 3 ins. wide by 21 ft. high, partly lined with masonry	1880–84	11,210	28	1,204	107
Hoosac (4¼ miles), Massachusetts, U.S.A.	1855–76	8,390	7	2,014	240
Loetschberg (9 miles), Berenese Oberland	1906–11	15,973	36	2,556	160
Mont Cenis (7⅝ miles), France to Italy. 2 tracks in single tunnel, 26 ft. 3 ins. wide by 24 ft. 7 ins. high. Through solid granite, brick and stone lined	1857–71	13,712	9	2,880	210
Severn (4⅜ miles). 2 tracks in single tunnel, 26 ft. wide by 24½ ft. high, lined with 3 ft. brickwork. Water-logged ground and expensive pumping. Ventilated by fan 40 ft. diam. Hawkshaw, Hayter, and Richardson, engineers	1879–86	7,674	6	2,250	293
Simplon (12¼ miles), Switzerland to Italy. 2 single-track tunnels, each 16 ft. 5 ins. wide by 19 ft. 6 ins. high, 56 ft. apart axis to axis. Enlarged in 1911, at 1,600,000*l.* A. Brandt, engineer	1898–1906	21,578	28	3,120	145
St. Gothard (9½ miles), Switzerland to Italy. 2 tracks in single tunnel, 26 ft. 3 ins. wide by 24 ft. 7 ins. high, in granite and lined with masonry. Louis Favre, engineer	1872–82	16,426	18	2,300	140

WATER TOWERS.

Water towers, brick, exclusive of tanks and pipes, 1*s.* to 1*s.* 4*d.* per ft. cub., 2*s.* to 5*s.* per gal. Water supply inside a building, including service pipes, taps, etc. 2*l.* 10*s.* to 3*l.* per tap.

Beverley Water Tower, Yorkshire (1915).—Built of reinforced concrete on the Hennebique system. Two circular tanks, one within the other, the inner one holding 4,000 gals and the other

7,200 gals., or a total of 11,200 gals. Extreme diameter 34 ft., and 10 ft. internal depth, with three 6-in. cast-iron outlets, 4-in. sides, 2-in. curved dome top, 4-in. bottom, with beams under, supported on three 12-in. × 12-in. columns or legs, 30 ft. high, with 12-in. × 8-in. braces to latter and half-way up. Total height from ground level to top of tank, 42 ft. 6 ins. Concrete foundations, 2 ft. deep. Cost, including materials and erection, 312*l.*, or 27*l.* 17*s.* per 1,000 gals.

Bramham Moor Water Tower, near Tadcaster, Yorkshire (1916).—Designed by the Trussed Concrete Steel Co. Two united rectangular tanks, 4,000 gals. and 6,000 gals., or a total of 10,000 gals.; two iron ladders inside the tanks for cleaning purposes, and 3-in. cast-iron outlets; 5-in. sides, 3½-in. flat top, 6-in. bottom, with 24-in. × 10-inch beams under, supported on four 10 in. × 10-in. columns or legs, 20 ft. high, with 10-in. × 6-in. braces to latter and half-way up. Foundations 2 ft. 6 ins. deep in addition. Cost, including materials and erection, 298*l.*, or 29*l.* 16*s.* per 1,000 gals.

Curragh Water Tower (1900).—Heavily built, 34 ft. square externally and 94 ft. high above ground. 6 stories. Concrete foundations 6 ft. thick, brick walls in cement 45 ins. thick below to 22 ins. at top. Flat concrete roof, asphalted. Contains two cast-iron tanks, 20,000 gals. each, or 40,000 gals. total. Lower floors used as a fire engine station. Building only, 9,300*l.*; cast-iron tanks and pipes, 1,630*l.*; special fittings, 70*l.* Total, 11,000*l.*

1*s.* 4*d.* per ft. cu. 275*l.* per 1,000 gals.

WATERWORKS.

Waterworks, comprising reservoirs, filter beds, mains, valves, hydrants, etc., complete:

	£	
Birmingham	3	per head of population.
Dublin	2	" "
Edinburgh	3½	" "
Glasgow	3	" "
Liverpool	4	" "
Manchester	3	" "
Generally speaking	2*l.* to 4	" "
Small waterworks in Ireland (20 to 25 gals. per head.)	2*l.* to 2½	" "

Batticaloa Water Supply, Eastern Province, Ceylon (1915–16).—Supplies a population of 6,000 with about 20 gals. per head per day. One central well 10 ft. diameter, and two auxiliary wells same diameter, connected by adits 500 ft. long, yielding 180,000 gals. per day. From the central well the water is pumped through a 7-in. steel delivery main to the reservoir, 4 miles distant, from which the town is supplied by gravitation by 2-in. and 1½-in. distributing mains to 75 standpipes. 11½ miles of pumping and service mains altogether. Pumping machinery in duplicate. 3-in. centrifugal pumps, belt-driven by 18 B.H.P. oil engines, each pump capable of delivering 10,000 gals. per hour against a total head of 60 ft., or a total pumping capacity of 100,000 gals. per diem working 10 hours. Wells lined with 12-in. concrete, roofed with concrete slabs. Storage reservoir of 100,000 gals., with concrete walls faced in brick cement rendered and roofed with corrugated iron on steel trusses. Cost, 9,533*l.*, or 95*l.* per 1,000 gals., or 1*l.* 12*s.* per head of population supplied.

New Magdalen Barracks Water Supply, Oxford (1896).—Supply from City of Oxford Water Company's mains, constant service, Siemens' meter supplied by Company. • Davey's lift and force pump worked by steam power, and 6 in. cast-iron mains, 3 in. cast-iron domestic supply mains, and 1½ in., 1 in., ¾ in., and ½ in. galvanised wrought-iron service pipes, 3 to 4½ ft. deep. Reserve tank of 13,000 gals. for fire purposes, 60 ft. high on Armoury roof, 18 fire hydrants, 20 sluice valves, 40 stop valves, 280 bib valves, 50 3-gal. flushing cisterns to w.c.'s, and 6 200-gal. cisterns to latrines. Occupation of barracks, 500 adults, 100 children, and 5 horses. Total cost, including 800*l.* for machinery and erection, 3,500*l.*, or 5*l.* 16*s.* 8*d.* per head of occupation, exclusive of horses. 6*s.* 6*d.* per yd. run of excavation, exclusive of machinery, but inclusive of all fitments.

(See also p. 1480.)

IMPOUNDING RESERVOIRS.

Impounding reservoirs for gravitation waterworks to large towns, including excavations, embankments, etc.

200*l.* to 700*l.* per million gallons storage.

	£	
Arnfield, for Manchester waterworks	432	per million gals. storage.
Crowden " "	561	" "
Hollingworth " "	458	" "
Tellowfold " "	722	" "
Monmouth	912	" "
Rooden, for Oldham	491	" "
Sheffield waterworks, structure only	210	" "
Ditto, including Parliamentary expenses, payments for compensation, etc.	485	" "
Swansea	550	" "
Swinshaw, for Ashton-under-Lyne and Stalybridge	405	" "
Walshaw Dean, for Halifax	469	" "

Curragh Old Waterworks Pumping Station.—Different dates, 1859, 1907, 1915, and 1921. Includes concrete reservoir, corrugated iron fence, brick engine house, boiler house, chimney shaft, workshop, coal yard, engineer's cottage, and new corrugated iron engine shed, engineer's hut, concrete tanks, old and new wells with bored Artesian tubes, 112 ft. and 276 ft. total depths respectively, barbed wire fencing, water-main connections, and 1,550*l.* worth of machinery, complete . . . . . 9,550*l.* total cost.

13½-in. Artesian bored tube well (1907), including boring 52 ft. deep sunk in sand and gravel from the bottom of existing dug well which is 8½ ft. diameter and 59 ft. deep . . . . . 3*l.* 5*s.* per ft. in depth.

Ditto including men's time, fixing plant, testing, and carriage, and hire of compressor . . . . . 7*l.* 10*s.* ditto.

(The cost of this Artesian well is included in the 9,550*l.* total.)

Curragh Old Waterworks Reservoir (1887–93). In connection with pumping station. Uncovered, with puddle clay embankments, stone-lined. Steel fence all round. Size, 320 ft. × 260 ft. × 6 ft. deep, and holds 3,100,000 gals. Total, 2,760*l.* 1½*d.* per foot cube. Reservoir now disused . . . . . 18*s.* per 1,000 gals.

Selby Waterworks Reservoir (1908). 800,000 gals. 12-in. concrete floor, brick walls, 50½ ins. thick at base and 22½ ins. at top, 6-in. concrete roof in arches of 7 ft. span. Total, 4,800*l.* . . . . . 6*l.* per 1,000 gals.

In the London Metropolitan area—

Cost of pumping averages 43 per cent. of the entire maintenance expenditure.
Cost of pumping alone averages 50*s.* per million gallons.
Repairs and renewals of water-mains and pipes, 34*s.* per million gallons.
Maintenance of water-mains or pipe-way, 24*l.* per mile.
Cost of filtration, 7*s.* 5*d.* per million gallons.

Assuan Dam (1898–1902 and 1907–12).—The Assuan or Aswan Dam was built for irrigation purposes at the head of the first cataract of the Nile, about 600 miles from Cairo and 350 miles above the Assiout barrage. It was formed across 5 channels of the river, which flowed at the rate of 16 miles an hour, and constructed of local granite masonry in Portland cement, on a similar rock foundation which had dykes of softer igneous material. The original dam was 1½ miles or 6,600 ft. long, 100 ft. thick at bottom, tapering to 24 ft. at top, with a maximum height of 130 ft. from base. Total weight of stonework over a million tons; 180 sluice openings, closed by steel gates; 1,000 Europeans and 20,000 natives were employed. The barrier affected the Nile for 140 miles higher up, and turned it into a regular lake. The greatest difference of level of water above and below the wall was 67 ft., and navigation was provided by a ladder of five locks, each 260 ft. long and 32 ft. wide. This first dam was completed in 1902, and held about 250,000 million gallons, which brought over a million acres of desert under cultivation. Engineer, Sir Wm. Willcocks, and contractors, Sir John Aird & Co. Cost was 2,500,000*l.* constructional work and 2,000,000*l.* for land and compensation charges, or 4,500,000*l.* altogether. This latter is equivalent to 18*l.* per million gallons of storage capacity, or 4*l.* 10*s.* per acre of irrigation area.

Between 1907 and 1912 the foregoing original dam was raised an additional 23 ft., thickened by 16 ft. on the downstream side, lock walls widened, and new dock gates provided, so that the impounding reservoir or lake was now 240 miles long, and the storage capacity increased by an extra 310,000 million gallons. Another million acres were also brought under cultivation. The greater depth submerged the Philae temples well up the river. Sir Benjamin Baker was consulting engineer. Cost of extension, including land and compensation charges, was 1,500,000*l.*, equivalent to 4*l.* 17*s.* per additional million gallons, or 1*l.* 10*s.* per additional acre.

Total present capacity as enlarged, 560,000 million gallons, bringing two million acres under total irrigation, at a total cost of 6,000,000*l.* This is equivalent to an average of 10*l.* 14*s.* per million gallons, or 3*l.* per acre of irrigation, as finally completed.

Burrinjuck Dam (1909-20).—Or Barren Jack. The highest dam in the Empire and in the Blue Mountains of New South Wales, at the confluence of three rivers—the Murrumbidgee, the Goodradigbee, and the Yass, which the dam ponds up 40 miles, 13 miles, and 19 miles respectively. The artificial lake so created has a surface area of 20 square miles, or 12,800 acres, and is 220 ft. greatest depth, giving a capacity of over 33,000,000,000 cubic ft., or about 206,250,000,000 gallons. The dam is a massive wall in a deep gorge with cliffs 1,000 ft. high and only 300 yds. apart, the sides being so steep that it was impossible to establish workshops upon them, and it was also across the bed of a river subject to floods. The granite masonry is 236 ft. high from rock to crest, set in cement, and 186 ft. thick at base, tapering to 18 ft. at top. The dam is of the arch type with convex side turned up stream; radius of curve 940 ft. and length of arc 900 ft. Flood-water tunnel 14 ft. × 13 ft., and two culverts cut through the cliffs at the ends of the dam itself. The water had to be conveyed 260 miles, and then distributed by miles of canals

Scraping Water Mains.

Various Towns.—Actual cost by pipe scraper driven by water pressure and supplied by Glenfield & Kennedy, Ltd., Kilmarnock:—

Year.	Place.	Diam. of Main.	Length of Main.	Total Cost.	Cost per Mile.	Cost per Yd. Run.	Obstructions removed, other than corrosion.	Gain in Delivery after Scraping.
		Ins.	Miles. yds.	£	£ s. d.	s. d.		Per cent.
1880	Bradford	18	4 1,100	634	137 1 7	1 6¾	Stones, lead, crowbar, etc.	56
1883 } 1885 }	Whitehaven	11	3 1,223	516	81 19 5	11¼	Mussels, stones, and lead	28
		13	2 1,056					
1887	Omagh	6	2 792	53	21 12 8	3	Lead and defective castings	300
1887	Roubaix	24	4 1,162	425	91 3 11	1 0½	Calcareous matter	—
1890	Dumfries	8	4 0	113	22 12 0	3	Stones	—
		9	1 0					
1891	Lanark	7	6 880	75	11 10 9	1½	Lead, wood, and stones	34
1891	Newport	5	0 75	8	187 14 8	2 1½	High-pressure hydraulic main	—
1892	Burntisland	8	3 1,320	252	67 4 0	9¼	Lead, wood, and stones	43
1894	Waterford	13	8 0	212	26 10 0	3½	Broken pipe, rope	40
1895	Cupar-Fife	7	3 880	67	19 2 10	2½	Broken pipe, rabbit	52
1895 } 1896 }	Merthyr-Tydvil	12	6 770	178	27 13 0	3⅜	Broken pipe, lead, and stones	82
		14	5 617	318	59 [illegible] 8	8	About 400 stones	30
1897	Alfreton	7	4 0	57	14 5 0	2	Pieces of pipe and stones	30
1897	Cumnock	5	1 880	52	25 15 4	3½	Bad joints, stones, etc.	50
		6	0 912					
1898	Kirriemuir	6	6 0	78	13 0 0	1⅜	Bad joints	75
1899	Dunfermline	12	14 0	270	19 5 8	2½	Lead and stones	30
1899	Plymouth	24	1 880	300	200 0 0	2 3½	—	—
1899	Tarapaca, South America	5	56 0	714	12 15 0	1¾	Chisel and piece of metal	27
		7					Stones and metal	27
		9					30 tons of incrustation	22
1900	Innerleithen	6	0 1,300	60	81 4 7	11	Stones and piece of wood	60
1900	Pontypridd Water Works	9	4 880	277	23 1 8	3¼	Stones, 36 lbs. lead, cast iron. Piece of wood, gate hinge. Steel bar and a bolt	Gain of 100 ft. head.
		10	4 880					
		12	3 0					
1900	Cockermouth	15	7 880	470	62 13 4	8½	Stones and 3 tons corrosion	99
1900	Mossel Bay, South Africa	4	8 1,170	785	36 4 8	5	Lead, yarn, and metal	88
		4½	1 0					
		5	12 0					
1902	Pelotas, Brazil	12	9 830	450	47 10 2	6½	Large stones, etc.	44

over 1½ million acres of parched land, allowing the conservation of water for some 2,000 farms. Total cost about 3,000,000*l.*, or 14*l.* 11*s.* per million gallons of storage capacity, or 2*l.* per acre of irrigation area.

Croton Dam (1896–1911).—Or the Cornell Dam, which holds up the waters of the Croton River to form the great Croton lake reservoir which supplies New York with water, 33 miles away. A diversion canal, 1,000 ft. long and 2,000 ft. broad, was first excavated to divert the river before the dam itself could be commenced. The latter is about 1,200 ft. long, a maximum width of 216 ft., and greatest height 300 ft. from rock to crest, making it the highest in the world. It contains 833,000 cubic yards of masonry, and required 1,500,000 cubic yards of excavation. Owing to the rock being rotten, the foundations were carried in places 130 ft. below river-bed. Spillway built of granite blocks, some weighing 10 tons each. The lake behind the dam is 20 miles long, and contains 32,000,000,000 gallons of water. Three villages and numerous isolated buildings and farms were cleared away, and 75 miles of stone wall built round the reservoir. The outlay was excessive, as a large part was due to alterations and work which had to be afterwards undone, including the removal of the first core wall and taking up the earth on either side of it. Total cost about 1,600,000*l.*, or 50*l.* per million gallons of storage capacity.

Wentwood Reservoir, Newport (1894–1904).—Situated at Llanvaches, some ten miles from Newport, Monmouthshire. It has a water area of 41 acres, a depth of 86 ft., and a capacity of 410,000,000 gallons. The great dam, which is 456 ft. above sea level, is 97 ft. high, 800 ft. long, and 700 ft. wide at base, gradually tapering to 30 ft. wide at top. The inside slope is pitched from top to bottom. The valve tower and outlet are placed quite independently of the dam at the eastern end, and the culvert, which runs for a length of 900 ft. through the dam, is 6 ft. diameter and carries two water mains. Water is drawn into the reservoir from two streams in the Newchurch valley by means of a tunnel, which ranges from 3 ft. diameter at the Newchurch end to 6 ft. at the reservoir end; length of tunnel, 3,683 yds. Total cost, about 390,000*l.*, or 951*l.* 4*s.* per million gallons of storage capacity.

Scraping Water Mains.

Ayr.—Scraping 14-in. and 16-in. cast-iron water mains, 14½ miles long, at Ayr, between Loch Findas and the service reservoir at Dalrymple, in 1915. Pipes laid 28 years before, but incrustation reduced capacity by 30 per cent. Scraper weighed 3 cwts., and was driven by a pressure of 15 ft. head of water. When this pressure was unobtainable the instrument was pulled through by a chain. Pipes were divided into sections with inspection boxes, and each section was done twice, the scraper travelling at the rate of 2 miles an hour. Capacity of mains was at once increased by 37 per cent.

For 14-in. pipes the scraping alone cost 13*l.* 8*s.* per mile, or 2*d.* per yd. run.
„ 16-in. „ „ „ 12*l.* „ „ 1⅞*d.* „
„ 14-in. pipes the total cost was 34*l.* 5*s.* „ „ 4¾*d.* „
„ 16-in. „ „ „ 46*l.* 10*s.* „ „ 6¼*d.* „

Scraping is necessary every 3 years, owing to rapid reincrustation.

Prestwick.—Scraping 6 in., 8 in., and 10 in. water mains leading from the filters to the town, in 1923. In all 7,100 lin. yds. of pipes were scraped, and over 8 tons of corrosion removed. The pressure heads after scraping, as taken at air valves along the mains, showed an increase overall of 20 ft. The cost worked out at 1*s.* 5*d.* per yd. run.

Cleaning.—Cleaning 4 in. water main by the patent Powrcleer apparatus, supplied by the British Pipe Cleaning Co., W. & J. Glossop, Hipperholme, Halifax, for a minimum quantity of 1,000 yds., 1*s.* 4*d.* per yd. run (August 1922).

SECTION XLVI

DEPRECIATION OF PLANT AND MACHINERY—INCOME-TAX ALLOWANCES

(Contributed by Alfred B. Searle, Licensed Appraiser and Valuer.)

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DEPRECIATION OF PLANT AND MACHINERY—INCOME-TAX ALLOWANCES.

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Depreciation is a term applied to the reduction in value which occurs in plant or machinery, no matter whether they are in use or stored. The amount of depreciation is affected by the condition in which they are kept and by the availability or otherwise of more suitable appliances.

The loss in value is most properly met by an annual charge (to which the term 'depreciation' is commonly applied); the total of such charges should, when the appliance is worn out, discarded, or replaced by another, be equal to the difference between the original cost and the sum obtained (if any) by the sale of the worn-out or discarded appliance. Thus if a machine costing 1,000*l.* is discarded as useless after ten years and then is sold for only 10*l.* the total depreciation is 990*l.*, the annual depreciation is 99*l.*, and the residual value is 10*l.* The depreciation may be affected by any sums spent on renewing parts of a machine or plant, though these are usually charged separately in the accounts, as *renewals*.

The following terms are important:

Deterioration is the loss in value due to the lapse of time and to the use of the appliance. It occurs more rapidly when a machine is used than when it is stored under good conditions, but may be just as serious if a machine is stored under unsuitable conditions. In deterioration is also included the loss in value which occurs directly the ownership of anything has been transferred from the seller to the buyer, the 'second-hand value' being always less than the market price when new; the difference forms part of the loss by deterioration.

Obsolescence is the loss in value which occurs when a more suitable appliance can be used for the same purpose. It occurs when a machine is discarded, long before it is worn out, because another machine is more profitable to use.

Renewals are the cost of replacing worn-out or damaged portions of machinery or plant. To some extent they reduce the depreciation, but for convenience are usually treated quite separately. The Inland Revenue officials, for some purposes, take renewals instead of depreciation when calculating allowances for income-tax assessments. Thus, instead of allowing 3*l.* per annum as the depreciation on a typewriter, they allow nothing until the typewriter is replaced by another one; then they allow the cost of the new machine less the sum obtained by the sale of the old one, or a sum estimated to be obtainable for it.

Residual Value is the value of a machine or plant at the end of a given period—usually, but not necessarily, when it is worn out or discarded. In dealing with the estimated life of plant or machinery, the residual value of such plant or machinery when its period of usefulness has expired must be taken into account, and with plant of special nature it may generally be assumed that in proportion to its special character its residual value will be low. Plant of general character, engines, boilers, shaftings, pulleys, etc., carries a high residual value in the event of displacement.

Diminishing Value is the reduction in the value of plant or machinery as the result of depreciation or obsolescence, or both. The term is also used to indicate the value obtained by deducting depreciation for one year at a given rate, and then applying the same rate to the reduced value so obtained. Thus, if a machine costing 1,000*l.* is depreciated at 10 per cent. per annum on the diminishing value it will be worth 900*l.* at the end of the first year, 900*l.* — 90*l.* or 810*l.* at the end of the second year, 810*l.* — 81*l.* or 729*l.* at the end of the third year, and so on. This method is largely used because of its convenience, but it requires a larger rate of depreciation than when the rate is calculated throughout on the original value. In recent years there has been a tendency to revert to the basis of original cost. For instance, a rate of 10 per cent. on the original cost will exhaust the value in ten annual instalments; but a rate of about 16½ per cent. would be required to exhaust the value in the ten years if calculated on the diminishing value remaining after the deduction of depreciation in each year.

The argument in favour of basing the calculation on the diminishing value is that the sums written off in the earlier years were greater when the repairs were small, and this tended to equalise matters. Too often, however, the two factors of rate and basis have not been settled together, and consequently the basis of diminishing value has had the effect of leaving a considerable value in the books when the plant has disappeared. For instance, a 5 per cent. rate generally carries the impression of a twenty years' life, yet taking 100*l.* as the cost, and writing off on the diminishing value, the balance left at the end of the twentieth year is 37*l.* 14*s.* After twenty-one years' service the residual value of the plant would be, roughly, one-third of the first cost, a figure far too high in most cases. Besides, by adopting the basis of original cost, the position is much clearer for any revision of the rate at any subsequent period.

Rate of Depreciation.—This is usually expressed as a percentage of the original value of the plant or machinery, or on what is known as the diminishing value. The rate of depreciation is based on the assumed durability of the appliance, on its residual value, and on whatever allowance should be made for its becoming obsolescent before it is worn out. The determination of the rate of depreciation of various kinds of machines, etc., requires special skill and experience, and has given rise to specially trained appraisers or valuers, each of whom has expert knowledge of certain classes of plant or machinery; a valuer who is an expert on brewing appliances would probably know little of cotton-spinning, bricks, or presses, and *vice versâ*. It is, therefore, important that valuations should be made by men of *special* knowledge and not (as is usually the case in valuations for rating assessments and some other purposes) by men with only a general knowledge.

As different parts of a plant and different machines wear out or become obsolescent at different speeds, it is desirable to decide on a rate for each separate machine or appliance, though some grouping is desirable.

There is much difference of opinion as to what are suitable rates of depreciation, especially when accurate data on which to base them are not available. The following figures are only approximate, but they give a useful *general* idea, which may be greatly modified in particular cases.

Motive Power, Boilers, Engines, etc.—Some authorities place the depreciation on engines as high as 12½ per cent., and boilers at 10 to 15 per cent. Much depends on stress of working and the water. Mathieson places the life of a boiler at fifteen years, with renewal of the furnace at the end of ten years, and recommends a rate of 7½ per cent. per annum on the diminishing value on this class, no provision being made for obsolescence. This is, however, an extreme view.

Power Transmitters.—Shafting, pulleys, and plant under this head have, as a rule, a high residual value, even if displaced, and a rate of 5 per cent. will usually be found sufficient. Belting should be classified as loose tools. In this class a rate of 10 per cent. would be desirable. No provision is made for obsolescence.

Process Plant, Fixed.—Under this head would be placed all heavy process plant, the renewal portions of which are classified under their separate heading. The deterioration would then be met by a rate of 2½ per cent., the renewal rate at 2½ per cent. An obsolescence rate depending on the nature of the processes will also be needed; it may be 6 per cent.

Process Plant (Wearable).—For this it is necessary to provide a heavy renewal rate. By the dissection of this plant the separation of the different details can be secured, and it is easy to apply to each a distinctive rate for renewals applicable to its character and requirements, based on experience. It will usually be at least 10 per cent.

Process Plant (Loose).—In the case of loose tools, the yearly valuation gives the most reliable results. In some cases there is an annual increase in this class, but this should verify itself. It is to be remembered that at a going-concern valuation this cannot, in the nature of the plant, work out at more than half the original cost value.

Accessory Plant.—Usually has a high residual value due to general utility, and consequently a rate for deterioration of 2½ per cent. and a renewal rate of 5 per cent. should suffice.

Horses, Carts, Harness, etc.—The risks and depreciation on this class are too great to include in any average rate. A revaluation annually gives probably the best results.

The following rates of depreciation have been authorised by the Government of Australia in connection with the Federal income-tax on industrial establishments:—Boilers, 5 per cent.; boring machinery, 10 per cent.; cables, aerial, 7·5 per cent.; cables, underground, 2·5 per cent.; condensers, 5 per cent.; cranes, 5 per cent.; elevators, electric, 7·5 per cent.; elevators, hydraulic 10 per cent.; engines, steam, 5 per cent.; foundry cupolas, 15 per cent.; furniture, 5 per cent.; generators, 5 per cent.; machine tools, 5 per cent.; machinery used in ordinary manufacturing, 5 per cent.; meters, switchboard, 7·5 per cent.; motor trucks, 10 per cent.; patterns, 15 per cent.; pumps, 5 per cent.; galvanised iron tanks for rain water, 5 per cent.; galvanised iron tanks for other water, 10 per cent. The figures are based on the *diminishing value* of the assets and not on their original cost.

The following table, by Preece, gives (*A*) the approximate life in years of the various classes of machinery, etc., in an electrical undertaking if properly maintained, and (*B*) the probable residual

value at the end of that term in per cent. of original cost. It affords a useful means of checking any suggested rate of depreciation on the appliances, etc., mentioned, but is very incomplete and tends to include figures in column A which are too large for present-day conditions.

	A.	B.		A.	B.
Foundations	100	nil	Cables (solid in wood trough)	40	12
Buildings	80	nil	Buildings (sub-station)	50	nil
Boilers (water tube)	25	5	Sub-station equipment	25	12
Boilers (Lancashire)	22	3	Accumulators	15	10
Dynamos and alternators	30	8	Arc lamp-posts	40	5
Engines and other machinery	25	6	Arc lamps	12	5
Cables (armoured)	35	15	Electric motors	25	9

Methods of Estimating Depreciation.

Appraisers and valuers have various methods of estimating the depreciation of plant and machinery, and two men of equal skill may not agree in their estimate because they use a different method, or because they have different ideas as to the durability of a particular appliance; the latter affects the rate of depreciation. The two methods generally adopted are: (1) To assume a definite rate of depreciation on either the plant and machinery as a whole or definite rates for each part thereof, and to deduct this from either the original cost or the book value. (2) To value each individual part of the plant and machinery each year and write off the difference in value from that of the previous valuation. The Inland Revenue officers usually employ a third method, based on renewals.

All these methods are faulty. In the first the result is hazardous, especially if based on a single rate of depreciation on the whole plant and machinery, because different parts depreciate at different rates, and no single figure or 'average' can be accurate. Even if the plant and machinery are divided into groups or each individual item is taken separately errors may still occur, as it is by no means easy to find an accurate rate of depreciation for some appliances. In the second method an independent valuer is essential, and the method is therefore costly. A common device is to use the first method, applied to the plant and machinery after dividing it into five or six groups, and to adjust this by a revaluation by an expert every five years. This is probably the best compromise between accuracy and cheapness.

When the first method alone is used, a distinction must be made in the rate of depreciation, according as this is deducted from the original cost of the appliance or from its diminished value (see *ante*).

Fire Insurance and Depreciation.—Whilst it is a sound, general policy to write as much off for depreciation as possible, such a course has an adverse effect on insurance against fire, as the value in the case of a fire would be affected in the claim for replacement. It is usual in some offices to append a declaration on the face of the policy that the depreciation written off in the books shall not be taken for the purpose of assessing a fire loss. Usually the assured is covered for the value of the plant at the time of the fire, and that the original cost of the plant, less depreciation, is not necessarily the basis of the claim. There appears to be no scale of depreciation in force for different kinds of plant recognised by the insurance companies, but these losses are generally settled as between the assessors and surveyors acting for both parties, or, failing their agreement, by arbitration: no special rates are applicable, but each case is settled on its merits. The principal factor appears to be the possession of definite and specific information on the value and cost of the plant, and the rate of depreciation should not in any way govern the claim in case of fire.

It is a general provision in fire insurances and policies that the company may elect to replace the plant; instances of this have rarely occurred, if ever, and probably the replacement clause was never intended as other than a protection to the insurance company.

Depreciation and Income-Tax.—The rate of depreciation allowed by the inspectors appointed under the Income-tax Acts differs considerably in different localities. For instance, the rate of depreciation allowed to engineers in Leicester is 7½ per cent. on the full value, while in Cardiff the rate is only 5 per cent. on the diminished value. Hosiery machinery in Leicester obtains 7½ per cent. as against 5 per cent. on lace machinery in Nottingham. Dyers' machinery in Leicester can get 10½ per cent., if justified on inquiry. Generally speaking, a distinction is made between motive power and process plant, and the general practice assumes 5 per cent. on motive power and 7½ per cent. to 10 per cent. on process plant; these allowances are in respect of both deterioration and renewals.

The Inland Revenue authorities have now reverted, in a number of cases, to the basis of original cost, and where, say, 5 per cent. is allowed on original cost, there is an alternative rate of 7½ per cent. allowed on diminishing value.

On *Fixtures* no allowance for depreciation is made, unless they are included under the head of plant. Any replacements are allowed in full against the year's working.

Renewals.—The practice adopted by the income-tax authorities provides for the charging up of renewals to capital account where depreciation is allowed, and they usually decline to allow both renewals and depreciation out of the year's profits. They will, however, permit, as an alternative to the allowance for wear and tear and obsolescence of plant and machinery, the cost of renewing

plant and machinery, under Schedule D. When this course is adopted, the amount to be allowed is the actual cost of the new plant and machinery (excluding any part of such cost which is attributable to additions or improvements, *i.e.* to an increase in capital) after deducting the scrap value or realised price of the plant and machinery replaced.

Example (*a*).—A machine which originally cost 1,000*l.* is worn out and replaced by a machine of similar power or size or capacity which now costs 1,500*l.* The whole of this expense of 1,500*l.* less, say, 100*l.*, the scrap value of the old machine (making a net amount of 1400*l.*) is allowable from the profits of the year in which it is incurred.

Example (*b*).—A machine which originally cost 1,000*l.* is worn out and replaced by one of greater power or size or capacity costing 2,500*l.* The amount to be allowed as an expense is in this case not the full 2,500*l.*, but only the cost of replacing the old machine by one of similar power or capacity, say, 1,500*l.*, less the scrap value of the old machine.

Although this method of allowance is alternative to the wear and tear allowance for the same class of plant, the two principles may run concurrently for different classes of assets in the same business. For example, the wear and tear allowance may be applied to fixed machinery, and the renewal method used for loose plant.

Example (*c*).—Assuming the total written down value of the trader's plant and machinery before the sale of the obsolete machine to be 10,000*l.*, the new machine to cost 1,400*l.* and the old one to be sold for 400*l.*, future wear and tear allowances will be made upon a value of 11,000*l.*, thus :—

	£
Written down value of total plant, etc.	10,000
Deduct written down value of the obsolete machine	400
	£9,600
Add cost of new machine	1,400
	£11,000

The obsolescence allowance is not made in quite the same way as the wear and tear allowance, for the latter is by statute an allowance from the assessment *after* the three years' average is struck. Thus the wear and tear allowance applicable to the year 1925–6 would be given as a deduction from the gross assessment for 1925–6 as follows :—

Trading profits (before allowing wear and tear)—	£
1922—Loss	5,000
1923—Profit	10,000
1924—Profit	13,000
	3)18,000
Gross assessment, 1925–6	£6,000
(If the total wear and tear allowance due for the year 1925–6 were 6,500*l.* a sum of 6,000*l.* would be allowed against the 1925–6 assessment, and the balance of 500*l.* carried forward for deduction in future years.)	
Wear and tear allowance	6,000
Net amount on which tax is payable for 1925–6	nil

An allowance for obsolescence in 1925 of, say, 10,000*l.* would, however, be a deduction from the commercial profits of 1925, turning them from a profit of, say, 9,800*l.* to a loss of 200*l.* The first assessment to be affected would be that of 1926–7, as follows :

	£
Profits 1923	10,000
1924	13,000
1925—Loss	200
	3)22,800
Gross assessment, 1926–7	£7,600
Less—	
Allowance for wear and tear, say, 6,800*l.*, for 1926–7, plus the unexhausted balance carried forward from 1925–6, 500*l.*	7,300
Net amount on which tax is payable for 1926–7	£300

The business year 1925 would also have come into the average for the tax years 1927–8 and 1928–9, by which time the allowance would have had its full effect, only the 'three years' average' was stopped in 1927. After that date (except by special arrangement) only one year's profits are taken in the assessment.

This 'renewal allowance' has been made statutory by each Finance Act since 1918.

SECTION XLVII

LEGAL NOTES FOR ENGINEERS

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SECTION XLVII

LEGAL NOTES FOR ENGINEERS.*

(Contributed by W. Valentine Ball, O.B.E., M.A., Barrister-at-Law, A Master of the Supreme Court.)

(1) LEGAL STATUS OF AN ENGINEER. (2) FEES. (3) EMPLOYMENT OF AN ENGINEER. (i.) *Generally*; (ii.) *Employment Abroad*; (iii.) *Wrongful Dismissal*; (iv.) *The Restrictive Covenant*, (v.) *Engineers and Compensation for Accidents*; (vi.) *Engineers and the National Insurance Act*; (vii.) *Effect of War on Contracts.* (4) SECRET COMMISSIONS. (5) DISCLOSURE OF SECRETS. (6) RIGHTS OF AN ENGINEER TO THE INVENTIONS OF A SERVANT. (7) THE ENGINEER AS WITNESS. (i.) *Generally*; (ii.) *Arrangements as to Fees*; (iii.) *Evidence before Parliamentary Committees.* (8) LIABILITY FOR NEGLIGENCE. (9) RIGHTS, POWERS, AND DUTIES OF AN ENGINEER UNDER A CONTRACT FOR WORKS. (i.) *Generally*; (ii.) *Specifications*; (iii.) *Plans and Drawings*; (iv.) *Extras*; (v.) *Certificates*; (vi.) *Penalties and Bonuses*; (vii.) *Defects, Repairs, and Maintenance*; (viii.) *Subcontractors and Specialists*; (ix.) *Whether the Employer's Engineer can act as Arbitrator in Relation to Disputes Arising under a Contract.* (10) THE ENGINEER AS ARBITRATOR. (i.) *Generally*; (ii.) *Who may be Arbitrator*; (iii.) *Proceedings before the Arbitrator*; (iv.) *The Award*; (v.) *Time for Making the Award*; (vi.) *The Fees of an Arbitrator*; (vii.) *Stating a Case for the Opinion of the Court*; (viii.) *Costs of a Reference.* (11) NOTES ON SALE AND PURCHASE OF MACHINERY.

(1) LEGAL STATUS OF AN ENGINEER.

Any person may describe himself or practise as an engineer, as the word engineer is not a term of art in the legal sense. Although the Institution of Civil Engineers may make rules of professional etiquette to be observed by its members, compliance with such rules will not be enforced in a court of law, save in so far as they involve a restatement of the ordinary law. For instance a rule which states that no consulting engineer shall advertise could not be enforced, whereas infringement of a rule that 'he shall not pay by commission or otherwise anyone who introduces clients' might offend against the common law (*Panama Telegraph Co.* v. *India Rubber Co.* (1875) L. R. 10 Ch. 515) or against the Secret Commissions Act.

(2) FEES.

If an engineer is consulted, there is an implied contract to pay him reasonable remuneration (*Manson* v. *Baillie* (1855) 2 Mac. H. L. Cas. 80). It is more satisfactory, however, to provide for payment of fees beforehand. In the case of a contract to design and supervise erection of works it is well to provide for payment of $\frac{1}{3}$ on signing the contract, $\frac{1}{3}$ when half the contract price has been paid to the contractor, and $\frac{1}{3}$ when the contractor has been fully paid. Provision should also be made for (1) payment for plans and drawings in case the works are abandoned; (2) travelling and hotel expenses. There is, of course, no fixed scale of remuneration for the engineer, but in deciding what is a reasonable charge, the Court would have regard to (i.) the standing of the engineer; (ii.) the nature and extent of the work undertaken and carried out. It is no answer to a claim for fees (*a*) that a particular undertaking has proved to be a failure if the failure was not due to any fault of the engineer—as where, for instance, an engineer is employed merely to *supervise* the erection of a dam which bursts on completion; or where an engineer is employed to draw plans for a newly invented machine which fails to work (*aliter* if the employer was relying on the engineer's skill and judgment: *Duncan* v. *Blundell* (1820) 3 Stark. N.P. 6); (*b*) that the work in question is not completed, if the failure to complete is not due to the engineer. Where an engineer is to be paid on completion and the work is abandoned before the time, the engineer is entitled to what is due for services rendered, and to what he has lost by not being allowed to complete the contract (*Horton* v. *Hemsley* (1908) *Times*, February 19).

* See also 'LEGAL POINTS FOR ROAD ENGINEERS,' p. 805.

(3) EMPLOYMENT OF AN ENGINEER.

(i.) **Generally.**—Where an engineer is to be employed for more than a year certain, the agreement must be in writing; and this is so, even if the employment is terminable at any time by six months' notice on either side (*Hanau* v. *Ehrlich* (1912), A.C. 39). The document must set forth all the terms. It is safer, however, to have the terms of an agreement always put into writing. Special care should be taken to (*a*) specify the times when the salary is to be paid; (*b*) provide for the contingency of illness, as illness does not necessarily determine the contract, nor will it justify dismissal without regular notice, unless the employee is so smitten with disease that he can never be expected to work again (*Cuckson* v. *Stones* (1858) 1 E. & E. 248); (*c*) provide for the notice which may be given on either side to determine the contract. If nothing is specified in the agreement, an engineer employed at a yearly salary is entitled to a year's notice (*Buckingham* v. *Surrey and Hants Canal Co.* (1882) 46 L. T. 885). An engineer wrongfully quitting his employment without notice forfeits the salary due for the part of the current year which he has served. The fact that a contract of employment for an indefinite period contains no express term as to notice to be given for its determination does not exclude the implication that such a notice is required (*Payzu* v. *Hannaford* 34 T. L. R. 442). The suspension of servant from his duties which prevents his earning his commission may amount to a wrongful dismissal (*Rubel* v. *Vos*, 34 T. L. R. 171). Dismissal without notice is only justifiable in a case of gross misconduct. If the 'employer' is a company or a municipal corporation or other local authority it is safer to insist that the contract be under seal. The Public Health Act, 1875, s. 174 (1) provides that every contract made by an urban authority whereof the value or amount exceeds 50*l.* shall be in writing and sealed with the common seal of such authority. A surveyor who prepared plans for a local board under a verbal contract was held entitled to recover nothing (*Hunt* v. *Wimbledon Local Board* (1878) L. R. 4 C. D. D. 48). Close examination of a contract between an engineer and a local authority may, however, show that it is not within this section (see *Douglass* v. *Rhyl U.D.C.* (1913) 2 Ch. 407). Where the engineer is in the employment of a local authority he must have no interest in any contract into which that body enters (see *Melliss* v. *Shirley Local Board* (1885) L. R. 14 Q.B.D. 911). An attempt was recently made to raise the question whether a consulting engineer is liable to pay excess profits duty under s. 39 of the Finance Act, 1915, but the Court of Chancery refused to decide the point, leaving it to the King's Bench Division (*Smeeton* v. *Attorney-General* 35 T. L. R. 706).

(ii.) **Employment Abroad.**—Where an engineer is about to accept employment abroad, he should be careful to see that provision is made for the payment of travelling and other expenses. No agreement to pay travelling expenses would be implied from an undertaking, say, to employ an engineer at a salary of 1,000*l.* a year at Malacca as from January 1, 1913. It is also well to provide in the agreement that any disputes which may arise shall be determined either by arbitration or according to English law.

(iii.) **Wrongful Dismissal.**—If an engineer is wrongfully dismissed, it is his duty to reduce the damages as far as possible by taking other employment if he can procure it (see *Storey* v. *Fulham Steel Works* (1908) 23 T. L. R. 306). The damages are then ascertained by subtracting what he has earned from what he would have earned.

(iv.) **The Restrictive Covenant.**—When employing an assistant, an engineer may find it necessary to bind him not to set up close by in competition. A restrictive covenant is legal, if it is not too wide; it must be only what is reasonably necessary for the protection of the parties. A covenant to prevent a dentist practising within 200 miles of York was held to be too wide (*Horner* v. *Graves*, 7 Bing. 735). On the other hand, a covenant which bound a canvasser not to enter an employment 'within twenty-five miles of London where the plaintiffs carry on business' was held by the House of Lords to be unreasonable (*Provident Clothing and Supply Co.* v. *Mason* (1913) 29 T. L. R. 727). Care should be taken not to make the restriction perpetual unless that is absolutely necessary, for the Court criticises a perpetual covenant more closely (*Eastes* v. *Russ* (1915) 30 T. L. R. 237). In a recent case the validity of a covenant affecting a man who was employed as works engineer at a bottleworks was considered (*Forsters* v. *Suggett* 35 T. L. R. 87).

(v.) **Engineers and Compensation for Accidents.**—An engineer whose remuneration (*e.g.* money, board and lodging, etc.) amounts to less than 250*l.* in the service of an employer is probably entitled to the benefits of the Workmen's Compensation Act, 1906.

(vi.) **Engineers and the National Insurance Act.**—A nice question may arise as to whether, say, a station engineer must be treated as an employed contributor within the meaning of the National Insurance Act, 1911. That act covers employment in any contract of service subject to the proviso that persons earning more than 160*l.** otherwise than in manual labour need not be insured. It is submitted that the station engineer earning less than 160*l.* must be insured, but that the consulting engineer who receives an annual fee of 100*l.* for advising a firm or company need not be insured. His is a contract not 'of service' but 'for services'—a distinction which has been drawn in the Court of Appeal.

* By the National Health Insurance Act, 1919, now raised to 250*l.*

(vii.) **Effect of War on Contracts.**—Contracts entered into during the war, between British citizens and the citizens of States at war with Great Britain, were illegal and could not be enforced, unless a licence to trade was granted to one of the belligerents. Subject, however, to certain exceptions, contracts entered into by the citizens of one belligerent State with citizens of another belligerent State before the outbreak of hostilities between their respective states are not dissolved by the outbreak of war but suspended until the war is over. During suspension no performance of the contract is permitted, nor will any action on it be entertained in English Courts, even though the cause of action arose before the war. But the war being now over the mutual obligations of performance and the rights of action revive. The exceptions are (*a*) Contracts entered into before the outbreak of hostilities which will inure to the aid of the enemy or which involve any dealing with the enemy (see *Furtado* v. *Rogers*, 3 Bos. & P. 91); and (*b*) Contracts entered into before the outbreak of hostilities which from their nature cannot be merely suspended (*Griswold* v. *Waddington* (1818) 16 Johnson's Rep. 438).

(4) SECRET COMMISSIONS.

The receipt of a secret commission or a bribe by an engineer would clearly justify his dismissal (*Boston Deep Sea Fishing Co.* v. *Ansell* (1888) 39 Ch. D. 339). In such a case there is a presumption that he was influenced, against his employers' interest, by the bribe (see *Hovenden* v. *Millhoff* (1900) 83 L. T. 11).

(5) DISCLOSURE OF SECRETS.

An engineer may be employed to do work of a confidential nature for others; or he may have to employ workmen to do confidential work for him (*e.g.* by employing a workman to make a model of a new and patentable machine). The law implies an agreement by the servant to keep his master's secrets, and he may be restrained by injunction from disclosing them (*Alperton Rubber Co.* v. *Manning and Others* (1917) 116 L. T. 499; 33 T. L. R. 205).

(6) RIGHTS OF AN ENGINEER TO THE INVENTIONS OF A SERVANT.

If a servant invents a machine in his employer's time and even when using his employer's materials, the invention does not become the property of the employer so as to prevent the servant taking out a patent for it (*Heald's Case*, 8 R. P. C. 430). But if the servant were to steal an idea and endeavour to patent it either before or after the termination of the service, the employer could oppose the grant of a patent in respect of it (*Thwaites' Application*, 9 R. P. C. 515). And if the servant obtains a grant of a patent in respect of the invention, he can only hold it as trustee for his employers (*British Reinforced Concrete Engineering Co.* v. *Lind* (1917) 33 T. L. R. 170). The engineer when employing a servant should take care to provide, by the agreement, that the inventions of the servant shall belong to him; but when himself entering into a contract of service he should be careful to sign nothing which will abrogate his rights.

(7) THE ENGINEER AS WITNESS.

(i.) **Generally.**—As the engineer frequently comes into contact with the law and the lawyers in the capacity of a *witness*, a few notes of a practical character on the duties of a witness may be found useful.

When invited to give evidence as an expert the engineer should: (*a*) arrange for a qualifying fee to be paid in any event; (*b*) examine the plans and documents, and, if necessary, obtain a view of the *locus in quo* before consenting to give evidence; (*c*) warn the parties consulting him of all the difficulties which are manifest to him; (*d*) ascertain, if possible, the contentions which are going to be put forward by the other side, and make himself familiar with any views which they may have published upon the matters in dispute. Having consented to give evidence, the engineer should (*a*) be ready to satisfy the lawyers with regard to any technical point which may be raised in consultation; (*b*) listen to the arguments and evidence in Court, and be prepared to deal with any points made by witnesses on the other side; (*c*) bring with him any entries in his diary or any notes which he may have made *at the time* with reference to the matters in dispute, for he may use such notes to refresh his memory. Thus, if an engineer has to report as to the condition of a structure, he may use in the witness box the notes which he made on the spot. But he could not use a copy of such notes unless he was prepared to produce the original; (*d*) make and bring to court a plan or model of the structure or machine under discussion, as this will save much wordy explanation; (*e*) search in libraries and in the published proceedings of the various institutions for any books and papers dealing with the matters in hand—especially any papers written by himself, in order that he may not be confronted with an adverse opinion given on a former occasion. A witness should bear in mind that it is his duty to state facts and express opinions, not to advocate the cause. As soon as he appears to be taking a biased view or attempting to fight the case it is more than likely that the tribunal will pay little heed to his evidence. A candid answer to an awkward question is often less dangerous than a long and evasive statement. In *Crosfield and Sons, Ltd.* v. *Techno-Chemical Laboratories Ltd.* (1913, 29 T. L. R. 378) Neville, J., expressed some views as to the function of an expert witness which may be thus summarised:—

(*a*) It is not competent in any action for witnesses to express their opinion upon any of the issues, whether of law or fact, which the Court or a jury has to determine.

(*b*) In patent cases, expert evidence is often necessary (i) to explain words or terms of science or art, or to inform the Court in case the import of a word in a document to be construed differs from its popular meaning; (ii) to instruct the Court in the laws of science; (iii) to describe the state of public knowledge at the date of the patent. 'It is rare,' added his lordship, 'to find any substantial difference of opinion between eminent experts upon matters of science whenever it is possible to dissociate the question from immediate connection with the issues in the action.'

(ii.) **Arrangements as to Fees.**—On being *subpœnaed* one is bound to attend as a witness provided sufficient conduct money is paid with the subpœna. Failure to attend might lead to an action for damages, while in the County Court the judge has power to fine a witness for non-attendance. A witness may refuse to give evidence until his expenses have been paid (*Newton* v. *Harland* (1840) 1 M. & G. 956). It should be noticed that the person liable to pay the fees is the party to the litigation, not the solicitor, unless he has expressly made himself liable (*Lee* v. *Everest* (1857) 26 L. J. Ex. 334). In order to save trouble it is best to arrange for and if possible secure payment of fees in advance. The fees 'allowed on taxation,' that is to say, the fees which an unsuccessful litigant will be ordered to pay in respect of witnesses called by the other side, are very small, but the party calling the witness will have to pay his agreed fee whatever it is. Where a case is tried at assizes in the town where the engineer lives or in London (when the engineer lives in London), the fee allowed is 1*l.* 1*s.* *per diem*, or where the engineer lives away from the town 1*l.* 1*s.* to 3*l.* 3*s.* But the taxing masters may also allow a qualifying fee of so much a day varying with the magnitude of the case. In 1875 a fee of 7*l.* 7*s.* was not considered excessive payment to a scientific witness. It is probable that a larger sum would be allowed at the present day. In addition he is allowed the travelling expenses reasonably and actually paid. In County Courts the fee allowed for qualifying to give evidence on Scale B is 1*l.* 1*s.* to 3*l.* 3*s.*; on Scale C, 1*l.* 1*s.* to 5*l.* 5*s.*; for attending Court on trial (*per diem*), Scale B, 1*l.* 1*s.* to 2*l.* 2*s.*; Scale C, 1*l.* 1*s.* to 3*l.* 3*s.*

The above scales were fixed before the war, and have not been altered. So far as they can the taxing masters will probably grant the maximum owing to high prices.

(iii.) **Evidence before Parliamentary Committees.**—When an engineer is summoned to appear as a witness before a committee of either House of Parliament he looks for his fees to the party who summons him—whether he is the promoter or an opponent. According to May's 'Parliamentary Practice' (1906) p. 434, an engineer summoned as a witness before a committee should report himself to the committee clerk on his arrival in London, or he will not be allowed his expenses for residence prior to the day of making his report; 3*l.* 3*s.* a day is the parliamentary allowance, but of course as between the engineer and the party summoning him the *quantum* of the fee is a matter of agreement.

(8) LIABILITY FOR NEGLIGENCE.

The liability of an engineer for negligence is similar to that of any other professional man. To render him liable it is not enough that there has been a less degree of skill than some other professional man might have shown. A fair average degree of skill is all that can be insisted upon (*Lamphier* v. *Phipos* (1838) 8 Car. & P. 475). If an engineer were so careless in the preparation of a tender that the cost of the works was grossly underestimated, he would probably be liable to pay damages, and he certainly could not recover his fees (*Moneypenny* v. *Hartland* (1826) 2 C. & P. 379). An engineer should be acquainted with any local bye-laws appertaining to the work in hand (*Monks* v. *Dillon* (1884) 12 L. R. Ir. 321). On the principle of *respondeat superior* an engineer is responsible for the acts or defaults of assistants employed by him (*Mackersy* v. *Ramsays* (1842) 9 C. & F. 818). The question 'To whom is the engineer liable for negligence?' depends upon the conditions of employment. If he is engineer in relation to a large contract he is not liable for anything done by him in his capacity as arbitrator between the employer and the contractor; but he is liable for damage resulting from negligence in supervision, *e.g.*, failure to examine and test work before it is hidden from view (*Leicester Guardians* v. *Trollope* (1911) 75 J. P. 197). The contractor, however, could not sue the engineer for an error in the specifications on the basis of which he made his tender. Where, however, the 'quantities' are prepared by the engineer, and his fees for their preparation are paid by the contractor, it is conceived that he could be sued for damages resulting from an error in those quantities (*Bolt* v. *Thomas*, 'The Law Affecting Engineers,' p. 58). If an engineer order extras without authority, the contractor may possibly sue him for damages for breach of warranty of authority (*Randall* v. *Trimen* (1856) 18 C.B. 786). The amount of damages recoverable for negligence is to be measured by the loss which the plaintiff has suffered. In *Saunders* v. *Broadstairs Local Board* (1890) 2 H. B. C. 160, two engineers claimed fees for preparing surveys, obtaining tenders, and superintending the execution of a contract for certain drainage works. The board counterclaimed for negligence and were awarded 2,046*l.*, the amount overpaid to the contractor by reason of the negligence of the engineers in over certifying the quantities; 2,400*l.* estimated cost of doing bad work over again; 240*l.* actual cost of repairs already done to defective work. Damages recovered by a workman against his employer for an accident might also be recovered from the engineer if it were shown that the accident was caused by the engineer's negligence (*Mosdell* v. *Mitchell*, 'Times,' January 20, 1891).

(9) RIGHTS, POWERS, AND DUTIES OF AN ENGINEER UNDER A CONTRACT FOR WORKS.

(i.) **Generally.**—Common forms of contract for large works usually set forth the powers, etc., of the engineer very clearly. The preparation of the contract is generally left to a lawyer, but the engineer should be on his guard against allowing a common printed form to be applied indiscriminately to the construction of works of a special nature. When difficulties arise it may be found that the common form does not provide for their elucidation.

(ii.) **Specifications.**—The contract should contain a clause providing that the employer will not be responsible for any mistakes or inaccuracies in the specifications which form part of the contract. Such a clause will, in the absence of fraud, afford him protection (*Pearson* v. *Dublin Corporation* (1907) A. C. 357). There should also be a clause calling the would-be contractor's attention to the fact that he must make surveys and borings for himself before making his tender. In that case, if unforeseen difficulties are met with the employer will not be responsible (*Thorn* v. *Mayor of London* (1876) L. R. 1 A.C. 120). Again, where a man undertakes to make *e.g.* sound hydraulic cylinders according to a specification, capable of withstanding a certain pressure, he takes upon himself the risk of the cylinders being able to withstand the named pressure when made according to the specification (*Hydraulic Co.* v. *Spencer* (1886) 2 T. L. R. 554). Carelessness in the preparation of a specification may involve the employer in added expense, for which the engineer may be liable (*Moneypenny* v. *Hartland* (1828) 2 C. & P. 378).

(iii.) **Plans and Drawings.**—These form part of the contract, and may, in the absence of a disclaiming clause, operate as a warranty that dimensions, measurements, etc., are correct. A clause disclaiming responsibility for accuracy should therefore be inserted in the contract. The engineer has no implied authority to alter plans and drawings so as to increase or lessen the burden imposed upon the contractor (*Cooper* v. *Langdon* (1841) 9 M. & W. 60). Delay in supplying the necessary plans and drawings may excuse the contractor from carrying out the work within the contract time (*Roberts* v. *Bury Commissioners* (1869) L. R. 5 C. P. 310). It is for the engineer who prepares them to see that they conform to local bye-laws (*Cubitt* v. *Smith* (1864) 11 L. T. 298). Plans and drawings made for the purpose of carrying out works are the property of the employer—not of the engineer (*Gibbon* v. *Pease* (1905) 1 K.B. 810). As to copyright in plans, see the Copyright Act, 1911, s. 5.

(iv.) **Extras.**—The duty of deciding what are 'extras' within the meaning of the contract is usually entrusted to the engineer. He has no implied authority to order extras (*Cooper* v. *Langdon* (1841) 9 M. & W. 60), although an agreement to work *to the satisfaction* of an engineer has been held to give him implied authority to order extras (*Robertson* v. *Jarvie* (1910) 45 S. L. R. 260). It has been held, however, that where the plaintiffs were employed by an architect (whose functions, for this purpose, correspond to those of an engineer) to supply door handles and door furniture for a building, and shortly before the delivery of the goods he informed the defendants, who were the builders, that the goods were being supplied by the plaintiffs, the defendants who used the goods in the building were liable to pay for them (*Ramsden* v. *Chessum* (1914) 78 J. P. 49). Extras should be authorised in the manner provided by the contract, which usually provides that all extras shall be ordered in writing (*Russell* v. *Saida Baudeira* (1862) 13 C. B. N. S. 149); but, in the case of a contract with a local authority, which must be under seal, the order for extras need not be under seal (*Williams* v. *Barmouth Urban Council* (1897) 77 L. T. 383). If a written certificate is rendered necessary by the contract, nothing else will suffice; but in a recent case a contractor proceeded with extra work as required by an engineer without any written order. On his claiming payment, an arbitrator found that the engineer was wrong and unreasonable, and that the work and materials required by him were not included in the contract. After much litigation the House of Lords eventually held that this decision was correct (*Brodie* v. *Cardiff Corporation* (1919) 120 L. T. 417). Although the whole scheme of works cannot be altered by virtue of the extra clause (*R.* v. *Peto*, 1 Y. & J. 37) power to *vary* the work will give the engineer authority to substitute one piece of machinery for another of which it is well known to be the mechanical equivalent (*Stevens* v. *Mewes & Davies*, Court of Appeal, June 7, 1910; Emden's 'Building Contracts,' Supplement 1911). The engineer should therefore see that he has power to *vary* the work. The engineer's decision as to what are extras may or may not be subject to revision in accordance with the arbitration clause. So far as the contractor is concerned, the fact that the engineer has given his final certificate (see *sub tit. Certificates, post*) may involve a final decision as to what is and what is not an extra (*Connor* v. *Belfast Water Commissioners* (1871) 5 L. R. Ir. C. L. 55). Power to extend the time for completion is generally given to the engineer. It may be that owing to the action of the Government acting under the Defence of the Realm Acts, the performance of a contract for works becomes illegal during the continuance of the War. In such a case it is conceived that no extension of time by the engineer will avail to keep the contract alive (see *Metropolitan Water Board* v. *Dick, Kerr & Co.*, 34 T. L. R. 111).

(v.) **Certificates.**—It is the duty of an engineer in relation to a contract for large works to grant or withhold the certificates upon which the contractor is paid. 'Progress certificates' are given from time to time as the work proceeds. They generally authorise payment to the extent of

80 per cent. upon the contract value of the work done from time to time. The remaining 20 per cent. is kept back usually, as to 15 per cent. until the final certificate is granted and as to 5 per cent. until the end of some stated period after the final certificate. This 20 per cent. is called the retention money (see *West Yorkshire Bank Ltd.* v. *Isherwood Bros.* (1912) 28 T. L. R. 593). The 'final certificate' is granted when the work is finished to the satisfaction of the engineer, and the contractor can sue for nothing until it has been granted (*Wallace* v. *Brandon and Byshottles U.D.C.* (1903) 2 H. B. C. 392). In deciding as to certificates the engineer acts as an arbitrator, and his decisions cannot be called in question (*Wadsworth* v. *Smith* (1871) L. R. 6 Q.B. 332); nor can he be compelled, and is better advised not to give reasons for his decision (*Stevenson* v. *Watson* (1879) L. R. 4 C. P. D. 148). No action lies against him for negligence in relation to certificates (*ib.*) (but see the case of *Goddard* v. *Ferguson*, *infra*). In exercising his discretion he must act as an arbitrator between employer and contractor (*Chambers* v. *Goldthorpe* (1901) 1 K.B. 624). It may, however, be that the decision of the engineer as to a certificate is subject to the arbitration clause, which has been held to be the case in relation to the form of contract approved by the Royal Institute of British Architects (*Robins* v. *Goddard* (1905) 1 K.B. 294). A fraudulent agreement between the employer and the engineer would however affect the validity of a certificate (*Kellett* v. *New Mills U.D.C.* (1900) 2 H. B. C. 330). The certificate of the engineer may be made a condition precedent to the contractor's right of action against the employer. If so an action cannot be maintained unless there has been improper dealing between the engineer and the employer (*Eaglesham* v. *McMaster* (1920) 2 K. B. 169). The statement that an engineer is not liable for negligence in relation to a certificate does not appear to be supported by the case of *Goddard* v. *Ferguson* (referred to by Mr. Saxon Snell in a paper read by him at the Royal Institute of British Architects, April 15, 1912). It was there held that an architect who grants a certificate which is successfully challenged by an employer in an action brought against him by a builder to recover the amount so certified to be due to him, is liable to repay to the employer the costs incurred by him in resisting the builder's claim. The Official Referee held the architect liable on the ground that when acting as agent for the building owner in granting certificates, he must be held responsible for the reasonable and probable consequences of giving a certificate subsequently held to be inaccurate or excessive. Certificates should always be given in writing in a formal manner. No engineer should pass any contract which does not contain a provision to this effect. As to when an engineer is disqualified from granting certificates, see paragraph ix., *infra*. An engineer has no right to delegate the power to grant a certificate to a subordinate, *e.g.* to the resident engineer (*Freeman & Sons* v. *Middleton Electric Traction Co.*, per Hamilton, J., July 15, 1910; Court of Appeal, January, 1911; Emden's 'Building Contracts,' Supplement, 1911).

(vi.) **Penalties and Bonuses.**—The question whether the contractor must pay penalties or not depends almost entirely upon the engineer. Penalties are imposed if the work is not carried out in accordance with the provisions of the contract as to time. The fact that extras are ordered will excuse the contractor from compliance with the conditions as to time (*Dodd* v. *Churton* (1897) 1 Q.B. 562), but the jurisdiction of the engineer does not extend to deciding this point (*Gallivan* v. *Killarney Urban Council* (1912) 2 Ir. R. 356). To avoid complication, however, it is best to insert a clause in the contract giving the engineer power to extend the time. With regard to the penalty clause generally nice questions sometimes arise as to whether it is capable of enforcement. If it is unreasonable on the ground that the punishment is too severe, the Court may refuse to enforce it; and it is for this reason that the words 'the sums to be regarded as liquidated damages and not as a penalty' are usually inserted after the sum named. The breach of an engineering contract involves damage of so uncertain a nature that the courts will generally treat the sum which the parties themselves have named as liquidated damages. Penalties will not be imposed if (*a*) the delay was caused by the act or default of the employer (*Thornhill* v. *Neats* (1860) 8 C. B. N. S. 831); (*b*) if there is delay in setting out the site or in delivering plans (*Roberts* v. *Bury Improvement Commissioners* (1870) L. R. 5 C. P. 310). The fact that the contractor has been delayed by a strike of his workmen, however, affords no excuse for delay (*Budgett* v. *Rimington & Co.* (1890) 25 Q.B. D. 320), nor, apparently, is the employer to be held liable for the acts of third parties causing delay (*Porter* v. *Tottenham U.C.* (1915) 1 K. B. 776). While a penalty clause is usually optional, it is obligatory in contracts made with certain local authorities (see Public Health Act (1875) s. 174 (2)). A bonus clause is sometimes inserted by virtue of which a contractor is enabled so much extra for expedition. If a contract contains such a clause, and the engineer has power to extend the time, it seems that his power to extend must be exercised not to enable the contractor to earn the bonus but only to avoid penalties (*Ware* v. *Lyttelton Harbour Board* (1882) 1 N. Z. R. 191).

(vii.) **Defects, Repairs, and Maintenance.**—In contracts relating to the erection of machinery clauses should be inserted providing for any defects which appear either before or after the issue of the final certificate. A useful form of this clause will be found in the printed conditions of contract issued by the Institution of Electrical Engineers. Its importance will be recognised when it is pointed out that when it is absent the final certificate of the engineer may possibly bar any further claim by the employer (*Lord Bateman* v. *Thompson* (1875) 2 H. B. C. 23). The time for the remedy of defects should be prolonged as much as possible, inasmuch as the very fact of there being a defects clause impliedly releases the contractor from liability for defects appearing after the stated time (*Sharp* v. *Great Western Railway Co.* (1841) 11 L. J. Ex. 17). The contractor can only be called upon to repair and maintain when compelled to do so by a repairing clause and a maintenance clause. The employer must give notice of want of repair. Mainten-

ance should be provided for in cases where the machinery or work is of a special character which is best known to the contractor. In the absence of any clause relating to defects and maintenance, it does not follow that on payment of the full price the employer thereby waives all claim for damages for work improperly done. It is a question of fact having regard to all the circumstances of the case whether the settlement was final and complete.

(viii.) **Subcontractors and Specialists.**—Most modern contracts involve the employment of subcontractors or specialists. A clause should be inserted in the head contract prohibiting the employment of any subcontractor or specialist unless approved by the engineer. In the absence of such a clause, the contractor might, possibly, farm out portions of the work to all and sundry (*British Waggon Co.* v. *Lea* (1880) 5 Q. B. D. 149). The engineer, apparently, has no implied authority to employ subcontractors (*Cowan* v. *Goderich* (1859) 10 U. C. C. P. 87). It is often well to specify the names of manufacturers of the raw materials which are to be used in the body of the contract. In order to preserve his right to supervise the work of any subcontractor or specialist, the engineer should secure the insertion in the head contract of a clause providing that payments to subcontractors shall be made by the contractor only upon the certificates of the engineer. It is also well to secure the insertion of a clause to the effect that, in the event of the contractor becoming insolvent, the subcontractor or specialist may be paid directly by the employer. All responsibility for delay or negligence on the part of a subcontractor is generally, by a special clause, placed upon the contractor (see, generally, *Crittall* v. *L. C. C.* (1910) 75 J. P. 203; *Hampton* v. *Glamorgan County Council* (1916) 115 L. T. R. 426, and the case of *Ramsden* v. *Chessum*, cited, *supra*, s. (9) (v.) (i.)).

(ix.) **Whether the Employer's Engineer can act as Arbitrator in Relation to Disputes Arising under a Contract.**—The position of the engineer in relation to a large contract has been rendered very difficult by certain recent decisions of the courts. In theory he is agent for the employer in the preparation of plans and specifications and in the supervision of the work, and he is arbitrator or *quasi* arbitrator between the employer and contractor in granting certificates, approving work done, granting extensions of time, etc. Sometimes he is made sole arbitrator to decide all disputes between the employer and the contractor, and a serious question has arisen in several recent cases as to how far a contractor can be forced to accept his decision whether in the matter of granting certificates, etc., or as arbitrator. In *Jackson* v. *Barry Railway Co.* (1893) 1 Ch. 238, it was held that the fact of the employer's engineer having expressed a view of the matter in dispute hostile to the contractor was not a sufficient justification for refusing to allow him to act as arbitrator in relation to that dispute. The Court of Appeal pointed out that the contractors had agreed to this form of reference, and what they relied on was the professional honour, practice, and intelligence of the engineer. There was nothing in the circumstances of the case to render it improbable that he would not arrive at an honest decision.

In *Ives* v. *Willans* (1894, 2 Ch. 478) the same result was arrived at, although in giving judgment Lord Justice Davey said: 'No doubt in a sense the engineer will be the judge of his own conduct, and no doubt that is a position which *prima facie* raises some surprise in a judicial mind; but that is the contract of the parties.' As already indicated later decisions appear to have practically altered the law, although the judges always took care to say that *Ives* v. *Willans* is still good law. The result of the recent cases may be thus summarised. A contractor will not be bound to submit to the arbitrament of the employer's engineer (*a*) if the matter in issue is an unseemly personal dispute raising a vindictive feeling between the engineer and the contractor, and the engineer has so strongly expressed his view that it amounts to a prejudgment (*Nuttall* v. *Manchester Corporation* (1893) 8 T. L. R. 513); (*b*) if the nature of the dispute is such that the cross-examination of the engineer is essential (*Freeman* v. *Chester R. D. C.* (1911) 1 K.B. 783); (*c*) if the matter in issue is something outside the original agreement, e.g., a dispute as to whether the engineer and contractor had agreed to vary the original agreement (*Aird* v. *Bristol Corporation* (1913) A. C. 241); (*d*) if the conduct of the engineer himself is practically the only point in dispute (*Blackwell* v. *Derby Corporation* (1909) 75 J. P. 129). Finally, it was held in *Roberts* v. *Hickman* (1913) A. C. 229 that the grant of a certificate by an architect will not be a condition precedent to the builder's right to sue if, by writing letters to the employer, and allowing himself to be influenced by their views, the architect has disqualified himself from acting judicially although guilty of no fraud or improper conduct.

If the method of arbitration provided for in many existing forms of contract is declared to be impossible for any of the above reasons the only alternative is litigation, a method of settling disputes which employers, contractors, and engineers always seem to desire to avoid. What can be done to avoid such a calamity in relation to future contracts? The following courses are open. Insert a clause (*a*) referring all disputes to an arbitrator to be mutually agreed or to be nominated by the president of one of the Institutes (see, *e.g.*, the form approved by the Institution of Electrical Engineers, clause 47); or (*b*) referring disputes to a *named* arbitrator; or (*c*) refer disputes to the president of one of the Institutes whoever he may be. The first of these suggestions appears to offer the best practical solution of the difficulty. The writer, however, ventures to make the following suggestion which might possibly work in practice. Frame the arbitration clause so as to leave the decision of every question arising under the contract to the engineer but subject to a proviso that should it appear to the Court on an application to stay any action or proceeding brought in relation to the contract that the engineer is disqualified from acting as arbitrator the matters in dispute will be referred to an engineer to be agreed between

the parties, or failing agreement to be nominated by the president of the Institution of Civil Engineers. Another alternative is suggested by Mr. E. J. Rimmer in his Arbitration Clause in 'Engineering Contracts' (Constable & Co.). It is that a proviso should be added to the arbitration clause stating that if any action is brought the defendant may either (*a*) have the action stayed or (*b*) have the matter referred to an independent arbitrator appointed in one or other of the manners above suggested.

(10) THE ENGINEER AS ARBITRATOR.

(i.) **Generally.**—Engineers are frequently called upon to act as arbitrators to decide disputes of a technical nature wholly unconnected with any contract in which the engineer has been employed. Arbitrations are conducted in accordance with the provisions of the Arbitration Act 1883. An arbitrator may be appointed (*a*) by the Court; (*b*) by the terms of the contract itself or (*c*) by a person nominated for that purpose in the contract, e.g., the president of the Institution of Civil Engineers. As to appointment by the Court, this occasionally takes place when a prolonged scientific enquiry is necessary. A 'referee' of this kind may have power either to wholly dispose of the dispute or make an enquiry and report to the Court, in which latter case the Court itself gives the judgment after considering the report. As references of this kind are rare in practice they will not be further dealt with.

As a rule the engineer finds himself made arbitrator pursuant to the arbitration clause in an agreement. Any dispute arising under any contract may thus be referred, and the parties will as a general rule be bound to proceed to arbitration for the purpose of settling a dispute instead of bringing an action at law. Where a contract contains an arbitration clause, if one party commences an action, the other may apply to the Court to stay the action pending a reference and the action will generally be stayed, unless there is some good reason for not allowing the arbitration to proceed. For instance, a contractor alleged that he had been induced by fraudulent representations as to the nature of the soil to enter into a particular sewerage contract, and brought an action for fraudulent misrepresentation. It was held that such an action ought not to be sent to arbitration (*Monro* v. *Bognor Urban District Council* (1915) 84 L. J. K. B. 1091). But the Court will stay an action, and allow an arbitration to proceed, although the question at issue is one which might be more suitably tried in a court of law—*e.g.* the construction of a contract (*Metropolitan Tunnel, etc.*, v. *London Electric Ry.* (1926) 1 Ch. 371). (See also par. 9 (ix.), *supra*.)

(ii.) **Who may be Arbitrator.**—Any person upon whom the parties agree may act as arbitrator. Thus if in a contract with a local authority it is specified that the borough engineer shall be arbitrator there is no objection to his so acting, and the contractor can be compelled to accept his award (*Ives* v. *Willans*, *supra*, 2 Ch. 478). That is the broad rule, but the Court, as has been shown, always has power to refuse to enforce the arbitration clause in a case where it is obvious that the arbitrator ought not to act owing to bias, etc. Frequently the clause provides for the appointment of an arbitrator by each party with power to the arbitrators in case of differences to appoint an umpire. When this is done the umpire and arbitrators generally find it convenient to sit together to decide the case.

(iii.) **Proceedings before the Arbitrator.**—Witnesses must be sworn in the usual way. Due notice must be given to either party of the time when it is proposed to hold the sitting. In a case of great complexity it is well to have a preliminary sitting in order to require the parties to formulate the points in difference between them. By this means the issues may be considerably narrowed. The arbitrator should hear both sides, who may be represented by solicitor or counsel. He must never hold private communication with one party on the subject matter of the reference. He has no power to examine witnesses in the absence of the parties. An arbitrator who takes evidence in the absence of, and without notice to, a tenant, is guilty of legal misconduct, for which his award may be set aside (*In re O'Connor*, 88 L. J. K. B. 1242; *Ramsden* v. *Jacobs* (1922) 1 K.B. 640). It is for the arbitrator to decide every question whether of law or fact. He may, however, consult a solicitor or, for that matter, any other expert on legal points. Indeed the writer was recently concerned in a case in which, with the consent of the parties, the arbitrator had his solicitor sitting by his side. He should take full notes of the evidence, unless, as is frequently the case, the parties agree to have a shorthand note.

(iv.) **The Award.**—If the case is complex, the engineer is well advised to consult his solicitor as to the form of the award. The following are the features of a valid award, which should be in writing. (*a*) *It must not exceed the submission.* Thus if the question submitted was whether the stone used for building a dam was according to specification, the arbitrator would have no power to award that the stone used was better than as specified and that the employer must pay for it. (*b*) *It must extend to all matters in dispute.* If several distinct questions are referred and the arbitrator omits to decide upon any one of them, the whole award is bad. If in the case mentioned he were asked to decide (i.) was the stone as specified; (ii.) was it suitable for the purpose, he would have to decide both questions. (*c*) *It must be certain.* The award must be so framed that its meaning is clear to the parties; but according to a legal maxim, that is certain which is capable of being rendered certain. Thus to award that A. and B. shall pay a debt in the proportion in which A. and B. hold shares in a ship is a sufficiently definite award (*Watson* v. *Watson* (1671)

3ty. 28). (*d*) *It must be final.* The award must peremptorily state the arbitrator's finding. A mere expression of opinion that A. ought to pay B. such sum as C. thinks proper would not be a final award. Finally (*e*) *it must not be impossible, unreasonable, inconsistent,* or *illegal.* An award which directed that one party should do something illegal, *e.g.* trespass upon the land of another, would be invalid.

(v.) **Time for Making an Award.**—In the absence of agreement, an award must be made (*a*) within three months of the date of entering on the reference, or (*b*) within three months after having been called on to act by notice in writing from one of the parties, or (*c*) on or before any later day to which the arbitrator may by writing under his hand extend the time for making the award (Arbitration Act, 1889, Schedule 1 (c)). The power to extend the time is important in the case of a long and complicated reference, but it must be exercised within the period of three months above referred to. Unless the arbitrator extends the time, or the parties agree to allow him to do so, an application must be made to the Court to extend the time; and such an application may be made whether the time for making the award has expired or not (*ib.*, s. 9).

(vi.) **The Fees of an Arbitrator.**—The arbitrator should name his fee beforehand. It is best fixed at so much *per diem* for the hearing. If no preliminary arrangement is made, he is entitled to charge what is fair and reasonable, and he can keep back his award until the fees are paid (*Ponsford* v. *Swain*, J. & H. 433). When deciding in the award as to costs he should state who is to pay his fees; but he may insist upon their being paid by the party who takes up the award. He should not reveal his decision until after these formalities have been observed. Sometimes the *quantum* of an arbitrator's fees is left to the decision of a taxing master. On such a taxation, if the evidence goes to show that, in the opinion of persons in the same profession as the arbitrator, that his charges are fair and reasonable, the taxing master must allow them. In *Mason* v. *Lovatt* (1907, 23 T. L. R. 486) a quantity surveyor was allowed to charge 527*l.* 10*s.* for a reference which lasted 22 days, the arbitrator subsequently taking 13 days to consider his opinion. In *Llandrindod Wells Water Co.* v. *Hawksley* (1904, 20 T. L. R. 241) the fees of an umpire and two arbitrators all being engineers were allowed at 476*l.* 12*s.*, in respect of a reference which lasted 2 days. The arbitrator should state how his fees are made up.

(vii.) **Stating a Case for the Opinion of the Court.**—Where a specific question is referred to an arbitrator, and he decides it, the fact that his decision is erroneous in point of law does not make the award bad on its face so as to admit of its being set aside (*In re King and Duveen* (1913) 2 K. B. 32); nor will the mere fact that the dispute involves questions of law induce the Court to stay a reference to arbitration (*Rowe* v. *Crossley* (1913) 108 L. T. 11). But where a point of law arises during a reference, the arbitrator, if he does not care to decide it, may state a case for the opinion of the Court (Arbitration Act, 1889, s. 19), or the Court may compel him to state a case (*ib.*). He can also make his award in the form of a special case, leaving it to the Court to decide how the judgment shall be entered. Refusal to state a case may constitute misconduct on the part of an arbitrator (*Czarnikow* v. *Roth Schmidt & Co.* (1922) 38 T. L. R. 595).

(viii.) **Costs of a Reference.**—On the question of costs, and as to the form of that part of his award which relates to costs, an arbitrator should consult his solicitor, because (*a*) highly technical questions arise with regard to costs and their taxation which no layman can be expected to understand, and (*b*) it is desirable that in this matter an arbitrator should observe as nearly as possible the principles which are recognised in courts of justice. Again, the defendant in the proceedings may have prepared a counter-claim in which he may have been successful wholly or in part. This further complicates the question of costs. It may be observed that there is no objection to an arbitrator employing a lawyer to advise him in the matter of costs or with reference to any other question which arises in a reference. In any event, and whether a solicitor is employed or not, the question of costs should be carefully considered, as the expenses of a reference are often wholly out of proportion to the sum in dispute. In litigation the general rule is 'costs follow the event'—an application of the maxim *vœ victis*. Unless the submission contains some special term as to costs, the arbitrator has full power to decide who is to pay them. He may award costs to be taxed 'as between solicitor and client'—which means that the successful party is nearly indemnified—or he may award costs to be taxed as between litigants in the ordinary way. He may also, in his discretion, award a fixed sum for costs (Arbitration Act, 1889, Schedule I. (i)), or he may declare that each party shall pay his own costs. In deciding whether to make a defendant pay costs, the arbitrator should (it is submitted) consider the nature of any offer made before the proceedings were commenced. Thus supposing a contractor claimed 5,000*l.* and the building owner made a firm offer of 4,000*l.* which was refused. After hearing the evidence, the arbitrator awards 4,000*l.* or less. In such a case he would be justified in disallowing the contractor any costs. An arbitrator can only make a successful plaintiff pay costs in exceptional circumstances as when (*e.g.*) it appears that although successful he should not have prosecuted his claim. It was held, however, in a case arising under the Small Holdings Act, 1908, the arbitrator in the exercise of his powers under that Act had wider powers in the matter of costs than a High Court judge (*Gray* v. *Baron Ashburton*, 115 L. T. R. 729).

(11) NOTES ON SALE AND PURCHASE OF MACHINERY.

The question which most frequently arises on the sale of machinery, motor cars, etc., is what is the warranty of fitness? Sometimes, of course, there is an express written warranty, but in the absence of that the matter is regulated by section 14 of the Sale of Goods Act, 1893, which provides (in effect) that there is no implied warranty or condition as to the quality or fitness for any particular purpose of goods supplied under a contract of sale, except (1) where the buyer expressly makes known the purpose for which the goods are required so as to show that the buyer relies on the seller's skill or judgment and the goods are of a description which it is in the course of the seller's business to supply (whether he be the manufacturer or not) there is an implied condition that the goods shall be reasonably fit for such purpose; provided that in the case of the sale of a specified article under its patent or other trade name, there is no implied condition as to its fitness for any particular purpose; (2) where the goods are bought by description from a seller who deals in goods of that description (whether he be the manufacturer or not) there is an implied condition that the goods shall be of merchantable quality; provided that if the buyer has examined the goods there shall be no implied condition as regards defects which such examination ought to have revealed; (3) an implied warranty or condition as to quality or fitness for a particular purpose may be annexed by the usage of trade; (4) an express warranty or condition does not negative a warranty or condition implied by the Sale of Goods Act unless inconsistent therewith. The result of these provisions is that in certain cases the vendor is made liable for latent defects, that is to say, for defects which would not be discoverable on an ordinary examination of the article. Sometimes a contract for the sale of machinery contains provisions for payment of the price by instalments after production of the certificate of the engineer that such instalments are due and payable. It was held in a Scotch case (*Howden* v. *Powell Duffryn Steam Coal Co.* (1912), S. C. 920, Ct. of Sess.) that where, in such circumstances, part of the machinery was rejected, but the manufacturers refused to accept the rejection, the production of the engineer's certificate was not a condition precedent to the right to recover payment.

In the case of an engine which is attached to the freehold, a question may arise, on a sale, as to when the property passes. In *Underwood Ltd.* v. *Burgh Castle Brick and Cement Syndicate* (1922, 1 K. B. 343), a horizontal condensing engine was sold at a price free on rail, London. It was bolted to and embedded in a flooring of concrete. Before it could be delivered on rail it had to be detached and dismantled. The sellers detached it, but in loading it on a truck they damaged it by accident so that the buyers refused to accept it. In an action by the sellers for goods bargained and sold it was held that the property in the engine had not passed to the buyers, inasmuch as the sellers had failed to do something necessary to put it in a deliverable state. Consequently the loss fell on the sellers and not on the buyers.

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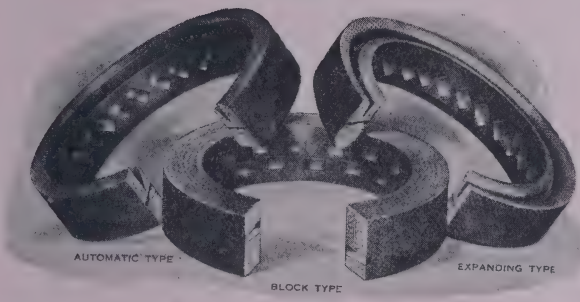

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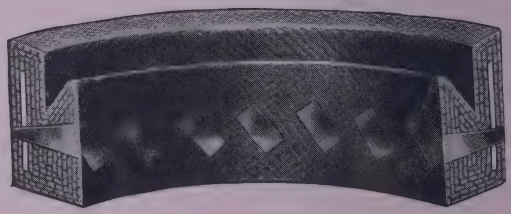

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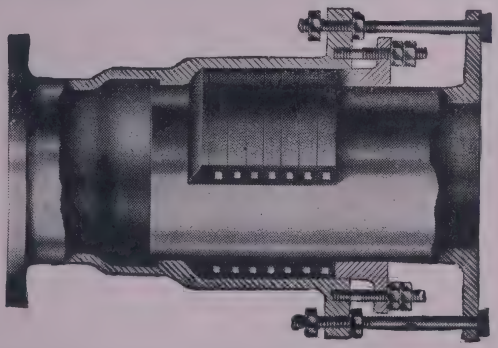

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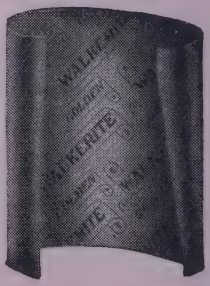

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Crystal Palace School of Practical Engineering, Sydenham, London, S.E. 19 *white page at end of book* 3152

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Daglish, Robt., & Co., Ltd., St. Helens, Lancs. ... ... *facing pages* 2600, 2601

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Davis & Timmins, Ltd., 34A York Road, King's Cross, N. 1, and Brook Road, Wood Green, London, N 22 ... ... *facing pages* 1208, 1209

Dawson, James, & Son, Ltd., Boultham Works, Lincoln, Eng. London Office: 60 Victoria St., Westminster, S.W. 1 ... ... *facing pages* 954, 955

Delta Metal Company, Ltd., Delta Works, East Greenwich, London, S.E. 10; and Dartmouth Street, Birmingham ... ... *facing pages* 280, 281

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Dorman, W. H. & Co., Ltd., Stafford. London Office: Criterion Buildings, Piccadilly Circus, W. 1 ... ... *facing pages* 1158, 1973

Dorman, Long & Co., Ltd., Middlesbrough, and 4 Central Buildings, Westminster, London, S.W. 1 ... ... *facing page* 349

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Elliston, Evans & Jackson, Ltd., 93 Old Street, London, E.C. 1 *facing pages* 2292, 2293

'Engineer,' The, 33 Norfolk Street, Strand, London, W.C. 2 *grey pages in front of book* vii, viii

Engineering Specialists, Ltd., Craven House, Kingsway, London, W.C. 2 *facing page* 1728

English Electric Company, Ltd., Queen's House, Kingsway, London, W.C. 2. Works: Preston, Coventry, Bradford, Stafford, and Rugby. Branch Offices: Birmingham, Cardiff, Glasgow, Liverpool, Manchester, Newcastle-on-Tyne, and Sheffield; Buenos Ayres, Rio de Janeiro, Montreal, Calcutta, Bombay, Madras, Tokio, Wellington, N.Z., Cape Town, and Singapore *grey page in front of book* xix *and facing pages* 1345, 2280

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Eternit Pietra Artificiale (London), Ltd., Norfolk House, Laurence Pountney Hill, London, E.C. 4 ... ... *facing page* 413

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Expanded Metal Co., Ltd., York Mansion, Petty France, Westminster, S.W. 1; and Stranton Works, West Hartlepool ... ... *facing pages* 436, 437

Ferodo, Ltd., Sovereign Mills, Chapel-en-le-Frith; and 222 Tottenham Court Road, London, W. 1 ... ... *facing pages* 918, 990

Ferro-Arc Welding Co., Ltd., 12, Grosvenor Gardens, Westminster, London, S.W. 1 *facing page* 2772

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Fielding & Platt, Ltd., Atlas Works, Gloucester; and 73A Queen Victoria Street, London, E.C. 4 ... ... *facing pages* 1417, 1959

Film Cooling Towers (1925), Ltd., 124 Chancery Lane, London, W.C. 2 *facing page* 1899

Firth, Thos., & Sons, Ltd., Norfolk Works, Savile Street East, Sheffield; and 8 The Sanctuary, Westminster, S.W. 1 ... ... *facing pages* 1136, 1137

Foster Instrument Co., Letchworth, Herts, England ... ... *facing page* 1144

François Cementation Co., Ltd., Bentley Works, Doncaster. Registered Office: 701 Salisbury House, London Wall, London, E.C. 2 ... ... *facing pages* 2578, 2579

Fry's Metal Foundries, Ltd., 25/42 Holland Street, Blackfriars, London, S.E. 1; and at Manchester, Bristol, Glasgow, and Dublin ... ... *facing page* 2743

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General Electric Co., Ltd., Magnet House, Kingsway, London, W.C. 2; Witton Engineering Works, near Birmingham; and Fraser & Chalmers' Engineering Works, Erith, Kent ... ... *facing pages* 2256, 2312

Gent & Co., Ltd., Faraday Works, Leicester; 25 Victoria Street, Westminster, S.W. 1; 52 Blackett Street, Newcastle-on-Tyne... ... ... *facing page* 2318

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Glasgow Engineers, Ltd., 89 James' Street, Glasgow, S.E. ... ... *facing pages* 928, 929

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Heath & Co., New Eltham, London, S.E. 9; City Office, 2 Tower Royal, Cannon Street, London, E.C. 4 ... ... *facing page* 1

Heenan & Froude, Ltd., 4 Chapel Walks, Manchester; Worcester Engineering Works, Worcester; Newton Heath Ironworks, Manchester; 150 New Bond Street, London, W. 1; and 79 West Regent Street, Glasgow ... *facing pages* 150, 1933, 2133

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Lewis & Tylor, Ltd., 9 St. Thomas's Street, London, S.E. 1. Works: Gripoly Mills, Cardiff; and at 45 Deansgate Arcade, Manchester; 213 West Campbell Street, Glasgow, C. 2; 20 Wind Street, Swansea; 13 Akenside Hill, Quayside, Newcastle-on-Tyne; also at Bombay and Calcutta ... ... *facing pages* 956, 957

Leyland & Birmingham Rubber Co., Ltd., Leyland, near Preston, Lancs.; 24-30 Duke Street, Aldgate, London, E. 1; 124 New Street, Birmingham; 29 Brown Street, Manchester; Cardiff, Glasgow, Edinburgh, Dublin; Johannesburg, Calcutta, and Buenos Aires ... ... *white page at end of book* 3145

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Stanley, W. F., & Co., Ltd., Great Turnstile, Holborn, and 286 High Holborn, London, W.C. 1; 13 Railway Approach, London Bridge, S.E. 1; 8 Victoria Street, Westminster, S.W. 1; and 68 Queen Street, Glasgow ... ... *facing pages* 122, 123

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United Water Softeners, Ltd., Aldwych House, London, W.C. 2 *facing pages* 1478, 1479, 1688, 1689, 1696, 1697

'Unit' Superheater & Pipe Co., Ltd., Unit Works, Upper Strand, Swansea; and at London, Glasgow, Manchester, etc. ... ... *facing page* 1680

Variable Speed Gear, Ltd., 6 Broadway, Westminster, London, S.W. 1 *facing pages* 1032, 1336

Vickers Boiler Co., Ltd., 50/64 Broadway, Westminster, London, S.W. 1 *facing pages* 1650, 1651

Walker, James, & Co., Ltd., Lion Works, Maybury Hill, Woking, Surrey (late Garford Street, West India Dock Road, London, E. 14); Liverpool, Glasgow, Newcastle, and Cardiff (*pink pages at commencement and end of Index to book*) *facing pages* 2902, 2903, 2976, 2977

Walker-Weston Company, Ltd., 75 Victoria Street, Westminster, London, S.W. 1 ... ... *facing page* 803

Walker, William, & Sons, Ltd., Bolton, England ... ... *facing page* 963

Wallsend Slipway & Engineering Co., Ltd., Wallsend-on-Tyne... *facing page* 2418

Ward, Thos. W., Ltd., Albion Works, Savile Street, Sheffield; and 18 Billiter Street, London, E.C. 3... ... ... *grey page in front of book* xiv

FOR CLASSIFIED DIRECTORY OF ADVERTISERS' SPECIALITIES, ALSO GLOSSARIES OF FRENCH, ITALIAN, SPANISH, & RUSSIAN TRADE TERMS, SEE PP. 2993, &c.

PAGE

Waygood-Otis, Ltd., 54/55 Fetter Lane, London, E.C. 4; 62/63 Lionel Street, Birmingham. Works: Falmouth Road, London, S.E. 1 ... ... *facing page* 932

Weir, G. & J., Ltd., Cathcart, Glasgow; 77 Billiter Buildings, Billiter Street, London, E.C. 3; and Bank Chambers, 26 Mosley Street, Newcastle-on-Tyne *facing pages* 1324, 1886

Weldless Steel Tube Co., Ltd., Icknield Port Road, Birmingham; Wednesfield, nr. Wolverhampton; and 39 Lime Street, London, E.C. 3 ... ... *facing page* 1663

Wells, A. C., & Co., Ltd., 102, 103 & 104 Midland Road, St. Pancras, London, N.W. 1; and Carnarvon Street, Cheetham, Manchester ... ... *facing page* 2484

Wesson, W., & Co., Ltd., Moxley, Wednesbury; and 54 Corporation Street, Manchester ... ... *grey page in front of book* xxxiii

Westinghouse Brake and Saxby Signal Co., Ltd., 82 York Road, King's Cross, London, N. 1; and Chippenham, Wilts ... ... *grey page in front of book* x *and facing page* 736

Westinghouse Morse Chain Co., Ltd., The Chalneries, Letchworth, Herts *grey page in front of book* xviii

Westminster Tool and Electric Co., Ltd., Westool Works, Putney, London, S.W.15, and 99 Waterloo Street, Glasgow ... ... *facing page* 1116

Weston Electrical Instrument Co., Ltd., 15 Gt. Saffron Hill, London, E.C. 1; and Newark, N.J., U.S.A. ... ... *facing pages* 2304, 2305

White, J. Samuel, & Co., Ltd., East Cowes, Isle of Wight; 28 Victoria Street, Westminster, S.W. 1; and 707/711 Royal Liver Building, Liverpool... *facing page* 2388

Whitecross Company, Ltd., Warrington; and 110 Fenchurch Street, London, E.C. 3 ... ... *facing page* 925

Willcox, W. H., & Co., Ltd., 32-38 Southwark Street, London, S.E. 1 *first grey page inside front cover* i

Willesden Paper & Canvas Works, Ltd., Willesden Junction, London, N.W.10 *grey page in front of book* xiii

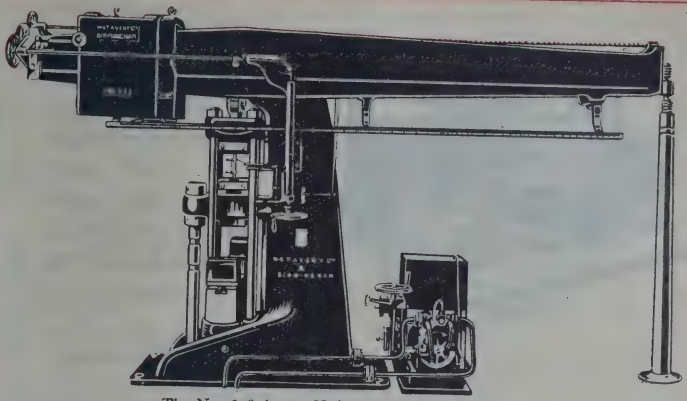
Woodite Co., Ltd., Mitcham Common, Surrey ... ... *facing page* 1720

Wrights' Ropes Ltd., Universe Works, Birmingham; Salisbury House, London Wall, London, E.C. 2; Tower Buildings, Liverpool; Bank Chambers, Fargate, Sheffield; Park Place, Cardiff; Sydney; Calcutta; Montreal; and Paris *facing page* 986

'W.R.' Patents, Ltd., Greek Street, Leeds ... ... *grey page in front of book* xvii

Yarrow & Co., Ltd., Scotstoun, Glasgow (formerly of Poplar, London) *facing page* 1656

FOR CLASSIFIED DIRECTORY OF ADVERTISERS' SPECIALITIES, ALSO GLOSSARIES OF FRENCH, ITALIAN, SPANISH, & RUSSIAN TRADE TERMS, SEE PP. 2993, &C.



The No. 618 Avery Universal Testing Machine

AVERY

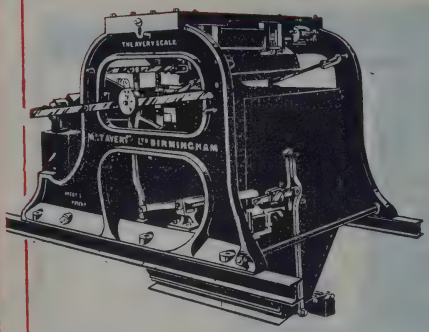
This machine is of the vertical type, and is "Universal" in character, permitting different forms of test to be made without change of tools.

It is designed upon the single-lever principle, the load upon the test piece being indicated by a poise weight traversing a graduated scale upon the steelyard.

The steelyard is graduated from zero to 50 tons, the finest subdivisions being .01 ton. Makers of the World's largest Testing Machines.

Write for list No. 827.

W&T.AVERY LTD
SOHO FOUNDRY BIRMINGHAM



The No. 48 Avery Patent Automatic Coal Weigher.

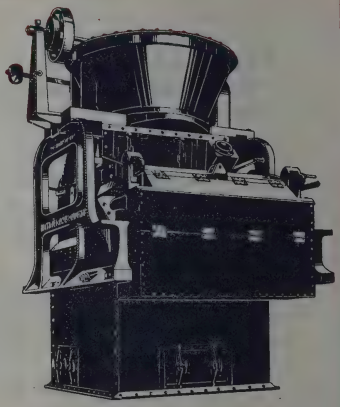
Is the embodiment of reliability, accuracy and efficiency, and specially designed to check accurately coal intake and consumption, with reduced labour costs.

Write for list No. 839 to Automatic Dept.

AVERY

ACCURATE.
RELIABLE.

This automatic weigher gives accurate records of pulverized fuel consumption without dust escape. Machine illustrated weighs 50 tons per hour from an overhead storage hopper, delivers to the pump, and automatically keeps an accurate record of all fuel consumed.



The No. 52 Avery Patent Dustproof Automatic Weigher for Pulverized Coal.

W&T.AVERY LTD
SOHO FOUNDRY BIRMINGHAM

A1557

'THE ENGINEER'S YEAR-BOOK' CLASSIFIED DIRECTORY OF LEADING ENGINEERING AND ALLIED FIRMS ADVERTISING IN THE 1928 EDITION.

A RELIABLE GUIDE FOR THE USE OF BUYERS OF ENGINEERING MATERIALS, MACHINERY, TOOLS, PLANT, APPLIANCES, ETC.

For Advertisers' Addresses, and Positions of their Announcements in the 'Year-Book,' consult foregoing Alphabetical List, pages 2977 to 2990

The aim of the Proprietors of 'The Engineer's Year-Book' is to include in this publication only the most reputable firms' announcements, so that readers desiring to order, or specify, the various specialities advertised, may do so with confidence.

***** French, Italian, Spanish, and Russian translations of the terms used in this Directory are given on pages 3059 to 3144.**

RÉPERTOIRE ANALYTIQUE DES ANNONCEURS POUR 1928.

Guide pratique des acheteurs de matériaux pour constructions mécaniques, de machines, d'outils, outillages, appareils, etc.

Les propriétaires de 'The Engineer's Year-Book' (L'Annuaire de l'Ingénieur) se sont efforcés de ne faire figurer dans la présente publication que les annonces des maisons les mieux réputées ; les lecteurs désireux de commander ou de spécifier les différentes spécialités annoncées peuvent donc le faire en toute confiance.

On trouvera pages 3059–3078 la liste des équivalents de ces termes en Français.

Pour les adresses des Annonceurs et les renvois à leurs annonces dans l'Annuaire, voir l'Index alphabétique ci-dessus, pages 2977–2990.

GUIDA CLASSIFICATA DELLE DITTE DI MAGGIOR IMPORTANZA CHE HANNO DEGLI ANNUNCI NELL' EDIZIONE DEL 1928.

Ai compratori di materiale per la meccanica, e di macchinario in genere, questa Guida è assai utile.

I proprietari della 'Engineer's Year-Book' (l' Annuario dell' Ingegnere) si sono limitati a pubblicare in questa guida solo i nomi delle case più rinomate; i lettori che desiderano ordinare o specificare specialità comprese in questi annunci lo possono quindi fare con tutta sicurezza.

A pagine 3079–3098 trovasi la traduzione in italiano dei termini usati in questo elenco.

Per gli indirizzi delle ditte aventi degli annunci ed il posto dove detti annunci appaiono nella guida vedesi l' elenco alfabetico a pagine 2977–2990.

GUÍA CLASIFICADA DE ANUNCIADORES PARA 1928

Esta Guía es muy conveniente para los compradores de materiales de ingeniería, maquinaria, herramientas, instalaciones, utensilios, etc.

La aspiración de los propietarios de 'The Engineer's Year-Book' ('El Anuario del Ingeniero') es incluir en esta publicación solamente los anuncios de las casas de la mejor reputación ; así es que los lectores que deseen pedir ó especificar cualquiera de los diversos artículos anunciados pueden hacerlo así con confianza.

Una traducción de los términos equivalentes en Castellano se hallará en la lista, páginas 3099–3120.

Para señas de anunciadores y referencias á sus anuncios, consúltese la precedente Lista alfabética, paginas 2977–2990.

ПОДРОБНЫЙ УКАЗАТЕЛЬ СПЕЦІАЛЬНОСТЕЙ АНОНСОДАТЕЛЕЙ 1928 г.

Удобное Руководство для Покупателей Инженерныхъ матеріаловъ, инструментовъ, машинъ, приспособленій, принадлежностей и пр. и пр.

Редакція 'The Engineer's Year-Book' (Инжечерный Ежегодникъ) въ настоящемъ изданіи включила объявленія лишь первоклассныхъ фирмъ, такъ что читатель можетъ съ полной увѣренностью снестись съ любой изъ этихъ фирмъ или помѣстить свои заказы на любыя изъ указанныхъ спеціальностей.

Переводъ терминовъ данъ также на Французскомъ и Италіянскомъ и Испанскомъ Русскомъ языкахъ—см. стр. 3121–3144.

Адреса фирмъ и свѣдѣнія объ ихъ спеціальностяхъ въ 'The Engineer's Year-Book' (Инженерный Ежегодникъ)—см. предыдущій алфавитный списокъ—стр. 2977–2990.

CLASSIFIED DIRECTORY OF ADVERTISERS' MANUFACTURES AND SPECIALITIES.

A RELIABLE GUIDE FOR BUYERS OF ENGINEERING MATERIALS, MACHINERY, TOOLS, PLANT, APPLIANCES, ETC.

***** French, Italian, Spanish, and Russian translations of the Terms used in this Directory are given on pages 3059 to 3141.**

Accumulator Acid.

Berk, F. W., & Co., Ltd.
Hart Accumulator Co., Ltd.

Accumulators.

See BATTERIES.

Accumulators (Hydraulic).

Berry, Henry, & Co., Ltd.
Glasgow Engineers, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.

Acetylene.

Allen-Liversidge, Ltd.
Bingham, Charles, & Co.
District Chemical Co., Ltd.
Hoggett, Young & Co.
Thorn & Hoddle, Ltd.

Acetylene Hand and Flare Lamps (Portable).

Braby, Fred., & Co., Ltd.

Acetylene Generating Plants.

British Oxygen Co., Ltd.
Carbic, Ltd.

Acetylene Generating Plants—*continued.*

Ferrox Company, Ltd.
Thorn & Hoddle, Ltd.

Admiralty Gunmetal Ingots.

Bull's Metal & Melloid Co., Ltd.
Delta Metal Co., Ltd.

Aerial Grinders (Electric).

Humphreys, J. H., & Sons.

Aero Engines.

Beardmore, Wm., & Co., Ltd.
Midland Motor Cylinder Co., Ltd. (Cylinder Castings for).

Aeronautical Engineers.

Beardmore, Wm., & Co., Ltd.

Aeroplane Accessories.

Cork Manufacturing Co., Ltd.
Ferrox Company, Ltd.

Aeroplane Builders.

Beardmore, Wm., & Co., Ltd.
White, J. Samuel, & Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Agricultural Tools and Machinery.

Blackstone & Co., Ltd.
Hardy Patent Pick Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Sanderson, Bros. & Newbould, Ltd.

Air Compressors.

Alley & MacLellan, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Belliss & Morcom, Ltd.
British Oxygen Co., Ltd.
Brotherhood, Peter, Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.
Dexine, Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Holland, Bernard, & Co.
Holman Bros., Ltd.
Lamson Pneumatic Tube Co., Ltd.
Liverpool Refrigeration Co., Ltd. (High Pressure).
United States Metallic Packing Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.
Westminster Tool and Electric Co., Ltd.

Air-Conditioning Plants.

Heenan & Froude, Ltd.

Air-Cooling and Humidifying Apparatus.

Film Cooling Towers (1925), Ltd.
Heenan & Froude, Ltd.
Potter, F. W., & Co.
Premier Cooler & Engineering Co., Ltd.
Sturtevant Engineering Co., Ltd.

Air Filters and Purifiers.

Film Cooling Towers (1925), Ltd.
Heenan & Froude, Ltd.
Premier Cooler and Engineering Co., Ltd.
Sturtevant Engineering Co., Ltd.

Air Heaters and Dryers.

Heenan & Froude, Ltd.
Royles, Ltd.
Underfeed Stoker Co., Ltd.

See also Heating & Ventilating.

Air Hoists.

Consolidated Pneumatic Tool Co., Ltd.
United States Metallic Packing Co., Ltd.

Air Meters.

Kent, George, Ltd.
Negretti & Zambra.

Air-Pump Discharge (Measurement of).

Lea Recorder Co., Ltd.

Air Pumps.

Bailey, Sir W. H., & Co., Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Hick, Hargreaves & Co., Ltd.
Mirrlees Watson Co., Ltd. (Mirrlees Leblanc Rotary Air Pumps and Steam Ejector Air Pumps).
Rotherham & Sons, Ltd.
Weir, G. & J., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Aircraft Manufacturers.

See Aeroplane Builders.

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990.

Aircraft Steels.

Firth, Thos., & Sons, Ltd.

Air Hardening Gear Steel.

Firth, Thos., & Sons, Ltd.

Alloy Steel Manufacturers.

Beardmore, Wm., & Co., Ltd.
Firth, Thos., & Sons, Ltd.

Alloys.

Bingham, Charles, & Co.
Booth, James, & Co. (1915), Ltd., ('Duralumin,' Regd. Trade Mark, Vickers' Special Alloy).
British Aluminium Co., Ltd.
Bull's Metal & Melloid Co., Ltd.
Delta Metal Co., Ltd.
Richards, J. H., & Co., Ltd.

Alternators.

English Electric Co., Ltd.
General Electric Co., Ltd.
Johnson & Phillips, Ltd.

Aluminium (Ingots, Sheets, Tube, Wire, Cable, Sections, etc.).

British Aluminium Co., Ltd.
London Electric Wire Co. & Smiths, Ltd.
Ward, Thos. W., Ltd.

Aluminium Castings and Fittings for All Trades.

Birmingham Aluminium Casting (1903) Co., Ltd.
Coan, Robert W., Ltd.
Fry's Metal Foundries, Ltd.
Mills (William), Ltd.
Sparklets, Ltd.

Aluminium Die Castings.

Coan, Robert W., Ltd.
Dorman, W. H., & Co., Ltd.
Fry's Metal Foundries, Ltd.
Mills (William), Ltd.
Sparklets, Ltd.

Aluminium Powder.

Ferrox Company, Ltd.

Aluminium Studs, Bolts and Nuts.

Davis & Timmins, Ltd.

Ammeters.

See INSTRUMENTS (ELECTRICAL).

Ammunition.

Nobel Industries, Ltd.
Imperial Chemical Industries, Ltd.

Analysis of Gases.

'Auto' Recorder Co.
'W. R.' Patents, Ltd.

Anti-corrosive Paint.

Carson, Walter, & Sons.

Anti-friction Metals.

See ALLOYS.

Anti-vibration.

Cork Manufacturing Co., Ltd.

Arc Lamps.

See ELECTRIC LIGHT FITTINGS.

Artesian Well Engineers.

Hardy Patent Pick Co., Ltd.

Asbestos Cement Corrugated Roofing Sheets.

Bell's Poilite & Everite Co., Ltd.
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').

Asbestos Cement Flat Sheets for Walls, Partitions, Ceilings, etc.

Bell's Poilite & Everite Co., Ltd.
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').

Asbestos Cement Roofing Tiles.

Bell's Poilite & Everite Co., Ltd. ('Poilite').
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').

Asbestos Coverings & Mattresses.

Anderson, Thomas, Ltd.
Beldam Asbestos Co., Ltd.
Bell's United Asbestos Co., Ltd.
Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.

Asbestos Goods, Fittings, Packing, etc.

Anderson, Thomas, Ltd.
Attwater & Sons.
Beldam Asbestos Co., Ltd.
Beldam Packing & Rubber Co., Ltd.
Bell's United Asbestos Co., Ltd.
British Fibrocement Works, Ltd.
Cresswell's Asbestos Co., Ltd.
Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Klinger, Richard, Ltd.
Pearson, E. J. & J., Ltd.
Walker, James, & Co., Ltd. ('Lion').
Willcox, W. H., & Co., Ltd.

Asbestos Packing ('Lascar').

Beldam Asbestos Co., Ltd.

Asbestos Packing ('Lion').

Walker, James, & Co., Ltd.

Asbestos Packing ('Reefer').

Bell's United Asbestos Co., Ltd.

Asphalte.

Callender, George M., & Co., Ltd.

Automatic Controllers (Electric).

Elliston, Evans & Jackson, Ltd.

Automatic Signals.

British Power Railway Signal Co., Ltd.

Automatic Weighing Machines.

Avery, W. & T., Ltd.

Axles (Railway).

Beardmore, Wm., & Co., Ltd.
Firth, Thos., & Sons, Ltd.

Balata Belting.

Barrow, Hepburn & Gale, Ltd. ('Bull Dog' Brand).
Dawson, James, & Son, Ltd.
Dick, R. & J., Ltd. (Original Balata Brand).
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Walker, William, & Sons, Ltd.

Balls and Ball Bearings.

Hoffmann Manufacturing Co., Ltd.
Skefko Ball Bearing Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Barometers.

Harling, W. H.
Heath & Co.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Townson & Mercer, Ltd.

Barrows (Steel).

Braby, Fredk., & Co., Ltd.

Batteries (Electrical Storage).

Berk, F. W., & Co., Ltd. (Acids for).
English Electric Co., Ltd.
General Electric Co., Ltd.
Gent & Co., Ltd.
Hart Accumulator Co., Ltd.
Siemens Bros. & Co., Ltd.

Battery Switchboards.

Gent & Co., Ltd.
Hart Accumulator Co., Ltd.

Bearing Metals, etc.

Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.
Fry's Metal Foundries, Ltd.
Richards, J. H., & Co., Ltd.

Bearings (Ball).

Hoffmann Manufacturing Co., Ltd.
Skefko Ball Bearing Co., Ltd.

Bearings (Chill Cast).

Richards, J. H., & Co., Ltd.

Bell's 'Reefer' Packing.

Bell's United Asbestos Co., Ltd.

Bells (Electric).

General Electric Co., Ltd.
Gent & Co., Ltd.

Belt and Rope Pulleys.

Hick, Hargreaves & Co., Ltd.

Belting, etc.—Leather, Cotton, Hair, India Rubber, etc.

Attwater & Sons.
Barrow, Hepburn & Gale, Ltd. ('Bull Dog' Balata).
Dawson, James, & Son, Ltd.
Dexine, Ltd.
Dick, R. & J., Ltd. (Original Balata).
Hendry, James, Ltd. (Leather).
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Lewis & Taylor, Ltd. ('Gripoly').
Leyland and Birmingham Rubber Co., Ltd.
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.
Walker, James, & Co., Ltd.
Walker, William, & Sons, Ltd.
Willcox, W. H., & Co., Ltd.
Woodite Co., Ltd.

Bending Presses.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.
Stewart, Duncan, & Co., Ltd.

Biflex Chains for Automobile Camshaft Drives.

Coventry Chain Co., Ltd.

Billets (Steel).

Firth, Thos., & Sons, Ltd.

Bitumen Damp-proof Sheeting.

Callender, George M., & Co., Ltd. ('Callendrite').

Blast Furnace Plant.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Galloways, Ltd.
Heenan & Froude, Ltd.

Blast Furnace Tuyeres.

Palatine Engineering Co., Ltd.

Blasting Powder.

Nobel Industries, Ltd.

Blowers.

See FANS.

Blowpipes (Acetylene Welding & Cutting).

British Oxygen Co., Ltd.
Ferrox Company, Ltd.
Hoggett, Young & Co.
Thorn & Hoddle, Ltd.

Boiler Discrustants.

Boilerine, Ltd.

Boiler and Pipe Coverings.

Anderson, Thomas, Ltd.
Bell's United Asbestos Co., Ltd.
British Fibrocement Works, Ltd.
Cresswell's Asbestos Co., Ltd.
Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Pearson, E. J. & J., Ltd.
Sankey, J. H., & Son, Ltd.

Boiler Blocks and Covers.

Pearson, E. J. & J., Ltd.

Boiler Cleaners (Mechanical and Electrical).

Crockatt, W., & Sons, Ltd.
Hulburd Patents, Ltd.
Willcox, W. H., & Co., Ltd.

Boiler Composition (for inside use).

Boilerine, Ltd.

Boiler Feed Filters.

See FEED WATER.

Boiler Feed Pumps.

Bailey, Sir W. H., & Co., Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Dexine, Ltd.
Pulsometer Engineering Co., Ltd.
Royles, Ltd.
Sulzer Bros.
Weir, G. & J., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Boiler Feed Water, Oil Elimination from.

Baker Oil Separator Co.
Kennicott Water Softener Co., Ltd.
United Water Softeners, Ltd.

Boiler Fittings.

See ENGINE AND BOILER FITTINGS.

Boiler Flue Gases (Analysis of).

'Auto' Recorder Co.

Boiler Furnaces.

Bennis, Ed., & Co., Ltd.
Cleworth, A. B., & Co., Ltd.
International Combustion, Ltd.
Leeds Forge Co., Ltd.
Superheater Co., Ltd. (Tubes, etc.).
Underfeed Stoker Co., Ltd.

'Boilerine.'

Boilerine, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Boiler Manufacturers.

Babcock & Wilcox, Ltd.
Beardmore, Wm., & Co., Ltd.
Clarke, Chapman & Co., Ltd.
Clarkson Thimble Tube Boiler Co.,Ltd.
Cochran & Co. (Annan), Ltd.
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.
Doxford, William, & Sons, Ltd.
Galloways, Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.
Spencer-Bonecourt, Ltd.
Spencer-Hopwood, Ltd.
Stirling Boiler Co., Ltd.
Sulzer Bros.
Thompson, John (Wolverhampton), Ltd.
Thompson (John) Water Tube Boilers, Ltd.
Thornycroft, John I., & Co., Ltd.
Vickers Boiler Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.
Ward, Thos. W., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Boiler Mountings.

Alley & MacLellan, Ltd.
Cochran & Co. (Annan), Ltd.
Crosby Valve & Engineering Co., Ltd.
Hopkinsons, Ltd.
Royles, Ltd.
Thompson, John (Wolverhampton), Ltd.

See also ENGINE AND BOILER FITTINGS.

Boiler Plates (Steel).

Beardmore, Wm., & Co., Ltd.
Leeds Forge Co., Ltd.

Boiler Preservatives.

Boilerine, Ltd.
Kennicott Water Softener Co., Ltd.
United Water Softeners, Ltd.

Boiler Repairs (Electric Arc Welding for).

A.-C. Welding Co.

Boiler Seatings.

Pearson, E. J. & J., Ltd.
Sankey, J. H., & Son, Ltd.

Boiler Setting.

Pearson, E. J. & J., Ltd.

Boiler Settings (Improved).

Pearson, E. J. & J., Ltd.

Boiler Tubes.

Booth, James, & Co (1915), Ltd.
Metallic Seamless Tube Co., Ltd.
Stewarts & Lloyds, Ltd.
Weldless Steel Tube Co., Ltd.

Bolts and Nuts (Iron, Steel, Copper, Naval Brass, etc.).

Bull's Metal and Melloid Co., Ltd.
Davis & Timmins, Ltd.

Books and Journals, Scientific.

Batsford, B. T., Ltd.
Chapman & Hall, Ltd.
'Electrical Review' (The).
'Engineer' (The).
Griffin, Charles, & Co., Ltd.
Lockwood (Crosby) & Son.
'Machinery Market' (The).
Rentell, S., & Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Borehole (Deep Well Pumps).

Sulzer Bros.

Boring Machines for Rock and Coal.

Consolidated Pneumatic Tool Co., Ltd.
Hardy Patent Pick Co., Ltd.
Holman Bros., Ltd.

Boring Tool Makers (Artesian).

Hardy Patent Pick Co., Ltd.

Brake and Clutch Linings.

Bell's United Asbestos Co., Ltd.
Cresswell's Asbestos Co., Ltd.
Ferodo, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.

Brake Blocks.

Bell's United Asbestos Co., Ltd.
Cresswell's Asbestos Co., Ltd.
Dexine, Ltd.
Ferodo, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Railway & General Engineering Co., Ltd.
Summerson, Thomas, & Sons, Ltd.

Brakes (Dynamometers).

Brotherhood, Peter, Ltd.
Heenan & Froude, Ltd.

Brakes (Electro-Mechanical).

Elliston, Evans & Jackson, Ltd.

Brakes (Railway).

Consolidated Brake & Engineering Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Brass and Bronze.

Booth, James, & Co. (1915), Ltd.
Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.
Ferrox Company, Ltd.
Kynoch, Ltd.
McPhail & Simpson.
Nobel Industries, Ltd.

Brass and Copper Bolts and Nuts.

See BOLTS AND NUTS.

Brass Founders and Finishers.

Guest & Chrimes, Ltd.
Railway & General Engineering Co., Ltd.
Swinney Brothers, Ltd.

Bridge Builders.

Heenan & Froude, Ltd.
Henderson & Glass.
Thompson, John (Wolverhampton), Ltd.
Ward, Thos. W., Ltd.

Bright Part Coatings.

Pegg & Ellam Jones, Ltd.

'BRITIMP' Metallic Packings.

British Metallic Packings Co., Ltd.

Bronze.

See BRASS AND BRONZE.

Buildings (Protection of, from Lightning).

Cutting, R. C., & Co.

Buildings (Waterproofing of).
Callender, George M., & Co., Ltd.

Bullet Proof Steel Plates.
Firth, Thos., & Sons, Ltd.

Bull's Metal and Melloid.
Bull's Metal and Melloid Co., Ltd.

Bush Valves for Air Pumps.
Beldam Packing and Rubber Co., Ltd.

Cable Laying Machinery.
Clarke, Chapman & Co., Ltd.
Johnson & Phillips, Ltd.
Siemens Bros. & Co., Ltd.
Taylor & Hubbard, Ltd.

Cables: Telegraph, Telephone, Electric Light, and Submarine.
Ateliers de Constructions Electriques de Charleroi.
British Aluminium Co., Ltd.
British Thomson-Houston Co., Ltd.
Callender's Cable and Construction Co., Ltd.
Craigpark Electric Cable Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
London Electric Wire Co. & Smiths, Ltd.
Macintosh Cable Co., Ltd.
Metallic Seamless Tube Co., Ltd.
Pirelli-General Cable Works, Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Smith, Frederick, & Co.
Standard Telephones & Cables, Ltd.

'Cab Tyre Sheathed' Cables.
Callender's Cable and Construction Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
St. Helens Cable and Rubber Co., Ltd.

'Callendrite' Dampcourse and Sheeting.
Callender, George M., & Co., Ltd.

Calorifiers.
Royles, Ltd.
Swinney Brothers, Ltd.

Calorimeters for Fuel Testing.
Drayton Regulator & Instrument Co., Ltd.

'Camel' Hair, 'Camel' Brand Belting (sole makers of).
Reddaway, F., & Co., Ltd.

Carbide of Calcium.
Allen-Liversidge, Ltd.
Bingham, Charles, & Co.
Braby, Fredk., & Co., Ltd.
British Oxygen Co., Ltd.
District Chemical Co., Ltd.
Hoggett, Young & Co.
Thorn & Hoddle, Ltd.

Carriages and Waggons (Railway).
Leeds Forge Co., Ltd.

Cartridge Machinery.
Fielding & Platt, Ltd.

Case Hardening.
District Chemical Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Case-Hardening Steels.

Firth, Thos., & Sons, Ltd.

Cash Carrier Systems.

Lamson Pneumatic Tube Co., Ltd.
Sturtevant Engineering Co., Ltd.

Cast Iron Tubbing and Curbs for Collieries.

Swinney Brothers, Ltd.

Castings and Forgings.

Beardmore, Wm., & Co., Ltd.
Birmingham Aluminium Casting (1903) Co., Ltd.
Bull's Metal and Melloid Co., Ltd.
Coan, Robert W., Ltd. (Aluminium)
Daglish, Robert, & Co., Ltd.
Delta Metal Co., Ltd. (Brass & Bronze).
Dorman, W. H., & Co., Ltd. (Grey Iron).
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Kirkstall Forge, Ltd.
McPhail & Simpson.
Mills (William), Ltd. (Aluminium).
Power Plant Co., Ltd.
Railway and General Engineering Co., Ltd.
Richards, J. H., & Co., Ltd.
Sparklets, Ltd.
Stewarts & Lloyds, Ltd.
Stone, J., & Co., Ltd.
Summerson, Thomas, & Sons, Ltd. (Iron & Steel Castings).
Wallsend Slipway & Engineering Co., Ltd.
Wesson, W., & Co., Ltd.

Cement.

Cement Marketing Co., Ltd. (Portland, Keenes', Parian).
Sankey, J. H., & Son, Ltd.

Cement Machinery.

Howes, S.
Sturtevant Engineering Co., Ltd.

Cement (Refractory).

Sankey, J. H., & Son, Ltd.

Cement Slates and Boards.

Bell's Poilite & Everite Co., Ltd. ('Poilite').
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').

Cement Testing Machines and Apparatus.

Adie, Patrick.
Bailey, Sir W. H., & Co., Ltd.
Townson & Mercer, Ltd.

Cementation Specialities.

François Cementation Co., Ltd.

Centre Grinders (Electric).

Humphreys, J. H., & Sons.

Centrifugal Pumps.

See Pumps.

Chain Wheels.

Coventry Chain Co., Ltd.
Renold (Hans), Ltd.

Chains and Chain Driving.

Coventry Chain Co., Ltd.
Renold (Hans), Ltd.
Westinghouse Morse Chain Co., Ltd.

Chalk.

Cement Marketing Co., Ltd.

'CHEKKO' Friction Fabrics.

Cresswell's Asbestos Co., Ltd.

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990.

Chemical and Electro-Chemical Apparatus.

Dexine, Ltd.
Siemens Bros. & Co., Ltd.
Townson & Mercer, Ltd.

Chemical Plant and Machinery.

British Aluminium Co., Ltd.
Daglish, Robt., & Co., Ltd.
Thompson, John (Wolverhampton), Ltd.

Chemicals.

Berk, F. W., & Co., Ltd.
Bingham, Charles, & Co.
District Chemical Co., Ltd.
Imperial Chemical Industries, Ltd.

Chimney Stacks.

Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Braby, Fredk., & Co., Ltd.
Cutting, R. C., & Co. (Contractors for Erection and Repair of).
Thompson, John (Wolverhampton), Ltd.

Chrome-Vanadium Steels.

Firth, Thos., & Sons, Ltd.

Chucks (Magnetic).

Humphreys, J. H., & Sons.
Rapid Magnetting Machine Co., Ltd.

Cinder Eliminating Fans.

Sturtevant Engineering Co., Ltd.

Clips ('Jubilee' Worm-Drive (Patent)).

Robinson, L. & Co.

Clocks (Electric).

See ELECTRIC CLOCKS.

Clutch Linings.

Bell's United Asbestos Co., Ltd.
Cresswell's Asbestos Co., Ltd.
Ferodo, Ltd.

Clutches.

Bell's United Asbestos Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Ferodo, Ltd.

Coal, Coke, and Ash Handling Plants.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).

Coal Drills and Cutters.

Consolidated Pneumatic Tool Co., Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Hardy Patent Pick Co., Ltd.

Coal Economy Specialists.

International Combustion, Ltd.

Coal Furnaces.

See FURNACES.

Coal Grinding, Elevating, and Conveying Machinery.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).

Coal Weighing Machines.

Avery, W. & T., Ltd.

Coatings (Bright Part) and Machinery Finishes.

Pegg & Ellam Jones, Ltd.

Cocks (Brass) for Water, Steam, and Gas.

Guest & Chrimes, Ltd.
Rotherham & Sons, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

CO_2 Recorders.

'Auto' Recorder Co.
Underfeed Stoker Co., Ltd.
'W. R.' Patents, Ltd.

Cold Storage.

Anderson, Thomas, Ltd.
British Oxygen Co., Ltd.
Brotherhood, Peter, Ltd.
Hall, J. & E., Ltd.
Haslam Foundry & Engineering Co. (1927), Ltd.
Heenan & Froude, Ltd.
Liverpool Refrigeration Co., Ltd.
Ruberoid Co., Ltd.
Willesden Paper & Canvas Works, Ltd.

Collapsible Gates.

Potter, F. W., & Co.

Colleges (Engineering).

Armstrong College, Newcastle-on-Tyne.
Birmingham University.
Bradford Technical College.
Crystal Palace School of Practical Engineering, London.
Glasgow Royal Technical College.
Heriot-Watt College, Edinburgh.
Imperial College of Science and Technology, London.
King's College, London.
Leeds University.
Liverpool University.
Loughborough Technical College.
Manchester College of Technology.
Northampton Polytechnic Institute.
Nottingham University College.
Polytechnic (The), London.

Collieries (Electrical Equipment of).

Ateliers de Constructions Electriques de Charleroi.
General Electric Co., Ltd.

Collieries (Steel Wire Ropes for).

Wrights' Ropes, Ltd.

Colliery Plant.

Bennis, Ed., & Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Clarke, Chapman & Co., Ltd.
Daglish, Robt., & Co., Ltd.
English Electric Co., Ltd.
Hardy Patent Pick Co., Ltd.
Hart, Thomas, Ltd.
Heenan & Froude, Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Liverpool Electric Cable Co., Ltd.
Patent Lightning Crusher Co., Ltd.
Railway and General Engineering Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Spencer-Bonecourt, Ltd.
Stewarts & Lloyds, Ltd.
Swinney Brothers, Ltd.
Ward, Thos. W., Ltd.

'COLOUR-TIPT' Welding Metals.

Peters, G. D. & Co., Ltd.

Colours, Paints, and Varnishes.

Carson, Walter, & Sons.
Imperial Chemical Industries, Ltd.
Pegg & Ellam Jones, Ltd.

Columns and Castings for Sewage, Gas, and Water Works.

Swinney Brothers, Ltd.

Concrete (Reinforced) Construction.

Expanded Metal Co., Ltd.
Walker-Weston Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Concrete (Reinforcement for).
Expanded Metal Co., Ltd.
Walker-Weston Co., Ltd.

Concrete Roads (Contractors for).
Walker-Weston Co., Ltd.

Condenser Tubes (Copper).
See COPPER TUBES.

Condensers, Evaporators, Water Softening and Distilling Apparatus, etc.
Babcock & Wilcox, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Belliss & Morcom, Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Crockatt, W., & Sons, Ltd.
Davey, Paxman & Co., Ltd.
Erith's Engineering Co., Ltd.
Heenan & Froude, Ltd.
Hick, Hargreaves & Co., Ltd.
Mirrlees Watson Co., Ltd.
Royles, Ltd.
Stewart, Duncan, & Co., Ltd.
Thompson, John (Wolverhampton), Ltd.
Weir, G. & J., Ltd.

Conduits.
See 'STEEL CONDUITS' and 'WIRING SYSTEMS.'

Constructional Engineers.
Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Braby, Fredk., & Co., Ltd.
Expanded Metal Co., Ltd.
Dorman, Long, & Co., Ltd.
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Henderson & Glass.

Constructional Engineers— *continued.*
Railway and General Engineering Co., Ltd.
Thompson, John (Wolverhampton), Ltd.
Ward, Thos. W., Ltd.

Consulting Engineers.
François Cementation Co., Ltd.

Contractors.
François Cementation Co., Ltd.

Contractors' Tools and Plant.
Consolidated Pneumatic Tool Co., Ltd.
Hardy Patent Pick Co., Ltd.
Holland, Bernard, & Co.

Controllers and Liquid Starters.
Elliston, Evans & Jackson, Ltd.
General Electric Co., Ltd.

Converters (Motor).
Ateliers de Constructions Electriques de Charleroi.
General Electric Co., Ltd.

Conveyors.
Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Glasgow Engineers, Ltd.
Hardy Patent Pick Co., Ltd.
Hart, Thomas, Ltd.
Heenan & Froude, Ltd.
Lamson Pneumatic Tube Co., Ltd.
Lewis & Taylor, Ltd.
Pneulec Ltd. (Sand).
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.
Underfeed Stoker Co., Ltd.

See also BELTING.

Cooling Towers.
Film Cooling Towers (1925), Ltd.
Heenan & Froude, Ltd.
Premier Cooler and Engineering Co., Ltd.

Copper.
Booth, James, & Co. (1915), Ltd.

Copper, Brass, & Gunmetal Tubes.
Booth, James, & Co. (1915), Ltd.

Copper Forgings.
Delta Metal Co., Ltd.

Copper Jointing Rings.
Hulburd Patents, Ltd.

Copper Rods and Sections.
Delta Metal Co., Ltd.

Copper Smelters and Wire Manufacturers.
Delta Metal Co., Ltd.
London Electric Wire Co. & Smiths, Ltd.
Shropshire Iron Co., Ltd.
Smith, Frederick, & Co.

Coppersmiths.
Stone, J., & Co., Ltd.

'CORK' Packings, Gaskets, and Washers.
Cork Manufacturing Co., Ltd.

Corrugated Iron.
Braby, Fredk., & Co., Ltd.

Corrugated Tiles and Sheets (Asbestos Cement).
Bell's Poilite and Everite Co., Ltd.
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').

Costs and Time Recorders.
Gent & Co., Ltd.

Cotton Belting.
Attwater & Sons.
Dawson, James, & Son, Ltd.
Lewis & Tylor, Ltd. ('Gripoly').
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.
Willcox, W. H., & Co., Ltd.

Cotton Driving Ropes.
Hart, Thomas, Ltd. ('Lambeth').
Kenyon, Wm., & Sons, Ltd. (Patent Inter-Stranded).

Counting Instruments.
Dickinson, F. E.

Couplings (Flexible).
See FLEXIBLE COUPLINGS.

Coventry Chain Couplings.
Coventry Chain Co., Ltd.

Coverings for Boilers, etc.
Bell's United Asbestos Co., Ltd.
Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Pearson, E. J. & J., Ltd.
Sankey, J. H., & Son, Ltd.

Cranes.
See LIFTING AND HOISTING MACHINERY.

Crucible Cast Steels.
Firth, Thos., & Sons, Ltd.

Crucibles.
Pearson, E. J. & J., Ltd.

Crude Oil Engines.
See OIL ENGINES.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Crushing and Pulverising Machinery.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Hardy Patent Pick Co., Ltd.
Howes, S.
International Combustion, Ltd.
Patent Lightning Crusher Co., Ltd.
Sturtevant Engineering Co., Ltd.

Cylinders.

Allen-Liversidge, Ltd.
Birmingham Aluminium Casting (1903) Co., Ltd.
Braby, Fredk., & Co., Ltd.
Dorman, W. H., & Co., Ltd. (Steam and Combustion Engines).
Midland Motor Cylinder Co., Ltd. (for Aero Engines, Motor Cars, Motor Cycles, and Refrigerators).
Mills (William), Ltd. (Aluminium).
Stewarts & Lloyds, Ltd.
Weldless Steel Tube Co., Ltd.

Damp Course & Bitumen Sheeting.

Callender, George M., & Co., Ltd. ('Callendrite').

'Daysohms' Electric Arc Welding.

Alloy Welding Processes, Ltd.

'Decolite' Fireproof Flooring.

Bell's United Asbestos Co., Ltd.

'Delta' Brand Metals and Alloys.

Delta Metal Co., Ltd.

Demagnetisers.

Humphreys, J. H., & Sons.

Destructors (Magnetic Separators for).

Rapid Magnetting Machine Co., Ltd.

Destructors (Refuse).

Heenan & Froude, Ltd.

'DEXINE' (for H.P. Steam, Acid, and Hydraulic Packing).

Dexine, Ltd.

'DEXONITE' ('Super Ebonite,' for Acids and Alkalies; Fittings and Electrical Insulation Material).

Dexine, Ltd.

Diamond Drillers.

François Cementation Co., Ltd.

Die Castings.

Coan, Robert W., Ltd. (Aluminium).
Fry's Metal Foundries, Ltd.
Dorman, W. H., & Co., Ltd.
Sparklets, Ltd.

Die Casting Machines.

Gwynnes Pumps, Ltd.

Die Steel.

Firth, Thos., & Sons, Ltd.

Diesel and Semi-Diesel Engines.

Beardmore, Wm., & Co., Ltd.
Belliss & Morcom, Ltd.
Davey, Paxman & Co., Ltd.
Doxford, William, & Sons, Ltd.
English Electric Co., Ltd.
Fielding & Platt, Ltd.
Holland, Bernard & Co.
Mirrlees, Bickerton & Day, Ltd.
Petters, Ltd.
Ruston & Hornsby, Ltd.
Sulzer Bros.
Swan, Hunter & Wigham Richardson, Ltd. ('Neptune' Polar type).
Wallsend Slipway & Engineering Co., Ltd.
White, J. Samuel, & Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Distemper.

Carson, Walter, & Sons.
Pegg & Ellam Jones, Ltd.

Distilling Apparatus (Fresh Water).

Caird & Rayner, Ltd.
Mirrlees Watson Co., Ltd.
Royles, Ltd.

'Dixtampo' Yellow Metal Rods for Hot Stamping and Forging.

Delta Metal Co., Ltd.

'Dixtrudo' High-speed Brass Screwing and Turning Rods.

Delta Metal Co., Ltd.

Dock Gates (Builders of).

Swan, Hunter & Wigham Richardson, Ltd.

Draught Gauges.

Hopkinsons, Ltd.

Drawing Office Requisites.

Harling, W. H.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Dredge Plant.

Clarke, Chapman & Co., Ltd.
Gwynnes Pumps, Ltd.

Drills and Drilling Machines.

Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Humphreys, J. H., & Sons (Portable Electric).
United States Metallic Packing Co., Ltd. (Portable Electric).
Ward, Thos. W., Ltd.
Westminster Tool and Electric Co., Ltd.

Driving Bands, Ropes, etc.

Barrow, Hepburn & Gale, Ltd.
Dawson, James, & Son, Ltd.
Hart, Thomas, Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.
Walker, William, & Sons, Ltd.
Willcox, W. H., & Co., Ltd.

Driving Chains.

Coventry Chain Co., Ltd.
Renold (Hans), Ltd.
Westinghouse Morse Chain Co., Ltd.

Drop Stamps and Presses.

Massey, B. & S., Ltd.

Drying Apparatus.

Erith's Engineering Co., Ltd.
Heenan & Froude, Ltd.
Musgrave & Co., Ltd.
Pneulec, Ltd.
Potter, F. W., & Co
Royles, Ltd.
Sturtevant Engineering Co., Ltd.

'DU-EX' Double Expansion Nipples.

Stone, J., & Co., Ltd.

Duff Jacks.

Consolidated Pneumatic Tool Co., Ltd.

'Duralumin' (Regd. Trade Mark, Vickers' Special Alloy).

Booth, James, & Co. (1915), Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Dust and Refuse Collecting Plants.
Sturtevant Engineering Co., Ltd.

Dyestuffs.
Imperial Chemical Industries, Ltd.

Dynamite.
Nobel Industries, Ltd.

Dynamo Brushes.
General Electric Co., Ltd.
Potter, F. W., & Co.

Dynamometers.
Brotherhood, Peter, Ltd.
Heenan & Froude, Ltd.

Dynamos and Motors.
Ateliers de Constructions Electriques de Charleroi.
British Thomson-Houston Co., Ltd.
Clarke, Chapman & Co., Ltd.
English Electric Co., Ltd.
General Electric Co. Ltd.
Johnson & Phillips, Ltd.
Standard Telephones & Cables, Ltd.

Ebonite.
Attwater & Sons.
Dexine, Ltd.
General Electric Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.

Economisers (Fuel).
Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Green, E., & Son, Ltd.
Spencer-Bonecourt, Ltd.
Thompson, John (Wolverhampton), Ltd.
Vickers Boiler Co., Ltd.
'W. R.' Patents, Ltd.

Educational Institutions.
See COLLEGES and SCHOOLS.

Electric Arc Cutting, and Welding Plant and Accessories.
A.-C. Welding Co.
Nobel Industries, Ltd.

Electric Blowers.
Westminster Tool and Electric Co., Ltd.

Electric Cables.
See CABLES: TELEGRAPH, TELEPHONE, ELECTRIC LIGHT AND SUBMARINE.

Electric Cables ('C.T.S.' Type).
See 'CAB TYRE SHEATHED' CABLES.

Electric Clocks.
General Electric Co., Ltd.
Gent & Co., Ltd. ('Pulsynetic' System).

Electric Fans.
See FANS.

Electric Furnaces.
Nobel Industries, Ltd.

Electric Generators.
See DYNAMOS AND MOTORS.

Electric Heaters.
Consolidated Pneumatic Tool Co., Ltd. (for Rivets and Tyres).

Electric Heating, and Cooking Apparatus.
British Thomson-Houston Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Electric Lifts and Cranes.

Ateliers de Constructions Electriques de Charleroi.
Babcock & Wilcox, Ltd.
Berry, Henry, & Co., Ltd.
Clarke, Chapman & Co., Ltd.
Elliston, Evans & Jackson, Ltd.
General Electric Co., Ltd.
Glasgow Engineers, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Smith, Major, & Stevens, Ltd.
Steven, A. & P., Ltd.
Taylor & Hubbard, Ltd.
Waygood-Otis, Ltd.

Electric Light Fittings and Electrical Accessories.

Benjamin Electric, Ltd.
British Thomson-Houston Co., Ltd. (Mazda Lamps).
Callender's Cable and Construction Co., Ltd.
Clarke, Chapman & Co., Ltd.
Craigpark Electric Cable Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Guest & Chrimes, Ltd. (Incandescent Lamps).
Henley's, W. T., Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
Potter, F. W., & Co.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Simplex Conduits, Ltd.
Standard Telephones & Cables, Ltd.

Electric Lighting Contractors.

British Thomson-Houston, Co., Ltd.
Clarke, Chapman & Co., Ltd.
Craigpark Electric Cable Co., Ltd.

Electric Lighting Contractors—*continued.*

English Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Standard Telephones & Cables, Ltd.
Weston Electrical Instrument Co., Ltd.

Electric Motors.

See Dynamos and Motors.

Electric Portable Drills and Hammers.

Consolidated Pneumatic Tool Co., Ltd.
Humphreys, J. H., & Sons.
United States Metallic Packing Co., Ltd.
Westminster Tool and Electric Co., Ltd.
Witton-Kramer Electric Works (Proprs. General Electric Co., Ltd.).

Electric Railways and Tramways.

Ateliers de Constructions Electriques de Charleroi.
Callender's Cable and Construction Co., Ltd.
Clarke, Chapman & Co., Ltd.
Craigpark Electric Cable Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd. (Electric Cables and Gear).
Liverpool Electric Cable Co., Ltd.
Standard Telephones & Cables, Ltd.

Electric Steel Manufacturers.

Firth, Thos., & Sons, Ltd.

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990.

Electric Welding.

A.-C. Welding Co.
Alloy Welding Processes, Ltd.
Braby, Fredk., & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Ferro-Arc Welding Co., Ltd.
Ferrox Company, Ltd.
Nobel Industries, Ltd.

Electric Wiring Systems.

See WIRING SYSTEMS (FLEXIBLE).

Electrical Counters.

Dickinson, F. E.

Electrical Engineers.

Alloy Welding Processes, Ltd.
Ateliers de Constructions Electriques de Charleroi.
Benjamin Electric, Ltd.
British Power Railway Signal Co., Ltd. (Signals).
British Thomson-Houston Co., Ltd.
Callender's Cable and Construction Co., Ltd.
Clarke, Chapman & Co., Ltd.
Craigpark Electric Cable Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Gent & Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
Pirelli-General Cable Works, Ltd.
Railway Signal Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Simplex Conduits, Ltd.
Standard Telephones & Cables, Ltd.
Weston Electrical Instrument Co., Ltd.

Electrical Instruments & Apparatus.

See INSTRUMENTS AND APPARATUS (ELECTRICAL).

Electrical Storage Cells and Batteries.

See STORAGE CELLS.

Electrodes (for Electric Arc Welding).

A.-C. Welding Co.
Alloy Welding Processes, Ltd. (A.W.P. Patent).
Consolidated Pneumatic Tool Co., Ltd. (Weldrick's Patent).
Ferro-Arc Welding Co., Ltd.
Nobel Industries, Ltd.
Peters, G. D. & Co., Ltd.

Elevators.

See LIFTING AND HOISTING.

Enamels, Colours, and Varnishes.

Carson, Walter, & Sons.
Imperial Chemical Industries, Ltd.
Pegg & Ellam Jones, Ltd.

End Mills.

Firth, Thos., & Sons, Ltd.

'Endural' Electric Cables.

Henley's, W. T., Telegraph Works Co., Ltd.

Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.

'Auto' Recorder Co.
Babcock & Wilcox, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Baker Oil Separator Co.
Beardmore, Wm., & Co., Ltd.
Beldam Packing and Rubber Co., Ltd.
Bennis, Ed., & Co., Ltd. (Stokers).
Brotherhood, Peter, Ltd.
Bull's Metal & Melloid Co., Ltd.

Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.—*continued.*

Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Cleworth, A. B., & Co., Ltd.
Crockatt, W., & Sons, Ltd.
Crosby Valve and Engineering Co., Ltd.
Davey, Paxman & Co., Ltd.
Erith's Engineering Co., Ltd.
Galloways, Ltd.
Green, E., & Son, Ltd.
Heenan & Froude, Ltd.
Hind, John, & Sons, Ltd.
Hopkinsons, Ltd.
Howden, James, & Co., Ltd.
Hulburd Patents, Ltd.
Kennicott Water Softener Co., Ltd.
Lea Recorder Co., Ltd.
Leeds Forge Co., Ltd. (Boiler Furnaces).
McPhail & Simpson.
Massey, B. & S., Ltd.
Mirrlees Watson Co., Ltd.
Pearson, E. J. & J., Ltd.
Royles, Ltd.
Spencer-Bonecourt, Ltd.
Spencer-Hopwood, Ltd.
Stewarts & Lloyds, Ltd. (Tubes).
Stirling Boiler Co., Ltd.
Superheater Company, Ltd.
Thompson, John (Wolverhampton), Ltd.
Tomey, Joseph, & Sons, Ltd.
Underfeed Stoker Co., Ltd.
United Kingdom Metallic Packing Syndicate, Ltd.
United States Metallic Packing Co., Ltd.
United Water Softeners, Ltd.
Walker, James, & Co., Ltd.
Weir, G. & J., Ltd.
Weldless Steel Tube Co., Ltd.
Willcox, W. H., & Co., Ltd.

Engine House Telegraphs.

Hopkinsons, Ltd.

Engine Packing.

Anderson, Thomas, Ltd.
Attwater & Sons.
Beldam Packing & Rubber Co., Ltd.
Bell's United Asbestos Co., Ltd. ('Reefer').
British Fibrocement Works, Ltd.
British Metallic Packings Co., Ltd. ('Britimp').
Bull's Metal and Melloid Co., Ltd.
Cresswell's Asbestos Co., Ltd.
Dexine, Ltd.
Hind, John, & Sons, Ltd.
Hulburd Patents, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Klinger, Richard, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.
Leyland & Birmingham Rubber Co., Ltd.
Reddaway, F., & Co., Ltd.
United Kingdom Metallic Packing Syndicate, Ltd.
United States Metallic Packing Co., Ltd.
Walker, James, & Co., Ltd. ('Lion').
Willcox, W. H., & Co., Ltd.
Willesden Paper & Canvas Works, Ltd.
Woodite Co., Ltd.

Engine Packing ('Lion').

Walker, James, & Co., Ltd.

Engine Packing ('Reefer').

Bell's United Asbestos Co., Ltd.

Engineering and Railway Supplies.

See Railway and Tramway Plant.

Engineering Training.
See Colleges.

Engineers (Aeronautical).
See Aeronautical Engineers.

Engineers (Electrical).
See Electrical Engineers.

Engineers (Hydraulic).
Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Gilkes, Gilbert, & Co., Ltd.
Gwynnes Pumps, Ltd.
Howden, James, & Co., Ltd.
Howes, S.
Leeds Engineering & Hydraulic Co., Ltd.
Stewart, Duncan, & Co., Ltd.
Tangyes, Ltd.

Engineers (Mechanical).
Belliss & Morcom, Ltd.
Daglish, Robert, & Co., Ltd.
Gwynnes Pumps, Ltd.
Nobel Industries, Ltd.
Spencer-Bonecourt, Ltd.
Spencer-Hopwood, Ltd.
Walker, James, & Co., Ltd.

Engineers' Tools and Fittings.
Beardmore, Wm., & Co., Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Crockatt, W., & Sons, Ltd.
English Electric Co., Ltd.
Fielding & Platt, Ltd.
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Hind, John, & Sons, Ltd.

Engineers' Tools and Fittings— *continued.*
Massey, B. & S., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Starrett, L. S., Co. (Great Britain), Ltd.
United States Metallic Packing Co., Ltd.
Ward, Thos. W., Ltd.
Westminster Tool and Electric Co., Ltd.
Willcox, W. H., & Co., Ltd.

Engines (Steam).
See Steam Engines.

Engravers, Draughtsmen, and Printers.
Spottiswoode, Ballantyne & Co., Ltd.
Swain, John, & Son, Ltd.

Evaporators, Condensers, Water Distilling Apparatus, etc.
Babcock & Wilcox, Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Heenan & Froude, Ltd.
McPhail & Simpson.
Mirrlees Watson Co., Ltd.
Royles, Ltd.
Spencer-Bonecourt, Ltd.
Spencer-Hopwood, Ltd.
Stewart, Duncan, & Co., Ltd.
Weir, G. & J., Ltd.

Evaporators for Sugar and Trade Liquors.
Mirrlees Watson Co., Ltd.

'Everite' Asbestos Cement Sheets and Pipes.
Bell's Poilite & Everite Co., Ltd.

Excavators and Transporters.

Berry, Henry, & Co., Ltd.
Ruston & Hornsby, Ltd. (Steam).
Taylor & Hubbard, Ltd.

Exhaust Heat Boilers.

Ruston & Hornsby, Ltd.

Expanded Metal.

Expanded Metal Co., Ltd.

Expanding Clips.

Robinson, L., & Co.

Explosives.

Nobel Industries, Ltd.

Extensometers.

Foster Instrument Co.

Extruded Metals.

Booth, James, & Co. (1915), Ltd.
British Aluminium Co., Ltd.
Delta Metal Co., Ltd.
King's Norton Metal Co., Ltd.
Nobel Industries, Ltd.

Factories (Lighting of).

Allen-Liversidge, Ltd.
Benjamin Electric, Ltd.
General Electric Co., Ltd.
Simplex Conduits, Ltd.
Wells, A. C., & Co., Ltd.

Fans: Blowing, Exhaust, Electric, etc.

Brotherhood, Peter, Ltd.
Daglish, Robt., & Co., Ltd.
English Electric Co., Ltd.
Erith's Engineering Co., Ltd.

Fans: Blowing, Exhaust, Electric, etc.—*continued.*

General Electric Co., Ltd.
Gilkes, Gilbert, & Co., Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Musgrave & Co., Ltd.
Potter, F. W., & Co.
Standard Telephones & Cables, Ltd.
Sturtevant Engineering Co., Ltd.
Westminster Tool and Electric Co., Ltd.

Feed-Water Controllers.

Hopkinsons, Ltd.

Feed-Water Heaters, Filters and Purifiers.

Babcock & Wilcox, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Baker Oil Separator Co.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Crockatt, W., & Sons, Ltd.
Erith's Engineering Co., Ltd.
Green, E., & Son, Ltd.
Kennicott Water Softener Co., Ltd.
McPhail & Simpson.
Royles, Ltd.
United Water Softeners, Ltd. ('Permutit').
Weir, G. & J., Ltd.

Feed-Water (Measurement of).

Lea Recorder Co., Ltd.

Felt and Felt Roofs.

Anderson, D., & Son, Ltd.
Callender, George M., & Co., Ltd.
Reddaway, F., & Co., Ltd.
Ruberoid Co., Ltd.
Willesden Paper & Canvas Works, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Felts for Printing Machinery, Paper Making, and Calico Printing Machinery.

Reddaway, F., & Co., Ltd.

Fencing Wire.

Rylands Brothers, Ltd.

'Ferodo' Friction Linings.

Ferodo, Ltd.

Ferro-Concrete.

See REINFORCED CONCRETE.

'Fibrent' Asbestos Cement Slates, Corrugated and Flat Sheets.

British Fibrocement Works, Ltd.

Fibre (Vulcanised).

Attwater & Sons.
Reddaway, F., & Co., Ltd.

Files.

Firth, Thos., & Sons, Ltd.

Filtering Apparatus.

Caird & Rayner, Ltd.
Heenan & Froude, Ltd.
Mirrlees Watson Co., Ltd.
Royles, Ltd.
United Water Softeners, Ltd.

Fire Alarms.

General Electric Co., Ltd.
Gent & Co., Ltd.
Siemens Bros. & Co., Ltd.

Fire Bricks and Fire Clay Goods.

Pearson, E. J. & J., Ltd.
Sankey, J. H., & Son, Ltd.

Fire Cement ('Pyruma').

Sankey, J. H., & Son, Ltd.

Fire Extinguishing Appliances.

Attwater & Sons.
Guest & Chrimes, Ltd.
Reddaway, F., & Co., Ltd.

Fireproof Partition and Wall Sheets.

Bell's Poilite & Everite Co., Ltd.
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London) Ltd. ('Italit').
Sankey, J. H., & Son, Ltd.

Firth's Stainless Steel.

Firth, Thos., & Sons, Ltd.

Flexible Couplings.

Dick, R. & J., Ltd.
Dorman, W. H., & Co., Ltd.
Power Plant Co., Ltd.
United Flexible Metallic Tubing Co., Ltd.

Flexible Metallic Tubing.

United Flexible Metallic Tubing Co., Ltd.

Floating Docks.

Swan, Hunter & Wigham Richardson, Ltd.

Floors, etc. (Fire-resisting).

Bell's United Asbestos Co., Ltd.
Expanded Metal Co., Ltd.

Flour-milling Machinery.

Hardy Patent Pick Co., Ltd.
Howes, S.
Ransomes, Sims & Jefferies, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Flue Covers and Linings.

Pearson, E. J. & J., Ltd.
Sankey, J. H., & Son, Ltd.

Fluxes for Oxy-acetylene Welding.

Thorn & Hoddle, Ltd.

'Foliac' Boiler Graphite.

Graphite Products, Ltd.

'Foliac' Graphite Pipe Joint Compound.

Graphite Products, Ltd.

'Foliac' Graphite Specialities.

Graphite Products, Ltd.

'Foliac' Silica-Graphite Paint.

Graphite Products, Ltd.

Forced and Induced Draught Apparatus.

Bennis, Ed., & Co., Ltd.
Erith's Engineering Co., Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Musgrave & Co., Ltd.
Potter, F. W., & Co.
Sturtevant Engineering Co., Ltd.

Forges (Portable).

Hardy Patent Pick Co., Ltd.
Sturtevant Engineering Co., Ltd.

Forging Furnaces.

See FURNACES.

Forging Hammers.

Massey, B. & S., Ltd.

Forging Presses.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.
Stewart, Duncan, & Co., Ltd.

Forgings and Castings.

See CASTINGS AND FORGINGS.

Founders.

Coan, Robert W., Ltd. (Aluminium).
Hall, J. & E., Ltd.
Haslam Foundry & Engineering Co. (1927), Ltd.
Mills (William), Ltd. (Aluminium).
Nobel Industries, Ltd.

Foundry Plant.

English Electric Co., Ltd.
Heenan & Froude, Ltd.
Pneulec, Ltd.
Willcox, W. H., & Co., Ltd.

Friction Clutches.

British Hele-Shaw Patent Clutch Co., Ltd.
Power Plant Co., Ltd.
Reddaway, F., & Co., Ltd.

Friction Linings.

Cresswell's Asbestos Co., Ltd.
Ferodo, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.

Fuel Economisers.

See ECONOMISERS.

Fuel Economy Systems.

Duffield, Lindley, & Co., Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
International Combustion, Ltd.

Furnace Roofs.

Cleworth, A. B., & Co., Ltd.

Furnaces (Boiler).

See ENGINE AND BOILER FITTINGS.

Furnaces (Electric).

Nobel Industries, Ltd.

Furnaces (Gas and Oil Heated and Industrial).

Bennis, Ed., & Co., Ltd.
Crossley Brothers, Ltd.
Duffield, Lindley, & Co., Ltd.
Erith's Engineering Co., Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Massey, B. & S., Ltd.
Pearson, E. J. & J., Ltd.
Pneulec, Ltd.

Galvanised Iron and Steel Manufacturers.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.

Galvanised Wire Netting.

Rylands Brothers, Ltd.

Galvanisers.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.
Shropshire Iron Co., Ltd.
Wesson, W., & Co., Ltd.

Gas Cleaning Plant.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).

Gas Engine Packing.

Dexine, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
United States Metallic Packing Co., Ltd.

Gas Furnaces.

See FURNACES.

Gas Meters.

Guest & Chrimes, Ltd. (Wet and Dry).
Kent, George, Ltd.

Gas, Oil, and Petrol Engines.

Beardmore, Wm., & Co., Ltd.
Bennis, Ed., & Co., Ltd.
Blackstone & Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Brotherhood, Peter, Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Crossley Brothers, Ltd.
Davey, Paxman & Co., Ltd.
Dorman, W. H., & Co., Ltd.
Fielding & Platt, Ltd.
Galloways, Ltd.
Mirrlees, Bickerton & Day, Ltd.
Petters, Ltd.
Premier Gas Engine Co., Ltd.
Ruston & Hornsby, Ltd.
Tangyes, Ltd.
Thornycroft, John I., & Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.
White, J. Samuel, & Co., Ltd.

Gas Producers.

Bennis, Ed., & Co., Ltd.
Blackstone & Co., Ltd.
Crossley Brothers, Ltd.
Davey, Paxman & Co., Ltd.
Duffield, Lindley, & Co., Ltd.
Fielding & Platt, Ltd.
Mirrlees, Bickerton & Day, Ltd.
Premier Gas Engine Co., Ltd.
Ruston & Hornsby, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Gas Retorts.
Pearson, E. J. & J., Ltd.

Gas Testing Apparatus.
Townson & Mercer, Ltd.

Gas Tubes and Fittings.
Stewarts & Lloyds, Ltd.
Weldless Steel Tube Co., Ltd.

Gauge Glasses.
Crockatt, W., & Sons, Ltd.
Hopkinsons, Ltd.
Klinger, Richard, Ltd.
Tomey, Joseph, & Sons, Ltd. ('Eureka').

Gauge Glass Protectors.
Hopkinsons, Ltd.
Hulburd Patents, Ltd.
Tomey, Joseph, & Sons, Ltd.

Gauge Glass Rings.
Crockatt, W., & Sons, Ltd.
Dexine, Ltd.
Hopkinsons, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Walker, James, & Co., Ltd. ('Wallico' Cone).
Woodite Co., Ltd. ('Woodite').

Gauge Glass Washers.
Dexine, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Tomey, Joseph, & Sons, Ltd.

Gauges.
See Steam Gauges.

Gear Boxes (Increasing & Reducing).
Coventry Chain Co., Ltd.

Geared Turbine Auxiliaries.
Beardmore, Wm., & Co., Ltd.
Power Plant Co., Ltd.
Weir, G. & J., Ltd.

Gearing.
Daglish, Robert, & Co., Ltd.
Kirkstall Forge, Ltd.
Power Plant Co., Ltd.

Gears (Hydraulic, Oil).
Variable Speed Gears, Ltd.

General Foundry Castings.
Fry's Metal Foundries, Ltd.

Generators (Electric).
See Dynamos and Motors.

Girders, Bridges, etc.
See Structural Iron and Steel Work.

Governors (Hydraulic).
Gilkes, Gilbert, & Co., Ltd.

Governors (Steam Engine).
Davey, Paxman & Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.

Grabbing Cranes (Electric).
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).

Grain and Seed Cleaning Machinery.
Howes, S.

Grain Weighing Machines.
Avery, W. & T., Ltd.

Graphite.
Graphite Products, Ltd. ('Foliac').

'Graphol' Lubricant.
Peters, G. D., & Co., Ltd.

Grease (Lubricating).
Willcox, W. H., & Co., Ltd.

Grease Separators.
Baker Oil Separator Co.
Kennicott Water Softener Co., Ltd.
Royles, Ltd.

Grinders.
See Grinding Machinery.

Grinding Machinery.
Consolidated Pneumatic Tool Co., Ltd.
Hardy Patent Pick Co., Ltd.
Howes, S.
Humphreys, J. H., & Sons (Portable Electric).
Patent Lightning Crusher Co., Ltd.
Pneulec, Ltd. (Electric Swing).
Ransomes, Sims & Jefferies, Ltd.
Renold (Hans), Ltd. (Mortise Chain Grinding Machinery).
Sturtevant Engineering Co., Ltd.

'Gripoly' Hair Belting.
Lewis & Tylor, Ltd.

Gun and Ammunition Works.
Beardmore, Wm., & Co., Ltd.

Gunmetal Ingots.
Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.

Hack Saw Blades.
Firth, Thos., & Sons, Ltd.
Sanderson Bros. & Newbould, Ltd.
Starrett, L. S., Co. (of Great Britain), Ltd.

Hammers (Steam, Compressed Air, Pneumatic Power, etc.).
Consolidated Pneumatic Tool Co., Ltd.
Massey, B. & S., Ltd.
United States Metallic Packing Co., Ltd.

Hand Cranes.
See Lifting and Hoisting Machinery, etc.

Hauling Plant.
See Winding and Hauling.

Hawsers (Galvanised Steel Wire).
Rylands Brothers, Ltd.
Whitecross Co., Ltd.

Heat Treatment of Metals.
Pneulec, Ltd. (Furnaces for).

Heating for Railway Carriages.
Westinghouse Brake and Saxby Signal Co., Ltd.

Heating, Ventilating, etc.
Boyle, Robert, & Son.
English Electric Co., Ltd.
Erith's Engineering Co., Ltd.
General Electric Co., Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Musgrave & Co., Ltd.
Potter, F. W., & Co.
Royles, Ltd.
Spencer-Bonecourt, Ltd.
Sturtevant Engineering Co., Ltd.
Sulzer Bros.
Westinghouse Brake and Saxby Signal Co., Ltd.

Helical Gearing.
Power Plant Co., Ltd.

High Speed Tool Steel.
Beardmore, Wm., & Co., Ltd.
Firth, Thos., & Sons, Ltd.
Sanderson Bros. & Newbould, Ltd.

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990

High Tensile Steels.

Firth, Thos., & Sons, Ltd.

Hoists.

See LIFTING AND HOISTING.

Hollow Rods and Sections (Brass, Copper, etc.).

Delta Metal Co., Ltd.

Hose Couplings.

Belliss & Morcom, Ltd.

Hose (Flexible Metallic).

United Flexible Metallic Tubing Co., Ltd.

Hose Pipe Clips.

Robinson, L., & Co.
Rotherham & Sons, Ltd.

Hose for Fire Brigades, Mills, etc.

Attwater & Sons.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Leyland and Birmingham Rubber Co., Ltd.
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.

Hose Pipes, Leather and Canvas Hose, etc.

India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Reddaway, F., & Co., Ltd.
Tullis, John, & Son, Ltd.
Willcox, W. H., & Co., Ltd.
Willesden Paper & Canvas Works, Ltd.
Woodite Co., Ltd.

Hot Brass Pressings.

Delta Metal Co., Ltd.

Hot Water Supply Boilers.

Royles, Ltd.

Hydraulic Gauges.

Berry, Henry, & Co., Ltd.
Hopkinsons, Ltd.
Tomey, Joseph, & Sons, Ltd.

Hydraulic Lifts.

See LIFTING AND HOISTING.

Hydraulic Machines, Tools, and Appliances, etc.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd. (Tweddell's System).
Glasgow Engineers, Ltd.
Gwynnes Pumps, Ltd.
Heenan & Froude, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.
Massey, B. & S., Ltd.
Stewart, Duncan, & Co., Ltd.
Variable Speed Gear, Ltd.

Hydraulic Packings.

Berry, Henry, & Co., Ltd.

Hydraulic Plants and Appliances.

Berry, Henry, & Co., Ltd.
English Electric Co., Ltd.
Gilkes, Gilbert, & Co., Ltd.
Glasgow Engineers, Ltd.
Howden, James, & Co., Ltd.
Howes, S.

Hydraulic Pumps.

Berry, Henry, & Co., Ltd.
Glasgow Engineers, Ltd.
Gwynnes Pumps, Ltd.
Stewart, Duncan, & Co., Ltd.
Variable Speed Gear, Ltd.

Hydraulic Tubes and Pipes.

Stewarts & Lloyds, Ltd.
Weldless Steel Tube Co., Ltd.

Hydrochloric Acid.

Berk, F. W., & Co., Ltd.
Nobel Industries, Ltd.

Hydro-Electric Plants.

English Electric Co., Ltd.

Hydrological Chemists.

Boilerine, Ltd.

Ice-making Machinery.

See REFRIGERATING MACHINERY.

India Rubber, Gutta Percha, and Bitumen Manufacturers.

Attwater & Sons.
Beldam Asbestos Co., Ltd.
Beldam Packing & Rubber Co., Ltd.
Callender's Cable & Construction Co., Ltd.
Callender, George M., & Co., Ltd.
Craigpark Electric Cable Co., Ltd.
Dexine, Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Leyland & Birmingham Rubber Co., Ltd.
Liverpool Electric Cable Co., Ltd.
Macintosh Cable Co., Ltd.
Reddaway, F., & Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Walker, James, & Co., Ltd. ('Lion').
Woodite Co., Ltd.

Indicators (Steam Engine).

Bailey, Sir W. H., & Co., Ltd.
Crosby Valve & Engineering Co., Ltd.

Industrial Gas Furnaces and Plants.

Crossley Brothers, Ltd.

Ingot Metals.

British Aluminium Co., Ltd.
Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.

Injectors, Ejectors, and General Jet Appliances.

See STEAM INJECTORS.

Inspection Blocks for Boilers.

Pearson, E. J. & J., Ltd.

Instruments and Apparatus (Electrical).

Coan, Robert W., Ltd.
Dickinson, F. E.
English Electric Co., Ltd.
Evershed & Vignoles, Ltd.
General Electric Co., Ltd.
Gent & Co., Ltd.
Hart Accumulator Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Lamson Pneumatic Tube Co., Ltd.
Railway Signal Co., Ltd.
Siemens Bros. & Co., Ltd.
Standard Telephones & Cables, Ltd.
Weston Electrical Instrument Co., Ltd.

Instruments: Surveying, Mathematical, Drawing, etc.

Adie, Patrick.
Harling, W. H.
Heath & Co. (Nautical).
Hind, John, & Sons, Ltd.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Insulating Materials.

Anderson, Thomas, Ltd.
Attwater & Sons (Mica, Leatheroid, Fibre, etc.).
Beldam Packing and Rubber Co., Ltd.
Bell's United Asbestos Co., Ltd.
Callender's Cable & Construction Co., Ltd.
Callender, George M., & Co., Ltd.
Craigpark Electric Cable Co., Ltd.
Dexine, Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Hobdell, Way & Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Kenyon, Wm., & Sons, Ltd.
Ruberoid Co., Ltd.
Sankey, J. H., & Son, Ltd. ('Fosalsil' (Moler)).
Siemens Bros. & Co., Ltd.
Willesden Paper & Canvas Works Ltd.
Woodite Co., Ltd.

Insulating Varnishes and Compounds.

Siemens Bros. & Co., Ltd.

Insulators.

Anderson, Thomas, Ltd.
Dexine, Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Siemens Bros. & Co., Ltd.

'Italit' Asbestos Sheets and Roofing Tiles.

Eternit Pietra Artificiale (London) Ltd.

Interheaters and Reheaters.

McPhail & Simpson.

Internal Combustion Engines.

See GAS, OIL, AND PETROL ENGINES.

Inverted Tooth Chains.

Coventry Chain Co., Ltd.

Iron Sheets.

Braby, Fredk., & Co., Ltd.

Iron and Steel Manufacturers and Merchants.

Hardy Patent Pick Co., Ltd.
Henderson & Glass.
Kirkstall Forge, Ltd.
Sanderson Bros. & Newbould, Ltd.
Shropshire Iron Co., Ltd.
Stewarts & Lloyds, Ltd.
Ward, Thos. W., Ltd.
Wesson, W., & Co., Ltd.

Iron and Steel Scrap.

Ward, Thos. W., Ltd.

Iron and Steel Tubes.

See TUBES AND FITTINGS.

Iron Tubes.

See TUBES AND FITTINGS.

Jacks (Hydraulic and Screw).

Leeds Engineering & Hydraulic Co., Ltd.

Jointing ('Beldamite').

Beldam Packing & Rubber Co., Ltd.

Jointing Cement.

Hopkinsons, Ltd. ('Metallic').
Kenyon, Wm., & Sons, Ltd. ('Kisol').

Jointing ('Klingerit').

Klinger, Richard, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Jointing Materials.

Beldam Asbestos Co., Ltd.
Beldam Packing and Rubber Co., Ltd.
Bell's United Asbestos Co., Ltd.
British Fibrocement Works, Ltd.
Cork Manufacturing Co., Ltd.
Dexine, Ltd.
Graphite Products, Ltd.
Hopkinsons, Ltd. ('Koru').
Hulburd Patents, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Klinger, Richard, Ltd.
Walker, James, & Co., Ltd. ('Lion' and 'Walkerite').
Willcox, W. H., & Co., Ltd.
Woodite Co., Ltd.

Joints ('Flexstel' Ball and Socket).

Dorman, W. H., & Co., Ltd.

Joints ('Lion' and 'Walkerite').

Walker, James, & Co., Ltd.

Joists (Steel).

Dorman, Long & Co., Ltd.
Henderson & Glass.
Ward, Thos. W., Ltd

Journals (Technical).

See BOOKS AND JOURNALS.

'JUBILEE' Worm-Drive Clips (Patent).

Robinson, L., & Co.

'KARRENA' Flat Suspended Furnace Roofs.

Cleworth, A. B. & Co., Ltd.

'Kisol' Cement for Boilers, Steam Pipes, etc.

Kenyon, Wm., & Sons, Ltd.

Lamps (Electric).

See ELECTRIC LIGHT FITTINGS, ETC.

Lamps (Industrial).

Allen-Liversidge, Ltd.
Carbic, Ltd.
Thorn & Hoddle, Ltd.
Wells, A. C., & Co., Ltd.

Lamps (Rear).

Coan, Robert W., Ltd.

Lancashire Boiler Settings (Improved).

Pearson, E. J. & J., Ltd.

Lathes.

See TOOL MAKERS.

Launches (Steam and Motor).

White, J. Samuel, & Co., Ltd.

Leather Belting.

See BELTING.

Lift Enclosures.

Glasgow Engineers, Ltd.
Potter, F. W., & Co.
Smith, Major, & Stevens, Ltd.
Stevens, A. & P., Ltd.
Waygood-Otis, Ltd.

Lifting and Hoisting Machinery and Lifting Tackle.

Babcock & Wilcox, Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Elliston, Evans, & Jackson, Ltd.
English Electric Co., Ltd.
Fielding & Platt, Ltd.
Fraser & Chalmers (Proprs. General Electric Co., Ltd.).
Glasgow Engineers, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Lifting and Hoisting Machinery and Lifting Tackle—*continued.*

Hardy Patent Pick Co., Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Power Plant Co., Ltd.
Smith, Major, & Stevens, Ltd.
Steven, A. & P., Ltd.
Tangyes, Ltd.
Taylor & Hubbard, Ltd.
United States Metallic Packing Co., Ltd.
Waygood-Otis, Ltd.
Witton-Kramer Electric Works (Proprs. General Electric Co., Ltd.).

Lifting Magnets.

Westminster Tool and Electric Co., Ltd.
Witton-Kramer Electric Works (Proprs. General Electric Co. Ltd.).

Lighting and Heating (Acetylene Gas Plants for).

Allen-Liversidge, Ltd.
Bingham, Charles, & Co.
Carbic, Ltd.
Hoggett, Young & Co.
Thorn & Hoddle, Ltd.
Wells, A. C., & Co., Ltd.

Lighting (Train).

Carbic, Ltd.
Leeds Forge Co., Ltd.
Nobel Industries, Ltd.
Rotax (Motor Accessories), Ltd.
Stone, J., & Co., Ltd.

Lightning Conductors.

Cutting, R. C., & Co.
Siemens Bros. & Co., Ltd.

Lime and Limestone.

Cement Marketing Co., Ltd.

Line Shaft Bearings (Ball and Roller).

Hoffmann Manufacturing Co., Ltd.

'Lion' Packing.

Walker, James, & Co., Ltd.

Liquid Air.

British Oxygen Co., Ltd.

Liquid Starters and Controllers.

Elliston, Evans, & Jackson, Ltd.

Liquid Weighing Machines.

Avery, W. & T., Ltd.

Loading and Transport Plants.

Fraser & Chalmers (Proprs. General Electric Co., Ltd.).

Locomotive Superheated Packing.

United States Metallic Packing Co., Ltd.

Locomotive Superheaters.

Superheater Company, Ltd.

Locomotives.

Beardmore, Wm., & Co., Ltd.
Blackstone & Co., Ltd.
Holland, Bernard, & Co.

Low Temperature Distillation Plants.

Coal Oil Extraction Ltd. (K. S. G. Process).

Lubricating Devices.

Rotherham & Sons, Ltd.
Tecalemit, Ltd. (High Pressure).

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990.

Lubricating Systems (High Pressure).

Tecalemit, Ltd.

Lubrication Experts.

Tecalemit, Ltd.

Lubricator Glasses.

Tomey, Joseph, & Sons, Ltd.

Lubricators and Lubricants.

Bell's United Asbestos Co., Ltd.
Crosby Valve and Engineering Co., Ltd.
Graphite Products, Ltd. ('Foliac').
Hulburd Patents, Ltd.
Peters, G. D., & Co., Ltd. ('Graphol').
Rotherham & Sons, Ltd.
Tecalemit, Ltd.
United Kingdom Metallic Packing Syndicate, Ltd.
United States Metallic Packing Co., Ltd.
Willcox, W. H., & Co., Ltd.

Machine and Hand Tools.

See ENGINEERS' TOOLS AND FITTINGS, *also* TOOL MAKERS.

Machine Output Recorders.

Dickinson, F. E.
Gent & Co., Ltd.

Machine Screws.

Davis & Timmins, Ltd.

Machinery (Electro-Magnets).

Rapid Magnetting Machine Co., Ltd.

Machinery Finishes.

Pegg & Ellam Jones, Ltd.

Machinery Guards.

Braby, Fredk., & Co., Ltd.
Potter, F. W., & Co.

Machinery Steel Manufacturers.

Beardmore, Wm., & Co., Ltd.

'Maconite' Insulated Cables.

Macintosh Cable Co., Ltd.

Magnet Steel.

Firth, Thos., & Sons, Ltd.

Magnetic Chucks.

Humphreys, J. H., & Sons.
Rapid Magnetting Machine Co., Ltd.

Magnetic Separators.

Hardy Patent Pick Co., Ltd.
Rapid Magnetting Machine Co., Ltd.
Witton-Kramer Electric Works (Proprs. General Electric Co., Ltd.).

Manganese Bronze.

Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.

Manganese Steel.

Firth, Thos., & Sons, Ltd.

Marine Engines, Boilers, and Auxiliary Machinery.

Babcock & Wilcox, Ltd.
Beardmore, Wm., & Co., Ltd.
Brotherhood, Peter, Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Cochran & Co. (Annan), Ltd.
Doxford, William, & Sons, Ltd.
Howden, James, & Co., Ltd.
Mirrlees Watson Co., Ltd.
Spencer-Bonecourt, Ltd.
Superheater Company, Ltd.
Swan, Hunter & Wigham Richardson, Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Marine Engines, Boilers, and Auxiliary Machinery
—continued.

Weir, G. & J., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Marine Glues.

Crockatt, W., & Sons, Ltd.

Marine Oil Engines.

Beardmore, Wm., & Co., Ltd.
Belliss & Morcom, Ltd.
Crossley Bros., Ltd.
Doxford, William, & Sons, Ltd.
Mirrlees, Bickerton & Day, Ltd.
Petters, Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.
White, J. Samuel, & Co., Ltd.

Marine Superheaters.

McPhail & Simpson.
Superheater Company, Ltd.

Mathematical, Drawing, and Surveying Instruments.

Adie, Patrick.
Harling, W. H.
Heath & Co.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Measuring Instruments (Electrical).

See INSTRUMENTS.

Mechanical Rubber Goods.

India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.

Mechanical Separators.

Gent & Co., Ltd.

Mechanical Stokers.

Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Erith's Engineering Co., Ltd.
Spencer-Bonecourt, Ltd.
Stirling Boiler Co., Ltd.
Thompson, John (Wolverhampton), Ltd.
Underfeed Stoker Co., Ltd.
Vickers Boiler Co., Ltd.

'Mesmeric' Case-Hardening Steel.

Firth, Thos., & Sons, Ltd.

Metal Cutting and Welding.

A.-C. Welding Co.
Allen-Liversidge, Ltd.
Alloy Welding Processes, Ltd.
British Oxygen Co., Ltd.
District Chemical Co., Ltd.
Ferro-Arc Welding Co., Ltd.
Ferrox Company, Ltd.
Hoggett, Young & Co.
Nobel Industries, Ltd.
Peters, G. D., & Co., Ltd.
Thorn & Hoddle, Ltd.

Metal Filament Lamps.

British Thomson-Houston Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Siemens Bros., & Co., Ltd.

Metal Merchants.

Ward, Thos. W., Ltd.

Metal Windows (Sashes and Casements).

Braby, Fredk., & Co., Ltd.

Metallic Packing.

See ENGINE PACKING.

Metallic Packing ('Britimp').

British Metallic Packings Co., Ltd.

Metallic Packing ('Osmanite').

Klinger, Richard, Ltd.

Metallic Piston Rod Packing ('Lion').

Walker, James, & Co., Ltd.

Metallic Piston Rod Packing ('Reefer').

Bell's United Asbestos Co., Ltd.

Metallic Piston Rod Packing ('Silvertown').

India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.

Metallic Piston Rod Packing ('United States').

United States Metallic Packing Co., Ltd.

Metal Scrap.

See SCRAP METALS.

Metallic Tubing (Flexible).

United Flexible Metallic Tubing Co., Ltd.

Metallurgical Engineers.

Ferro-Arc Welding Co., Ltd.

Metals: Bearing, Anti-friction, etc.

Booth, James & Co. (1915), Ltd. ('Duralumin,' Regd. Trade Mark, Vickers Special Alloy).
British Aluminium Co., Ltd.

Metals: Bearing, Anti-friction, etc.—*continued.*

Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.
Fry's Metal Foundries, Ltd.
Kynoch, Ltd.
Nobel Industries, Ltd.
Rapid Magnetting Machine Co., Ltd. (Scrap Metals).
Richards, J. H., & Co., Ltd.
Stone, J., & Co., Ltd.
Thermit, Ltd.

Metals (Scrap).

Ward, Thos. W., Ltd.

Meteorological Instruments.

Harling, W. H.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Meters (Air, Gas, Steam, and Water).

Crosby Valve Engineering Co., Ltd.
Guest & Chrimes, Ltd.
Kent, George, Ltd.
Negretti & Zambra.
Palatine Engineering Co., Ltd.

Meters (Coal).

Lea Recorder Co., Ltd.

Mica.

Attwater & Sons.

Micrometers.

Starrett, L. S., Co. (Great Britain Ltd.

Microscopes.

Harling, W. H.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.

Mill Bandings and Twines.

Hart, Thomas, Ltd.
Kenyon, Wm., & Sons, Ltd.

Mill Gearing, Shafting, etc.

See SHAFTING AND GEARING.

Milling Cutters and Blanks.

Firth, Thos., & Sons, Ltd.

Mills (Pulverizing).

Patent Lightning Crusher Co., Ltd.

Mine Signal Indicators.

Gent & Co., Ltd.
Hopkinsons, Ltd.

Mineral Wool.

Bell's United Asbestos Co., Ltd.
Hobdell, Way & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.

Miners' Safety Lamps.

General Electric Co., Ltd.

Mining and Hauling Plant.

Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.

Mining and Hauling Plant— *continued.*

English Electric Co., Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Hardy Patent Pick Co., Ltd.
Hart, Thomas, Ltd.
Henley's, W. T., Telegraph Works Co., Ltd. (Electrical Plant).
Holman Bros., Ltd.
Kenyon, Wm., & Sons, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Patent Lightning Crusher Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.
Spencer-Bonecourt, Ltd.
United Flexible Metallic Tubing Co., Ltd.

Mining Cables and Accessories.

Callender's Cable and Construction Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Macintosh Cable Co., Ltd.
Pirelli-General Cable Works, Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros., & Co., Ltd.

Mining Engineers.

François Cementation Co., Ltd.

Mining Explosives.

Nobel Industries, Ltd.

Mining Machinery.

See MINING AND HAULING PLANT.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990

Mining Signals (Watertight).
General Electric Co., Ltd.
Gent & Co., Ltd.
Siemens Bros., & Co., Ltd.

Mining Steel.
Firth, Thos., & Sons, Ltd.

Mining Tools.
Consolidated Pneumatic Tool Co., Ltd.
Hardy Patent Pick Co., Ltd.
Holman Bros., Ltd.

Motor Car Accessories.
Booth, James & Co. (1915), Ltd. ('Duralumin' for, Registered Trade Mark, Vickers' Special Alloy).
Coan, Robert W., Ltd.
Mills (William), Ltd.
Nobel Industries, Ltd.
Rotax (Motor Accessories), Ltd.
Rotherham & Sons, Ltd.

Motor Chassis Frames.
Beardmore, Wm., & Co., Ltd.

Motor Converters.
Ateliers de Constructions Electriques de Charleroi.

Motor Lubricants.
Bell's United Asbestos Co., Ltd.
Graphite Products, Ltd.
Willcox, W. H., & Co., Ltd.

Motor Starters.
General Electric Co., Ltd.

Motor Step Mats.
Coan, Robert W., Ltd.

Motor Vehicles (Commercial).
Thornycroft, John I., & Co., Ltd.

Multiple Effect Evaporators.
Mirrlees Watson Co., Ltd.
Stewart, Duncan, & Co., Ltd.

Name Plates for all Trades.
Coan, Robert W., Ltd.

Nickel & Nickel Chrome Steels.
Firth, Thos., & Sons, Ltd.

Nitric Acid.
Berk, F. W., & Co., Ltd.

Nitrogen.
British Oxygen Co., Ltd.

Number Plates.
Coan, Robert W., Ltd.

Nuts.
Davis & Timmins, Ltd.

Oil Blenders.
Cresswell's Asbestos Co., Ltd.

Oil Burning Installations.
Doxford, William, & Sons, Ltd.
Howden, James, & Co., Ltd.
Swinney Brothers, Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co. Ltd.

Oil Cabinets.
Wells, A. C., & Co., Ltd.

Oil Coolers.
Heenan & Froude, Ltd.
Swinney Brothers, Ltd.

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Oil Eliminators.

Baker Oil Separator Co.
Kennicott Water Softener Co., Ltd.
Premier Cooler & Engineering Co., Ltd.
Royles, Ltd.
United Water Softeners, Ltd.

Oil Filters.

Wells, A. C., & Co.
Swinney Brothers, Ltd.

Oil Furnaces.

See Furnaces.

Oil, Gas, and Petrol Engines.

Beardmore, Wm., & Co., Ltd.
Belliss & Morcom, Ltd.
Bennis, Ed., & Co., Ltd.
Blackstone & Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Brotherhood, Peter, Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Crossley Brothers, Ltd.
Davey, Paxman & Co., Ltd.
Dorman, W. H., & Co., Ltd.
Doxford, William, & Sons, Ltd.
English Electric Co., Ltd.
Fielding & Platt, Ltd.
Hick, Hargreaves & Co., Ltd.
Mirrlees, Bickerton & Day, Ltd.
Petters, Ltd.
Premier Gas Engine Co., Ltd.
Ruston & Hornsby, Ltd.
Sulzer Bros.
Swan, Hunter & Wigham Richardson, Ltd.
Tangyes, Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.

Oil, Gas, and Petrol Engines—*continued.*

Westinghouse Brake and Saxby Signal Co., Ltd.
White, J. Samuel, & Co., Ltd.

Oil Locomotives (Internal Combustion).

Blackstone & Co., Ltd.
Holland, Bernard, & Co.
Ruston & Hornsby, Ltd.

Oil Mill Machinery.

Waygood-Otis, Ltd.

Oil Testing Apparatus.

Townson & Mercer, Ltd.

Oils, Lubricating Compounds, etc.

Graphite Products, Ltd.
Willcox, W. H., & Co., Ltd.

Overhead Cranes and Runways.

Leeds Engineering & Hydraulic Co., Ltd.

Oxy-Acetylene Welding and Cutting.

Allen-Liversidge, Ltd.
Alloy Welding Processes, Ltd.
Bingham, Charles, & Co.
Braby, Fredk., & Co., Ltd.
British Oxygen Co., Ltd.
Carbic, Ltd.
Coan, Robert W., Ltd.
District Chemical Co., Ltd.
Ferro-Arc Welding Co., Ltd.
Ferrox Company, Ltd.
Hoggett, Young & Co.
Thorn & Hoddle, Ltd.

For Advertisers' Addresses and positions of their announcements, consult foregoing Alphabetical List, pages 2977 to 2990.

Oxygen.

Bingham, Charles, & Co.
British Oxygen Co., Ltd.

Oxygen and Hydrogen Generating Plants.

Bingham, Chas., & Co.
British Oxygen Co., Ltd.

Packing ('Britimp').

British Metallic Packings Co., Ltd.

Packing ('Langite' Oil Resisting).

Cork Manufacturing Co., Ltd.

Packing ('Lascar').

Beldam Asbestos Co., Ltd.

Packing ('Lion').

Walker, James, & Co., Ltd.

Packing ('Pilot').

Beldam Packing & Rubber Co., Ltd.

Packing (Steam).

See ENGINE PACKING.

Packing ('United States').

United States Metallic Packing Co., Ltd.

Painting Machines.

Consolidated Pneumatic Tool Co., Ltd.
Wells, A. C., & Co., Ltd.

Paints, Colours, Enamels, and Varnishes.

Carson, Walter, & Sons.
Imperial Chemical Industries, Ltd.
Pegg & Ellam Jones, Ltd.

Paints for Preserving Iron and Steel Work.

Callender, G. M., & Co., Ltd. ('Bitusol').
Carson, Walter, & Sons.
Graphite Products, Ltd.
Imperial Chemical Industries, Ltd.
Pegg & Ellam Jones, Ltd.
Ruberoid Co., Ltd. ('Flexduro').

Paper and Pulp Making Machinery.

Daglish, Robt., & Co., Ltd.

Paper Makers' Felts.

Reddaway, F., & Co., Ltd.

Paper (Waterproof).

Willesden Paper & Canvas Works, Ltd.

Partition Contractors and Fireproof Builders.

Bell's Poilite & Everite Co., Ltd.
British Fibrocement Works, Ltd.
Expanded Metal Co., Ltd.

Pelton Wheels.

Gilkes, Gilbert, & Co., Ltd.
Howes, S.

Perforated Metals.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.

Petrol Engines.

See OIL AND GAS ENGINES.

Phosphor Bronze.

Bull's Metal and Melloid Co., Ltd.
Delta Metal Co., Ltd.
Ferrox Company, Ltd.
Fry's Metal Foundries, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Picks, Shovels, etc.

Hardy Patent Pick Co., Ltd.

Pipe Bending Machines.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Leeds Engineering & Hydraulic Co., Ltd.

Pipe Coils.

Liverpool Refrigeration Co., Ltd.
Superheater Company, Ltd.

Pipe Coverings.

Bell's United Asbestos Co., Ltd.
British Fibrocement Works, Ltd.
Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Thompson, John (Wolverhampton), Ltd.
Willcox, W. H., & Co., Ltd.

Pipe Lines.

Swinney Brothers, Ltd.
Thompson, John (Wolverhampton), Ltd.

Pipes and Fittings.

See TUBES AND FITTINGS.

Piston Packing.

Bell's United Asbestos Co., Ltd.
Dexine, Ltd.
Hind, John, & Sons, Ltd. ('Rowan').
Walker, James, & Co., Ltd. ('Lion').

Piston Rings.

Hind, John, & Sons, Ltd. ('Rowan').
Leeds Engineering and Hydraulic Co., Ltd.

Planing, Slotting, Screwing, and Shaping Machines.

Fielding & Platt, Ltd.
Ward, Thos. W., Ltd.

Planished Steel Sheets.

Braby, Fredk., & Co., Ltd.
Firth, Thos., & Sons, Ltd.

Plaster.

Cement Marketing Co., Ltd.
Sankey, J. H., & Son, Ltd.

Plastic Metal (Richards').

Richards, J. H., & Co., Ltd.

Plumbers' Brasswork.

Guest & Chrimes, Ltd.

Pneumatic Conveying Plants.

Lamson Pneumatic Tube Co., Ltd.
Sturtevant Engineering Co., Ltd.

Pneumatic Despatch Tubes, etc.

Lamson Pneumatic Tube Co., Ltd.
Sturtevant Engineering Co., Ltd.

Pneumatic Tools and Appliances.

Consolidated Pneumatic Tool Co., Ltd.
Fielding & Platt, Ltd.
Massey, B. & S., Ltd.
United States Metallic Packing Co., Ltd.

'Poilite' Asbestos Sheets and Roofing Tiles.

Bell's Poilite & Everite Co., Ltd.

Polishing Machinery.

Rapid Magnetting Machine Co., Ltd.

Portable Electric Drills and Hammers.

See ELECTRIC PORTABLE DRILLS AND HAMMERS.

Portable Engines.

Davey, Paxman & Co., Ltd.
Holland, Bernard, & Co.
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.

Portland Cement.

Cement Marketing Co., Ltd.
Sankey, J. H., & Son, Ltd.

Portland Cement (Testing Machines for).

Adie, Patrick.
Bailey, Sir W. H., & Co., Ltd.
Townson & Mercer, Ltd.

Powdered Coal Plants.

Duffield, Lindley, & Co., Ltd.
International Combustion, Ltd.

Power Hammers.

See HAMMERS.

Power Presses.

Nobel Industries, Ltd.

Power Transmission Appliances.

British Hele-Shaw Patent Clutch Co., Ltd.
Dawson, James, & Son, Ltd.
Firth, Thos., & Sons, Ltd.
Hart, Thomas, Ltd.
Hoffmann Manufacturing Co., Ltd.
Kenyon, Wm., & Sons, Ltd.
Kirkstall Forge, Ltd.
Power Plant Co., Ltd.
Reddaway, F., & Co., Ltd.
Skefko Ball Bearing Co., Ltd.
Westinghouse Morse Chain Co., Ltd.

Preservatives (Boiler).

Boilerine, Ltd.
Graphite Products, Ltd.
Kennicott Water Softener Co., Ltd.
United Water Softeners, Ltd.

Preservatives (Wood).

Anderson, D., & Son, Ltd. ('Sidol').
Carson, Walter, & Sons.

Printers, Lithographers, Draughtsmen, and Engravers.

Spottiswoode, Ballantyne & Co., Ltd.
Swain, J., & Son, Ltd.

Producer Gas Plants.

See GAS PRODUCERS.

Propellers.

Bull's Metal and Melloid Co., Ltd.
Howden, James, & Co., Ltd.
Premier Cooler and Engineering Co., Ltd. (Aeroplane).
Stone, J., & Co., Ltd.
Thornycroft, John I., & Co., Ltd.

Publications (Technical).

See BOOKS AND JOURNALS.

Pulleys.

See BELT AND ROPE PULLEYS.

Pulp-making Machinery.

Daglish, Robt., & Co., Ltd.

Pulverised Fuel Equipment.

Duffield, Lindley, & Co., Ltd.
Underfeed Stoker Co., Ltd.
International Combustion, Ltd.

Pulverizer Mills.

Patent Lightning Crusher Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Pump Buckets.

Crockatt, W., & Sons, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.

Pumps and Pumping Machinery.

Ateliers de Constructions Electriques de Charleroi.
Bailey, Sir W. H., & Co., Ltd.
Baker Oil Separator Co.
Beldam Packing and Rubber Co., Ltd. (Valves for).
Berry, Henry, & Co., Ltd.
Blackstone & Co., Ltd.
Caird & Rayner, Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd. (Vacuum).
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.
English Electric Co., Ltd.
Erith's Engineering Co , Ltd.
Fielding & Platt, Ltd.
Galloways, Ltd.
Gilkes, Gilbert, & Co., Ltd. (Centrifugal).
Gwynnes Pumps, Ltd.
Holland, Bernard, & Co. (Vacuum).
Leeds Engineering and Hydraulic Co., Ltd.
Mirrlees Watson Co., Ltd. (Vacuum).
Pulsometer Engineering Co., Ltd. (Vacuum and Centrifugal).
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.
Stewart, Duncan, & Co., Ltd.
Stone, J., & Co., Ltd.
Sulzer Bros.
Tangyes, Ltd.
Thompson, John (Wolverhampton), Ltd.
Weir, G. & J., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.
Willcox, W. H., & Co., Ltd.

Pumps (Deep Well).

Sulzer Bros.

Pumps (Variable Delivery, Oil).

Variable Speed Gear, Ltd.

Punching, Shearing, and Bending Machines.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.

Pyrometers.

Bailey, Sir W. H., & Co., Ltd.
Foster Instrument Co.
Negretti & Zambra.
Siemens Bros. & Co., Ltd.

Quarrying Tools.

Hardy Patent Pick Co., Ltd.

Quasi-Arc Welding Accessories and Electrodes.

Ferrox Company, Ltd.

Radiator Clips.

Robinson, L., & Co.

Radio Telegraphy Apparatus.

British Thomson-Houston Co., Ltd.
General Electric Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Siemens Bros. & Co., Ltd.

Rail Manufacturers.

Dorman, Long & Co., Ltd.
Railway & General Engineering Co., Ltd.
Summerson, Thomas, & Sons, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Rails and Fastenings.

Railway and General Engineering Co., Ltd.
Summerson, Thomas, & Sons, Ltd.

Railway Brakes.

Consolidated Brake & Engineering Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Railway Couplings.

Firth, Thos., & Sons, Ltd.

Railway Crankshafts.

Firth, Thos., & Sons, Ltd.

Railway Points and Crossings.

Railway and General Engineering Co., Ltd.
Summerson, Thomas, & Sons, Ltd.

Railway Ramps.

Summerson, Thomas, & Sons, Ltd.

Railway Re-railing Ramps.

Firth, Thos., & Sons, Ltd.

Railway and Tramway Plant.

British Aluminium Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
British Power Railway Signal Co., Ltd. (Signals).
Clarke, Chapman & Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Kirkstall Forge, Ltd.

Railway and Tramway Plant—*continued.*

Leeds Forge Co., Ltd.
Liverpool Electric Cable Co., Ltd.
Railway and General Engineering Co., Ltd.
Railway Signal Co., Ltd.
Reddaway, F., & Co., Ltd.
Standard Telephones & Cables, Ltd.
Summerson, Thomas, & Sons, Ltd.
United Flexible Metallic Tubing Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Railway Signals and Safety Appliances.

British Power Railway Signal Co., Ltd.
General Electric Co., Ltd.
Railway Signal Co., Ltd.
Siemens Bros. & Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

Railway Stop Blocks.

Summerson, Thomas, & Sons, Ltd.

Railway Tyres & Axles.

Firth, Thos., & Sons, Ltd.

Railway Wheel Centres.

Firth, Thos., & Sons, Ltd.

Railways: Light, Portable, etc.

Hardy Patent Pick Co., Ltd.

Reamers and Taps.

Firth, Thos., & Sons, Ltd.

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Recorders (Speed).

Consolidated Pneumatic Tool Co., Ltd. (for Locomotives and Trains).

Recorders (Time).

Gent & Co., Ltd.

Recorders (Water).

Gent & Co., Ltd.
Kent, George, Ltd.
Lea Recorder Co., Ltd.
Palatine Engineering Co., Ltd.

Recording Instruments.

Auto Recorder Co.
Bailey, Sir W. H., & Co., Ltd.
Crosby Valve & Engineering Co., Ltd.
Dickinson, F. E.
Drayton Regulator & Instrument Co., Ltd.
Evershed & Vignoles, Ltd.
Gent & Co., Ltd.
Heenan & Froude, Ltd.
Kent, George, Ltd.
Lea Recorder Co., Ltd.
Palatine Engineering Co., Ltd.
Rotherham & Sons, Ltd.
'W. R.' Patents, Ltd.
Weston Electrical Instrument Co.,Ltd.

Recovery Plants.

McPhail & Simpson.

Reducing Valves.

See VALVES AND COCKS.

Reduction Gears.

Beardmore, Wm., & Co., Ltd.
Stone, J., & Co., Ltd.

Refractories.

Duffield, Lindley, & Co., Ltd.

Refrigerating Machinery.

British Oxygen Co., Ltd.
Brotherhood, Peter, Ltd.
Hall, J. & E., Ltd.
Haslam Foundry & Engineering Co. (1927), Ltd.
Heenan & Froude, Ltd.
Liverpool Refrigeration Co., Ltd.
Midland Motor Cylinder Co., Ltd. (Cylinder Castings for).
Pulsometer Engineering Co., Ltd.
Sulzer Bros.

Refrigerating Tubes and Coils.

Booth, James, & Co. (1915), Ltd.
Hall, J. & E., Ltd.
Haslam Foundry & Engineering Co. (1927), Ltd.
Liverpool Refrigeration Co., Ltd.
Stewarts & Lloyds, Ltd.

Refuse Destructors.

Heenan & Froude, Ltd.

Refuse Utilization Plants.

Heenan & Froude, Ltd.

Regulators (Automatic).

Crosby Valve & Engineering Co., Ltd.
Drayton Regulator & Instrument Co., Ltd.

Regulators (Feed Water).

Crosby Valve and Engineering Co., Ltd.

Reinforced Concrete Construction.

Expanded Metal Co., Ltd.
Walker-Weston Co., Ltd.

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Reservoirs (Waterproofing of).

Callender, George M., & Co., Ltd. ('Callendrite').

Riveters (Electric).

United States Metallic Packing Co., Ltd.

Riveters (Hydraulic & Pneumatic).

Berry, Henry, & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Fielding & Platt, Ltd. (Tweddell's System).
Leeds Engineering and Hydraulic Co., Ltd.

Rivet Heaters.

Berry, Henry, & Co., Ltd.

Rivets (Iron, Steel, Copper, Naval Brass, etc.).

British Aluminium Co., Ltd.
Stone, J., & Co., Ltd.

Road (Concrete) Contractors.

Walker-Weston Co., Ltd.

Rock Drills.

Consolidated Pneumatic Tool Co., Ltd.
Hardy Patent Pick Co., Ltd.
Holman Bros., Ltd.

'Rok' Roofing.

Anderson, D., & Son, Ltd.

Roller Bearings.

Hoffmann Manufacturing Co., Ltd.

Roller Chains (Heavy).

Coventry Chain Co., Ltd.

Rolling Mill Engines.

Galloways, Ltd.
Hick, Hargreaves & Co., Ltd.

Rolling Mills.

Stewart, Duncan, & Co., Ltd.

Rolling Mills (Electrical Equipment of).

General Electric Co., Ltd.

Rolling Stock.

See RAILWAY AND TRAMWAY PLANT.

Roofing Contractors.

Anderson, D., & Son, Ltd.
Bell's Poilite & Everite Co., Ltd. ('Poilite').
Braby, Fredk., & Co., Ltd.
British Fibrocement Works, Ltd.
Callender, George M., & Co., Ltd.
Eternit Pietra Artificiale (London), Ltd. ('Italit').
Ruberoid Co., Ltd.
Willesden Paper & Canvas Works, Ltd.

Roofing Felts.

Anderson, D., & Son, Ltd.

Roofs, Iron Buildings, etc.

Anderson, D., & Son, Ltd.
Bell's Poilite & Everite Co., Ltd. ('Poilite').
Braby, Fredk., & Co., Ltd.
British Aluminium Co., Ltd.
Expanded Metal Co., Ltd.
Heenan & Froude, Ltd.
Henderson & Glass.
Ruberoid Co., Ltd.
Thompson, John (Wolverhampton), Ltd.
Ward, Thos. W., Ltd.
Willesden Paper & Canvas Works, Ltd.

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Rope Pulleys.

See BELT AND ROPE PULLEYS.

Ropes: Wire, Hemp, Manilla, Leather, Cotton, and Asbestos.

Hart, Thomas, Ltd. ('Lambeth' Cotton).
Kenyon, Wm., & Sons, Ltd. (Patent Inter-Stranded Cotton).
Shropshire Iron Co., Ltd.
Whitecross Co., Ltd.
Willcox, W. H., & Co., Ltd.
Wrights' Ropes, Ltd.

Ropeways (Aerial).

See AERIAL ROPEWAYS.

'Rosseline' (for Gas and Oil Engines).

Boilerine, Ltd.

Rotary Converters.

Ateliers de Constructions Electriques de Charleroi.
General Electric Co., Ltd.

Rubber Flooring and Tiling.

India Rubber, Gutta Percha, & Telegraph Works Co., Ltd.
Leyland & Birmingham Rubber Co., Ltd.

Rubber Goods (General).

India Rubber, Gutta Percha, & Telegraph Works Co., Ltd.
Leyland & Birmingham Rubber Co., Ltd.

'Ruberoid' Roofing.

Ruberoid Co., Ltd.

Rust Preventives.

Callender, G. M., & Co., Ltd. ('Bitusol').
Crockatt, W., & Sons, Ltd. (Anti-Rust Varnish).
Graphite Products, Ltd.
Pegg & Ellam Jones, Ltd.

Rustless Steel.

Firth, Thos., & Sons, Ltd.

Saws for Wood & Metal Cutting.

Firth, Thos., & Sons, Ltd.

Scale and Corrosion in Boilers (Preventives of).

Baker Oil Separator Co.
Boilerine, Ltd.
Erith's Engineering Co., Ltd.
Kennicott Water Softener Co., Ltd.
Royles, Ltd.
United Water Softeners, Ltd.

Scaling Tools.

Crockatt, W., & Sons, Ltd.

Schools and Colleges (Engineering).

Armstrong College, Newcastle-on-Tyne.
Birmingham University.
Bradford Technical College.
Crystal Palace School of Practical Engineering, London.
Glasgow Royal Technical College.
Heriot-Watt College, Edinburgh.
Imperial College of Science and Technology, London.
King's College, London.
Leeds University.
Liverpool University.
Loughborough Technical College.
Manchester College of Technology.

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Schools and Colleges (Engineering) —*continued.*

Northampton Polytechnic Institute.
Nottingham University College.
Polytechnic (The), London.

Scientific Instruments.

Booth, James, & Co. (1915), Ltd. ('Duralumin' for, Regd. Trade Mark, Vickers' Special Alloy).
Foster Instrument Co.
Harling, W. H.
Heath & Co.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Scrap Metals.

Ward, Thos. W., Ltd.

Scrap Presses.

Berry, Henry, & Co., Ltd.
Leeds Engineering and Hydraulic Co., Ltd.

Screw Propellers.

Bull's Metal and Melloid Co., Ltd.
Firth, Thos., & Sons, Ltd.
Howden, James, & Co., Ltd.
Stone, J., & Co., Ltd.
Thornycroft, John I., & Co., Ltd.

Screws.
(Iron, Steel, Copper, & Naval Brass).

Davis & Timmins, Ltd.

Sections and Rods (Extruded), Brass, Bronze, etc.

Delta Metal Co., Ltd.

Semi-Diesel Engines.

See DIESEL AND SEMI-DIESEL ENGINES.

Separation of Oil from Condensed Steam.

Baker Oil Separator Co.
Erith's Engineering Co., Ltd.
Kennicott Water Softener Co., Ltd.
Premier Cooler and Engineering Co., Ltd.
Royles, Ltd.
United Water Softeners, Ltd.

Separators (Magnetic).

Hardy Patent Pick Co., Ltd.
Rapid Magnetting Machine Co., Ltd.

Settings (Boiler).

Pearson, E. J. & J., Ltd.

Sewage Disposal Appliances.

Stone, J., & Co., Ltd.

Sextants.

Heath & Co.

Shaft Sinkers.

François Cementation Co., Ltd.

Shafting and Gearing.

Beardmore, Wm., & Co., Ltd.
British Hele-Shaw Patent Clutch Co., Ltd.
Daglish, Robt., & Co., Ltd.
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Kirkstall Forge, Ltd.
Power Plant Co., Ltd.
Westinghouse Brake and Saxby Signal Co., Ltd.

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Shearing, Punching, Bending, and Shaping Machines.

Berry, Henry, & Co., Ltd.
Fielding & Platt, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.

Sheet Metal Work, Cylinder Cases, etc.

Braby, Fredk., & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.

Ship Builders.

Beardmore, Wm., & Co., Ltd.
Cochran & Co. (Annan), Ltd.
Doxford, William, & Sons, Ltd.
Spencer-Bonecourt, Ltd.
Swan, Hunter & Wigham Richardson, Ltd.
Thornycroft, John I., & Co., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Ship and Engine Repairers.

Beardmore, Wm., & Co., Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.
Yarrow & Co., Ltd.

Ships' Insulation.

Anderson, Thomas, Ltd.

Shoes and Dies.

Firth, Thos., & Sons, Ltd.

Siemens Martin Steel.

Firth, Thos., & Sons, Ltd.

Sieves and Screens.

Potter, F. W., & Co.

Signals

See RAILWAY SIGNALS.

Silicate Cotton and Slag Wool Coverings.

Hobdell, Way, & Co., Ltd.
Kenyon, Wm., & Sons, Ltd.

Skylights.

Braby, Fredk., & Co., Ltd.

Slating.

Bell's Poilite & Everite Co., Ltd.

Slide Rules.

See INSTRUMENTS, MATHEMATICAL, ETC.

Slide Valves (Parallel).

Bailey, Sir W. H., & Co., Ltd.
Bull's Metal and Melloid Co., Ltd.
Hopkinsons, Ltd.

Sluice Gates and Valves.

Alley & MacLellan, Ltd.
Guest & Chrimes, Ltd. (Valves for Water, Steam, Sewage, and Gas).
Premier Cooler and Engineering Co., Ltd.
Swinney Brothers, Ltd.

Smiths' Hearths and Plant.

Hardy Patent Pick Co., Ltd.
Massey, B. & S., Ltd.

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Smoke Preventers and Steam Generators.

Green, E., & Son, Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.

Smoke, Steam, & Fume Removal.

Sturtevant Engineering Co., Ltd.

Solder.

Fry's Metal Foundries, Ltd.

Soldering Machines.

Gilkes, Gilbert, & Co., Ltd.

Solid Rubber Cables.

See CABLES.

Solid Rubber Tyres for Commercial Vehicles.

Leyland and Birmingham Rubber Co., Ltd.

Soot Removers.

Willcox, W. H., & Co., Ltd.

'Speedicut' High-Speed Steel.

Firth, Thos., & Sons, Ltd.

'Speedicut' High-Speed Tools.

Firth, Thos., & Sons, Ltd.

Spraying Machines.

Wells, A. C. & Co., Ltd.

Spur and Bevel Gearing.

Daglish, Robt., & Co., Ltd.
Power Plant Co., Ltd.

Squares.

Starrett, L. S., Co. (Great Britain), Ltd.

Stainless and Rustless Steel.

Firth, Thos., & Sons, Ltd.

Staircases (Fire-resisting).

Braby, Fredk., & Co., Ltd.
Expanded Metal Co., Ltd.

Stair Treads.

British Aluminium Co., Ltd.
Coan, Robert W., Ltd. (Aluminium).
Ferodo, Ltd.
Potter, F. W., & Co.

Stampings.

Delta Metal Co., Ltd.

Stamps (Friction and Steam Drop).

Massey, B. & S., Ltd.

Stanchions (Steel).

Henderson & Glass.
Ward, Thos. W., Ltd.

Steam Boilers.

See BOILER MANUFACTURERS.

Steam, Compressed Air, and Pneumatic Power Hammers.

Massey, B. & S., Ltd.

Steam De-Superheaters.

Superheater Company, Ltd.

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Steam Dryers and Purifiers.

Alley & MacLellan, Ltd.
Baker Oil Separator Co.
Drayton Regulator & Instrument Co., Ltd.
Erith's Engineering Co., Ltd.
Hopkinsons, Ltd.
Royles, Ltd.
United States Metallic Packing Co., Ltd.

Steam Engines.

Babcock & Wilcox, Ltd.
Beardmore, Wm., & Co., Ltd.
Belliss & Morcom, Ltd.
Brotherhood, Peter, Ltd.
Clarke, Chapman & Co., Ltd.
Cochran & Co. (Annan), Ltd.
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.
Fielding & Platt, Ltd.
Galloways, Ltd.
Gwynnes Pumps, Ltd.
Hick, Hargreaves & Co., Ltd.
Howden, James, & Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Sulzer Bros.
Tangyes, Ltd.
Thompson, John (Wolverhampton), Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.
Ward, Thos. W., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.

Alley & MacLellan, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Baker Oil Separator Co.
Crockatt, W., & Sons, Ltd.

Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.—*continued.*

Crosby Valve & Engineering Co., Ltd.
Drayton Regulator & Instrument Co., Ltd. (Steam Traps)
Engineering Specialists, Ltd.
Hopkinsons, Ltd.
Hulburd Patents, Ltd.
Klinger, Richard, Ltd.
Negretti & Zambra (Water Gauges).
Premier Cooler and Engineering Co., Ltd. (Steam Traps).
Royles, Ltd.
Tomey, Joseph, & Sons, Ltd. (Makers of all classes of Pressure and Hydraulic Gauges).
United States Metallic Packing Co., Ltd. ('Bradford' Steam Trap).
Westinghouse Brake and Saxby Signal Co., Ltd.
Willcox, W. H., & Co., Ltd.
Woodite Co., Ltd.

Steam Generation System.

Duffield, Lindley, & Co., Ltd.

Steam Hammers.

See HAMMERS.

Steam Heating Tubes (Flexible).

United Flexible Metallic Tubing Co. Ltd.

Steam Injectors.

Bailey, Sir W. H., & Co., Ltd.
Hopkinsons, Ltd.
Thompson, John (Wolverhampton), Ltd.
Willcox, W. H., & Co., Ltd.

Steam Jointing.

See JOINTING MATERIALS.

Steam Meters.

Kent, George, Ltd.

Steam Packing.

Attwater & Sons.
Beldam Asbestos Co., Ltd.
Beldam Packing and Rubber Co., Ltd.
Bell's United Asbestos Co., Ltd.
British Fibrocement Works, Ltd.
British Metallic Packings Co., Ltd. ('Britimp').
Dexine, Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Hind, John, & Sons, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Klinger, Richard, Ltd. ('Osmanite').
Reddaway, F., & Co., Ltd.
United Kingdom Metallic Packing Syndicate, Ltd.
United States Metallic Packing Co., Ltd.
Walker, James, & Co., Ltd. ('Lion').
Willcox, W. H., & Co., Ltd.
Willesden Paper & Canvas Works, Ltd.
Woodite Co., Ltd.

Steam Packing ('Britimp').

British Metallic Packings Co., Ltd.

Steam Packing ('Lion').

Walker, James, & Co., Ltd.

Steam Packing ('Reefer').

Bell's United Asbestos Co., Ltd.

Steam Pipes.

See TUBES & FITTINGS.

Steam Pumps.

See PUMPS.

Steam Separators.

Hopkinsons, Ltd.

Steam Ships, Launches, and Yachts.

Beardmore, Wm., & Co., Ltd.
Cochran & Co. (Annan), Ltd.
Thornycroft, John I., & Co., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Steam Traps.

See STEAM GAUGES, ETC.

Steam Turbines and Fittings.

Beardmore, Wm., & Co., Ltd.
Belliss & Morcom, Ltd.
Brotherhood, Peter, Ltd.
Drayton Regulator & Instrument Co., Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Howden, James, & Co., Ltd.
Thornycroft, John I., & Co., Ltd.
Wallsend Slipway & Engineering Co., Ltd.
White, J. Samuel, & Co., Ltd.
Yarrow & Co., Ltd.

Steam Valves (Automatic).

Crosby Valve & Engineering Co., Ltd.
Drayton Regulator & Instrument Co., Ltd.

Steel Balls.

Hoffmann Manufacturing Co., Ltd.
Skefko Ball Bearing Co., Ltd.

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Steel (Blooms and Billets).

Beardmore, Wm., & Co., Ltd.
British Rolling Mills, Ltd.
Wesson, W., & Co., Ltd.

Steel (Bright Turned, Drawn and Cold Rolled.)

British Rolling Mills, Ltd.

Steel Conduits for Electric Wiring.

General Electric Co., Ltd.
Simplex Conduits, Ltd.
Stewarts & Lloyds, Ltd.

Steel Forgings and Castings.

See CASTINGS AND FORGINGS.

Steel Manufacturers and Merchants.

Beardmore, Wm., & Co., Ltd.
British Rolling Mills, Ltd.
Dorman, Long & Co., Ltd.
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Henderson & Glass.
Kirkstall Forge, Ltd.
Leeds Forge Co., Ltd.
Sanderson Bros. & Newbould, Ltd.
Shropshire Iron Co., Ltd.
Stewarts & Lloyds, Ltd.
Ward, Thos. W., Ltd.
Wesson, W., & Co., Ltd.

Steel Rails and Accessories.

Beardmore, Wm., & Co., Ltd.
Dorman, Long & Co., Ltd.
Railway and General Engineering Co., Ltd.
Summerson, Thomas, & Sons, Ltd.

Steel Rods.

British Rolling Mills, Ltd.
Firth, Thos., & Sons, Ltd.

Steel Rollers.

Hoffmann Manufacturing Co., Ltd.

Steel Rules.

Starrett, L. S., Co. (Great Britain), Ltd.

Steel Sections.

Bennis, Ed., & Co., Ltd.
Dorman, Long & Co., Ltd.
Heenan & Froude, Ltd.
Henderson & Glass.
Thompson, John (Wolverhampton), Ltd.
Ward, Thos. W., Ltd.

Steel Sheets.

Braby, Fredk., & Co., Ltd.

Steel Tubes.

See TUBES AND FITTINGS.

Stokers (Mechanical).

See MECHANICAL STOKERS.

Stone Pulverizing Mills.

Patent Lightning Crusher Co., Ltd.

Storage Battery Switchboards.

Hart Accumulator Co., Ltd.

Storage Bins (For Steel Furniture).

Braby, Fredk., & Co., Ltd.

Storage Cells and Batteries.

English Electric Co., Ltd.
General Electric Co., Ltd.
Hart Accumulator Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Siemens Bros. & Co., Ltd.

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Strainmeters.

Foster Instrument Co.

Structural Iron and Steel Work, etc.

Babcock & Wilcox, Ltd.
Bennis, Ed., & Co., Ltd.
Expanded Metal Co., Ltd.
Hardy Patent Pick Co., Ltd.
Heenan & Froude, Ltd.
Henderson & Glass.
Railway and General Engineering Co., Ltd.
Thompson, John (Wolverhampton), Ltd.
Ward, Thos. W., Ltd.

Submarine Cables.

See CABLES.

Suction Gas Plants.

Crossley Brothers, Ltd.
Davey, Paxman & Co., Ltd.
Fielding & Platt, Ltd.
Mirrlees, Bickerton & Day, Ltd.
Ruston & Hornsby, Ltd.
Tangyes, Ltd.

Sugar Mills and Machinery.

Mirrlees Watson Co., Ltd.
Ruston & Hornsby, Ltd.
Stewart, Duncan, & Co., Ltd.

Sulphuric Acid.

Berk, F. W., & Co., Ltd.
District Chemical Co., Ltd.
Hart Accumulator Co., Ltd.
Nobel Industries, Ltd.

Superheaters and Steam Pipes.

Babcock & Wilcox, Ltd.
Clarke, Chapman & Co., Ltd.
Davey, Paxman & Co., Ltd.

Superheaters and Steam Pipes—*continued.*

Galloways, Ltd.
Howden, James, & Co., Ltd.
McPhail & Simpson.
Spencer-Bonecourt, Ltd.
Stirling Boiler Co., Ltd.
Superheater Company, Ltd.
Thompson, John (Wolverhampton), Ltd.
'Unit' Superheater & Pipe Co., Ltd.
Vickers Boiler Co., Ltd.
Yarrow & Co., Ltd.

Surface Combustion.

Spencer - Bonecourt, Ltd. (Kirke's Patents).

Surface Gauges.

Starrett, L. S., Co. (Great Britain), Ltd.

Surveying and Drawing Instruments.

Adie, Patrick.
Harling, W. H.
Heath & Co.
Negretti & Zambra.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Thornton, A. G., Ltd.

Switch Gear.

Callender's Cable and Construction Co., Ltd.
Elliston, Evans & Jackson, Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Henley's (W. T.) Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Potter, F. W., & Co.
Simplex Conduits, Ltd.

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Tachometers.

Dickinson, F. E.

Tanks and Cisterns.

Brady, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.

Technical Training.

See SCHOOLS AND COLLEGES.

Telegraph Engineers.

Callender's Cable and Construction Co., Ltd.
Craigpark Electric Cable Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
Pirelli-General Cable Works, Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Standard Telephones & Cables, Ltd.

Telegraph Insulator Bolts and all kinds of Ironwork for Telegraph and Telephone.

Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Siemens Bros. & Co., Ltd.

Telegraph Poles (Iron).

Siemens Bros. & Co., Ltd.

Telegraph Wire.

See WIRE.

Telephone Equipment.

General Electric Co., Ltd.
Gent & Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Siemens Bros. & Co., Ltd.
Standard Telephones & Cables, Ltd.

Temperature Controls and Regulators.

Crosby Valve & Engineering Co., Ltd.
Drayton Regulator & Instrument Co., Ltd.

Tempering Furnaces.

See FURNACES.

Testing Instruments (Electrical).

See INSTRUMENTS.

Testing Machines.

Adie, Patrick.
Avery, W. & T., Ltd.
Foster Instrument Co.

Testing Machines for Portland Cement.

Adie, Patrick.
Bailey, Sir W. H., & Co., Ltd.
Townson & Mercer, Ltd.

'Thermit' Welding.

Nobel Industries, Ltd.
Thermit, Ltd.

Thermometers.

Crosby Valve & Engineering Co., Ltd.
Drayton Regulator & Instrument Co., Ltd.
Foster Instrument Co.
Harling, W. H.

Thermometers – *continued.*

Heath & Co.
Negretti & Zambra.
Siemens Bros. & Co., Ltd.
Stanley, W. F., & Co., Ltd.
Steward, J. H., Ltd.
Townson & Mercer, Ltd.

Thermostatic Valves.

Hopkinsons, Ltd.

Thrust Bearings (Ball).

Hoffmann Manufacturing Co., Ltd.
Skefko Ball Bearing Co., Ltd.

Timber Seasoning.

Erith's Engineering Co., Ltd.
Sturtevant Engineering Co., Ltd.

Time Recorders.

Gent & Co., Ltd.

Tip Waggons.

Braby, Fredk., & Co., Ltd.

Tool Makers, Machinists, etc.

Beardmore, Wm., & Co., Ltd.
Clarke, Chapman & Co., Ltd.
Consolidated Pneumatic Tool Co., Ltd.
Crockatt, W., & Sons, Ltd.
English Electric Co., Ltd.
Fielding & Platt, Ltd.
Firth, Thos., & Sons, Ltd.
Hardy Patent Pick Co., Ltd.
Hind, John, & Sons, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Massey, B. & S., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Siemens Bros. & Co., Ltd.
Simplex Conduits, Ltd.

Tool Makers, Machinists, etc.— *continued.*

Starrett, L. S., Co. (Great Britain), Ltd.
United States Metallic Packing Co., Ltd.
Ward, Thos. W., Ltd.
Westminster Tool and Electric Co., Ltd.
Willcox, W. H., & Co., Ltd.

Tool Steel.

Firth, Thos., & Sons, Ltd. (High Speed and Carbon).
Hardy Patent Pick Co., Ltd.
Sanderson Brothers & Newbould, Ltd.
Wesson, W., & Co., Ltd.

Traction Engines (Steam and Electric).

Davey, Paxman & Co., Ltd.
Petters, Ltd.
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.

Trade Mark Plates.

Coan, Robert W., Ltd.

Train Lighting Plant.

Leeds Forge Co., Ltd.
Stone, J., & Co., Ltd.

Tramways & Railways (Electrical).

See ELECTRIC RAILWAYS AND TRAMWAYS.

Tramways (Steel Wire Ropes for).

Whitecross Company, Ltd.
Wrights' Ropes, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Transformer Gaskets.

Cork Manufacturing Co., Ltd.

Transformers (Electric Power).

English Electric Co., Ltd.
Johnson & Phillips, Ltd.

Transmission (Hydraulic, Oil).

Variable Speed Gear, Ltd.

Transporters.

Fraser & Chalmers (Proprs., General Electric Co., Ltd.).

Trench Braces.

Consolidated Pneumatic Tool Co., Ltd.

Tube Cleaners.

Crockatt, W., & Sons, Ltd.
Willcox, W. H., & Co., Ltd.

Tubes and Fittings.

Babcock & Wilcox, Ltd.
British Aluminium Co., Ltd.
Bull's Metal and Melloid Co., Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
McPhail & Simpson.
Royles, Ltd.
Stewarts & Lloyds, Ltd. (Iron and Steel).
'Unit' Superheater & Pipe Co., Ltd.
United Flexible Metallic Tubing Co. Ltd.
Weldless Steel Tube Co., Ltd. (Iron and Steel).
Wesson, W., & Co., Ltd. (Gas, Hydraulic, etc.).

See also STEEL CONDUITS.

Tubes (Pneumatic).

Booth, James, & Co. (1915), Ltd.
Lamson Pneumatic Tube Co., Ltd.

Tubing (Flexible Metallic).

United Flexible Metallic Tubing Co., Ltd.

Tunnelling Plants.

Holman Bros., Ltd.

Turbine Gears.

See GEARED TURBINES.

Turbine Governors.

Gilkes, Gilbert, & Co., Ltd.

Turbine Pumps.

Pulsometer Engineering Co., Ltd.

Turbines (Steam).

See STEAM TURBINES.

Turbines, Water Wheels, and Water Motors.

Gilkes, Gilbert, & Co., Ltd.
Howden, James, & Co., Ltd.
Howes, S.

Turbo Alternators.

General Electric Co., Ltd.

Turbo Generators.

See DYNAMOS AND MOTORS.

Turbo Pumps.

Weir, G. & J., Ltd.

Turned Work (any Metal).

Davis & Timmins, Ltd.

Turntables.

Summerson, Thomas, & Sons, Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

'Tweddell's System,' Hydraulic Machinery.

Fielding & Platt, Ltd.

Twist Drills.

Firth, Thos., & Sons, Ltd.

Tyre Presses.

Berry, Henry, & Co., Ltd.
Leeds Engineering & Hydraulic Co., Ltd.

Underframes and Bogies.

Leeds Forge Co., Ltd.

Underslating.

Willesden Paper & Canvas Works, Ltd.

Vacuum Cleaners.

Holland, Bernard, & Co.
Sturtevant Engineering Co., Ltd.

Vacuum and Steam Traps.

Bailey, Sir W. H., & Co., Ltd.
Hopkinsons, Ltd.
Premier Cooler and Engineering Co., Ltd.
United States Metallic Packing Co., Ltd.

Vacuum Evaporators for Chemical Liquids.

Mirrlees Watson Co., Ltd.
Stewart, Duncan, & Co., Ltd.

Vacuum Gauges.

Hopkinsons, Ltd.

Vacuum Pans (Concentrating).

Mirrlees Watson Co., Ltd.
Stewart, Duncan, & Co., Ltd.

Vacuum Pumps.

See PUMPS.

Valve Castings.

Firth, Thos., & Sons, Ltd.

Valve Reseaters.

Crockatt, W., & Sons, Ltd.

Valves and Cocks.

Alley & MacLellan, Ltd.
Bailey, Sir W. H., & Co., Ltd.
Beldam Packing and Rubber Co., Ltd.
Berry, Henry, & Co., Ltd.
Crosby Valve and Engineering Co., Ltd.
Crockatt, W., & Sons, Ltd.
Dick, R. & J., Ltd.
Drayton Regulator & Instrument Co., Ltd.
Engineering Specialists, Ltd. (VEE-REG Valves).
Fielding & Platt, Ltd.
Heenan & Froude, Ltd.
Hopkinsons, Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd. (Rubber Valves).
Klinger, Richard, Ltd.
Leeds Engineering and Hydraulic Co., Ltd.
Leeds Forge Co., Ltd.
Palatine Engineering Co., Ltd.
Premier Cooler and Engineering Co., Ltd.
Reddaway, F., & Co., Ltd.
Royles, Ltd.
Stewarts & Lloyds, Ltd.
United States Metallic Packing Co., Ltd.
Walker, James, & Co., Ltd.

Valves and Cocks—*continued.*

Weir, G. & J., Ltd.
Willcox, W. H., & Co., Ltd.
Woodite Co., Ltd.

Variable Speed Oil Transmission Gears.

Variable Speed Gear, Ltd.

Varnishes.

Carson, Walter, & Sons.
Crockatt, W., & Sons, Ltd. (Anti-Rust Varnish).
Imperial Chemical Industries, Ltd.
Pegg & Ellam Jones, Ltd.

Ventilating Engineers.

Boyle, Robert, & Son.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Musgrave & Co., Ltd.
Potter, F. W., & Co.
Sturtevant Engineering Co., Ltd.

Ventilating, Heating, etc.

Boyle, Robert, & Son.
Daglish, Robt., & Co., Ltd.
English Electric Co., Ltd.
Erith's Engineering Co., Ltd.
General Electric Co., Ltd.
Heenan & Froude, Ltd.
Howden, James, & Co., Ltd.
Musgrave & Co., Ltd.
Potter, F. W., & Co.
Royles, Ltd.
Standard Telephones & Cables, Ltd.
Sturtevant Engineering Co., Ltd.

Ventilating Shafts.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.

Viscosity Apparatus.

See OIL TESTING APPARATUS.

Voltmeters.

See INSTRUMENTS (ELECTRICAL).

Vulcanite and Vulcanised Fibre.

Attwater & Sons.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Reddaway, F., & Co., Ltd.

Waggons (Railway).

Leeds Forge Co., Ltd.

Walker's ('Lion') Packings.

Walker, James, & Co., Ltd.

Wall and Ceiling Sheets.

Bell's Poilite & Everite Co., Ltd. ('Poilite').
British Fibrocement Works, Ltd.
Eternit Pietra Artificiale (London) Ltd. ('Italit').
Willesden Paper and Canvas Works, Ltd.

Waste Heat Boilers.

Clarkson Thimble Tube Boiler Co., Ltd.
Spencer-Bonecourt, Ltd.

Waste Water Meters.

Gent & Co., Ltd.
Kent, George, Ltd.
Palatine Engineering Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Water Cooling Apparatus.

Brotherhood, Peter, Ltd.
Film Cooling Towers (1925), Ltd.
Heenan & Froude, Ltd.
Premier Cooler and Engineering Co., Ltd.

Water Distilling Apparatus, etc.

Caird & Rayner, Ltd.
Mirrlees Watson Co., Ltd.
Royles, Ltd.
Stone, J., & Co., Ltd.

See also CONDENSERS.

Water Gauges, etc.

See STEAM GAUGES.

Water Level Indicators.

Gent & Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Kent, George, Ltd.
Klinger, Richard, Ltd.
Negretti & Zambra.

Water Meters and Water Fittings.

Crosby Valve & Engineering Co., Ltd.
Guest & Chrimes, Ltd.
Kent, George, Ltd.
Lea Recorder Co., Ltd.
Palatine Engineering Co., Ltd.

Water Power Engineers.

Daglish, Robt., & Co., Ltd.
English Electric Co., Ltd.
Gilkes, Gilbert, & Co., Ltd.
Howes, S.

Water Recorders.

Bailey, Sir W. H., & Co., Ltd.
Gent & Co., Ltd.
Heenan & Froude, Ltd.
Kent, George, Ltd.
Lea Recorder Co., Ltd.
Palatine Engineering Co., Ltd.

Water Regulators.

Crosby Valve and Engineering Co., Ltd. (Feed Water).

Water Softening and Purifying Apparatus.

Babcock & Wilcox, Ltd.
Baker Oil Separator Co.
Caird & Rayner, Ltd.
Erith's Engineering Co., Ltd.
Kennicott Water Softener Co., Ltd.
Royles, Ltd. (Reisert's System).
Thompson, John (Wolverhampton), Ltd.
Underfeed Stoker Co., Ltd. ('Usco' System).
United Water Softeners, Ltd. ('Permutit' and 'Lassen-Hjort' Systems).

See also FEED WATER HEATERS, ETC.

Water Towers.

Film Cooling Towers (1925), Ltd.
Premier Cooler and Engineering Co., Ltd.

Water-Tube Boilers.

See BOILER MANUFACTURERS.

Water Wheels, Water Motors, and Turbines.

Gilkes, Gilbert, & Co., Ltd.
Howden, James, & Co., Ltd.
Howes, S.

Waterproofing Compounds.

Callender, George M., & Co., Ltd. ('Callendrite').

Wedge Gate Valves.

Hopkinsons, Ltd.

Weighbridges.

Avery, W. & T., Ltd.

Weighing Machines.

Avery, W. & T., Ltd.
Bennis, Ed., & Co., Ltd.
Howes, S.

Welding and Cutting of Metals.

A.-C. Welding Co.
Allen-Liversidge, Ltd.
Alloy Welding Processes, Ltd.
British Oxygen Co., Ltd.
Carbic, Ltd.
Coan, Robert W., Ltd.
District Chemical Co., Ltd.
Ferro-Arc Welding Co., Ltd.
Ferrox Company, Ltd.
Harvey, G. A., & Co. (London), Ltd.
Hoggett, Young & Co.
Nobel Industries, Ltd.
Peters, G. D. & Co., Ltd.
Thorn & Hoddle, Ltd.

Welding Wire ('Rylax').

Rylands Brothers, Ltd.

Wheel Gearing.

Daglish, Robert, & Co., Ltd.
Firth, Thos., & Sons, Ltd.
Kirkstall Forge, Ltd.
Power Plant Co., Ltd.

Wheels (Steel).

Renold (Hans), Ltd.

White Lines (Permanent).

Coan, Robert, W., Ltd.

Whiting.

Cement Marketing Co., Ltd.
Sankey, J. H., & Son, Ltd.

'Willesden' Paper and Canvas.

Willesden Paper & Canvas Works, Ltd.

Winding and Hauling Engines and Plant.

Clarke, Chapman & Co., Ltd.
Daglish, Robt., & Co., Ltd.
Davey, Paxman & Co., Ltd.
Ferodo, Ltd.
Fraser & Chalmers (Proprs., General Electric Co., Ltd.).
Galloways, Ltd.
Holman Bros., Ltd.
Power Plant Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Ruston & Hornsby, Ltd.

Winding and Hauling Ropes.

Hart, Thomas, Ltd. ('Lambeth' Cotton Ropes).
Kenyon, Wm., & Sons, Ltd. (Cotton Ropes).
Whitecross Co., Ltd.
Wrights' Ropes, Ltd.

See also ROPES.

Wire Gauze.

Harvey, G. A., & Co. (London), Ltd.
Potter, F. W., & Co.

Wire Manufacturers.

British Aluminium Co., Ltd.
Delta Metal Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

Wire Manufacturers—*continued.*

Dorman, Long & Co., Ltd. (Steel).
Firth, Thos., & Sons, Ltd. (Stainless Steel).
London Electric Wire Co. & Smiths, Ltd.
Rylands Brothers, Ltd.
Shropshire Iron Co., Ltd.
Smith, Frederick, & Co.
Whitecross Company, Ltd. (Telegraph).
Wrights' Ropes, Ltd.

Wire (Insulated) Manufacturers.

Callender's Cable & Construction Co., Ltd.
Craigpark Electric Cable Co., Ltd.
English Electric Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Johnson & Phillips, Ltd.
Liverpool Electric Cable Co., Ltd.
London Electric Wire Co. & Smiths, Ltd.
Macintosh Cable Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Standard Telephones & Cables, Ltd.

Wire Rope Tramways.

Wrights' Ropes, Ltd.

Wire Ropes.

Rylands Brothers, Ltd.
Whitecross Company, Ltd.
Wrights' Ropes, Ltd. (Flattened Strand & Locked Coil).

Wire Ropeways.

Wrights' Ropes, Ltd.

Wire Work and Woven Wire.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.
Potter, F. W., & Co.

Wireless Apparatus.

General Electric Co., Ltd.
Gent & Co., Ltd.
India Rubber, Gutta Percha, and Telegraph Works Co., Ltd.
Negretti & Zambra.
Siemens Bros. & Co., Ltd.

Wiring Systems (Flexible).

Callender's Cable & Construction Co., Ltd.
General Electric Co., Ltd.
Henley's, W. T., Telegraph Works Co., Ltd.
Macintosh Cable Co., Ltd.
St. Helens Cable and Rubber Co., Ltd.
Siemens Bros. & Co., Ltd.
Simplex Conduits, Ltd.

'Woodite,' for Steam, Electrical, and Hydraulic Packings.

Woodite Co., Ltd.

Wood Preservatives.

Anderson, D., & Son, Ltd. ('Sidol').
Carson, Walter, & Sons.

Wood-Working Machinery.

English Electric Co., Ltd.

Workshops (Lighting of).

Allen-Liversidge, Ltd.
Benjamin Electric, Ltd.
General Electric Co., Ltd.
Thorn & Hoddle, Ltd.
Wells, A. C., & Co., Ltd.

Wrought and Sheet Ironwork.

Braby, Fredk., & Co., Ltd.
Harvey, G. A., & Co. (London), Ltd.
Kenyon, Wm., & Sons, Ltd.
Potter, F. W., & Co.

Zincs (Non-encrusting) for Primary Batteries.

General Electric Co., Ltd.
Siemens Bros. & Co., Ltd.

FOR ADVERTISERS' ADDRESSES AND POSITIONS OF THEIR ANNOUNCEMENTS, CONSULT FOREGOING ALPHABETICAL LIST, PAGES 2977 TO 2990.

'THE ENGINEER'S YEAR-BOOK' GLOSSARIES OF TRADE TERMS USED IN THE CLASSIFIED DIRECTORY AND BUYERS' GUIDE IN FRENCH, ITALIAN, SPANISH, AND RUSSIAN.

TRADUCTION DES RUBRIQUES FIGURANT DANS LE 'RÉPERTOIRE ANALYTIQUE DES SPÉCIALITÉS ANNONCÉES' (pages 2993–3056).

Pour les noms des fabricants des spécialités ci-dessous, se reporter aux rubriques correspondantes en anglais dans le 'Classified Directory and Buyers' Guide' ('Répertoire Analytique des Annonceurs'), pages 2993–3056.
Pour les adresses des Annonceurs et les renvois à leurs annonces dans l'Annuaire, voir l'Index alphabétique, pages 2977–2990.

FRANÇAIS.	ANGLAIS.
A	
Accessoires d'aéroplanes	Aeroplane Accessories
Accessoires de machines et de chaudières, foyers, tubes, etc.	Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.
Accouplements flexibles	Flexible Couplings
Accumulateurs	Accumulators. *See* Batteries
Accumulateurs (Éléments et Batteries d')	Storage Cells and Batteries
Accumulateurs (Tableaux de distribution pour)	Storage Battery Switchboards
Accumulateurs électriques	Storage Cells
Accumulateurs hydrauliques	Accumulators (Hydraulic)
Acétylène	Acetylene
Acide azotique	Nitric Acid
Acide chlorhydrique	Hydrochloric Acid
Acide pour accumulateurs	Accumulator Acid
Acide sulfurique	Sulphuric Acid
Acier à aimant	Magnet Steel
Acier à haute résistance à la traction	High Tensile Steel
Acier à outils	Tool Steel
Acier au chrome-vanadium	Chrome - Vanadium Steels
Acier au nickel et au nickel-chrome	Nickel and Nickel Chrome Steels
Acier au manganèse	Manganese Steel
Acier (blooms et billettes)	Steel (Blooms and Billets)
Acier compound	Case Hardening Steels
Acier d'appareils d'aviation	Aircraft Steels
Acier de machine trempé à l'air	Air Hardening Gear Steel
Acier électrique, Fabricants de	Electric Steel Manufacturers
Acier en barres	Steel Rods
Acier fondu au creuset	Crucible Cast Steels
Acier immaculable et sans rouille	Stainless and Rustless Steel
Acier immaculable de Firth	Firth's Stainless Steel
Acier (Poli, tourné, étiré et laminé à froid)	Steel (Bright Turned, Drawn, and Cold-Rolled)
Acier pour boute-relles et étampes	Die Steels
Acier pour machines, Fabricants de	Machinery Steel Manufacturers
Acier rapide à outils	High-Speed Tool Steel
Acier rapide 'Speedicut'	Speedicut' High-Speed Steels
Acier sans-rouille	Rustless Steel
Acier Siemens-Martin	Siemens - Martin Steel
Aéronautique (Ingénieurs)	Aeronautical Engineers
Aéronautique, moteurs pour	Aero Engines
Agrafes (Commande à vis sans fin 'Jubilee' — brevetée)	Clips ('Jubilee' Worm Drive (Patent))
Agrafes à expansion	Expanding Clips

FRANÇAIS.	ANGLAIS.
Agrafes pour tuyaux flexibles	Hose Pipe Clips
Agrafes 'Jubilee' pour commandes à vis sans fin (Brevetées)	'Jubilee' Worm Drive Clips (Patent)
Agrafes de radiateurs	Radiator Clips
Aiguillages et croisements de chemin de fer	Railway Points and Crossings
Air liquide	Liquid Air
Alésoirs et tarauds	Reamers and Taps
Alliages	Alloys
Alliages d'acier, Fabricants de	Alloy Steel Manufacturers
Alternateurs	Alternators
Aluminium (lingots, feuilles, tubes, fils, câbles, sections, etc.)	Aluminium (Ingots, Sheets, Tube, Wire, Cables, Sections, etc.)
Aluminium en poudre	Aluminium Powder
Amiante (Produits, garnitures, etc.)	Asbestos Goods, Fittings, etc.
Amiante (Recouvrements et matelas d')	Asbestos Coverings and Mattresses
Analyse des gaz de fumée	Boiler Flue Gases (Analysis of)
Anneaux pour verres d'indicateurs de niveau	Gauge Glass Rings
Anneaux et bagues de cuivre pour jointures	Copper Jointing Rings
Anti-incrustant pour chaudières (pour usage interne)	Boiler Composition (for inside use)
Antirouille 'Foliac'	'Foliac' Silica—Graphite Paint
Antirouilles	Rust Preventive
Antivibration	Anti-Vibration
Appareils à adoucir et purifier l'eau. *Voir aussi* Réchauffeurs d'eau d'alimentation	Water Softening and Purifying Apparatus. *See also* Feed Water Heaters, etc.
Appareils à charbon pulvérisé	Powdered Coal Plants
Appareils à distiller l'eau, etc. *Voir aussi* Condenseurs	Water-Distilling Apparatus, etc. *See also* Condensers
Appareils à filtrer	Filtering Apparatus
Appareils à mesurer le charbon	Meters (Coal)
Appareils à mesurer la viscosité. *Voir* appareils pour essais d'huiles	Viscosity Apparatus. *See* Oil Testing Apparatus
Appareils à nettoyer les chaudières (Mécaniques et électriques)	Boiler Cleaners (Mechanical and Electrical)
Appareils à rafraîchir et à humidifier l'air	Air-Cooling and Humidifying Apparatus
Appareils à recueillir la poussière et les déchets	Dust and Refuse Collecting Plants
Appareils à refroidissement d'eau	Water-Cooling Apparatus
Appareils automatiques pour la conduite des feux	Mechanical Stokers
Appareils chimiques et électro-chimiques	Chemical and Electro-Chemical Apparatus
Appareils de distillation à basse température	Low-Temperature Distillation Plants
Appareils de graissage	Lubricating Devices
Appareils de halage	Hauling Plant. *See* Winding and Hauling
Appareils de levage	Lifting and Hoisting Machinery
Appareils de manutention du charbon, du coke et de la cendre	Coal, Coke, and Ash Handling Plants
Appareils de mise en marche pour moteurs	Motor Starters
Appareils de pesage	Weighing Machines
Appareils de radiotélégraphie	Radio-Telegraphy Apparatus
Appareils de récupération	Recovery Plants
Appareils de séchage	Drying Apparatus
Appareils de télégraphie sans fil	Wireless Telegraphic Apparatus

Pour les noms des fabricants des spécialités ci-dessus, se reporter aux rubriques correspondantes en anglais dans le 'Classified Directory and Buyers' Guide' ('Répertoire Analytique des Annonceurs'), pages 2993–3056.

FRANÇAIS.	ANGLAIS.
Appareils de tirage par refoulement ou par aspiration	Forced and Induced Draught Apparatus
Appareils de transmission de la force motrice	Power Transmission Appliances
Appareils de transport pneumatiques	Pneumatic Conveying Plants
Appareils électriques pour le chauffage et la cuisine	Electric Heating and Cooking Apparatus
Appareils extincteurs d'incendies	Fire Extinguishing Appliances
Appareils générateurs d'acétylène	Acetylene Generating Plants
Appareils générateurs d'oxygène et d'hydrogène	Oxygen and Hydrogen Generating Plants
Appareils hydro-électriques	Hydro-Electric Plants
Appareils mesureurs pour mines	Minemeters
Appareils pour la distillation de l'eau douce	Distilling Apparatus (Fresh Water)
Appareils pour disposer des matières d'égout	Sewage Disposal Appliances
Appareils pour l'éclairage électrique et accessoires électriques	Electric Light Fittings and Electrical Accessories
Appareils pour essais de gaz	Gas Testing Apparatus
Appareils pour essais d'huiles	Oil Testing Apparatus
Appareils pour l'utilisation des ordures	Refuse Utilisation Plants
Appareils vérificateurs	Testing Machines
Apprêts pour machines	Machinery Finishes
Arbres coudes de locomotives	Railway Crankshafts
Arbres de transmission et engrenages	Shafting and Gearing
Ardoisage	Slating
Armatures pour béton	Concrete (Reinforcement for)
Ascenseurs hydrauliques	Hydraulic Lifts. *See* Lifting and Hoisting
Asphalte	Asphalte
Ateliers (Éclairage des)	Workshops (Lighting of)
Attelages de train	Railway Couplings
Automobiles, accessoires de	Motor Car Accessories
Auxiliaires de turbines à engrenage	Geared Turbine Auxiliaries
Avertisseurs d'incendie	Fire Alarms
Avions, Fabricants de (*voir* Aéroplanes, Constructeurs de)	Aircraft Manufacturers. *See* Aeroplane Builders
Azote	Nitrogen

B

Baguettes de laiton 'Dixtrudo' pour filetage et tournage à grande vitesse	'Dixtrudo High-speed Brass Screwing and Turning Rods
Baguettes de métal jaune 'Dixtampo' pour étampage et forgeage à chaud	'Dixtampo' Yellow Metal Rods for Hot Stamping and Forging
Balais pour dynamos	Dynamo Brushes
Balances automatiques	Automatic Weighing Machines
Bandages en caoutchouc massif pour véhicules industriels	Solid Rubber Tyres for Commercial Vehicles
Bandages et essieux de voiture de C.D.F.	Railway Tyres and Axles
Bandes et ficelles pour usines	Mill Bandings and Twines
Baromètres	Barometers
Bascules	Weighbridges
Bassins à flot	Floating Docks
Bâtiments (Imperméabilisation des)	Buildings (Waterproofing of)

Pour les noms des fabricants des spécialités ci-dessus, se reporter aux rubriques correspondantes en anglais dans le 'Classified Directory and Buyers' Guide' ('Répertoire Analytique des Annonceurs'), pages 2993–3056.

FRANÇAIS.	ANGLAIS.
Bâtiments(Protection contre la foudre)	Buildings (Protection of, from Lightning)
Bâtiments	Buildings
Batteries d'accumulateurs électriques	Batteries (Electrical Storage)
Berceaux de chaudières	Boiler Seatings
Béton armé	Ferro-Concrete. *See* Reinforced Concrete
Billes en acier	Steel Balls
Billes et paliers à billes	Balls and Ball-Bearings
Billettes ou largets d'acier	Billets (Steel)
Blanc d'Espagne	Whiting
Blochets d'arrêt de chemins de fer	Railway Stop Blocks
Blocks-appuis et couvertures pour chaudières	Boiler Blocks and Covers
Boilerine '	' Boilerine '
Boîtes de vitesses (Multiplication et démultiplication)	Gear Boxes (Increasing and Reducing)
Boulons et écrous (Fer, acier, cuivre, bronze de marine, etc.)	Bolts and Nuts (Iron, Steel, Copper, Naval Brass, etc.)
Bonbonnes à huile	Oil Drums
Boulons pour isolateurs télégraphiques, et tous genres de ferrures pour Télégraphie et Téléphonie	Telegraph Insulator Bolts and all kinds of Ironwork for Telegraph and Telephone
Bourrage marque ' Lion '	Engine Packing (' Lion ')
Bourrage métallique pour tiges de pistons, marque ' Lion '	Metallic Piston Rod Packing (' Lion ')
Bourrage métallique pour tiges de pistons, marque ' United States '	Metallic Piston Rod Packing (' United States ')
Bourrages, garnitures, rondelles ' CORK '	' CORK ' Packings, Gaskets and Washers
Bourrages pour machines	Engine Packing
Bourrages pour machines à vapeur	Packing (Steam). *See* Engine Packing
Bourrages pour moteurs à gaz	Gas Engine Packing
Bourrages Walker marque ' Lion '	Walker's (' Lion ') Packings
Boutons, écrous & boulons d'aluminium	Aluminium Studs, Bolts, and Nuts
Bretelles de tranchées	Trench Braces
Briques réfractaires et articles en argile réfractaire	Fire Bricks and Fire Clay Goods
Bronze	Bronze. *See* Brass and Bronze
Bronze au manganèse	Manganese Bronze
Bronze en lingots	Gunmetal Ingots
Bronze en lingots pour la marine	Admiralty Gun-Metal Ingots
Bronze phosphoreux	Phosphor Bronze
Brouettes (en acier)	Barrows (Steel)
Broyeurs aériens (électriques)	Aerial Grinders, Electric
C	
Câbles (télégraphiques, téléphoniques, sous-marins, pour l'éclairage électrique)	Cables: Telegraph, Telephone, Electric Light, and Submarine
Câbles d'extraction et de halage	Winding and Hauling Ropes
Câbles de transmission en coton	Cotton Driving Ropes
Câbles électriques	Electric Cables
Câbles électriques (' Type C.T.S.') *Voir* Câbles ' Recouverts de Pneumatiques de Voitures '	Electric Cables (' C.T.S.' Type) (see ' Cab Tyre Sheathed ' Cables
Cables isolés ' Maconite '	' Maconite ' Insulated Cables
Câbles et accessoires de mines	Mining Cables and Accessories
Câbles métalliques	Wire Ropes
Câbles métalliques (Tramways à)	Wire Rope Tramways

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FRANÇAIS.	ANGLAIS.
Câbles sous gaine, 'Cab Tyre'	'Cab Tyre' Sheathed Cables
Cages d'ascenseurs	Lift Enclosures
Calorifiants	Calorifiers
Calorimètres pour l'essai des combustibles	Calorimeters for Fuel Testing
Canalisations	Conduits. *See* 'Steel Conduits' and 'Wiring Systems'
Canons et Munitions, Fabriques de	Gun and Ammunition Works
Caoutchouc massif (Câbles en)	Solid Rubber Cables. *See* Cables
Carbure de calcium	Carbide of Calcium
Carreaux et tuiles en caoutchouc	Rubber Flooring and Tiles
Chaînes à galets (grosses chaînes)	RollerChains (Heavy)
Chaînes à dents renversées	Inverted Tooth Chains
Chaînes Biflex pour commandes d'arbres à cames d'automobiles	Biflex Chains for Automobile Camshaft Drives
Chaînes de transmission	Driving Chains
Chaloupes (à vapeur et à moteur)	Launches (Steam and Motor)
Chalumeaux (pour soudure autogène et coupe des métaux à l'acetylène)	Blowpipes (Acetylene Welding and Cutting)
Châssis et bogies	Underframes and Bogies
Châssis pour automobiles	Motor Chassis Frames
Châteaux d'eau	Water Towers
Chaudières (Accessoires de)	Boiler Fittings. *See* Engine and Boiler Fittings
Chaudières à l'eau chaude	Hot Water Supply Boilers
Chaudières à réchauffage	Exhaust Heat Boilers
Chaudières à vapeur. *Voir* Constructeurs de chaudières	Steam boilers. *See* Boiler Manufacturers
Chaudières de concentration par le vide	Vacuum Pans (Concentrating)
Chaudières tubulaires. *Voir* Constructeurs de chaudières	Water-Tube Boilers *See* Boiler Manufacturers
Chaudronniers de cuivre	Coppersmiths
Chauffage des voitures de chemins de fer	Heating for Railway Carriages
Chauffage, ventilation, etc.	Heating, Ventilating, etc.
Chauffe-rivets	Rivet Heaters
Chauffeurs électriques	Electric Heaters
Chaux et calcaires	Lime and Limestone
Cheminées	Chimney stacks
Chemins de fer: Voies portatives, voies étroites, etc.	Railways: Light, Portable, etc.
Chemins de fer et tramways électriques	Electric Railways and Tramways
Chemins de roulement aériens	Overhead Runways
Chimistes hydrologiques	Hydrological Chemists
Ciment de Portland	Portland Cement
Ciment de Portland (Machines à essayer le)	Portland Cement (Testing Machines for)
Ciment graphite 'Foliac' pour chaudières, tuyaux de vapeur, gaz, air, et eau	'Foliac' Graphite Pipe Joint Compound
Ciment 'Kisol' pour chaudières, tuyaux de vapeur, etc.	'Kisol' Cement for Boilers, Steam Pipes, etc.
Ciment pour joints	Jointing Cement
Ciment (réfractaire)	Cement (Refractory)
Ciment réfractaire ('Pyruma')	Fire Cement ('Pyruma')

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FRANÇAIS.	ANGLAIS.
Ciments (Portland, Keene et Parian)	Cements (Portland, Keenes', & Parian)
Coffres d'emmagasinage (Pour mobiliers en acier)	Storage Bins (for Steel Furniture)
Colle marine	Marine Glues
Collèges d'arts et manufactures	Colleges (Engineering)
Colonnes et pièces coulées pour égouts, gaz et conduites d'eau	Columns and Castings for Sewage, Gas, and Water Works
Combustion de surface	Surface Combustion
Commandes par chaînes	Chains and Chain Driving
Compositions non conductrices	Non-conducting Compositions
Compresseurs d'air	Air-Compressors
Compteurs d'air	Air Meters
Compteurs à gaz	Gas Meters
Compteurs à l'eau	Water Meters
Compteurs d'eau	Recorders (Water)
Compteurs d'eau d'évacuation	Waste Water Meters
Compteurs de vapeur	Steam Meters
Condenseurs, évaporateurs, appareils pour adoucir et distiller l'eau, etc.	Condensers, Evaporators, Water Softening and Distilling Apparatus, etc.
Condenseurs kinétiques 'Contraflo'	'Contraflo' Kinetic Condensers
Conduites	Pipe Lines
Conservation par le froid	Cold Storage
Constructeurs d'aéroplanes	Aeroplane Builders
Constructeurs d'appareils de ventilation	Ventilating Engineers
Constructeurs de chaudières	Boiler Manufacturers
Constructeurs de navires	Ship Builders
Constructeurs de ponts	Bridge Builders
Constructions en béton armé	Concrete (Reinforced) Construction
Constructions en fer et en acier, etc.	Structural Iron and Steel Work, etc.
Contrôleurs électriques automatiques	Automatic Controllers (Electric)
Contrôleurs et démarreurs à liquide	Controllers and Liquid Starters
Convertisseurs Rotatifs	Rotary Converters
Convoyeurs. *Voir aussi* Courroies	Conveyors. *See also* Belting
Cordes et câbles : en fils métalliques, chanvre, manille, cuir, coton et amiante	Ropes: Wire, Hemp, Manilla, Leather, Cotton, and Asbestos
Cornues à gaz	Gas Retorts
Coulées pour soupapes	Valve Castings
Couleurs, peintures et vernis	Colours, Paints, and Varnishes
Couplages de chaînes Coventry	'Coventry' Chain Couplings
Courroie en poils 'Gripoly'	'Gripoly' Hair Belting
Courroies, câbles, etc. de transmission	Driving Bands, Ropes, etc.
Courroies de Balata	Balata Belting
Courroies de coton	Cotton Belting
Courroies de cuir. *Voir* Courroies	Leather Belting. *See* Belting
Courroies en poil de chameau marque 'Camel' (Seuls fabricants des)	'Camel' Hair 'Camel' Brand Belting (Sole makers of)
Courroies, etc. (cuir, coton, poils, caoutchouc, etc.)	Belting, etc.: Leather, Cotton, Hair, India Rubber, etc.
Couvertures et revêtements de carneaux	Flue Covers and Linings
Craie	Chalk
Creusets	Crucibles
Cribles et tamis	Sieves and Screens
Cuivre	Copper
Cylindres	Cylinders

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FRANÇAIS.	ANGLAIS.
D	
Dalles et planches en ciment	Cement Slates and Boards
Découpage et soudure autogène des métaux	Metal Cutting and Welding
Démagnétiseurs	Demagnetizers
Démarreurs à liquide et combinateurs	Liquid Starters and Controllers
Désincrustants pour chaudières	Boiler Discrustants
Destructeurs (Séparateurs magnétiques pour)	Destructors (Magnetic Separators for)
Destructeurs de déchets	Destructors (Refuse)
Désurchauffeurs de vapeur	Steam De-Superheaters
Détrempe	Distemper
'DEXINE' (pour vapeur H.P., garnitures acides et hydrauliques)	'DEXINE' (for H.P. Steam, Acid and Hydraulic Packings)
'DEXONITE' (superébonite, pour acides et alcalis; garnitures, et pour isolation électrique)	'DEXONITE (Super Ebonite, for Acids and Alkalies; fittings, and Electrical insulation material)
'Duralumin' 'Vickers'	'Duralumin' 'Vickers'
Dynamite	Dynamite
Dynamomètres	Dynamometers
Dynamos et moteurs	Dynamos and Motors
E	
Eau d'alimentation des chaudières (Élimination de l'huile de l')	Boiler Feed-Water, Oil Elimination from
Ébonite	Ebonite
Éclairage des trains	Lighting (Train)
Éclairage des usines	Factories (Lighting of)
Éclairage et chauffage (Installations de gaz acétylène pour)	Lighting and Heating (Acetylene Gas Plants for)
Écoles et collèges de mécanique	Schools and Colleges (Engineering)
Économiseurs de combustible	Fuel Economisers. *See* Economisers
Écrous	Nuts
Électriques (Instruments et appareils)	Electrical Instruments and Apparatus. *See* Instruments and Apparatus (Electrical)
Électro-aimants de levage	Lifting Magnets
Électrodes (pour la soudure à l'arc électrique)	Electrodes (for Electric Arc Welding
Éléments et batteries d'accumulateurs électriques. *Voir* Accumulateurs électriques	Electrical Storage Cells and Batteries. *See* Storage Cells
Élévateurs. *Voir* Levage et halage	Elevators. *See* Lifting and Hoisting
Éliminateurs d'huile	Oil Eliminators
Émaux, couleurs et vernis	Enamels, Colours, and Varnishes
Embrayages	Clutches
Embrayages à frottement	Friction Clutches
Enduits imperméabilisants	Waterproofing Compounds
Enduits pour parties brillantes	Bright Part Coatings
Enduits pour parties brillantes et apprêts pour machines	Coatings (Bright Part) and Machinery Finishes
'Endural' Câbles électriques	'Endural' Electric Cables
Engrenages	Gearing
Engrenages, arbres de transmission, etc., pour usines. *Voir* Arbres de transmission et engrenages	Mill Gearing, Shafting, etc. *See* Shafting and Gearing
Engrenages cylindriques et coniques	Spur and Bevel Gearing
Engrenages de réduction	Reduction Gears

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FRANÇAIS.	ANGLAIS.
Engrenages de turbines. *Voir* Turbines à engrenages	Turbine Gears. *See* Geared Turbines
Engrenages hélicoïdaux	Helical Gearing
Engrenages (hydrauliques, à bain d'huile)	Gears (Hydraulic Oil)
Enlèvement de la vapeur et des fumées	Smoke, Steam, and Fume Removal
Enregistreurs à eau	Water Recorders
Enregistreurs d'acide carbonique	CO_2 Recorders
Enregistreurs de dépenses et de temps	Costs and Time Recorders
Enregistreurs de rendements de machines	Machine Output Recorders
Enregistreurs de vitesse	Recorders (Speed)
Enseignement mécanique. *Voir* Collèges	Engineering Training. *See* Colleges
Enseignement technique. *Voir* Écoles et Collèges	Technical Training. *See* Schools and Colleges
Entrepreneurs	Contractors
Entrepreneurs d'éclairage électrique	Electric Lighting Contractors
Entrepreneurs de cloisons et constructions incombustibles	Partition Contractors and Fireproof Builders
Entrepreneurs de toitures	Roofing Contractors
Équerres	Squares
Équipements téléphoniques	Telephone Equipment
Escaliers incombustibles	Staircases (Fire-Resisting)
Essais électriques (Instruments d'). *Voir* Instruments	Testing Instruments (Electrical). *See* Instruments
Essieux (Chemins de fer)	Axles (Railway)
Étampages	Stampings
Etoffes à friction 'CHEKKO'	'CHEKKO' Friction Fabrics
Évaporateurs à effet multiple	Multiple Effect Evaporators
Évaporateurs à vide pour liquides chimiques	Vacuum Evaporators for Chemical Liquids
Évaporateurs, condenseurs, Appareils pour la distillation de l'eau, etc.	Evaporators, Condensers, Water Distilling Apparatus, etc.
Évaporateurs pour l'industrie sucrière et des liqueurs	Evaporators for Sugar and Trade Liquors
Excavateurs et transporteurs	Excavators and Transporters
Explosifs	Explosives
Explosifs pour mines	Mining Explosives
F	
Fabricants de caoutchouc, gutta-percha et bitume	India Rubber, Gutta Percha, and Bitumen Manufacturers
Fabricants de chaudières	Boiler Manufacturers
Fabricants de fils isolés	Wire (Insulated Manufacturers
Fabricants de fils métalliques	Wire Manufacturers
Fabricants d'outils de forage de puits artésiens	Boring Tool Makers (Artesian)
Fabricants d'outils, machinistes, etc.	Tool Makers, Machinists, etc.
Fabricants de rails	Rail Manufacturers
Fabricants et marchands d'acier	Steel Manufacturers and Merchants
Fabricants et marchands de fer et d'acier	Iron and Steel Manufacturers and Merchants
Fenêtres métalliques (Châssis et croisées)	Metal Windows (Sashes and Casements)
Fer et acier galvanisés, Fabricants de	Galvanised Iron and Steel Manufacturers
Fers et aciers pour constructions	Structural Iron and Steel Work

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FRANÇAIS.	ANGLAIS.
Feuilles et tuyaux en ciment d'amiante 'Everite'	'Everite' Asbestos Cement Sheets and Pipes
Feuilles et tuiles d'amiante marque 'Poilite'	'Poilite' Asbestos Sheets and Roofing Tiles
Feuilles 'Rok' pour toitures	'Rok' roofing
Feutre et toitures de feutre	Felt and Felt Roofs
Feutres pour fabricants de papier	Paper Makers' Felts
Feutres pour imprimeries, papeteries et imprimeries sur étoffes	Felts for Printing Machinery, Paper Making, and Calico Printing Machinery
Feutres pour toitures	Roofing Felts
Feux et outillage de forges	Smiths' Hearths and Plant
Fibre vulcanisée	Fibre (Vulcanised)
'Fibrent,' tôles d'amiante ciment plates et ondulées	'Fibrent' Asbestos Cement Corrugated and Flat Sheets
Fils métalliques pour clôtures	Fencing Wire
Fil 'Rylax' pour soudure autogène	Welding Wire ('Rylax')
Fils télégraphiques	Telegraph Wire. *See* Wire
Filtres d'air	Air Filters
Filtres d'eau d'alimentation de chaudières. *Voir* Eau d'alimentation	Boiler Feed Filters. *See* Feed Water
Filtres d'huile	Oil Filters
Fonceurs de puits	Shaft Sinkers
Fondeurs	Founders
Fondeurs de cuivre	Brass Founders
Fonte coulée	Cast Iron
Forges portatives	Forges (Portable)
Fourneaux de forge	Forging Furnaces. *See* Furnaces
Fournitures pour bureaux de dessins	Drawing Office Requisites
Fournitures pour constructions mécaniques et chemins de fer. *Voir* Matériel de chemins de fer et de tramways	Engineering and Railway Supplies. *See* Railway and Tramway Plant

FRANÇAIS.	ANGLAIS.
Fours à gaz	Gas Furnaces. *See* Furnaces
Fours chauffés au gaz et au pétrole et fours industriels	Furnaces (Gas and Oil Heated and Industrial)
Fours et matériels industriels à gaz	Industrial Gas Furnaces and Plants
Foyers à houille	Coal Furnaces. *See* Furnaces
Foyers de chaudières	Boiler Furnaces
Foyers de chaudières. *Voir* Accessoires de machines et de chaudières	Furnaces (Boiler). *See* Engine and Boiler Fittings
Foyers de chaudières, tubes, etc.	Boiler Furnaces, Tubes, etc.
Fraises	Milling Cutters
Freins de chemins de fer	Brakes (Railway)
Freins dynamométriques	Brakes (Dynamometers)
Freins (Electro-Mécaniques)	Brakes (Electro-Mechanical)
Fumifuges et générateurs de vapeur	Smoke Preventers and Steam Generators
G	
Galvanisateurs	Galvanisers
Garde-fous pour machines	Machinery Guards
Garniture 'Lascar'	Packing ('Lascar')
Garniture d'amiante 'Lascar'	Asbestos Packing ('Lascar')
Garniture ('Britimp')	Packing ('Britimp')
Garniture ('Langite' réfractaire à l'huile)	Packing ('Langite Oil Resisting)
Garniture 'Lion'	'Lion' Packing
Garniture d'amiante (marque 'Lion')	Asbestos Packing ('Lion')
Garniture marque 'United States'	Packing ('United States')
Garniture 'Pilot'	Packing ('Pilot')
Garniture pour surchauffeurs de locomotives	Locomotive Superheated Packing

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FRANÇAIS.	ANGLAIS.
Garnitures d'embrayages	Clutch Linings
Garnitures de chaudières. *Voir aussi* Accessoires de machines et chaudières	Boiler Mountings. *See also* Engine and Boiler Fittings
Garnitures de freins et d'embrayages	Brake and Clutch Linings
Garnitures de joints	Jointing Materials
Garnitures de pistons	Piston Packing
Garnitures hydrauliques	Hydraulic Packings
Garnitures métalliques. *Voir* Bourrages pour machines	Metallic Packing. *See* Engine Packing
Garnitures métalliques 'Britimp.'	'Britimp' Metallic Packings
Garniture métallique ('Silvertown') pour tiges de pistons	Metallic Piston Rod Packing ('Silvertown')
Garniture pour joint de vapeur ('Britimp')	Steam Packing ('Britimp')
Garnitures pour machines à vapeur	Steam Packing
Garnitures pour transformateurs	Transformer Gaskets
Gaze métallique	Wire Gauze
Gazogènes	Gas Producers
Génératrices électriques. *Voir* Dynamos et Moteurs	Generators (Electric). *See* Dynamos and Motors
Graisse (pour graisseurs)	Grease (Lubricating)
Graisseurs et graisses	Lubricators and Lubricants
Graphite	Graphite
Graphite 'Foliac' Antiencrustante pour Chaudières	'Foliac' Boiler Graphite
Graveurs, dessinateurs et imprimeurs	Engravers, Draughtsmen, and Printers
Grues. *Voir* Appareils de levage	Cranes. *See* Lifting and Hoisting Machinery
Grues à main. *Voir* Appareils de levage	Hand Cranes. *See* Lifting and Hoisting Machinery
Grues preneuses (électriques)	Grabbing Cranes (Electric)
H	
Haussières (en acier galvanisé)	Hawsers (Galvanized Steel Wire)
Hélices	Propellers, Screw Propellers
Horloges électriques	Clocks, Electric. *See* Electric Clocks
Horloges enregistreuses	Time Recorders
Houillières (câbles d'acier pour)	Collieries (Steel Wire Ropes for)
Houillières (équipement électrique pour)	Collieries (Electrica Equipment of)
Huiles, composés lubrifiants, etc.	Oils, Lubricating Compounds, etc.
Hydrofuge et revêtement au bitume	Damp Course and Bitumen Sheeting
Hydrofuge et revêtement 'Callendrite'	'Callendrite' Dampcourse and Sheeting
I	
Imperméabilisation des réservoirs	Reservoirs (Waterproofing of)
Imprimeurs, lithographes, dessinateurs et graveurs	Printers, Lithographers, Draughtsmen, and Engravers
Indicateurs d'effort (de tension)	Strainmeters
Indicateurs d'élongation	Extensometers
Indicateurs de niveau d'eau	Water Level Indicators
Indicateurs de signaux de mines	Mine Signal Indicators
Indicateurs de tirage	Draught Gauges
Indicateurs de vide	Vacuum Gauges
Indicateurs de vitesse marins	Marine Speed Indicators

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FRANÇAIS.	ANGLAIS.
Indicateurs pour machines à vapeur	Indicators (Steam Engine)
Ingénieurs (Aéronautiques). Voir Aéronautiques (Ingénieurs)	Engineers (Aeronautical). See Aeronautical Engineers
Ingénieurs des mines	Mining Engineers
Ingénieurs électriciens	Electrical Engineers
Ingénieurs en bâtiment	Constructional Engineers
Ingénieurs hydrauliques	Engineers (Hydraulic), Water-Power Engineers
Ingénieurs mécaniciens	Engineers (Mechanical)
Ingénieurs métallurgiques	Metallurgical Engineers
Ingénieurs télégraphistes	Telegraph Engineers
Injecteurs, Ejecteurs et appareils généraux à jet. *Voir* Injecteurs pour machines à vapeur	Injectors, Ejectors, and General Jet Appliances. *See* Steam Injectors
Injecteurs pour machines à vapeur	Steam Injectors
Installation de chaudières	Boiler Setting
Installations à gaz pauvre. *Voir* Gazogènes	Producer Gas Plants. *See* Gas Producers
Installations à gaz pauvre par aspiration	Suction Gas Plants
Installations d'éclairage des trains	Train Lighting Plant
Installations de chargement et de transport	Loading and Transport Plants
Installations de distribution	Switch Gear
Installations et appareils hydrauliques	Hydraulic Plants and Appliances
Installations pour le forage des puits de pétrole	Oil-Burning Installations

FRANÇAIS.	ANGLAIS.
Institutions d'enseignement. *Voir* Collèges et Écoles	Educational Institutions. *See* Colleges and Schools
Instruments aéronautiques	Aeronautical Instruments
Instruments d'arpentage, de mathématiques, de dessin, etc.	Instruments: Surveying, Mathematical, Drawing, etc.
Instruments d'arpentage et de dessin	Surveying and Drawing Instruments
Instruments enregistreurs	Recording Instruments
Instruments et appareils électriques	Instruments and Apparatus (Electrical)
Instruments météorologiques	Meteorological Instruments
Instruments scientifiques	Scientific Instruments
Instruments scientifiques, de dessin et d'arpentage	Mathematical, Drawing, and Surveying Instruments
Isolateurs	Insulators
J	
Joint 'Beldamite'	Jointing ('Beldamite')
Joints ('Flexstel' à rotule)	Joints ('Flexstel' Ball and Socket)
Joints ('Lion' et 'Walkerite')	Joints ('Lion' and 'Walkerite')
Joints étanches à la vapeur. *Voir* Matériaux pour joints	Steam Jointing. *See* Jointing Materials
Journaux techniques. *Voir* Livres et journaux	Journals (Technical). *See* Books and Journals
L	
Laine de scorie	Mineral Wool
Laiton et bronze	Brass and Bronze
Lames de scies alternatives	Hack Saw Blades

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FRANÇAIS.	ANGLAIS.
Laminoirs (Équipement électrique pour)	RollingMills (Electrical Equipment of)
Lampes à acétylène à main et de chantier (transportables)	Acetylene Hand and Flare Lamps (Portable)
Lampes (arrière)	Lamps (Rear).
Lampes à l'arc	Arc Lamps
Lampes à filaments métalliques	Metal Filament Lamps
Lampes de sûreté de mineurs	Miners' SafetyLamps
Lampes électriques	Lamps (Electric)
Lampes industrielles	Lamps (Industrial)
Levage et montage	Lifting and Hoisting
Lignes blanches (permanentes)	White Lines (Permanent)
Livres et journaux scientifiques	Books and Journals, Scientific
Locomotives	Locomotives
Locomotives à pétrole (combustion interne)	Oil Locomotives (Internal Combustion)
Logements de chaudières	Settings (Boiler)
Logements de chaudières (perfectionnés)	Boiler Settings (Improved)
Logements de chaudières de Lancashire (perfectionnés)	Lancashire Boiler Settings (Improved)
Lubrifiants pour moteurs	Motor Lubricants
Lucarnes	Skylights
M	
Machines automatiques, Fabricants de	Automatic Machine Makers
Machines à aléser et à dresser	Boring and Facing Machines
Machines à broyer, élever et transporter le charbon	Coal Grinding, Elevating and Conveying Machinery
Machines à broyer et à pulvériser	Crushing and Pulverising Machinery
Machines à calculer	Counting Instruments
Machines à cintrer les tuyaux	Pipe-Bending Machines
Machines à ciment	Cement Machinery
Machines à cisailler, poinçonner et cintrer	Shearing, Punching, and Bending Machines
Machines à électro-aimants	Machinery (Electro-Magnets)
Machines à essayer le ciment	Cement Testing Machines
Machines à essayer le ciment de Portland	Testing Machines for Portland Cement
Machines à fabriquer le papier et la pâte à papier	Paper and Pulp Making Machinery
Machines à fabriquer les cartouches	Cartridge Machinery
Machines à faire la glace. *Voir* Machines réfrigérantes	Ice-making Machinery. *See* Refrigerating Machinery
Machines à fraiser	Milling Machines
Machines à laver le charbon	Coal-washing Machinery
Machines à moudre	Grinding Machinery
Machines à mouler en matrices	Die-Casting Machines
Machines à nettoyer les grains et semences	Grain and Seed Cleaning Machinery
Machines à peindre	Painting Machines
Machines à peser le charbon	Coal Weighing Machines
Machines à peser les grains	Grain Weighing Machines
Machines à peser les liquides	Liquid Weighing Machines
Machines à poinçonner, cisailler et cintrer	Punching, Shearing, and Bending Machines
Machines à polir	Polishing Machinery
Machines à poser les câbles	Cable-laying Machinery

Pour les noms des fabricants des spécialités ci-dessus, se reporter aux rubriques correspondantes en anglais dans le 'Classified Directory and Buyers' Guide' ('*Répertoire Analytique des Annonceurs*'), *pages* 2993–3056.

FRANÇAIS.	ANGLAIS.
Machines à raboter, mortaiser, fileter et étaux-limeurs	Planing, Slotting Screwing, and Shaping Machines
Machines à réduire en pulpe	Pulp-making Machinery
Machines à souder	Soldering Machines
Machines à travailler le bois	Wood-working Machinery
Machines à vapeur	Steam Engines
Machines de levage et de halage et palans	Lifting and Hoisting Machinery and Lifting Tackle
Machines de sondage (pour roches et houille)	Boring Machines for Rock and Coal
Machines d'huilerie	Oil Mill Machinery
Machines et appareils d'extraction et de halage	Winding and Hauling Engines and Plant
Machines et appareils pour mines. *Voir* Installations de mines et d'extraction	Mining Machinery. (*See* Mining and Hauling Plant)
Machines hydrauliques	Engines (Hydraulic)
Machines hydrauliques système 'Tweddell'	'Tweddell's System' Hydraulic Machinery
Machines locomobiles	Portable Engines
Machines, outils et appareils hydrauliques, etc.	Hydraulic Machines, Tools and Appliances, etc.
Machines-outils et outils à main. *Voir* Outils et accessoires de Mécaniciens. *Voir aussi* Fabricants d'outils	Machine and Hand Tools. *See* Engineers' Tools and Fittings, *also* Tool Makers
Machines pour minoteries	Flour-Milling Machinery
Machines pour usines de laminage	Rolling Mill Engines
Machines réfrigérantes	Refrigerating Machinery
Mandrins électromagnétiques	Magnetic Chucks
Manganèse et alliages de manganèse	Manganese and Manganese Alloys
Manomètres, robinets, indicateurs de niveau d'eau, soupapes de sûreté, tiroirs, indicateurs, séparateurs d'eau de condensation, etc.	Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.
Marches d'escaliers	Stair Treads
Marteaux de forge	Foundry Hammers
Marteaux mécaniques. *Voir* Marteaux	Power Hammers. *See* Hammers
Marteaux mécaniques à vapeur, à l'air comprimé et pneumatiques	Steam, Compressed Air, and Pneumatic Power Hammers
Marteaux-pilons. *Voir* Marteaux	Steam Hammers. *See* Hammers
Marteaux-pilons, marteaux à l'air comprimé, marteaux pneumatiques, etc.	Hammers (Steam, Compressed Air, Pneumatic Power etc.)
Matériaux pour joints	Jointing Materials
Matériel à combustible pulvérisé	Pulverised Fuel Equipment
Matériel de chemins de fer et de tramways	Railway and Tramway Plant
Matériel d'épuration du gaz	Gas Cleaning Plant
Matériel d'exploitation houillère	Colliery Plant
Matériel de dragage	Dredge Plant
Matériel de fonderie	Foundry Plant
Matériel de hauts-fourneaux	Blast Furnace Plant
Matériel de percement de tunnels	Tunnelling Plants

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FRANÇAIS.	ANGLAIS.
Matériel roulant. *Voir* Matériel de chemins de fer et de tramways	Rolling Stock. *See* Railway and Tramway Plant
Matières isolantes	Insulating Materials
Mécanisme de transmission lubrifié pour vitesse variable	Variable Speed Oil Transmission Gears
Mèches et perceuses	Drills and Drilling Machines
Mélangeurs d'huiles	Oil Blenders
'Mésmeric,' acier trempé à la surface	'Mesmeric' Case Hardening Steel
Mesurage de l'eau d'alimentation	Feed-Water (Measurement of)
Mesures électriques. *Voir* Instruments	Measuring Instruments (Electrical). *See* Instruments
Métal 'Bull's' et 'Melloid'	Bull's Metal and Melloid
Métal 'Delta'	Delta Metal
Métal déployé	Expanded Metal
Métal plastique 'Richards'	Plastic Metal (Richards')
Métaux anti-friction	Anti-friction Metals
Métaux de ramasse	Metals (Scrap)
Métaux en lingots	Ingot Metals
Métaux perforés	Perforated Metals
Métaux pour coussinets, etc.	Bearing Metals, etc.
Métaux pour coussinets, anti-friction, etc.	Metals: Bearing, Anti-friction, etc.
Métaux refoulés	Extruded Metals
Meules. *Voir* Machines à broyer	Grinders. *See* Grinding Machinery
Meules à centrer (électriques)	Centre Grinders (Electric)
Mica	Mica
Micromètres	Micrometers
Microscopes	Microscopes
Monte-charges. *Voir* Levage et Montage	Hoists. *See* Lifting and Hoisting
Monte-charges et grues électriques	Electric Lifts and Cranes
Moteurs à l'essence. *Voir* Moteurs à pétrole et à gaz	Petrol Engines. *See* Oil and Gas Engines
Moteurs à gaz, à pétrole et à l'essence	Gas, Oil, and Petrol Engines
Moteurs à pétrole, à gaz et à l'essence	Oil, Gas, and Petrol Engines
Moteurs à pétrole lourd. *Voir* Moteurs à pétrole	Crude Oil Engines. *See* Oil Engines
Moteurs Diesel et semi-Diesel	Diesel and Semi-Diesel Engines
Moteurs électriques. *Voir* Dynamos et Moteurs	Electric Motors. *See* Dynamos and Motors
Moteurs marins à pétrole	Marine Oil Engines
Moteurs marins, chaudières et machines auxiliaires marines	Marine Engine Boiler, and Auxiliary Machinery
Moulages de précision sous pression	Die Castings
Moulages en aluminium sous pression	Aluminium Die Castings
Moulages et pièces forgées	Castings and Forgings
Moulins (broyeurs-pulvérisateurs)	Mills (Pulverising)
Moulins broyeurs-pulvérisateurs de pierre	Stone Pulverising Mills
Moulins et machines pour sucreries	Sugar Mills and Machinery
Moutons à friction et à vapeur	Stamps (Friction and Steam Drop)
Moutons et presses	Drop Stamps and Presses
N	
Navires, chaloupes et yachts à vapeur	Steam Ships, Launches, and Yachts
Négociants en métaux	Metal Merchants
Nettoie-tubes	Tube Cleaners
Niveaux d'eau. *Voir* Indicateurs pour machines à vapeur	Water Gauges etc. *See* Steam Gauges

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FRANÇAIS.	ANGLAIS.
O	
Oscillographes	Oscillographs
Outillage d'exploitations minières	Mining Tools
Outillage et accessoires pour mécaniciens	Engineers' Tools and Fittings
Outillage et matériel d'entrepreneurs	Contractors' Tools and Plant
Outillage pour exploitations de carrières	Quarrying Tools
Outillages et machines pour fabriques de produits chimiques	Chemical Plant and Machinery
Outils détartreurs	Scaling Tools
Outils et appareils pneumatiques	Pneumatic Tools and Appliances
Ouvrages en cuivre pour plombiers	Plumbers' Brasswork
Ouvrages en fer forgé et en tôle	Wrought and Sheet Ironwork
Oxygène	Oxygen
P	
Packing 'Lion' pour machines à vapeur	Steam Packing ('Lion')
Paillassons d'automobiles	Motor Step Mats
Paliers (moulés en coquilles)	Bearings (Chill Cast)
Paliers à billes	Bearings (Ball)
Paliers à galets	Roller Bearings
Paliers pour transmissions (A billes et rouleaux)	Line Shaft Bearings (Ball and Roller)
Paliers à rouleaux	Roller Bearings
Paliers de butée (à billes)	Thrust Bearings (Ball)
Papier imperméable	Paper (Waterproof)
Papier et toile 'Willesden'	'Willesden' Paper and Canvas
Parafoudres	Lightning Conductors
Parquetages, etc., incombustibles	Floors etc. (Fire-Resisting)
Parquetage incombustible 'Decolite'	'Decolite' Fireproof Flooring
Patins et bouterelles (étampes)	Shoes and Dies
Pièces en laiton pressé à chaud	Hot Brass Pressings
Peinture anti-corrosive	Anti-Corrosive Paint
Peinture Silica-Graphite 'Foliac'	'Foliac' Silica-Graphite Paint
Peintures, couleurs, émaux et vernis	Paints, Colours, Enamels, and Varnishes
Peintures pour la préservation du fer et de l'acier	Paints for preserving Iron and Steel Work
Perceuses et marteaux-perforateurs électriques portatifs	Electric Portable Drills and Hammers
Perforatrices	Rock Drills
Perforatrices et haveuses pour houillères	Coal Drills and Cutters
Pétrole (Foyers à). *Voir* Foyers	Oil Furnaces. *See* Furnaces
Pics, pelles, etc.	Picks, Shovels, etc.
Pièces de fonderie générale	General Foundry Castings
Pièces de forge et moulages. *Voir* Moulages et pièces de forge	Forgings and Castings. *See* Castings and Forgings
Pièces forgées en cuivre	Copper Forgings
Pièces forgées et moulages en acier. *Voir* Moulages et pièces de forge	Steel Forgings and Castings. *See* Castings and Forgings
Pistons de pompes	Pump Buckets
Placards à huiles	Oil Cabinets
Planimètres	Surface Gauges
Plaques à marques de fabrique	Trade Mark Plates
Plaques d'acier rabotées	Planished Steel Sheets
Plaques indicatrices pour toutes industries	Name Plates for all Trades
Plaques numériques	Number Plates
Plaques tournantes	Turntables

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FRANÇAIS.	ANGLAIS.
Plâtre	Plaster
Pompes (à débit variable, à huile)	Pumps (Variable Delivery, Oil)
Pompes à l'air	Air Pumps
Pompes à pression à capacité variable	Variable Capacity Pressure Pumps
Pompes à turbines	Turbine Pumps
Pompes à vapeur. *Voir* Pompes	Steam Pumps. *See* Pumps
Pompes centrifuges	Centrifugal Pumps. *See* Pumps
Pompes d'alimentation pour chaudières	Boiler Feed Pumps
Pompes hydrauliques	Hydraulic Pumps
Pompes et machines d'épuisement	Pumps and Pumping Machinery
Pompes (pour puits profonds)	Pumps (Deep Well)
Pompes 'Roturbo'	Roturbo Pumps
Ponts (Câbles d'acier pour suspension de)	Bridges (Wire Rope Suspension)
Portes de bassins (Constructeurs de)	Dock Gates (Builders of)
Portes pliantes	Collapsible Gates
Poste et accessoires de découpage et de soudure à l'arc électrique	Electric Arc Cutting and Welding Plant and Accessories
Postes d'humidification de l'air	Air Conditioning Plants
Poteaux télégraphiques en fer	Telegraph Poles (Iron)
Poudre de mine	Blasting Powder
Poulies	Pulleys
Poulies à câble. *Voir* Poulies à courroie et à corde	Rope Pulleys. *See* Belt and Rope Pulleys
Poulies pour courroies et cordes	Belt and Rope Pulleys
Poutres, ponts, etc. *Voir* Fers et Aciers pour constructions	Girders, Bridges, etc. *See* Structural Iron and Steel Work
Préservatifs pour le bois	Preservatives (Wood)
Presses à bandages	Tyre Presses
Presses à cintrer	Scrap Presses
Presses à déchets	Drawing Presses
Presses à forger	Forging Presses
Presses mécaniques	Power Presses
Produits chimiques	Chemicals
Produits en caoutchouc pour la mécanique	Mechanical Rubber Goods
Produits généraux en caoutchouc	Rubber Goods (General)
Profilés en acier	Steel Sections
Propulsion des navires par l'électricité	Electric Ship Propulsion
Protecteurs d'indicateurs de niveau	Gauge Glass Protectors
Publications techniques. *Voir* Livres et journaux	Publications (Technical). *See* Books and Journals
Puits artésiens (Foreurs de)	Artesian Well Engineers
Purgeurs d'eau de condensation. *Voir* Manomètres etc.	Steam Traps. *See* Steam Gauges etc.
Purgeurs d'eau de condensation automatiques et par le vide	Vacuum and Steam Traps
Pyromètres.	Pyrometers

R

Raccord 'DU-EX' à double expansion	'DU-EX' Double Expansion Nipples
Raccords pour tuyaux flexibles	Hose Couplings
Rails en acier et accessoires	Steel Rails and Accessories
Rails et accessoires de fixation	Rails and Fastenings
Ramasse (Métaux de)	Scrap Metals
Rampes de chemins de fer	Railway Ramps
Ranchers en acier	Stanchions (Steel)
Réchauffeurs et échauffeurs intermédiaires	Interheaters and Reheaters
Réchauffeurs, filtres et purificateurs d'eau d'alimentation	Feed-Water Heaters, Filters and Purifiers

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FRANÇAIS.	ANGLAIS.
Recuisage	Annealing
Recuit. *Voir* Fours à recuire	Tempering Furnaces. *See* Furnaces
Refroidisseurs d'huile	Oil Coolers
Règles à calculer. *Voir* Instruments scientifiques etc.	Slide Rules. *See* Instruments, Mathematical, etc.
Règles en acier	Steel Rules
Régulateurs automatiques	Regulators (Automatic)
Régulateurs d'eau d'alimentation	Water Regulators (Feed)
Régulateurs de température	Temperature Regulators
Régulateurs pour machines à vapeur	Governors (Steam Engine)
Réparations de navires et de machines	Ship and Engine Repairers
Réparation des chaudières (Soudure à l'arc électrique pour la)	Boiler Repairs (Electric Arc Welding for)
Réservoirs et citernes	Tanks and Cisterns
Revêtement hydrofuge au bitume	Bitumen Damp-proof Sheeting
Revêtements en coton silicaté et en laine de scorie	Silicate Cotton and Slag Wool Coverings
Revêtements pour chaudières etc.	Coverings for Boilers, etc.
Revêtements pour chaudières et tuyaux	Boiler and Pipe Coverings
Revêtements pour murs et plafonds	Wall and Ceiling Sheets
Revêtements pour tuyaux	Pipe Coverings
Riblons de fer et d'acier	Iron and Steel Scrap
Rivets en fer, acier, cuivre, bronze de marine, etc.	Rivets (Iron, Steel, Copper, Naval Brass, etc.)
Riveuses électriques	Riveters (Electric)
Riveuses hydrauliques et pneumatiques	Riveters (Hydraulic and Pneumatic)
Robinets en cuivre pour eau, vapeur et gaz	Cocks (Brass) for Water, Steam, and Gas
Rodeurs de sièges de soupapes	Valve Reseaters
Rondelles pour verres d'indicateurs de niveau	Gauge Glass Washers
'Rosseline' (pour moteurs à gaz et à pétrole)	'Rosseline' (for Gas and Oil Engines)
Roues à empreintes pour chaînes	Chain Wheels
Roues d'engrenage	Wheel Gearing
Roues, moteurs et turbines hydrauliques	Water Wheels, Water Motors, and Turbines
Roues Pelton	Pelton Wheels
Rouleaux en acier	Steel Rollers
Routes bétonnées (Entrepreneurs de construction de)	Concrete Roads (Contractors for)

S

Sabots de freins	Brake Blocks
Scies pour bois et métaux	Saws for Wood and Metal Cutting
Séchage du bois de construction	Timber Seasoning
Sécheurs et épurateurs de vapeur	Steam Dryers and Purifiers
Sections refoulées brevetées en laiton, bronze, etc.	Sections (Patent Extruded), Brass, Bronze, etc.
Segments de pistons	Piston Rings
Séparateurs d'eau de condensation	Steam Separators
Séparateurs de graisse	Grease Separators
Séparateurs de suie	Soot Removers
Séparateurs électromagnétiques	Separators(Magnetic)
Séparateurs magnétiques	Magnetic Separators
Séparateurs mécaniques	Mechanical Separators

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FRANÇAIS.	ANGLAIS.	FRANÇAIS.	ANGLAIS.
Séparation de l'huile de l'eau de condensation	Separation of Oil from Condensed Steam	Substances pour conserver le bois	Wood Preservatives
Serpentins	Pipe Coils	Suce-poussières	Vacuum Cleaners
Sextants	Sextants	Surchauffeurs	Superheaters
Signaux. *Voir* Chemins de fer—Signaux	Signals. *See* Railway Signals	Surchauffeurs de locomotives	Locomotive Superheaters
Signaux de chemins de fer et dispositifs de sûreté	Railway Signals and Safety Appliances	Surchauffeurs marins	Marine Superheaters
Signaux étanches pour mines	Mining Signals (Watertight)	Surfaces de frottement	Friction Surfaces
Solives en acier	Joists (Steel)	Surfaces de frottement 'Ferodo'	'Ferodo' Friction Surfaces
Sondeuses à diamants	Diamond Drillers	Systèmes de conducteurs flexibles	Wiring Systems (Flexible)
Sonnettes (électrique)	Bells (Electric)	Systèmes de placement de conducteurs électriques. *Voir* Systèmes de placement de fils électriques flexibles	Electric Wiring Systems. *See* Wiring Systems (Flexible)
Soudure	Solder		
Soudure autogène 'Thermit'	'Thermit' Welding		
Soudure à l'arc électrique 'Daysohms'	'Daysohms' Electric Arc Welding	Systèmes de transport de monnaie	Cash Carrier Systems
Soudure électrique	Electric Welding	Systèmes pour l'économie du combustible	Fuel Economy Systems
Soudure et découpage de métaux	Welding and Cutting of Metals		
Soudure oxy-acétylénique	Oxy-Acetylene Welding		
Souffleries. *Voir* Ventilateurs	Blowers. *See* Fans	**T**	
Souffleries à éliminer les escarbilles	Cinder Eliminating Fans	Tableaux de distribution des accumulateurs	Battery Switchboards
Souffleurs de carneaux	Flue Blowers	Tachymètres	Tachometers
Souffleurs électriques	Electric Blowers	Taquets ou sabots de mise en rail (plaques d'accès)	Railway Re-railing Ramps
Soupapes automatiques à vapeur	Steam Valves (Automatic)	Tarières rubanées ou américaines	Twist Drills
Soupapes à manchon pour pompes à l'air	Bush Valves for Air Pumps	Tartrifuges et antirouilles pour chaudières	Scale and Corrosion in Boilers (Preventives of)
Soupapes de réduction. *Voir* Soupapes	Reducing Valves. *See* Valves	Tartrifuges pour chaudières	Boiler Preservatives
Soupapes et robinets	Valves and Cocks	Thermomètres	Thermometers
Sous-ardoisage	Underslating	Teintures	Dyestuffs
Spécialistes pour l'économie de la houille	Coal Economy Specialists	Tiges et sections creuses (en laiton, cuivre, etc.)	Hollow Rods and Sections (Brass Copper, etc.)
Spécialités de Graphite 'Foliac'	'Foliac' Graphite Specialities	Tiges et sections de cuivre	Copper Rods and Sections
Spécialités pour cémentation	Cementation Specialities	Tiroirs	Slide Valves

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FRANÇAIS.	ANGLAIS.
Tissus et ouvrages en fils métalliques	Wire Work and Woven Wire
Toiles métalliques galvanisées	Galvanized Wire Netting
Toits, constructions en fer, etc.	Roofs, Iron Buildings, etc.
Toiture 'Ruberoid'	'Ruberoid' Roofing
Tôle de fer ondulée	Corrugated Iron
Tôles à chaudières (acier)	Boiler Plates (Steel)
Tôles d'acier	Steel Sheets
Tôles d'acier imperforable	Bullet-proof Steel Plates
Tôles de fer	Iron Sheets
Tôles de toiture d'amiante cimentées ondulées	Asbestos Cement Corrugated Roofing Sheets
Tôles découpées, enveloppes de cylindres, etc.	Sheet Metal Work, Cylinder Cases, etc.
Tôles plates d'amiante cimentée (pour murailles, cloisons, plafonds, etc.)	Asbestos Cement Flat Sheets (for Walls, Partitions Ceilings, etc.)
Tôles réfractaires pour cloisons et murailles	Fireproof Partition and Wall Sheets
Totalisateurs électriques.	Electrical Counters
Tournage (tou métal)	Turned Work (any Metal)
Tours. *Voir* Fabricants d'outils	Lathes. *See* Tool Makers
Tours et outils à grande vitesse	'Speedicut' High-Speed Tools
Tours réfrigérantes	Cooling Towers
Tracteurs à vapeur et électriques	Traction Engines (Steam and Electric)
Trains finisseurs	End Mills
Traitement thermique des métaux	Heat Treatment of Metals
Tramways, Câbles aériens en acier pour	Tramways (Steel Wire Ropes for)
Tramways et Chemins de fer électriques. *Voir* Chemins de fer et Tramways électriques	Tramways and Railways (Electrical). *See* Electric Railways and Tramways

FRANÇAIS.	ANGLAIS.
Transformateurs (Énergie électrique	Transformers (Electric Power)
Transmissions (hydrauliques, à huile)	Transmission (Hydraulic, Oil)
Transformateurs en cascade	Motor Converters
Transporteurs	Transporters
Transporteurs aériens par câbles	Wire Ropeways
Trempe de surface	Case Hardening
Treuils (à vapeur, à l'électricité, à l'essence	Winches (Steam, Electric & Petrol)
Treuils (friction)	Winches (Friction)
Trou de sonde (Pompes à puits profonds)	Borehole (Deep Well Pumps)
Tubes	Tubes
Tubes à dépêches pneumatiques etc.	Pneumatic Despatch Tubes, etc.
Tubes d'acier. *Voir* Tubes	Steel Tubes. *See* Tubes
Tubes d'acier pour canalisations électriques	Steel Conduits for Electric Wiring
Tubes de chaudières	Boiler Tubes
Tubes de condenseurs (cuivre rouge) *Voir* Tubes de cuivre rouge	Condenser Tubes (Copper). *See* Copper Tubes
Tubes de cuivre rouge	Copper Tubes
Tubes en fer	Iron Tubes. *See* Tubes
Tubes en fer et en acier	Iron and Steel Tubes
Tubes et accessoires	Tubes and Fittings
Tubes et serpentine réfrigérateurs	Refrigerating Tubes and Coils
Tubes et tuyaux hydrauliques	Hydraulic Tubes and Pipes
Tubes métalliques flexibles	Tubing (Flexible Metallic)
Tubes pneumatiques	Tubes (Pneumatic)
Tubulures d'observation pour chaudières	Inspection Blocks for Boilers
Tuiles d'amiante	Asbestos Roofing Tiles

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FRANÇAIS.	ANGLAIS.
Tuiles et tôles ondulées (Ciment-Amiante)	Corrugated Tiles and Sheets (Asbestos-Cement)
Turbines à vapeur	Turbines (Steam). *See* Steam Turbines
Turbines à vapeur et accessoires	Steam Turbines and Fittings
Turbines, roues hydrauliques et moteurs hydrauliques	Turbines, Water Wheels, and Water Motors
Turbo-alternateurs	Turbo Alternators
Turbo - génératrices. *Voir* Dynamos et Moteurs	Turbo - Generators. *See* Dynamos and Motors
Turbo-pompes	Turbo-Pumps
Tuyaux. *Voir* Tubes	Pipes. *See* Tubes
Tuyaux de vapeur. *Voir* Tubes	Steam Pipes. *See* Tubes
Tuyaux de ventilation	Ventilating Shafts
Tuyaux et accessoires pour gaz	Gas Tubes and Fittings
Tuyaux flexibles en cuir et en toile etc.	Hose Pipes, Leather and Canvas Hose, etc.
Tuyaux flexibles pour brigades de pompiers, usines, etc.	Hose for Fire Brigades, Mills, etc.
Tuyaux flexibles pour le chauffage à vapeur	Steam Heating Tubes (Flexible)
Tuyaux métalliques flexibles	Hose (Flexible Metallic), Metallic Tubing (Flexible)
Tuyères de haut fourneaux	Blast Furnace Tuyères
U	
Ustensiles et machines agricoles	Agricultural Tools and Machinery
V	
Vannes à sièges obliques	Wedge Gate Valves
Vannes et robinets-vannes	Sluice Gates and Valves
Vaporisateurs	Spraying Machines
Véhicules à traction motrice (pour le commerce)	Motor Vehicles (Commercial)
Ventilateurs : soufflants, aspirants, électriques, etc.	Fans : Blowing, Exhaust, Electric, etc.
Ventilateurs électriques. *Voir* Ventilateurs	Electric Fans. *See* Fans
Ventilation, chauffage, etc.	Ventilating, Heating, etc.
Vérins Duff	Duff Jacks
Vérins hydrauliques et à vis	Jacks (Hydraulic and Screw)
Vernis	Varnishes
Vernis et enduits isolants	Insulating Varnishes and Compounds
Verres d'indicateurs de niveau d'eau	Gauge Glasses
Verres pour graisseurs	Lubricating Glasses
Vide (Pompes à). *Voir* Pompes	Vacuum Pumps. *See* Pumps
Vieux métaux	Metal Scrap. *See* Scrap Metals
Vis (fer, acier, cuivre et bronze marin)	Screws (Iron, Steel Copper, and Naval Brass)
Vis mécaniques	Machine Screws
Voitures et wagons de chemins de fer	Carriages and Wagons (Railway)
Voltmètres. *Voir* Instruments électriques	Voltmeters. *See* Instruments (Electrical)
Vulcanite et fibre vulcanisée	Vulcanite and Vulcanised Fibre
W	
Wagons à bascule	Tip Wagons
Wagons de chemins de fer	Wagons (Railway
'Woodite'	'Woodite'
Z	
Zincs non incrustants pour piles	Zincs (Non-encrusting for Primary Batteries)

Pour les noms des fabricants des spécialités ci-dessus, se reporter aux rubriques correspondantes en anglais dans le 'Classified Directory and Buyers' Guide' ('Répertoire Analytique des Annonceurs'), pages 2993–3056.

TRADUZIONE DELLE RUBRICHE CHE FIGURANO NELLA GUIDA CLASSIFICATA DELLE VARIE SPECIALITÀ COMPRESE NEGLI ANNUNCI (pag. 2993–3056).

Per i nomi dei fabbricanti delle specialità elencate su questa pagina il lettore è pregato di vedere le rubriche corrispondenti in lingua inglese nel 'Classified Directory and Buyers' Guide' ('Guida classificata degli annunci'), pag. 2993–3056. *Per gli indirizzi delle ditte aventi degli annunci ed il posto dove detti annunci appaiono nella guida vedesi l' elenco alfabetico a pagine* 2977–2990.

ITALIANO.	INGLESE.
A	
Abbaini	Skylights
Accessori di bronzo	Gunmetal fittings
Accessori per aeroplani	Aeroplane Accessories
Accessori per automobili	Motor Car Accessories
Accessori per caldaie	Boiler Fittings. *See* Engine and Boiler Fittings
Accessori per motrici e caldaie, focolari, tubi, ecc.	Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.
Acciai a tempera di superficie	Case Hardening Steels
Acciai al cromo-vanadio	Chrome - Vanadium Steels
Acciai al nichelio ed al cromo-nichelio	Nickel and Nickel Chrome Steels
Acciai fusi al crogiuolo	Crucible Cast Steels
Acciaio (Imbrunito, tornito, tirato e laminato a freddo)	Steel (Bright Turned, Drawn, and Cold-Rolled)
Acciai per aviazione	Aircraft Steels
Acciai per stampi	Die Steels
Acciaio a tempera d'aria per ingranaggi	Air Hardening Gear Steel
Acciaio ad alta tensione	High Tensile Steel
Acciaio al manganese	Manganese Steel
Acciaio (lingotti)	Steel (Blooms and Billets)
Acciaio elettrico, Fabbricanti di	Electric Steel Manufacturers
Acciaio immacolato ed irruginibile	Stainless and Rustless Steel
Acciaio irruginibile	Rustless Steel
Acciaio irruginibile di Firth	Firth's Stainless Steel
Acciaio 'Mesmeric' a tempera di superficie	'Mesmeric' Case Hardening Steel
Acciaio per macchine, Fabbricanti di	Machinery Steel Manufacturers
Acciaio per magneti	Magnet Steel
Acciaio per utensili	Tool Steel
Acciaio, pezzi profilati di	Steel Sections
Acciaio rapido per utensili	High-Speed Tool Steel
Acciaio rapido 'Speedicut'	'Speedicut' High speed Steels
Acciaio Siemens - Martin	Siemens - Martin Steel
Accoppiamenti ferroviari	Railway Couplings
Accoppiatori per Tubi flessibili	Hose Couplings
Accumulatori	Accumulators. *See* Batteries
Accumulatori (di elementi e batterie)	Storage Cells and Batteries
Accumulatori elettrici	Storage Cells
Accumulatori idraulici	Accumulators (Hydraulic)
Acetilene	Acetylene
Acetilene, Impianti per generare	Acetylene Generating Plants

ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Acido idrocloridico	Hydrochloric Acid	Apparecchi di Radio-Telegrafia	Radio-Telegraphic Apparatus
Acido nitrico	Nitric Acid	Apparecchi di ricupero	Recovery Plants
Acido per accumulatori	Accumulator Acid	Apparecchi di trazione	Hauling Plant. *See* Winding and Hauling
Acido solforico	Sulphuric Acid		Steam De-Superheaters
Acqua di alimentazione (misurazione dell')	Feed-Water (Measurement of)	Apparecchi eliminatori del calore di surriscaldamento del vapore	
Acqua per alimentazione caldaie (Eliminazione dell'olio dall')	Boiler Feed-Water, Oil elimination from	Apparecchi elettrici per il riscaldamento e per la cucina	Electric Heating and Cooking Apparatus
Affilatrici di punte	Drill Sharpeners	Apparecchi e macchine per sollevamento	Lifting and Hoisting Machinery and Lifting Tackle
Alberi ferroviari a gomito	Railway Crank-shafts	Apparecchi interruttori	Switch Gear
Alesatori per sedi di valvole	Valve Reseaters	Apparecchi per essiccare (Essiccatoi)	Drying Apparatus
Alesatoi e maschi	Reamers and Taps	Apparecchi per estinguere incendi	Fire Extinguishing Appliances
Alluminio (lingotti, fogli, tubi, fili, cavi, sezioni, ecc.)	Aluminium (Ingots, Sheets, Tubes, Wire, Cables, Sections, etc.)	Apparecchi per filtrare	Filtering Apparatus
Alluminio, Polvere d'	Aluminium Powder	Apparecchi per galvanizzare	Galvanisers
Alternatori	Alternators	Apparecchi per il raffreddamento ad acqua	Water-Cooling Apparatus
Alternatori a turbina	Turbo Alternators	Apparecchi per il tiraggio forzato per aspirazione e pressione	Forced and Induced Draught Apparatus
Amianto (articoli, guarnizioni, ecc.)	Asbestos Goods, Fittings, etc.	Apparecchi per la distillazione del l'acqua dolce	Distilling Apparatus (Fresh Water)
Amianto (rivestimenti e materassi)	Asbestos Coverings and Mattresses	Apparecchi per la distillazione del l'acqua ecc. *Vedere anche* Condensatori	Water Distilling Apparatus etc. *See also* Condensers
Analisi dei gas prodotti dalla combustione nelle caldaie	Boiler Flue Gases (Analysis of)	Apparecchi per l'analisi degli olii	Oil Testing Apparatus
Anelli per giunti di rame	Copper Jointing Rings	Apparecchi per la determinazione della viscosità. *Vedere* Apparecchi per l'analisi degli olii	Viscosity Apparatus. *See* Oil Testing Apparatus
Anelli per tubi di vetro per livelli	Gauge Glass Rings		
Anelli per pistone	Piston Rings		
Anelli per vetri di livello d' acqua	Gauge Glass Washers		
Anti-vibrazione	Anti-Vibration		
Appaltatori	Contractors		
Appaltatori da strade (concreto)	Road (Concrete) Contractors		
Apparecchi automatici per l'alimentazione del fuoco nelle caldaie	Mechanical Stokers		
Apparecchi chimici ed elettro-chimici	Chemical and Electro-Chemical Apparatus		

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pag. 2993–3056.

ITALIANO.	INGLESE.
Apparecchi per la prova del gas	Gas Testing Apparatus
Apparecchi per lo scarico di fognature	Sewage Disposal Appliances
Apparecchi per la pulizia delle caldaie	Boiler Cleaners (Mechanical and Electrical)
Apparecchi per la trasmissione della forza motrice	Power Transmission Appliances
Apparecchi per l'illuminazione elettrica ed accessori per uso elettrico	Electric Light Fittings and Electrical Accessories
Apparecchi per maneggiare il carbone, il coke e la cenere	Coal, Coke, and Ash Handling Plants
Apparecchi per neutralizzare e purificare l'acqua. *Vedere anche* Riscaldatori dell' acqua d' alimentazione ecc.	Water Softening and Purifying Apparatus. *See also* Feed Water Heaters, etc.
Apparecchi per pesare	Weighing Machines
Apparecchi per rinfrescare ed inumidire l'aria	Air-Cooling and Humidifying Apparatus
Apparecchi per telegrafia senza fili	Wireless Telegraphic Apparatus
Ardesia per tetti	Slating
Aria liquida	Liquid Air
Armature per cemento armato	Concrete (Reinforcement for)
Articoli bianchi (permanenti)	White Lines (Permanent)
Articoli di gomma (in genere)	Rubber Goods (General)
Articoli di gomma elastica meccanica	Mechanical Rubber Goods
Ascensori idraulici	Hydraulic Lifts. *See* Lifting and Hoisting
Asfalto	Asphalte
Assi (ferroviari)	Axles (Railway)
Attrezzi e macchine agricole	Agricultural Tools and Machinery
Ausiliari per turbine ad ingranaggio	Geared Turbine Auxiliaries
Autocarri (commerciali)	Motor Vehicles (Commercial)
Automobili, Starters per	Motor Starters
B	
Bacchette di metallo giallo 'Dixtampo' per stampatura e forgiatura a caldo	'Dixtampo' Yellow Metal Rods for Hot Stamping and Forging
Bacchette di ottone 'Dixtrudo' per filettatura e tornitura a grande velocità	'Dixtrudo' High Speed Brass Screwing and Turning Rods
Bacini galleggianti	Floating Docks
Barometri	Barometers
Bascules automatiche	Automatic Weighing Machines
Batterie (Accumulatori)	Batteries (Electrical Storage)
Batterie di accumulatori elettrici	Electrical Storage Cells and Batteries. *See* Storage Cells
Bianco di Spagna	Whiting
Billette (acciaio)	Billets (Steel)
Blocchi d' appoggio ferroviari	Railway Stop Blocks
Blocchi di sostegno e rivestimenti per caldaie	Boiler Blocks and Covers
'Boilerine'	'Boilerine'
Bronzo	Bronze. *See* Brass and Bronze
Bronzo al manganese	Manganese Bronze
Bronzo fosforoso	Phosphor Bronze
Bulloni e dadi (ferro, acciaio, rame, bronzo marino, ecc.)	Bolts and Nuts (iron, steel, copper, naval brass, etc.)
Bulloni, Chiodi e serraviti d' alluminio	Aluminium Studs, Bolts and Nuts

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ITALIANO.	INGLESE.
Bulloni isolatori per telegrafo ed ogni genere di lavoro in ferro per telegrafo e telefono	Telegraph Insulator Bolts and all kinds of Ironwork for Telegraph and Telephone
C	
Calce e pietra calcarea	Lime and Limestone
Calcolatrici	Counting Instruments
Caldaie a tubi d'acqua. *Vedere* Fabbricanti caldaie	Water-tube Boilers. *See* Boiler Manufacturers
Caldaie a vapore. *Vedi* Fabbricanti caldaie	Steam Boilers. *See* Boiler Manufacturers
Caldaie per la concentrazione del vuoto	Vacuum Pans (concentrating)
Caldaie per la fornitura d'acqua calda	Hot Water Supply Boilers
Caldaie riscaldate dal calore dello scappamento	Exhaust Heat Boilers
Caloriferi	Calorifiers
Calorimetri per l'assaggio dei combustibili	Calorimeters for Fuel Testing
Camini	Chimney Stacks
Campanelli (elettrici)	Bells (Electric)
Cannelli (Saldatura e tagliatura ad acetelene)	Blowpipes (Acetylene Welding and Cutting)
Cantieri navali	Ship Builders
Carbone polverizzato, Impianti di	Powdered Coal Plants
Carburo di calce	Carbide of Calcium
Carburo di calcio	Calcium Carbide
Carrelli (in acciaio)	Barrows (Steel)
Carri (ferroviari)	Wagons (Railway)
Carta (impermeabile	Paper (Waterproof)
Carta e canevaccio 'Willesden'	'Willesden' Paper and Canvas
Casse di acciaio (per mobili di acciaio)	Storage Bins (for Steel Furniture)
Casse di condensazione	Steam Separators
Cassette di distribuzione	Slide Valves
Catene a dentatura invertita	Inverted Tooth Chains
Catene biflesse per comandi d'alberi di distribuzione di automobili	Biflex Chains for Automobile Camshaft Drives
Catene di comando	Driving Chains
Catene e comando a catena	Chains and Chain Driving
Catene per rulli (pesanti)	Roller Chains (Heavy)
Cavi armati 'Cab Tyre'	'Cab Tyre' Sheathed Cables
Cavi da miniera ed accessori	Mining Cables and Accessories
Cavi (di filo di acciaio zincato)	Hawsers (Galvanized Steel Wire)
Cavi elettrici 'Endural'	'Endural' Electric Cables
Cavi elettrici. *Vedi* Cavi: Telegrafo, Telefono, Luce Elettrica e Sommergibile	Electric Cables. *See* Cables: Telegraph, Telephone, Electric Light and Submarine
Cavi elettrici (Tipo 'O.T.S.'). *Vedi* Cavi 'Cab Tyre Sheathed'	Electric Cables ('O.T.S.' Type). *See* 'Cab Tyre Sheathed' Cables
Cavi isolati con 'Maconite'	'Maconite' Insulated Cables
Cavi solidi di gomma	Solid Rubber Cables *See* Cables
Cavi (telegrafici, telefonici, per luce elettrica e sottomarini)	Cables: Telegraph, Telephone, Electric Light and Submarine
Celle frigorifere	Cold Storage
Cementazione, Specialità per	Cementation Specialities
Cementi (Portland, Keene e di Paro)	Cements (Portland) Keenes', & Parian,
Cemento armato	Ferro-Concrete. *See* Reinforced Concrete
Cemento d'amianto 'Fibrent' — lastre ondulate e piatte	'Fibrent' Asbestos Cement Corrugated and Flat Sheets

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ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Cemento di Portland	Portland Cement	Collari per tubi flessibili	Hose Pipe Clips
Cemento 'Kisol' per caldaie, tubi di vapore, ecc.	'Kisol' Cement for Boilers, Steam Pipes, etc.	Colle marine	Marine Glues
Cemento per giunti	Jointing Cement	Collegi (d'ingegneria)	Colleges (Engineering)
Cemento Portland (Macchine per assaggio di)	Portland Cement (Testing Machines for)	Colonne, e fusioni per fogne, gas e acqua potabile	Columns and Castings for Sewage, Gas and Water Works
Cemento (refrattario)	Cement (Refractory)	Colori, vernici e copali	Colours, Paints and Varnishes
Cemento refrattario ('Pyruma')	Fire Cement ('Pyruma')	Combustione superficiale	Surface Combustion
Ceppi per freni	Brake Blocks	Composizione di grafite 'Foliac' per guarnizioni di tubi	'Foliac' Graphite Pipe Joint Compound
Chassis e carrelli	Underframes and Bogies	Composizioni impermeabili	Waterproofing Compounds
Chimici idrologici	Hydrological Chemists	Composizioni isolanti	Non-conducting Compositions
Chiodi (ferro, acciaio, rame, bronzo marino, ecc.)	Rivets (Iron, Steel, Copper, Naval Brass, etc.)	Composizione per giunti 'Beldamite'	Jointing ('Beldamite')
Chiuse e valvole a saracinesca	Sluice Gates and Valves	Composizioni per parti lucide	Bright Part Coatings
Cilindri	Cylinders	Composizioni per parti lucide e macchine	Coatings (Bright Part) and Machinery Finishes
Cinghie, corde, ecc.	Driving Bands, Ropes, etc.	Composizioni per preservare le caldaie	Boiler Preservatives
Cinghie di balata	Balata Belting	Compressori d'aria	Air Compressors
Cinghie di cotone	Cotton Belting	Condensatori a energia cinetica	'Contraflo' Kinetic Condensers
Cinghie di crine 'Gripoly'	'Gripoly' Hair Belting	Condensatori, Evaporatori, Apparecchi per addolcire l'acqua, e per la sua distillazione, ecc.	Condensers, Evaporators, Water Softening and Distilling Apparatus, etc.
Cinghie di cuoio. *Vedere* Cinghie	Leather Belting. *See* Belting	Condotti	Conduits
Cinghie di pelo di cammello Marca 'Cammello' (Unici fabbricanti di)	'Camel' Hair, 'Camel' Brand Belting (Sole Makers of)	Condotti	Pipe Lines
Cinghie, ecc.: Cuoio, cotone, pelo, gomma, ecc.	Belting, etc., Leather, Cotton, Hair, Indiarubber, etc.	Contatori a vapore	Steam Meters
Collari da radiatori	Radiator Clips	Contatori d'acido carbonico	CO_2 Recorder
Collari di raccordo per comandi a vite perpetua 'Jubilee' (Brevettati)	'Jubilee' Worm Drive Clips (Patent)	Contatori d'acqua	Recorders (Water)
Collari allargabili	Expanding Clips	Contatori d'acqua	Water Recorders
Collari di raccordo ('Jubilee' per comandi a vite perpetua, brevettati)	Clips ('Jubilee' Worm Drive (Patent))	Contatori d'acqua	Water Meters

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ITALIANO.	INGLESE.
Contatori d'aria	Air Meters
Contatori di gas	Gas Meters
Contatori (aria)	Meters (Air)
Contatori (carbone)	Meters (Coal)
Contatori elettrici	Electrical Counters
Contatori (gas)	Meters (Gas)
Contatori (acqua)	Meters (Water)
Contatori del rendimento delle macchine	Machine Output Recorders
Contatori per acqua da scarico	Waste Water Meters
Contatori per miniere	Minemeters
Convertitori	Rotary Converters
Copali	Varnishes
Copali e materie isolanti	Insulating Varnishes and Compounds
Coperchi e rivestimenti per condotte fumo	Flue Covers and Linings
Coperture di silicato di cotone e lana di scorie	Silicate Cotton and Slag Wool Coverings
Copertüre per caldaie e tubi	Boiler and Pipe Coverings
Coperture per tetti 'Rok'	'Rok' Roofing
Coperture per tetti 'Ruberoid'	'Ruberoid' Roofing
Corde: metalliche di canapa, manilla, cuoio, cotone, ed amianto	Ropes: Wire, Hemp, Manilla, Leather, Cotton, Asbestos
Corredi telefonici	TelephoneEquipment
Costruzioni, Ingegneri di	Constructional Engineers
Costruttori aeronautici. *V.* Costruttori di aeroplani	Aircraft Manufacturers. *See* Aeroplane Builders
Costruttori di aeroplani	Aeroplane Builders
Costruttori di apparecchi per la ventilazione	Ventilating Engineers
Costruttori di caldaie	Boiler Manufacturers
Costruttori di Pozzi Artesiani	Artesian Well Engineers
Costruzioni in cemento armato	Concrete (Reinforced) Construction
Costruzioni in ferro, in acciaio, ecc.	Structural Iron and Steel Work, etc.
Crivelli e Buratti	Sieves and Screens
Crogiuoli	Crucibles
Cuscinetti a sfere	Bearings (Ball)
Cuscinetti (colati in Conchiglia)	Bearings (Chill Cast)
D	
Dadi	Nuts
Demagnetizzatori	Demagnetizers
'DEXINE' (per guarnizioni da vapore ad alta pressione, da acidi e idrauliche)	'DEXINE' (for H.P. Steam, Acid, and Hydraulic Packings)
'DEXONITE' (Superebonite per acidi e alcali; guarniture e materiale d'isolamento elettrico)	'DEXONITE' (Super Ebonite, for Acids and Alkalies; fittings, and Electrical insulation material)
Digestitori	Digesters
Dinamite	Dynamite
Dinamo e motori	Dynamos and Motors
Dinamometri	Dynamometers
Disincrostanti per caldaie	Boiler Discrustants
Disincrostanti per caldaie (per uso interno)	Boiler Composition (for inside use)
Dispositivi per Lubricazione	Lubricating Devices
Distruttori (Destructors) di immondizie	Destructors (Refuse)
'Duralumin'	'Duralumin'
E	
Ebonite	Ebonite
Economia di carbone, Specialisti di	Coal Economy Specialists

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ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Economia di combustibile, Sistemi per	Fuel Economy Systems	Fabbricanti di gomma, gutta-percha e bitume	India Rubber, Gutta Percha, and Bitumen Manufacturers
Economizzatori, di combustibili	Fuel Economisers. *See* Economisers	Fabbricanti di macchine utensili	Tool Makers, Machinists, etc.
Elettrodi (per saldatura ad arco elettrico)	Electrodes (for Electric Arc Welding)	Fabbricanti di utensili per trivellare (pozzi artesiani)	Boring Tool Makers (Artesian)
Elevatori. *Vedere* Apparecchi di sollevamento	Elevators. *See* Lifting and Hoisting	Fabbricanti e commercianti di acciaio	Steel Manufacturers and Merchants
Eliche	Propellers, Screw Propellers	Fabbricanti e commercianti di ferro e acciaio	Iron and Steel Manufacturers and Merchants
Eliminatori dell' olio	Oil Eliminators	Fabbricati (per render impermeabili)	Buildings (Waterproofing of)
Eliminazione di fumo, vapore ed esalazioni	Smoke, Steam, and Fume Removal	Fabbricati (protezione contro il fulmine dei)	Buildings, Protection of, from Lightning
Equipaggiamento per Combustibile polverizzato	Pulverised Fuel Equipment	Fabbricati	Buildings
Escavatori di Pozzi	Shaft Sinkers	Fabbriche di armi e munizioni	Gun and Ammunition Works
Escavatori e trasportatori	Excavators and Transporters	Feltri per macchine tipografiche	Felts for Printing Machinery
Esplosivi	Explosives	Feltri per tettoie	Roofing Felts
Esplosivi per miniere	Mining Explosives	Feltro e tetti di feltro	Felt and Felt Roofs
Essiccatoi e depuratori a vapore	Steam Dryers and Purifiers	Feltro per fabbricanti di carta	Paper Makers' Felts
Evaporatori a vacuo per liquidi chimici	Vacuum Evaporators for Chemical Liquids	Ferri ed acciai per costruzioni	Structural Iron and Steel Work
Evaporatori ad effetto multiplo	Multiple Effect Evaporators	Ferro ed acciaio galvanizzati, Fabbricanti di	Galvanised Iron and Steel Manufacturers
Evaporatori, condensatori, impianti per la distillazione dell' acqua	Evaporators, Condensers, Water Distilling Apparatus, etc.	Ferro ed accacio, Rottami di	Iron and Steel Scrap
Evaporatori per zucchero e liquori	Evaporators for Sugar and Trade Liquors	Ferrovie a scartamento ridotto, portatili, ecc.	Railways; Light, Portable, etc.
		Ferrovie e tramvie elettriche	Electric Railways and Tramways
F		Ferrovie portatili	Portable Railways
Fabbricanti di filo isolato	Wire (Insulated) Manufacturers	Fettuccie e spaghi per cotonifici	Mill Bandings and Twines
Fabbricanti di filo metallico	Wire Manufacturers	Fibbra vulcanizzata	Fibre (vulcanised)

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ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Filo di ferro per siepi	Fencing Wire	Forni a gas	Gas Furnaces. *See* Furnaces
Filo per saldare (' Rylax ')	Welding Wire (' Rylax ')	Forni a gas ed impianti industriali	Industrial Gas Furnaces and Plants
Filo telegrafico	Telegraph Wire. *See* Wire	Forni da forgia	Forging Furnaces. *See* Furnaces
Filovie	Wire Ropeways	Forni e tubi per caldaie, ecc.	Boiler Furnaces, Tubes, etc.
Filtri d' aria	Air Filters	Forni (industriali con riscaldamento a gas e ad olio)	Furnaces (Gas and Oil Heated and Industrial)
Filtri per l' acqua d'alimentazione delle caldaie	Boiler Feed Filters. *See* Feed Water	Forni per tempera. *Vedere* Forni	Tempering Furnaces. *See* Furnaces
Filtri per l' olio	Oil Filters	Forniture per disegnatori	Drawing Office Requisites
Finestre di metallo (Telai e riquadri)	Metal Windows (Sashes and Casements)	Forniture per la meccanica e per le ferrovie	Engineering and Railway Supplies. *See* Railway and Tramway Plant
Focolai (caldaie) *Vedi* Accessori per motrici e caldaie	Furnaces (Boiler). *See* Engine and Boiler Fittings	Frantoi per polverizzatori di pietre	Stone Pulverising Mills
Focolai per caldaie	Boiler Furnaces	Freni(dinamometrici)	Brakes (Dynamometers)
Fogli di amianto 'Poilite' e tegole per tetti	'Poilite' Asbestos Sheets and Roofing Tiles	Freni (elettro-meccanici)	Brakes (Electro-Mechanical)
Fogli incatramati	Dampcourse and Bitumen Sheeting	Freni (per materiale ferroviario)	Brakes (Railways)
Fogli incatramati marca 'Callendrite'	'Callendrite' Dampcourse and Sheeting	Fresa con coda	End Mills
Fondazioni di caldaie	Boiler Settings	Fresatrici	Milling Machines
Fondazioni per caldaie	Settings (Boiler)	Frese	Milling Cutters
Fondazioni per caldaie Lancashire (perfezionate)	Lancashire Boiler Settings (Improved)	Fucine da fabbro e relativi impianti	Smiths' Hearths and Plant
Fondazioni perfezionate per caldaie	Boiler Settings (Improved)	Fucine portatili	Forges (Portable)
Fonderie	Founders	Funi d' estrazione e di trazione	Winding and Hauling Ropes
Fonderie di ottone	Brass Founders	Funi di comando di cotone	Cotton Driving Ropes
Forature (Pompe per Pozzi profondi)	Borehole (Deep Well Pumps)	Funi metalliche	Wire Ropes
Forni a carbone	Coal Furnaces. *See* Furnaces	Fusioni a stampo	Die Castings
Forni ad olio. *Vedere* Forni	Oil Furnaces. *See* Furnaces	Fusioni e pezzi forgiati	Castings and Forgings
		Fusti per olio	Oil drums
		G	
		Gabbie per ascensori	Lift Enclosures
		Gasogeni	Gas Producers
		Generatori elettrici. *Vedere* Dinamo e Motori	Generators (Electric). *See* Dynamos and Motors

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ITALIANO	INGLESE.
Gesso	Chalk
Getti per valvole	Valve Castings
Ghisa	Cast Iron
Giornali (tecnici). *Vedere* Libri e giornali	Journals (Technical). *See* Books and Journals
Giunti a frizione	Friction Clutches
Giunti flessibili	Flexible Couplings
Giunzioni (' Flexstel ' a ginocchiera)	Joints (' Flexstel ' Ball and Socket)
Gomma, Macchinario per	Rubber Machinery
Grafite ' Foliac ' specialità	' Foliac ' Graphite Specialities
Grafite ' Foliac ' per caldaie	' Foliac ' Boiler Graphite
Grafite ' Foliac ' per tubature, Composizione di	' Foliac ' Graphite Pipe Joint Compound
Grafite-silica ' Foliac,' Pittura di	' Foliac ' Silica-Graphite Paint
Grafite (piombaggine)	Graphite
Grasso lubrificante	Grease (Lubricating)
Grue	Cranes. *See* Lifting and Hoisting Machinery
Grue a cucchiaio (elettriche)	Grabbing Cranes (Electric)
Grue a mano	Hand Cranes. *See* Lifting and Hoisting Machinery
Grue a ponte	Overhead Runways
Guardie per livelli	Gauge Glass Protectors
Guarniture interne per freni e giunti a frizione	Brake and Clutch Linings
Guarniture interne per giunti a frizione	Clutch Linings
Guarniture per caldaie. *Vedere anche* Accessori per motrici e caldaie	Boiler Mountings. *See also* Engine and Boiler Fittings
Guarnizione (' Langite ' resistente all' olio)	Packing (' Langite Oil Resisting)
Guarnizioni (' Britimp ')	Packing (' Britimp ')
Guarnizioni d'amianto (' Lascar ')	Asbestos Packing (' Lascar ')
Guarnizioni d'amianto marca ' Lion '	Asbestos Packing ' Lion '
Guarnizioni di vapore (' Britimp ')	Steam Packing (' Britimp ')
Guarnizioni e ranelle ' CORK '	' CORK ' Packings, Gaskets and Washers
Guarnizioni idrauliche	Hydraulic Packings
Guarnizioni (' Lion ' e ' Walkerite ')	Joints (' Lion ' and ' Walkerite ')
Guarnizioni (marca ' Lascar ')	Packing (' Lascar
Guarnizioni marca ' Lion '	' Lion ' Packing
Guarnizioni marca ' United States '	Packing ' United States '
Guarnizioni metalliche	Metallic Packing. *See* Engine Packing
Guarnizioni metalliche ' Britimp '	' Britimp ' Metallic Packings
Guarnizioni metalliche per Gambi di Stantuffi (' Silvertown ')	Metallic Piston Rod Packing (' Silvertown ')
Guarnizioni metalliche per stantuffo (' Lion ')	Metallic Piston Rod Packing (' Lion ')
Guarnizioni metalliche per stantuffo (' United States ')	Metallic Piston Rod Packing (' United States ')
Guarnizioni per giunti	Jointing Materials
Guarnizioni per macchine	Engine Packing
Guarnizioni per motori a gas	Gas Engine Packing
Guarnizioni per motrici (' Lion ')	Engine Packing (' Lion ')
Guarnizioni per motrici a vapore. *Vedere* Guarnizioni per giunti	Steam Jointing. *See* Jointing Materials
Guarnizioni per trasformatori	Transformer Gaskets

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pag. 2993-3056.

ITALIANO.	INGLESE.
Guarnizione (' Pilot ')	Packing (' Pilot ')
Guarnizioni per stantuffi	Piston Packing
Guarnizioni per surriscaldatori di locomotive	Locomotive Superheated Packing
Guarnizioni per vapore	Steam Packing
Guarnizioni per vapore ' Lion '	Steam Packing 'Lion'
Guarnizioni (vapore)	Packing (Steam). *See* Engine Packing
Guarnizioni Walker marca ' Lion '	Walker's (' Lion ') Packings
I	
Illuminazione degli stabilimenti	Factories (Lighting of)
Illuminazione dei treni	Lighting (Train)
Illuminazione delle officine	Workshop (Lighting of)
Illuminazione e riscaldamento (Impianto a gas acetilene per)	Lighting and Heating (Acetylene Gas Plants for)
Impianti a gas povero. *Vedere* Gasogeni	Producer Gas Plants. *See also* Gas Producers
Impianti a gas povero ad aspirazione	Suction Gas Plants
Impianti ed accessori per il taglio e la Saldatura ad arco elettrico	Electric Arc Cutting and Welding Plant and Accessories
Impianti da distillazione a bassa temperatura	Low Temperature Distillation Plants
Impianti e macchinari per industrie chimiche	Chemical Plant and Machinery
Impianti idraulici ed apparecchi	Hydraulic Plants and Appliances
Impianti idro-elettrici	Hydro-Electric Plants
Impianti per il caricamento e trasportatori	Loading and Transport Plants
Impianti per la condizionatura dell' aria.	Air Conditioning Plants
Impianti per l'utilizzazione dei rifiuti	Refuse Utilization Plants
Impianti per l'illuminazione dei treni	Train Lighting Plant
Imprese per costruzioni di fabbricati incombustibili	Partition Contractors and Fireproof Builders
Imprese per costruzioni di tetti	Roofing Contractors
Imprese per luce elettrica	Electric Lighting Contractors
Incisori, disegnatori e tipografi	Engravers, Draughtsmen, and Printers
Incrostazioni e corrosioni nelle caldaie (Preservativi contro le)	Scale and Corrosion in Boilers (Preventives of)
Indicatori delle velocità per navi	Marine Speed Indicators
Indicatori del livello d'acqua	Water Level Indicators
Indicatori della pressione della tirata	Vacuum Gauges
Indicatori di segnali per miniere	Mine Signal Indicators
Indicatori di tirata	Draught Guages
Indicatori (per motrici a vapore)	Indicators (Steam Engine)
Ingegneri aeronautici	Aeronautical Engineers
Ingegneri elettrotecnici	Electrical Engineers
Ingegneri idraulici	Engineers (Hydraulic) Water-Power Engineers
Ingegneri meccanici	Engineers (Mechanical)
Ingegneri metallurgici	Metallurgical Engineers
Ingegneri minerari	Mining Engineers
Ingegneri telegrafisti	Telegraph Engineers
Ingranaggi	Gearing
Ingranaggi (idraulici ad olio)	Gears (Hydraulic, Oil)

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ITALIANO.	INGLESE.
Ingranaggi, alberi di trasmissione, ecc.	Mill Gearing, Shafting, etc. *See* Shafting and Gearing
Ingranaggi cilindrici e conici	Spur and Bevel Gearing
Ingranaggi di riduzione	Reduction Gears
Ingranaggi elicoidali	Helical Gearing
Ingranaggi per turbine. *Vedere* Turbine ad ingranaggi	Turbine Gears. *See* Geared Turbines
Injettori, Ejettori, ed Apparecchi generali per spruzzo. *Vedere* Injettori per caldaie a vapore	Injectors, Ejectors and General Jet Appliances. *See* Steam Injectors
Injettori per caldaie a vapore	Steam Injectors
Innesti 'Coventry' per catene	'Coventry' Chain Couplings
Insegnamento meccanico. *Vedere* Collegi	Engineering Training. *See* Colleges
Insegnamento tecnico. *Vedere* Scuole e Collegi	Technical Training. *See* Schools and Colleges
Intonaco	Plaster
Isolatori	Insulators
Istituti tecnici. *Vedere* Collegi e Scuole	Educational Institutions. *See* Colleges and Schools
Istrumenti aeronautici	Aeronautical instruments
Istrumenti meteorologici	Meteorological Instruments
Istrumenti di prova (elettrici). *Vedere* Istrumenti	Testing Instruments (Electrical). *See* Instruments
L	
Lame dritte per seghe	Hack Saw Blades
Lamiere di acciaio	Steel Sheets
Lamiere di acciaio piallate	Planished Steel Sheets
Lamiere di ferro	Iron Sheets
Lamiere di ferro corrugate	Corrugated Iron
Lamiere per caldaie (acciaio)	Boiler Plates (Steel)
Lamiere stagnate	Tin Plates
Laminatoi (macchinario elettrico per laminatoi)	Rolling Mills (Electrical Equipment of)
Lampade ad acetilene a mano e da cantieri (portabili)	Acetylene Hand and Flare Lamps (Portable)
Lampade ad arco	Arc Lamps
Lampade a filamento metallico	Metal Filament Lamps
Lampade di sicurezza per minatori	Miners' Safety Lamps
Lampade elettriche	Lamps (Electric)
Lampade industriali	Lamps (Industrial)
Lampade (posteriori)	Lamps (Rear)
Lana minerale	Mineral Wool
Lancie (a vapore ed a motore)	Launches (Steam and Motor)
Lastre d'acciaio a prova di palla	Bullet Proof Steel Plates
Lastre e tubi di cemento d'amianto 'Everite'	'Everite' Asbestos Cement Sheets and Pipes
Lastre ondulate di cemento d'amianto per tetti	Asbestos Cement Corrugated Roofing Sheets
Lastre piatte di cemento d'amianto (per muri, pareti, soffitti, ecc.)	Asbestos Cement Flat Sheets (for Walls, Partitions, Ceilings etc.)
Lastre refrattarie per pareti e per muri	Fireproof Partition and Wall Sheets
Lastre (rame ed ottone)	Plates (Copper and Brass)
Lavori al tornio (qualunque metallo)	Turned Work (any Metal)
Lavori in ferro ed in lamiera	Wrought and Sheet Iron Work

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ITALIANO.	INGLESE.
Lavori in lamierino e coperture di cilindri, ecc.	Sheet Metal Work, Cylinder Cases, etc.
Lavori in ottone di piombino	Plumbers' Brasswork
Lavoro di pressa	Presswork
Leghe	Alloys
Leghe d'acciaio, Fabbricanti di	Alloy Steel Manufacturers
Legname, Preservativi di	Wood Preservatives
Libri e giornali scientifici	Books and Journals, Scientific
Lingotti di bronzo	Gunmetal Ingots
Lingotti di bronzo per la Marina	Admiralty Gunmetal Ingots
Livelli d'acqua, ecc. *Vedere* Manometri	Water Gauges, etc. *See* Steam Gauges
Locomobili	Portable Engines
Locomotive	Locomotives
Locomotive ad olio (a scoppio)	Oil Locomotives (Internal Combustion)
Locomotive trattori (a vapore ed elettriche)	Traction Engines (Steam and Electrical)
Lubrificanti per motori	Motor Lubricants
Lubrificatori e lubrificanti	Lubricators and Lubricants
M	
Macchinari per alti forni	Blast Furnace Plant
Macchinari per dragaggio	Dredge Plant
Macchinari per fonderie	Foundry Plant
Macchinari per la depurazione del gas	Gas Cleaning Plant
Macchinari per la perforazione delle gallerie	Tunnelling Plants
Macchinari per miniere da carbone	Colliery Plant
Macchinario per miniere	Mining Machinery. *See* Mining and Hauling Plants
Macchine automatiche, Fabb. di	Automatic Machine Makers
Macchine cesoie, punzonatrici e per centrare	Shearing, Punching, and Bending Machines
Macchine da pesare i grani	Grain Weighing Machines
Macchine da pesare il carbone	Coal Weighing Machines
Macchine da pesare i liquidi	Liquid Weighing Machines
Macchine di prova	Testing Machines
Macchine frantumatrici	Grinding Machinery
Macchine idrauliche sistema 'Tweddell'	'Tweddell's' System Hydraulic Machinery
Macchine idrauliche, utensili, apparecchi idraulici, ecc.	Hydraulic Machines, Tools and Appliances, etc.
Macchine lucidatrici	Polishing Machinery
Macchine (Magneto-elettriche)	Machinery (Electro-Magnets)
Macchine per alesare e spianare	Boring and Facing Machines
Macchine per frantumare e polverizzare	Crushing and Pulverising Machinery
Macchine frigorifere	Refrigerating Machinery
Macchine per il cemento	Cement Machinery
Macchine per inverniciare	Painting Machines
Macchine per la fabbricazione della carta e della cellulosa	Paper and Pulp-Making Machinery
Macchine per la fabbricazione delle cartuccie	Cartridge Machinery
Macchine per la fabbricazione de ghiaccio. *Vedere* Macchine frigorifere	Ice-Making Machinery. *See* Refrigerating Machinery

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ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Macchine per la fabbricazione della carta e per la stampatura del cotone	Paper-Making and Calico - Printing Machinery	Magli (vapore, aria compressa, pneumatici, ecc.)	Hammers (Steam, Compressed Air, Pneumatic Power, etc.)
		Magneti di sollevamento	Lifting Magnets
Macchine per la fabbricazione della cellulosa	Pulp-Making Machinery	Mandrini magnetici	Magnetic Chucks
Macchine per la lavorazione del legno	Wood-Working Machinery	Manganese e leghe di manganese	Manganese and Manganese Alloys
		Manicotti	Clutches
Macchine per la lavatura del carbone	Coal Washing Machinery	Manometri per vapore, rubinetti, livelli d'acqua, valvole di sicurezza, cassetti, indicatori, scaricatori dell' acqua di condensazione, ecc.	Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.
Macchine per la posa dei cavi	Cable-Laying Machinery		
Macchine per la prova del cemento	Cement-Testing Machines		
Macchine per la prova del cemento Portland	Testing Machines for Portland Cement	Martelli per forgiatori	Foundry Hammers
		Martelli meccanici. *Vedere* Martelli	Power Hammers. *See* Hammers
Macchine per la pulitura del frumento e dei semi	Grain and Seed Cleaning Machinery	Martinetti (idraulici e a vite)	Jacks (Hydraulic and Screw)
Macchine per mulini da grano	Flour-Milling Machinery	Materiale mobile per ferrovie e tramvie	Railway and Tramway Plant
Macchine per oleifici	Oil Mill Machinery	Materiale rotabile. *Vedere* Macchinari per ferrovie e tramvie	Rolling Stock. *See* Railway and Tramway Plant
Macchine per stampare matrici	Die Casting Machines		
Macchine piegatubi	Pipe-bending Machines		
Macchine soffianti. *Vedere* Ventilatori	Blowers. *See* Fans	Materie coloranti	Dyestuffs
		Materie isolanti	Insulating Material
Macchine per spruzzare. Spruzzatrici	Spraying Machines	Matrici fusi in alluminio	Aluminium Die Castings
Macchine utensili ed utensili a mano. *Vedere* Utensili per meccanici ed accessori, così pure fabbricanti di utensili	Machine and Hand Tools. *See* Engineers' Tools and Fittings, *also* Tool Makers	Mattoni refrattari ed articoli di terra refrattaria	Firebricks and Fire Clay Goods
		Meccanismi di trasmissione ad olio a velocità variabile	Variable Speed Oil Transmission Gears
Macinazione del carbone, elevatrici e trasportatrici	Coal Grinding, Elevating, and Conveying Machinery	Meccanismi registratori di spese e tempo	Costs and Time Recorders
Magli a vapore, ad aria compressa e pneumatici	Steam, Compressed Air, and Pneumatic Power Hammers	Mescolatori d'Olii	Oil Blenders
		Metalli antifrizione	Anti-Friction Metals
		Metalli in lingotti	Ingot Metals
Magli a vapore. *Vedere* Magli	Steam Hammers. *See* Hammers	Metalli lavorati in sagome	Expanded Metal
		Metalli, Negozianti di	Metal Merchants

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ITALIANO.	INGLESE.
Motalli per cuscinetti, ecc.	Bearing Metals, etc.
Metalli per cuscinetti, antifrizione, ecc.	Metals: Bearing, Anti-Friction, etc.
Metalli perforati	Perforated Metals
Metalli (rottame)	Metals (Scrap)
Metalli trafilati	Extruded Metals
Metallo 'Bull's' e 'Melloid'	Bull's Metal and Melloid
Metallo 'Delta'	Delta Metal
Metallo plastico ('Richards')	Plastic Metal ('Richards')
Mica	Mica
Micrometri	Micrometers
Microscopi	Microscopes
Miniere da carbone (Funi di acciaio per)	Collieries (Steel Wire Ropes for)
Miniere di carbone (Macchinario elettrico per)	Collieries (Electrical Equipment of)
Misuratori degli sforzi	Strainmeters
Misuratori dell'allungamento	Extensometers
Mistura di colla per verniciatori	Distemper
Mola aerea (elettrica)	Aerial Grinders (Electric)
Mole a centro (elettriche)	Centre Grinders (Electric)
Mole a smeriglio. *Vedi* Macchine frantumatrici	Grinders. *See* Grinding Machinery
Molini (polverizzatori)	Mills (Pulverizing)
Montacarichi. *Vedere* Apparecchi di sollevamento	Hoists. *See* Lifting and Hoisting
Montacarichi e grue elettriche	Electric Lifts and Cranes
Montanti di acciaio	Stanchions (Steel)
Motori di aviazione	Aero Engines
Motori a benzina. *Vedere* Motori ad olio ed a gas	Petrol Engines. *See* Oil and Gas Engines
Motori ad olio, gas e benzina	Oil, Gas, and Petrol Engines
Motori ad olio pesante. *Vedere* Motori a petrolio	Crude Oil Engines. *See* Oil Engines
Motori Diesel e Semi-Diesel	Diesel and Semi-Diesel Engines
Motori a gas d'aria di petrolio	Petrol Air Gas Machines
Motori a gas, olio e benzina	Gas, Oil, and Petro Engines
Motori elettrici. *Vedere* Dinamo e motori	Electric Motors. *See* Dynamos and Motors
Motori idraulici	Engines (Hydraulic)
Motori tipo marina ad olio	Marine Oil Engines
Motori tipo marina, caldaie e macchine ausiliari	Marine Engines, Boiler and Auxiliary Machinery
Motrici a vapore	Steam Engines
Motrici per laminatoi	Rolling Mill Engines
Mulini e macchinario per lo zucchero	Sugar Mills and Machinery
N	
Nettatubi	Tube Cleaners
Nitrogeno	Nitrogen
O	
Olii, composizioni lubrificanti, ecc.	Oils, Lubricating Compounds, etc.
Olio, Istallazioni ad	Oil Burning Installations
Orologi elettrici	Clocks, Electric. *See* Electric Clocks
Orologi registratori	Time Recorders
Oscillografi	Oscillographs
Ossigeno	Oxygen
Ossigeno ed idrogeno, Generatori di	Oxygen and Hydrogen Generating Plants
Ottone e bronzo	Brass and Bronze

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ITALIANO.	INGLESE.
P	
Pali telegrafici ferro)	Telegraph Poles (iron)
Parafulmini	Lightning Conductors
Parafumo e generatori di vapore	Smoke Preventers and Steam Generators
Paragradini	Stair Treads
Pattini e stampi	Shoes and Dies
Pavimenti, ecc. (incombustibili)	Floors etc. (Fire-Resisting)
Pavimenti incombustibili 'Decolite'	'Decolite' Fireproof Flooring
Perforatrici da carbone e tagliatrici	Coal Drills and Cutters
Perforatrici da roccia	Rock Drills
Perforatrici per roccie e per carbone	Boring Machines for Rock and Coal
Pezzi forgiati e fusioni. *Vedere* Fusioni e pezzi forgiati	Forgings and Castings. *See* Castings and Forgings
Pezzi forgiati in acciaio e fusioni. *Vedere* Fusioni e pezzi forgiati	Steel Forgings and Castings. *See* Castings and Forgings
Pezzi fuciuati di rame	Copper Forgings
Pezzi fusi generali di fonderia	General Foundry Castings
Pezzi pressati a forza idraulica	Hydraulic Pressings
Piallatrici, mortizzatrici, filettatrici e limatrici	Planing, Slotting, Screwing, and Shaping Machines
Piattaforme giranti	Turn-tables
Picconi, badili, ecc.	Picks, Shovels, etc.
Pirometri	Pyrometers
Piroscafi, lancie e yachts a vapore	Steam Ships, Launches, and Yachts
Pistoni per pompa	Pump Buckets
Pittura anticorrosiva	Anti-corrosive Paint
Placche con Marche di Fabbrica	Trade Mark Plates
Placche con nomi, per ogni industria	Name Plates for all Trades
Planimetri	Surface Gauges
Pneumatici di gomma solida per veicoli commerciali	Solid Rubber Tyres for Commercial Vehicles
Polvere da mina	Blasting Powder
Pompe ad aria	Air Pumps
Pompe a pressione di capacità variabile	Variable Capacity Pressure Pumps
Pompe a turbina	Turbine Pumps
Pompe a vapore. *Vedere* Pompe	Steam Pumps. *See* Pumps
Pompe a vuoto. *Vedere* Pompe	Vacuum Pumps. *See* Pumps
Pompe centrifughe. *Vedere* Pompe	Centrifugal Pumps. *See* Pumps
Pompe idrauliche	Hydraulic Pump
Pompe ed impianti di sollevament d' acqua	Pumps and Pumping Machinery
Pompe per caldaie	Boiler Feed Pumps
Pompe (per olio, ad efflusso vario)	Pumps (Variable Delivery, Oil)
Pompe (per pozzi profondi)	Pumps (Deep Well)
Pompe roturbo	Roturbo Pumps
Ponti, costruttori di	Bridge Builders
Ponti (pensili)	Bridges (Wire Rope Suspension)
Porte da Darsene (Costruttori di)	Dock Gates (Builders of)
Porte pieghevoli	Collapsible Gates
Preparati di gomma per pavimenti, e piastrelle	Rubber Flooring and Tiles
Preservativi (del legno)	Preservatives (Wood)
Pressature di Ottone a Caldo	Hot Brass Pressings
Presse a centrare	Bending Presses
Presse a forza meccanica	Power Presses
Presse per cerchioni	Tyre Presses
Presse per forgiare	Forging Presses
Presse per rottame	Scrap Presses
Prodotti chimici	Chemicals

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ITALIANO.	INGLESE.
Propulsione elettrica delle navi	Electric Ship Propulsion
Pubblicazioni (tecniche). *Vedere* Libri e Giornali	Publications (Technical). *See* Books and Journals
Puleggie	Pulleys
Puleggie per cinghie di trasmissione e corde	Belt and Rope Pulleys
Puleggie per corde. *Vedere* Puleggie per cinghie e corde	Rope Pulleys. *See* Belt and Rope Pulleys
Pulitori a vuoto	Vacuum Cleaners
Punte americane	Twist Drills
Punzonatrici, cesoie e macchine a centrare	Punching, Shearing and Bending Machines
Punzoni e stampi	Punches and Dies
Q	
Quadri e avviatori a liquido	Controllers and Liquid Starters
Quadri per batterie di accumulatori	Storage Battery Switchboards
Quadri per batterie elettriche	Battery Switchboards
R	
Raccolta di polvere e rifiuti, Impianti di	Dust and Refuse Collecting Plants
Raccordo 'DU-EX' a doppia espansione	'DU-EX' Double Expansion Nipples
Ramai	Coppersmiths
Rame	Copper
Rampe ferroviarie	Railway Ramps
Recipienti per olio	Oil Cabinets
Refrigeratori d'olio	Oil Coolers
Regolatori (automatici)	Regulators (Automatic)
Regolatori d'acqua (d'alimentazione)	Water Regulators (Feed)
Regolatori di temperatura	Temperature Regulators
Regolatori (per motrici a vapore)	Governors (Steam Engine)
Regole in acciaio	Steel Rules
Regoli calcolatori. *Vedere* Strumenti matematici, ecc.	Slide Rules. *See* Instruments, Mathematical, etc.
Reostati d'avviamento a liquido e controllori	Liquid Starters and Controllers
Reostati elettrici automatici	Automatic Controllers (Electric)
Rete di filo di ferro zincato	Galvanized Wire Netting
Rete metallica	Wire Gauze
Rete metalliche e filo ferro	Wire Work and Woven Wire
Ribaditrici elettriche	Riveters (Electric)
Ribaditrici idrauliche e pneumatiche	Riveters (Hydraulic and Pneumatic)
Riparazioni di caldaie (saldatura ad arco elettrico per)	Boiler Repairs (Electric Arc Welding for)
Riparazioni di navi e di motrici	Ship and Engine Repairers
Ripari per macchine	Machinery Guards
Riscaldamento, ventilazione, ecc.	Heating, Ventilating, etc.
Riscaldamento per vetture ferroviarie	Heating for Railway Carriages
Riscaldatori di chiodi per ribaditura	Rivet Heaters
Riscaldatori elettrici	Electric Heaters
Riscaldatori e riscaldatori intermedi	Interheaters and Reheaters
Riscaldatori, filtri e purificatori dell'acqua d'alimentazione	Feed-Water Heaters, Filters and Purifiers

Per i nomi dei fabbricanti delle specialità elencate su questa pagina il lettore è pregato di vedere le rubriche corrispondenti in lingua inglese nel 'Classified Directory and Buyers' Guide' (*'Guida classificata degli annunci'*). *pag.* 2993–3056.

ITALIANO.	INGLESE.
Rivestimenti per caldaie, ecc.	Coverings for Boilers, etc.
Rivestimenti per muri e soffitti	Wall and Ceiling sheets
Rivestimento impermeabile al catrame	Bitumen Damp-Proof Sheeting
Rivestimento per tubi	Pipe Coverings
'Rosseline' per motori a gas e ad olio	'Rosseline' (for Gas and Oil Engines)
Rotaie, fabbricanti di	Rail Manufacturers
Rotaie d' acciaio ed accessori	Steel Rails and Accessories
Rotaie e mezzi d'attacco	Rails and Fastenings
Rottame di metallo	Scrap Metals
Rubinetti (ottone) per acqua, vapore e gas	Cocks (Brass) for Water, Steam, and Gas
Rulli d'acciaio	Steel Rollers
Ruote dentate	Wheel Gearing
Ruote idrauliche, motori e turbine idrauliche	Water Wheels, Water Motors and Turbines
Ruote Pelton	Pelton Wheels
Ruote per catene	Chain Wheels
S	
Saldatrici	Soldering Machines
Saldatura	Solder
Saldatura ad arco elettrico . 'Daysohms'	'Daysohms' Electric Arc Welding
Saldatura 'Thermit'	'Thermit' Welding
Saldatura all' ossigeno e acetilene	Oxy-Acetylene Welding
Saldatura elettrica	Electric Welding
Saldatura e tranciatura dei metalli	Welding and Cutting of Metals
Sale e cerchioni ferroviari	Railway Tyres and Axles
Scale incombustibili	Staircase (Fire Resisting)
Scambi e livelli ferroviari	Railway Points and Crossings
Scaricatori. *Vedere* Manometri, ecc.	Steam Traps. *See* Steam Gauges, etc.
Scaricatori di vapore ed a vuoto	Vacuum and Steam Traps
Scarpe di accesso	Railway Re-railing Ramps
Scatole del cambio di velocità (aumento e riduzione)	Gear Boxes (Increasing and Reducing)
Scuole e collegi d' ingegneria	Schools and Colleges (Engineering)
Sedi per caldaie	Boiler Seatings
Seghe per legname e per metalli	Saws for Wood and Metal Cutting
Segnali d'incendio	Fire Alarms
Segnali. *Vedere* Segnali ferroviari	Signals. *See* Railway Signals
Segnali ferroviari ed apparecchi di sicurezza	Railway Signals and Safety Appliances
Segnali per miniere (impermeabili)	Mining Signals (Watertight)
Separatori a magnete	Magnetic Separators
Separatori della fuligine	Soot Removers
Separatori dell' olio dall' acqua di condensazione	Separation of Oil from Condensed Steam
Separatori di grasso	Grease Separators
Separatori (magnetici)	Separators (Magnetic)
Separatori magnetici per 'Destructors' (distruttori di immondizie)	Destructors (Magnetic Separators for)
Separatori meccanici	Mechanical Separators
Serbatoi e cisterne	Tanks and Cisterns
Serbatoi (per rendere impermeabile gli)	Reservoirs (Waterproofing of)
Sestanti	Sextants
Sezioni trafilate brevettate di bronzo, ottone, ecc.	Sections (Patent Extruded), Brass, Bronze, etc.
Sfere e cuscinetti a sfere	Balls and Ball-Bearings
Sfere d'acciaio	Steel Balls
Sistemi di conduttura (flessibili)	Wiring Systems (Flexible)

Per i nomi dei fabbricanti delle specialità elencate su questa pagina lettore è pregato di vedere le rubriche corrispondenti in lingua inglese nel 'Classified Directory and Buyers' Guide' ('Guida classificata degli annunci'), pag. 2993–3056.

ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Sistemi di trasporto di denaro alla cassa a mezzo filo, per negozi	Cash Carrier Systems	Strumenti misuratori (elettrici). *Vedere* Strumenti	Measuring Instruments (Electrical). *See* Instruments
Sistemi per la montatura del filo elettrico. *Vedi* Sistemi per montare il filo (flessibile)	Electric Wiring Systems. *See* Wiring Systems (Flexible)	Strumenti per la topografia e disegno	Surveying and Drawing Instruments
Smalti, colori e copali	Enamels, colours and varnishes	Strumenti per matematica, disegno e topografia	Mathematical, Drawing, and Surveying Instruments
Sopporti a rulli	Roller Bearings	Strumenti registratori	Recording Instruments
Sopporti di spinta (a sfere)	Thrust Bearings (Ball)	Strumenti scientifici	ScientificInstruments
Supporti per alberi intermedi (a sfere e a rulli)	Line Shaft Bearings (Ball and Roller)	Stuoie da pedane di automobile	Motor Step Mats
Sostegni per scavi	Trench Braces	Superfici di attrito	Friction Surfaces
Sottofondo per ardesia	Underslating	Superfici di attrito 'Ferodo'	'Ferodo' Friction Surfaces
Spazzole per motori elettrici	Dynamo Brushes	Surriscaldatori	Superheaters
Squadre	Squares	Surriscaldatori per locomotive	Locomotive Superheaters
Staderoni	Weighbridges	Surriscaldatori tipo marina	Marine Superheaters
Stagionatura del legname	Timber Seasoning		
Stampature	Stampings	T	
Stampi a frizione ed a vapore	Stamps (Friction and Steam Drop)	Tachigrafi	Recorders (Speed)
Stampi e presse	Drop Stamps and Presses	Tacometri	Tachometers
Stanghe e sezioni di rame	Copper Rods and Sections	Targhette con numeri	Number Plates
Stanghe vuote e sezioni (ottone, rame, ecc.)	Hollow Rods and Sections (Brass, Copper, etc.)	Tegole e lamiere ondulate (Cemento all'amianto)	Corrugated Tiles and Sheets (Asbestos Cement)
Strade di concreto (Appaltatori di)	Concrete Roads (Contractors for)	Taglio e saldatura autogena dei metalli	Metal Cutting and Welding
Strumenti di topografia, matematica e disegno	Instruments: Surveying, Mathematical, Drawing, etc.	Tegole di amianto	Asbestos Roofing Tiles
Strumenti ed apparecchi elettrici	Instruments and Apparatus(Electrical)	Tegole e tavole di cemento	Cement Slates and Boards
Strumenti ed apparecchi elettrici	Electrical Instruments and Apparatus. *See* Instruments and Apparatus(Electrical)	Telai per automobili (chassis)	Motor Chassis Frames
		Tempera della superficie	Case Hardening
		Tessuti a Frizione 'CHEKKO'	'CHEKKO' Friction Fabrics
		Termometri	Thermometers
		Tetti, Fabbricati in ferro, ecc.	Roofs, Iron Buildings, etc.

Per i nomi dei fabbricanti delle specialità elencate su questa pagina il lettore è pregato di vedere le rubriche corrispondenti in lingua inglese nel 'Classified Directory and Buyers' Guide' ('Guida classificata degli annunci'), pag. 2993–3056.

ITALIANO.	INGLESE.	ITALIANO.	INGLESE.
Tipografi, litografi, disegnatori e incisori	Printers, Lithographers, Draughtsmen, and Engravers	Tubi di ferro. *Vedere* Tubi	Iron Tubes. *See* Tubes
Torni. *Vedere* Costruttori macchine utensili	Lathes. *See* Tool Makers	Tubi di ferro e di acciaio	Iron and Steel Tubes
Torri d'acqua	Water Towers	Tubi di rame	Copper Tubes
Torri di raffreddamento	Cooling Towers	Tubi ed accessori	Tubes and Fittings
Tramvie e ferrovie (elettriche). *Vedere* Ferrovie e tramvie elettriche	Tramways and Railways (Electrical). *See* Electric Railways and Tramways	Tubi ed accessori per gas	Gas Tubes and Fittings
Tramvie (funi di acciaio per)	Tramways (Steel Wire Ropes for)	Tubi e serpentine per refrigeranti	Refrigerating Tubes and Coils
Trapani a Diamante	Diamond Drillers	Tubi flessibili in cuoio, tela, ecc.	Hose Pipes, Leather and Canvas Hose, etc.
Trapani e magli elettrici portatili	Electric Portable Drills and Hammers	Tubi flessibili metallici	Hose (Flexible Metallic), Metalli Tubing (Flexible)
Trapani e perforatrici	Drills and Drilling Machines	Tubi flessibili per riscaldamento a vapore	Steam Heating Tubes (Flexible)
Trasformatori (forza elettrica)	Transformers (Electric Power)	Tubi idraulici	Hydraulic Tubes and Pipes
Trasformatori a cascata	Motor Converters	Tubi (metallici flessibili)	Tubing (Flexible Metallic)
Trasmissione (idraulica, ad olio)	Transmission (Hydraulic, Oil)	Tubi per caldaie	Boiler Tubes
Trasmissioni ed ingranaggi	Shafting and Gearing	Tubi per condensatori (rame). *Vedere* Tubi di rame	Condenser Tubes (Copper). *See* Copper Tubes
Trasportatori	Transporters	Tubi per corpi di pompieri, stabilimenti, ecc.	Hose for Fire Brigades, Mills, etc.
Trasportatori. *Vedere anche* Cinghie	Convevors. *See also* Belting	Tubi per posta pneumatica	Pneumatic Despatch Tubes, etc.
Trasporto pneumatico, Impianti di	Pneumatic Conveying Plants	Tubi (pneumatici)	Tubes (Pneumatic)
Trattamento a caldo di metalli	Heat Treatment of Metals	Tubi vapore. *Vedere* Tubi	Steam Pipes. *See* Tubes
Travate, ponti, ecc. *Vedere* Lavori in ferro ed acciaio	Girders, Bridges, etc. *See* Structural Iron and Steel Work	Tubiere per alti forni	Blast Furnace Tuyères
Travi in acciaio	Joists (Steel)	Turbine a vapore ed accessori	Steam Turbines and Fittings
Tubatura d'ispezione per caldaie	Inspection Blocks for Boilers	Turbine, ruote idrauliche e motori idraulici	Turbines, Water Wheels and Water Motors
Tubi	Tubes	Turbine (Vapore). *Vedere* Turbine a vapore	Turbines (Steam). *See* Steam Turbines
Tubi a serpentino	Pipe Coils	Turbo-Generatori. *Vedere* Dinamo e motori	Turbo-Generators. *See* Dynamos and Motors
Tubi d'acciaio. *Vedere* Tubi	Steel Tubes. *See* Tubes	Turbo-Pompe	Turbo-Pumps
Tubi d'acciaio per fili elettrici	Steel Conduits for Electric Wiring		

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ITALIANO.	INGLESE.
U	
Utensili da miniera	Mining Tools
Utensili ed accessori per meccanici	Engineers' Tools and Fittings
Utensili ed apparecchi pneumatici	Pneumatic Tools and Appliances
Utensili ed impianti per impresari	Contractors' Tools and Plant
Utensili per cavi	Quarrying Tools
Utensili per disincrostare	Scaling Tools
Utensili rapidi 'Speedicut'	'Speedicut' High-Speed Tools
V	
Vagoni a bilico	Tip Wagons
Vagoni (ferroviari)	Wagons (Railway)
Valvole a cassetto a cuneo	Wedge Gate Valves
Valvole a manicotto per pompe d'aria	Bush Valves for Air Pumps
Valvole di riduzione. *Vedere* Valvole	Reducing Valves. *See* Valves
Valvole e rubinetti	Valves and Cocks
Valvole per vapore (Automatiche)	Steam Valves (Automatic
Ventilatori	Ventilating Shafts
Ventilatori elettrici	Electric Blowers
Ventilatori elettrici. *Vedere* Ventilatori	Electric Fans. *See* Fans
Ventilatori per eliminazione di cenere	Cinder Eliminating Fans
Ventilatori: soffianti, aspiranti, elettrici, ecc.	Fans: Blowing, Exhaust, Electric, etc.
Ventilazione, riscaldamento, ecc.	Ventilating, Heating, etc.
Verghe d'acciaio	Steel Rods
Vericelli a motore e relativo impianto	Winding and Hauling Engines and Plant
Verricelli Duff	Duff Jacks
Vernici antiruggine per ferro e acciaio	Paints for Preserving Iron and Steel Work
Vernici, colori, smalti e copali	Paints, Colours, Enamels and Varnishes
Vernici per macchine	Machinery Finishes
Verricelli (a frizione)	Winches (Friction)
Vetri per indicatori di livello	Gauge Glasses
Vetri per lubrificatori	Lubricating Glasses
Vetture e vagoni ferroviari	Carriages and Wagons (Railway)
Viti (ferro, acciaio, rame e bronzo marino)	Screws (Iron, Steel, Copper and Naval Brass)
Viti meccaniche	Machine Screws
Voltometri. *Vedere* Strumenti (Elettrici)	Voltmeters. *See* Instruments (Electrical)
Vulcanite e fibbra vulcanizzata	Vulcanite and Vulcanised Fibre
W	
'Woodite'	'Woodite'
Z	
Zinco (non incrostante per pile)	Zincs (Non-encrusting for Primary Batteries)

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TRADUCCIÓN DE LOS TÍTULOS CONTENIDOS EN LA 'GUÍA CLASIFICADA DE ANUNCIOS' DE ARTICULOS ESPECIALES (páginas 2993-3056).

Para hallar los nombres de los fabricantes de los artículos especiales mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3056. *Parat señas de anunciadores y referencias á sus anuncios, consúltese la precedene Lista alfabética, páginas* 2977–2990.

ESPAÑOL.	INGLÉS.
A	
Abrazaderas de Indicadores de Cristal	Gauge Glass Rings
Abridores de pozos de minas	Shaft Sinkers
Accesorios de Aeroplanos	Aeroplane Accessories
Accesorios de Calderas. *Véase* Accesorios de Máquinas y Calderas	Boiler Fittings. *See* Engine and Boiler Fittings
Accesorios de Máquinas y Calderas, Hornos y Tubos de Calderas, etca.	Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.
Aceites, Composiciones Lubricantes, etca.	Oils, Lubricating Compounds, etc.
Acero con Manganeso	Manganese Steel
Acero de Aleación, Fabricantes de	Alloy Steel Manufacturers
Acero de Firth que no se mancha	Firth's Stainless Steel
Acero de gran resistencia a la tensión	High Tensile Steel
Acero en secciones	Steel Sections
Acero Eléctrico, Fabricantes de	Electric Steel Manufacturers
Acero 'Mesmeric' templado superficialmente	'Mesmeric' Case Hardening Steel
Acero para aparatos aéreos	Aircraft Steels
Acero para engranajes que se templa al aire	Air Hardening Gear Steel
Acero para Herramientas	Tool Steel
Acero para Herramientas de Gran Velocidad	High Speed Tool Steel
Acero para imanes	Magnet Steel
Acero para Maquinaria, Fabricantes de	Machinery Steel Manufacturers
Acero que no se mancha ni se oxida	Stainless and Rustless Steel
Acero que no se oxida	Rustless Steel
Acero (Torneado brillante, Estirado y Laminado en frío)	Steel (Bright Turned, Drawn, and Cold-Rolled)
Aceros al Cromo-Vanadio	Chrome - Vanadium Steels
Aceros al niquel y niquel-cromo	Nickel and Nickel Chrome Steels
Aceros fundidos en crisol	Crucible Cast Steels
Aceros para matrices	Die Steels
Aceros Siemens-Martin	Siemens - Martin Steel
Aceros 'Speedicut' para grandes velocidades	'Speedicut' High-speed Steels
Aceros templados superficialmente	Case Hardening Steels
Acetileno	Acetylene
Acetileno, Instalaciones Generadoras de	Acetylene Generating Plants
Acido Clorhídrico	Hydrochloric Acid
Acido Nítrico	Nitric Acid
Acido para Acumuladores	Accumulator Acid
Acido Sulfúrico	Sulphuric Acid
Acoplamientos de cadena 'Coventry'	'Coventry' Chain Couplings
Acumuladores. *Véase* Baterías	Accumulators. *See* Batteries

ESPAÑOL.	INGLÉS.	ESPAÑOL.	INGLÉS.
Acumuladores Hidráulicos	Accumulators (Hydraulic)	Amianto-cemento en hojas lisas (para tabiques, cielos rasos, etca.)	Asbestos Cement Flat Sheets (for Walls, Partitions, Ceilings, etc.)
Aerómetros	Air Meters	Amianto - cemento 'Fibrent' en hojas acanaladas y lisas	'Fibrent' Asbestos Cement Corrugated and Flat Sheets
Aeronáutica (Ingenieros)	Aeronautical Engineers	Amianto 'Poilite' en Hojas y Tejas	'Poilite' Asbestos Sheets and Roofing Tiles
Aeronáutica (Motores)	Aero Engines	Análisis de Gases de la Chimenea de la Cadera	Boiler Flue Gases (Analysis of)
Aeroplanos, Constructores de	Aeroplane Builders	Anillos de Cobre para Juntas	Copper Jointing Rings
Afiladores de Taladros	Drill Sharpeners	Anillos de Embolos	Piston Rings
Agua Caliente, Calderas de Abastecimiento	Hot Water Supply Boilers	Antivibración	Anti-Vibration
Agua de Alimentación de Calderas (Eliminación de Aceite del)	Boiler Feed Water (Oil Elimination from)	Aparatos Conmutadores	Switch Gear
Agujas y Pasos de Nivel de Ferrocarriles	Railway Points and Crossings	Aparatos de Alumbrado Eléctrico	Electric Light Fittings, etc.
Ahogahumos y Generadoras de Vapor	Smoke Preventers and Steam Generators	Aparatos de Arrancadade Automóviles	Motor Starters
Aire Líquido	Liquid Air	Aparatos de Arrancada (Liquido) y Refrenadores	Liquid Starters and Controllers
Aisladores	Insulators	Aparatos de Telégrafos sin Hilos	Wireless Telegraph Apparatus
Alambre	Wire	Aparatos de Tiro Forzado e Inducido	Forced and Induced Draught Apparatus
Alambre para Cercas	Fencing Wire	Aparatos de transmisión de aceite con velocidad variable	Variable Speed Oil Transmission Gears
Alambre para Soldar ('Rylax')	Welding Wire ('Rylax')	Aparatos Eléctricos de Calefacción y Cocina	Electric Heating and Cooking Apparatus
Alambre para Telégrafos. *Véase* Alambre	Telegraph Wire. *See* Wire	Aparatos Filtrantes	Filtering Apparatus
Alarmas de Incendios	Fire Alarms	Aparatos hidráulicos (aceite)	Gears (Hydraulic, Oil)
Aleaciones	Alloys	Aparatos para Destilar Agua. *Véase también* Condensadores	Water Distilling Apparatus, etc. *See also* Condensers
Alfombrillas para automóviles	Motor Step Mats	Aparatos para Destilar Agua Potable	Distilling Apparatus (Fresh Water)
Alternadores	Alternators	Aparatos para Dulcificar y Purificar Agua. *Véase también* Calentadores de Agua de Alimentación	Water Softening and Purifying Apparatus. *See also* Feed Water Heaters, etc.
Alumbrado de Fábricas	Factories (Lighting of)		
Alumbrado de Talleres	Workshops (Lighting of)		
Alumbrado de Trenes	Lighting (Train)		
Alumbrado y Calefacción (Instalaciones de Gas Acetileno)	Lighting and Heating (Acetylene Gas Plants for)		
Aluminio en Polvo	Aluminium Powder		
Aluminio (Lingotes, Planchas, Tubos, Alambre, Cables, Secciones, etca.)	Aluminium (Ingots, Sheets, Tube, Wire Cable, Sections, etc.)		
Amianto-cemento en hojas acanaladas para tejados	Asbestos Cement Corrugated Roofing Sheets		

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ESPAÑOL.	INGLÉS.	ESPAÑOL.	INGLÉS.
Aparatos para Enfriar Agua	Water-Cooling Apparatus	Artículos de caucho en general	Rubber Goods (General)
Aparatos para Extinguir Incendios	Fire Extinguishing Appliances	Artículos Especiales de Grafito 'Foliac'	'Foliac' Graphite Specialities
Aparatos para Medir la Elasticidad	Extensometers	Artículos para Dibujantes y Delineadores	Drawing Office Requisites
Aparatos para Medir la Tensión	Strainmeters	Ascensores Eléctricos y Gruas Eléctricas	Electric Lifts and Cranes
Aparato para probar aceite	Oil Testing Apparatus	Asentamiento de Calderas	Boiler Setting
Aparatos para probar gas	Gas Testing Apparatus	Asentamientos de Calderas Perfeccionados	Boiler Settings (Improved)
Aparatos para viscosidad. *Véase* Aparatos para probar aceite	Viscosity Apparatus. *See* Oil Testing Apparatus	Asentamientos Perfeccionados de Calderas de Lancashire	Lancashire Boiler Settings (Improved)
Aparatos para Refrigerar y Humedecer el Aire	Air-Cooling and Humidifying Apparatus	Asfalto	Asphalte
Aparatos para Secar	Drying Apparatus	Asientos de Calderas	Boiler Seatings
Aparatos Químicos y Electroquímicos	Chemical and Electro-Chemical Apparatus	Automóviles, Accesorios de	Motor Car Accessories
Aparatos Radiotelegráficos	Radio - Telegraphic Apparatus		
Aparatos Sopladores Eléctricos	Electric Blowers	**B**	
Aparatos Soplantes: de Expulsión, Extracción, Eléctricos, etca.	Fans: Blowing, Exhaust, Electric, etc.	Barnices	Varnishes
Aparatos Soplantes Eléctricos. *Véase* Aparatos Soplantes	Electric Fans. *See* Fans	Barnices para Metales Pulimentados y Preparaciones para Perfeccionar Maquinaria	Coatings (Bright Part) and Machinery finishes
Aparatos soplantes eliminadores de cenizas	Cinder Eliminating Fans	Barnices y Composiciones Aisladores	Insulating Varnishes and Compounds
Aparatos y Accesorios de Alumbrado Eléctrico	Electric Light Fittings and Electrical Accessories	Barometros	Barometers
Arandelas de Indicadores de Cristal	Gauge Glass Washers	Barras 'Dixtrudo' para hacer y Tornear Tornillos de Bronce a Gran Velocidad	'Dixtrudo' High-Speed Brass Screwing and Turning Rods
Armaduras de Tejados	Underslating	Básculas para carbón de hulla y carbón	Coal Weighing Machines
Armazones Inferiores y Carretillas de Locomotoras	Underframes and Bogies	Bastidores completos de Automóviles	Motor Châssis Frames
Artículos, Accesorios, etca., de Amianto	Asbestos Goods, Fittings, etc.	Baterías (Acumulación Eléctrica)	Batteries (Electrical Storage)
Artículos de caucho para maquinaria	Mechanical Rubber Goods	Bloques para Facilitar la Inspección de Calderas	Inspection Blocks for Boilers
		Bloques y Cubiertas para Calderas	Boiler Blocks and Covers

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ESPAÑOL.	INGLÉS.
'Boilerine'	'Boilerine'
Bolas de acero	Steel Balls
Bolas y Cojinetes de Bolas	Balls and Ball Bearings
Bombas Atmosféricas de Vacío. *Véase* Bombas	Vacuum Pumps. *See* Pumps
Bombas Centrífugas. *Véase* Bombas	Centrifugal Pumps. *See* Pumps
Bombas de Aire	Air Pumps
Bombas de Alimentación de Calderas	Boiler Feed Pumps
Bombas de descarga variable (petróleo)	Pumps (Variable Delivery, Oil)
Bombas de presión de capacidad variable	Variable Capacity Pressure Pumps
Bombas de turbina	Turbine Pumps
Bombas de Vapor. *Véase* Bombas	Steam Pumps. *See* Pumps
Bombas hidráulicas	Hydraulic Pumps
Bombas para pozos profundos	Pumps (Deep Well)
Bombas 'Roturbo'	Roturbo Pumps
Bombas y Maquinaria para Elevar e Impulsar Líquidos	Pumps and Pumping Machinery
Bronce. *Véase* Latón y Bronce	Bronze. *See* Brass and Bronze
Bronce con Manganeso	Manganese Bronze
Bronce Fosfórico	Phosphor Bronze
Bronces para Calderas. *Véase también* Accesorios de Máquinas y Calderas	Boiler Mounting. *See also* Engine and Boiler Fittings
Buques, Lanchas y Yates de Vapor	Steam Ships, Launches, and Yachts
C	
Cables aislados con 'Maconite'	'Maconite' Insulated Cables
Cables de Caucho Sólido. *Véase* Cables	Solid Rubber Cables. *See* Cables
Cables Eléctricos. *Véase* Cables: Telégrafo, Teléfono, Alumbrado Eléctrico y Submarinos	Electric Cables. *See* Cables: Telegraph, Telephone, Electric Light and Submarine
Cables Eléctricos (Tipo 'C.T.S.')	Electric Cables ('C.T.S.' Type). *See* 'Cab' Tyre Sheathed Cables
Cables Eléctricos 'Endural'	'Endural' Electric Cables
Cables Forrados 'Cab Tyre'	'Cab Tyre' Sheathed Cables
Cables Submarinos. *Véase* Cables	Submarine Cables. *See* Cables
Cables: Telégrafo, Teléfono, Alumbrado Eléctrico y Submarinos	Cables: Telegraph, Telephone, Electric Light, and Submarine
Cables y Accesorios para Explotación de Minas	Mining Cables and Accessories
Cadenas 'Biflex' para ejes de levas de automóviles	Biflex Chains for Automobile Camshaft Drives
Cadenas de dientes invertidos	Inverted Tooth Chains
Cadenas para apisonadoras pesadas	Roller Chains (Heavy)
Cadenas de Transmisión	Driving Chains
Cadenas y Transmisión de Fuerza por Cadenas	Chains and Chain Drivings
Cajas de Ascensores	Lift Enclosures
Cajas de engranaje de aumento y reducción	Gear Boxes (Increasing and Reducing)
Cajas de Escaleras Resistentes al Fuego	Staircases (Fire-resisting)
Cal y Piedra Caliza	Lime and Limestone
Calabrotes de Alambre de Acero Galvanizado	Hawsers (Galvanised Steel Wire)
Calentadores de remaches	Rivet Heaters
Calderas de Calor Agotado	Exhaust Heat Boilers
Calderas de Tubos de Agua. *Véase* Fabricantes de Calderas	Water-Tube Boilers. *See* Boiler Manufacturers
Calderas de Vapor. *Véase* Fabricantes de Calderas	Steam Boilers. *See* Boiler Manufacturers
Caldereros	Coppersmiths
Calefacción de Coches de Ferrocarril	Heating for Railway Carriages

Para hallar los nombres de los fabricantes de los artículos especiales antes mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3056

ESPAÑOL.	INGLÉS.	ESPAÑOL.	INGLÉS.
Calefacción, Ventilación, etca.	Heating, Ventilating, etc.	Chapas para Revestir Paredes y Cielos Rasos	Wall and Ceilin Sheets
Calentadores de Agua de Alimentación Filtros y Purificadores	Feed-Water Heaters, Filters and Purifiers	Chimenea de Ventilación	Ventilating Shafts
Calentadores eléctricos	Electric Heaters	Chimeneas	Chimney Stacks
'Callendrite,' Forro de Paredes contra la Humedad	'Callendrite' Dampcourse and Sheeting	Cilindros	Cylinders
Caloríferos	Calorifiers	Cinc en Piezas contra Incrustaciones para Baterias Primarias	Zincs (Non-encrusting for Primary Batteries)
Calorimetros para Probar Combustibles	Calorimeters for Fuel Testing	Claraboyas	Skylights
Camisas de Calderas y Tubos	Boiler and Pipe Coverings	Cobre	Copper
Camisas para Calderas, etca.	Coverings for Boilers, etc.	Coches y Vagones de Ferrocarril	Carriages & Wagons (Railway)
Campanas Eléctricas	Bells (Electric)	Cojinetes de Bolas	Bearings (Ball)
Cañones y Municiones, Fábricas de	Gun and Ammunition Works	Cojinetes de bolas de empuje	Thrust Bearings (Ball)
Carbón pulverizado, Instalaciones para	Powdered Coal Plants	Cojinetes de bolas y de rodillos para ejes	Line Shaft Bearings (Ball and Roller)
Carburo de Calcio	Carbide of Calcium	Cojinetes de Fundición Resfriada	Bearings (Chill Cast)
Carretillas de mano (acero)	Barrows (Steel)	Cojinetes de Rodillos	Roller Bearings
Carreteras de hormigón (Contratistas para)	Concrete Roads (Contractors for)	Colas Marinas	Marine Glues
Cedazos y Cribas	Sieves and Screens	Colegios de Ingeniería	Colleges(Engineering)
Cementación (artículos especiales)	Cementation Specialities	Colores, Pinturas y Barnices	Colours, Paints, and Varnishes
Cemento de Portland	Portland Cement	Columnas y Piezas de Fundición para Obras de Alcantarillado, Gas y Agua	Columns and Castings for Sewage, Gas, and Water Works
Cemento de Portland (Máquinas para Hacer Pruebas)	Portland Cement (Testing Machines for)	Combustibles, Sistemas de economizarios	Fuel Economy Systems
Cemento 'Kisol' para Calderas, Tubos de Vapor, etca.	'Kisol' Cement for Boilers, Steam Pipes, etc.	Combustión Superficial	Surface Combustion
Cemento para Juntas	Jointing Cement	Composición de Grafito 'Foliac' para Juntas de Tubos	'Foliac' Graphite Pipe Joint Compound
Cemento (Refractario)	Cement (Refractory).	Composición Desincrustadora para usarla en el Interior de las Calderas	Boiler Composition (for inside use)
Cemento para hogares ('Pyruma')	Fire Cement ('Pyruma')	Composiciones Impermeables	Waterproofing Compounds
Cementos (Portland, Keenes', & Parian)	Cements (Portland, Keenes', and Parian)	Composiciones no conductoras	Non-conducting Compositions
Chapas de Acero	Steel Sheets	Composiciones para Resguardar Piezas de Metal Pulimentadas	Bright Part Coatings
Chapas de Acero alisadas	Planished Steel Sheets		

Para hallar los nombres de los fabricantes de los artículos especiales antes mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3056.

ESPANOL.	INGLÉS.
Compresores de Aire	Air-Compressors
Compuertas de dique (Constructores de)	Dock Gates (Builders of)
Compuertas de Esclusa y Válvulas	Sluice Gates and Valves
Condensadores Cinemáticos 'Contraflo'	'Contraflo' Kinetic Condensers
Condensadores, Evaporadores, Aparatos para Dulcificar y Destilar el Agua, etca.	Condensers, Evaporators, Water Softening and Distilling Apparatus, etc.
Conductos. *Véase* Conductos de Acero y Sistemas de Alambres Eléctricos	Conduits. *See* 'Steel Conduits' and 'Wiring Systems'
Conductos de Acero para Alambres Eléctricos	Steel Conduits for Electric Wiring
Conexiones Flexibles	Flexible Couplings
Conos de Fricción	Friction Clutches
Construcciones de Hormigón Armado	Reinforced Concrete Construction
Constructores de Buques	Ship Builders
Constructores de Puentes	Bridge Builders
Contadores de Agua	Meters (Water)
Contadores de Agua Perdida	Waste Water Meters
Contadores de aire	Meters (Air)
Contadores de carbón	Meters (Coal)
Contadores de gas	Gas Meters
Contadores eléctricos	Electrical Counters
Contadores para minas	Minemeters
Contratistas	Contractors
Contratistas de Alumbrado Eléctrico	Electric Lighting Contractors
Contratistas de Paredes Divisorias y Constructores de Obras contra Incendios	Partition Contractors and Fireproof Builders
Contratistas de Tejados	Roofing Contractors
Correaje 'Gripoly' de pelo	'Gripoly' Hair Belting
Correaje de Transmisión de Balata	Balata Belting
Correas de Algodón para Transmisión	Cotton Belting
Correas de Cuero. *Véase* Correas de Transmisión	Leather Belting. *See* Belting
Correas de Transmisión de Pelo de Camello, Unicos Fabricantes de la Marca 'Camel'	'Camel' Hair, 'Camel' Brand Belting (Sole Makers of)
Correas de Transmisión, etca., de Cuero, Algodón, Pelo, Caucho, etca.	Belting, etc.—Leather, Cotton, Hair, India Rubber, etc.
Correas y Cuerdas de Transmisión, etca.	Driving Bands, Ropes, etc.
Corte y Soldadura de Metales	Metal Cutting and Welding
Crisoles	Crucibles
Cubiertas de Algodón con Silicato y Lana de Escoria	Silicate Cotton and Slag Wool Coverings
Cubiertas y Colchones de Amianto	Asbestos Coverings and Mattresses
Cubiertas y Forros de Humeros	Flue Covers and Linings
Cuerdas de Alambre	Wire Ropes
Cuerdas de Alambre, Cáñamo, Abacá, Cuero, Algodón y Amianto	Ropes: Wire, Hemp, Manilla, Leather, Cotton, and Asbestos
Cuerdas de Algodón para Transmisión	Cotton Driving Ropes
Cuerdas para Enrollar y para Tracción	Winding and Hauling Ropes
Cuerpos de Bombas	Pump Buckets
Curación de la madera	Timber Seasoning
D	
Dados Inferiores y Matrices	Shoes and Dies
'Decolite': Material para Suelos Resistente al Fuego	'Decolite' Fireproof Flooring
Depósitos de Aceites	Oil Cabinets

Para hallar los nombres de los fabricantes de los artículos especiales antes mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3056.

ESPAÑOL.	INGLÉS.
Depósitos de Agua (Impermeabilidad de)	Reservoirs (Waterproofing of)
Depósitos para Conservar en Frio	Cold Storage
Depuradoras de Gas	Gas Cleaning Plant
Descostradores de calderas	Boiler Discrustants
Desmagnetizadores	Demagnetizers
Desperdicios de metales	Scrap Metals
Destructores de Basura	Refuse Destructors
'DEXINE' (Para empaquetadura de vapor de alta presión, ácidos y obra hidráulica	'DEXINE' (for H.P. Steam, Acid and Hydraulic Packings)
'DEXONITE' (Ebonita de grado superior, para ácidos y álcalis; accesorios y material de aislamiento eléctrico)	'DEXONITE' (Super Ebonite, for Acids, and Alkalies; fittings, and Electrical insulation material)
Dinamita	Dynamite
Dinamómetros	Dynamometers
Dinamos y Motores	Dynamos and Motors
Diques flotantes	Floating Docks
Dragas y Elementos para Dragar	Dredge Plant
'Duralumin'	'Duralumin'
E	
Ebonita	Ebonite
Economía de Carbón, Especialistas en	Coal Economy Specialists
Economizadores	Economisers
Economizadores de Combustible. *Véase* Economizadores	Fuel Economisers. *See* Economisers
Edificios	Buildings
Edificios (Impermeabilidad de)	Buildings (Waterproofing of)
Edificios (Protección contra Exhalaciones Eléctricas)	Buildings (Protection of, from Lightning)
Ejercicio de Ingeniería. *Véase* Colegios	Engineering Training. *See* Colleges
Ejes de cigüeña para locomotoras	Railway Crankshafts
Ejes para Ferrocarriles	Axles (Railway)
Ejes Superiores para Movimiento de Gruas, etca.	Overhead Runways
Ejes y Engranajes	Shafting and Gearing
Electrodos para soldadores de arco eléctrico	Electrodes (for Electric Arc Welding)
Elevadores. *Véase* Maquinaria para Elevar Pesos	Elevators. *See* Lifting and Hoisting
Eliminación de humo, vapor y humos	Smoke, Steam, and Fume Removal
Eliminadores de Aceite	Oil Eliminators
Embragues	Clutches
Empaquetadura ('Britimp')	Packing ('Britimp')
Empaquetadura 'Langite' resistente a los aceites	Packing ('Langite' Oil Resisting)
Empaquetaduras, rellenos y arandelas de CORCHO	'CORK' Packings, Gaskets and Washers
Empaquetadura ('Pilot')	Packing ('Pilot')
Empaquetaduras para transformadores	Transformer Gaskets
Empaquetadura ('Estados Unidos')	Packing ('United States')
Empaquetadura (Vapor). *Véase* Empaquetadura de Máquinas	Packing (Steam). *See* Engine Packing
Empaquetadura de Amianto ('Lascar')	Asbestos Packing ('Lascar')
Empaquetadura de Amianto ('Lion')	Asbestos Packing ('Lion')
Empaquetadura de Embolos	Piston Packing
Empaquetadura de Máquinas	Engine Packing

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ESPAÑOL.	INGLÉS.
Empaquetadura de Máquinas (' Lion ')	Engine Packing (' Lion ')
Empaquetadura de Vapor	Steam Packing
Empaquetadura de Vapor (' Lion ')	Steam Packing (' Lion ')
Empaquetadura ' Lion '	' Lion ' Packing
Empaquetadura ' Lion ' de Walker	Walker's (' Lion ') Packings
Empaquetadura Metálica. *Véase* Empaquetadura de Máquinas	Metallic Packing. *See* Engine Packing
Empaquetaduras metálicas ' Britimp '	' Britimp ' Metallic Packings
Empaquetadura Metálica ' Estados Unidos ' para Varillas de Émbolo	Metallic Piston Rod Packing (' United States ')
Empaquetadura Metálica ' Lion ' para Varillas de Émbolo	Metallic Piston Rod Packing (' Lion ')
Empaquetadura Metálica para Vástagos de Émbolo (' Silvertown ')	Metallic Piston Rod Packing (' Silvertown ')
Empaquetadura para Máquinas de Gas	Gas Engine Packing
Empaquetadura Recalentada para Locomotoras	Locomotive Superheated Packing
Empaquetaduras hidráulicas	Hydraulic Packings
Enfriadores de vapor	Steam De-Superheaters
Enganches de Ferrocarril	Railway Couplings
Engranaje de Ruedas	Wheel Gearing
Engranaje Espiral	Helical Gearing
Engranajes	Gearing
Engranajes de Reducción	Reduction Gears
Engranajes de Turbinas. *Véase* Turbinas con Engranaje	Turbine Gears. *See* Geared Turbines
Engranajes Rectos y Cónicos	Spur and Bevel Gearing
Engranajes y Ejes para Fábricas, etca. *Véase* Ejes y Engranajes	Mill Gearing, Shafting, etc. *See* Shafting and Gearing
Enseñanza Técnica Práctica. *Véase* Escuelas y Colegios	Technical Training. *See* Schools and Colleges
Entrecalentadores y Recalentadores	Interheaters and Reheaters
Equipo de Teléfonos	Telephone Equipment
Equipo para Combustible Pulverizado	Pulverised Fuel Equipment
Escamas y Corrosión de las Calderas (Preventivos de)	Scale and Corrosion in Boilers (Preventives of)
Escantillones	Draught Gauges
Escobillas de Dinamos	Dynamo Brushes
Escuadras de Acero	Squares
Escudos de Protección para Maquinaria	Machinery Guards
Escuelas y Colegios de Ingenieros	Schools and Colleges (Engineering)
Esmaltes, Colores y Barnices	Enamels, Colours, and Varnishes
Establecimiento de Ferrocarriles y Tranvías	Railway and Tramway Plant
Estampación Metálica	Stampings
Evaporadores, Condensadores, Aparatos Destiladores de Agua, etca.	Evaporators, Condensers, Water Distilling Apparatus, etc.
Evaporadores al Vacío para Líquidos Químicos	Vacuum Evaporators for Chemical Liquids
Evaporadores de Efecto Múltiple	Multiple Effect Evaporators
Excavadoras eléctricas	Grabbing Cranes (Electric)
Excavadoras y Transportadoras	Excavators and Transporters

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ESPAÑOL.	INGLÉS.
Explosivos	Explosives
Explosivos para Minas	Mining Explosives
F	
Fabricantes de Alambre	Wire Manufacturers
Fabricantes de Alambres Aislados	Wire (Insulated) Manufacturers
Fabricantes de Calderas	Boiler Manufacturers
Fabricantes de Caucho, Gutapercha y Betún	India Rubber, Gutta Percha, and Bitumen Manufacturers
Fabricantes de Herramientas, Maquinistas, etca.	Tool Makers, Machinists, etc.
Fabricantes de Herramientas para Hacer Pozos Artesianos	Boring Tool Makers (Artesian)
Fabricantes y Comerciantes de Acero	Steel Manufacturers and Merchants
Fabricantes y Comerciantes de Hierro y Acero	Iron and Steel Manufacturers and Merchants
Fajas y Guita para Fábricas	Mill Bandings and Twines
Faroles (traseros)	Lamps (Rear)
Ferrocarriles Económicos, Portátiles, etca.	Railways: Light, Portable, etc.
Ferrocarriles y Tranvías Eléctricos	Electric Railways and Tramways
Fibra Vulcanizada	Fibre (Vulcanised)
Fieltro y Techos de Fieltro	Felt and Felt Roofs
Fieltros para Fabricantes de Papel	Paper Makers' Felts
Fieltros para Máquinas de Imprimir, Maquinaria para Fabricar Papel y para Estampar Telas de Algodón	Felts for Printing Machinery, Paper Making, and Calico Printing Machinery
Fieltros para Tejados	Roofing Felts
Filtradores de Aire	Air Filters
Filtros de Aceites	Oil Filters
Filtros de Alimentación de Calderas. *Véase* Agua de Alimentación	Boiler Feed Filters. *See* Feed Waters.
Forros de Paredes Resistentes á la Humedad	Damp Course and Bitumen Sheeting
Forros Embetunados contra la Humedad	Bitumen Damp-proof Sheeting
Forros para Tubos	Pipe Coverings
Fraguas y Instalaciones de Herrería	Smiths' Hearths and Plant
Fraguas Portátiles	Forges (Portable)
Frenos Automáticos Eléctricos	Automatic Controllers (Electric)
Frenos de Ferrocarriles	Railway Brakes
Frenos (Dinamómetros)	Brakes (Dynamometers)
Frenos (Electromecánicos)	Brakes (Electro-Mechanical)
Frenos (Ferrocarril)	Brakes (Railway)
Fresa Escoriadora con Espiga	End Mills
Fresas	Milling Cutters
Fresas. *Véase* Maquinaria para Fresar	Grinders. *See* Grinding Machinery
Fresas de Taladro y Machos de Tarraja	Reamers and Taps
Fundidores	Founders
Fundidores de Latón	Brass Founders
G	
Galvanizadores	Galvanisers
Gatos Duff	Duff Jacks
Gatos Hidráulicos y de Tornillo para Levantar Pesos	Jacks (Hydraulic and Screw)

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ESPAÑOL.	INGLÉS.
Generadores Eléctricos. *Véase* Dinamos y Motores	Generators (Electric). *See* Dynamos and Motors
Grabadores, Delineantes e Impresores	Engravers, Draughtsmen, and Printers
Grafito	Graphite
Grafito, especialidades de, 'Foliac'	'Foliac' Graphite Specialities
Grafito 'Foliac' para Calderas	'Foliac' Boiler Graphite
Grasa Lubricante	Grease (Lubricating)
Greda	Chalk
Grifos de Latón para Agua, Vapory Gas	Cocks (Brass) for Water, Steam, and Gas
Gruas. *Véase* Maquinaria para Elevar Pesos	Cranes. *See* Lifting and Hoisting Machinery
Gruas a Brazo. *Véase* Maquinaria de Elevar Pesos	Hand Cranes. *See* Lifting and Hoisting Machinery

H

Hélices Propulsoras	Screw Propellers
Herraje de Chapas y de Hierro Batido	Wrought and Sheet Ironwork
Herramientas de Mano y Mecánicas. *Véase* Herramientas y Accesorios para Ingenieros	Machine and Hand Tools. *See* Engineers' Tools and Fittings. *Also* Tool Makers
Herramientas para Explotar Canteras	Quarrying Tools
Herramientas para Minas	Mining Tools
Herramientas par Rascar Metales	Scaling Tools
Herramientas 'Speedicut' para grandes velocidades	'Speedicut' High-Speed Tools
Herramientas y Accesorios para Ingenieros	Engineers' Tools and Fittings
Herramientas y Maquinaria para la Agricultura	Agricultural Tools and Machinery
Herramientas y Máquinas para Contratistas de Obras	Contractors' Tools and Plant
Herramientas y Utensilios Neumáticos	Pneumatic Tools and Appliances
Hierro Fundido	Cast Iron
Hierro y acero en recortes	Iron and Steel Scrap
Hierro y Acero Galvanizados, Fabricantes de	Galvanised Iron and Steel Manufacturers
Hierro ondulado	Corrugated Iron.
Hojas de Sierras Tajaderas	Hack Saw Blades
Hojas y Tubos de amianto cemento 'Everite'	'Everite' Asbestos Cement Sheets and Pipes
Hojas incombustibles para divisiones y paredes	Fireproof Partition and Wall Sheets
Hormigón Armado. *Véase* Construcciones de Hormigón Armado	Ferro-Concrete. *See* Reinforced Concrete
Hornos Calentados con Gas y Petróleo e Industriales	Furnaces (Gas and Oil Heated and Industrial)
Hornos de Aceite. *Véase* Hornos	Oil Furnaces. *See* Furnaces
Hornos de Calderas	Boiler Furnaces
Hornos de Calderas. *Véase* Accesorios de Máquinas y Calderas	Furnaces (Boiler). *See* Engine and Boiler Fittings
Hornos de Carbón. *Véase* Hornos etca.	Coal Furnaces. *See* Furnaces
Hornos de Forjar. *Véase* Hornos	Forging Furnaces. *See* Furnaces

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ESPAÑOL.	INGLÉS.
Hornos de Gas. *Véase* Hornos	Gas Furnaces. *See* Furnaces
Hornos e Instalaciones de Gas Industriales	Industrial Gas Furnaces and Plants
Hornos para Templar. *Véase* Hornos	Tempering Furnaces. *See* Furnaces
I	
Imánes para Atraer Cuerpos	Lifting Magnets
Impresores, Litógrafos, Delineantes y Grabadores	Printers, Lithographers, Draughtsmen, and Engravers
Indicadores (Máquinas de Vapor)	Indicators (Steam Engine)
Indicadores de Cristal	Gauge Glasses
Indicadores de Nivel de Agua	Water Level Indicators
Indicadores de Nivel de Agua, etca. *Véase* Manómetros	Water Gauges, etc. *See* Steam Gauges
Indicadores de señales para minas	Mine Signal Indicators
Indicadores Hidráulicos	Hydraulic Gauges
Indicadores Marinos de Velocidad	Marine Speed Indicator
Ingenieros (Aeronáuticos). *Véase* Aeronautica (Ingenieros)	Engineers (Aeronautical). *See* Aeronautical Engineers
Ingenieros constructores	Constructional Engineers
Ingenieros de Fuerza Hidráulica	Water Power Engineers
Ingenieros de Minas	Mining Engineers
Ingenieros de Pozos Artesianos	Artesian Well Engineers
Ingenieros Metalúrgicos	Metallurgical Engineers
Ingenieros de Telégrafos	Telegraph Engineers
Ingenieros de Ventilación	Ventilating Engineers
Ingenieros Eléctricos	Electrical Engineers
Ingenieros Hidráulicos	Engineers (Hydraulic)
Ingenieros Mecánicos	Engineers (Mechanical)
Instalación de Altos Hornos	Blast Furnace Plant
Instalación de Alumbrado de Trenes	Train Lighting Plant
Instalación de Fabricas de Fundición	Foundry Plant
Instalaciones de Carga y Transporte	Loading and Transport Plants
Instalaciones de Gas de Succión	Suction Gas Plants
Instalaciones de Petróleo	Oil Burning Installations
Instalaciones Generadoras de Oxígeno e Hidrógeno	Oxygen and Hydrogen Generating Plants
Instalaciones de Tracción. *Véase* Máquinas de Izar y Tirar	Hauling Plant. *See* Winding and Hauling
Instalaciones destiladoras de baja temperatura	Low Temperature Distillation Plants
Instalaciones Hidro-Eléctricas	Hydro-Electric Plants
Instalaciones neumáticas de transporte	Pneumatic Conveying Plants
Instalaciones para Aprovechar Materias	Recovery Plants
Instalaciones para Acondicionar el Aire	Air Conditioning Plants
Instalaciones para el Manejo de Carbón, Coque y Cenizas	Coal, Coke, and Ash Handling Plants
Instalaciones para Explotación de Minas y Arrastres	Mining and Hauling Plant
Instalaciones para Producir Gas. *Véase* Productores de Gas	Producer Gas Plants. *See* Gas Producers

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ESPAÑOL.	INGLÉS.
Instalaciones para recoger basura y residuos	Dust and Refuse Collecting Plants
Instalaciones para Utilizar Basuras	Refuse Utilization Plants
Instalaciones y Accesorios para Cortar y Soldar, por Arco Eléctrico	Electric Arc Cutting and Welding Plant and Accessories
Instalaciones y Maquinaria para Industrias Químicas	Chemical Plant and Machinery
Instalaciones y Utensilios Hidráulicos	Hydraulic Plants and Appliances
Instituciones de Instrucción. *Véase* Colegios y Escuelas	Educational Institutions. *See* Colleges and Schools
Instrumentos Científicos	Scientific Instruments
Instrumentos de Aeronautica	Aeronautical Instruments
Instrumentos de Agrimensura, Matemáticas, Dibujo, etca.	Instruments: Surveying, Mathematical, Drawing, etc
Instrumentos de Agrimensura y Dibujo	Surveying and Drawing Instruments
Instrumentos de Matemáticas, Dibujo y Agrimensura	Mathematical, Drawing, and Surveying Instruments
Instrumentos Eléctricos de Medición. *Véase* Instrumentos	Measuring Instruments (Electrical). *See* Instruments
Instrumentos Meteorológicos	Meteorological Instruments
Instrumentos para conta	Counting Instruments
Instrumentos para Pruebas Eléctricas. *Véase* Instrumentos	Testing Instruments (Electrical). *See* Instruments
Instrumentos Registradores	Recording Instruments
Instrumentos y Aparatos Eléctricos. *Véase* Instrumentos y Aparatos (Eléctricos)	Electrical Instruments and Apparatus. *See* Instruments and Apparatus (Electrical)
Inyectores, Expulsores y Accesorios Generales. *Véase* Inyectores de Vapor	Injectors, Ejectors, and General Jet Appliances. *See* Steam Injectors
Inyectores de Vapor	Steam Injectors
J	
'Jubilee': Marca de los sujetadores con movimiento de rosca (Patente)	'Jubilee' Worm-Drive Clips (Patent)
Juntas de 'Beldamite'	Jointing ('Beldamite')
Juntas de Vapor. *Véase* Materiales para Juntas	Steam Jointing. *See* Jointing Materials
Juntas Flexibles. *Véase* Conexiones Flexibles	Couplings (Flexible) *See* Flexible Couplings
Juntas ('Lion' y 'Walkerite')	Joints ('Lion' 'Walkerite')
Juntas (tipo rótula 'Flexstel')	Joints ('Flexstel' Ball and Socket)
L	
Ladrillos Refractarios y Artículos de Arcilla Refractaria	Fire Bricks and Fire Clay Goods
Laminadores (Equipo Eléctrico de)	Rolling Mills (Electrical Equipment of)
Lámparas de Arco. *Véase* Aparatos para Alumbrado Eléctrico	Arc Lamps. *See* Electric Light Fittings
Lámparas de mano y de llamarada de acetileno (tipo portátil)	Acetylene Hand and Flare Lamps (Portable)
Lámparas de Filamento Metálico	Metal Filament Lamps
Lámparas de Seguridad para Mineros	Miners' Safety Lamps
Lámparas Eléctricas. *Véase* Aparatos de Alumbrado Eléctrico, etca.	Lamps (Electric). *See* Electric Light Fittings, etc.

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ESPAÑOL.	INGLÉS.
Lamparas Industriales	Lamps (Industrial)
Lana de Escoria	Mineral Wool
Lanchas de Vapor y de Motor	Launches (Steam and Motor)
'Lascar,' Empaquetadura	Packing ('Lascar')
Latón y Bronce	Brass and Bronze
Libros y Periódicos Cientificos	Books and Journals, Scientific
Limpiadores al vacio	Vacuum Cleaners
Limpiadores de Calderas (Mecánicos y Eléctricos)	Boiler Cleaners (Mechanical and Electrical)
Limpiatubos	Tube Cleaners
Líneas blancas (permanentes)	White Lines (Permanent)
Lineas de Tubos	Pipe Lines
Lingotes de Acero	Billets (Steel)
Lingotes de Bronce de Cañón	Gunmetal Ingots
Lingotes de Bronce de Cañón para el Almirantazgo	Admiralty Gun-metal Ingots
Llantas Sólidas de Caucho para Vehiculos Comerciales	Solid Rubber Tyres for Commercial Vehicles
Llantas y ejes para ferrocarril	Railway Tyres and Axles
Locomotoras	Locomotives
Locomotoras de Petróleo (combustión interna)	Oil Locomotives (Internal Combustion)
Lubricadores y Lubricantes	Lubricator and Lubricants
Lubricantes para Motores	Motor Lubricants
M	
Mandriles Magnéticos	Magnetic Chucks
Manganeso y Aleaciones de Manganeso	Manganese and Manganese Alloys
Mangueras Flexibles Metálicas	Hose (Flexible Metallic)
Mangueras para Bomberos, Fábricas, etca.	Hose for Fire Brigades, Mills, etc.
Manguitos de Empalme de Mangueras	Hose Couplings
Manómetros del condensador	Vacuum Gauges
Manómetros, Grifos, Indicadores de Nivel de Agua, Válvulas de Seguridad, Valvulas de Distribución, Indicadores, Válvulas de Retención de Vapor, etca.	Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.
Maquinaria Hidráulica, 'Sistema de Tweddell'	'Tweddell's System Hydraulic Machinery
Maquinaria para Amolar	Grinding Machinery
Maquinaria para Cemento	Cement Machinery
Maquinaria para Elevar Pesos y Aparejos para Izar	Lifting and Hoisting Machinery and Lifting Tackle
Maquinaria para Fabricar Cartuchos	Cartridge Machinery
Maquinaria para Fabricar Hielo. *Véase* Maquinaria Refrigerante	Ice-making Machinery. *See* Refrigerating Machinery
Maquinaria para Fabricar Papel y Pasta para Papel	Paper and Pulp-making Machinery
Maquinaria para Hacer Pasta para Papel	Pulp-making Machinery
Maquinaria para Hacer Tuneles	Tunnelling Plants
Maquinaria para Labrar Madera	Wood-working Machinery
Maquinaria para Lavar Carbón	Coal-washing Machinery
Maquinaria para Limpiar Cereales y Semillas	Grain and Seed Cleaning Machinery
Maquinaria para Minas de Carbón	Colliery Plant

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ESPAÑOL.	INGLÉS.
Maquinaria para Moler, Elevar y Conducir Carbón	Coal Grinding, Elevating and Conveying Machinery
Maquinaria para Pulimentar	Polishing Machinery
Maquinaria para Tender Cables	Cable-Laying Machinery
Maquinaria para Trabajos de Minas. *Véase* Instalaciones de Mineria y Tracción	Mining Machinery. *See* Mining and Hauling Plant
Maquinaria para Triturar y Pulverizar	Crushing and Pulverising Machinery
Maquinaria Refrigerante	Refrigerating Machinery
Maquinas Automáticas, Fabricantes de	Automatic Machine Makers
Máquinas de adujar con eje flexible	Flexible Shaft Coiling Machines
Máquinas de Fresar	Milling Machines
Máquinas de Gasolina. *Véase* Máquinas de Petróleo y de Gas	Petrol Engines. *See* Oil and Gas Engines
Máquinas de Izar y Tirar	Winding and Hauling
Máquinas de Petróleo, de Gas y de Esencia de Petróleo	Oil, Gas, and Petrol Engines
Máquinas de pesar automáticas	Automatic Weighing Machines
Máquinas de Tracción, de Vapor y Eléctricas	Traction Engines (Steam and Electric)
Máquinas de Vapor	Steam Engines
Máquinas de Volar, Constructores de. *Véase* Aeroplanos, Constructores de	Aircraft Manufacturers. *See* Aeroplane Builders
Máquinas Electromagnéticas	Machinery (Electro-Magnets)
Máquinas, Herramientas y Utensilios Hidráulicos, etca.	Hydraulic Machines, Tools and Appliances, etc.
Máquinas Laminadoras	Rolling Mill Engines
Máquinas Marinas de Petróleo	Marine Oil Engines
Máquinas Motrices de Aceite Crudo. *Véase* Máquinas de Petróleo	Crude Oil Engines. *See* Oil Engines
Máquinas Motrices de Gas, Petróleo y Gasolina	Gas, Oil, and Petrol Engines
Máquinas Motrices de Vapor. *Véase* Máquinas de Vapor	Engines (Steam). *See* Steam Engines
Máquinas Motrices Diesel y Semi-Diesel	Diesel and Semi-Diesel Engines
Máquinas Motrices é Instalaciones de Izar y Tirar	Winding and Hauling Engines and Plant
Máquinas Motrices Hidráulicas	Engines (Hydraulic)
Máquinas Motrices Móviles	Portable Engines
Máquinas para Agujerear, Cortar y Combar	Punching, Shearing, and Bending Machines
Máquinas para Cepillar, Escoplear, Atornillar y Moldear	Planing, Slotting, Screwing, and Shaping Machines
Máquinas para Combar Tubos	Pipe Bending Machines
Máquinas para Cortar, Agujerear y Cimbrar	Shearing, Punching, and Bending Machines
Máquinas para Elevar. *Véase* Maquinaria para Elevar Pesos, etca.	Hoists. *See* Lifting and Hoisting
Máquinas para Hacer Pruebas	Testing Machines
Máquinas para Pesar, Básculas	Weighing Machines
Máquinas para Pintar	Painting Machines
Máquinas para Probar Cemento	Cement Testing Machines
Máquinas para Pruebas de Cemento de Portland	Testing Machines for Portland Cement
Máquinas para Renovar Asientos de Válvulas	Valve Reseaters
Máquinas para Soldar	Soldering Machines

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ESPAÑOL.	INGLÉS.	ESPAÑOL.	INGLÉS.
Máquinas para Sondear en Roca y Carbón	Boring Machines for Rock and Coal	Metal Delta	Delta Metal
		Metal en recortes. *Véase* recortes de Metal	Metal Scrap. *See* Scrap Metals
Máquinas para Taladrar y para Igualar Superficies	Boring and Facing Machines	Metal Expansivo	Expanded Metal
		Metal plástico de Richards	Plastic Metal (Richards')
Máquinas para la fundición de matrices	Die-Casting Machines	Metales, Comerciantes en	Metal Merchants
Máquinas de pesar líquidos	Liquid Weighing Machines	Metales en Lingotes	Ingot Metals
		Metales Exturbados	Extruded Metals
Máquinas pesadoras de cereales	Grain Weighing Machines	Metales para Cojinetes, etca.	Bearing Metals, etc.
Máquinas y Calderas Marinas y Maquinaria Auxiliar	Marine Engines, Boilers, and Auxiliary Machinery	Metales Perforados	Perforated Metals
		Metales: para Cojinetes, Antifricción, etc.	Metals: Bearing, Anti-friction, etc.
Martillos de Forjar	Forging Hammers		
Martillos de Golpe y Martinetes	Drop Stamps and Presses	Metales para Disminuir la Fricción	Anti-friction Metals
Martinetes (de Fricción y de Caida Libre de Vapor)	Stamps (Friction and Steam Drop)	Mezcladores de aceites	Oil Blenders
Martinetes de Fuerza Mecánica. *Véase* Martinetes de Vapor	Power Hammers. *See* Hammers	Mica	Mica
		Micrómetro	Micrometers
		Microscopios	Microscopes
Martinetes de Vapor. *Véase* Martinetes	Steam Hammers. *See* Hammers	Minas de Carbón (Cuerdas de Alambre de Acero para)	Collieries (Steel Wire Ropes for)
Martinetes de Vapor, de Aire Comprimido, Neumáticos, etca.	Hammers (Steam, Compressed Air, Pneumatic Power, etc.)	Minas de Carbón (Equipo Eléctrico de)	Collieries (Electrical Equipment of)
		Molinetes de Fricción	Winches (Friction)
Material Rodante. *Véase* Establecimiento de Ferrocarriles y Tranvías	Rolling Stock. *See* Railway and Tramway Plant	Molinos Aereos Eléctricos	Aerial Grinders (Electric)
		Molinos de Aceite	Oil Mill Machinery
		Molinos de Centrar (Eléctricos)	Centre Grinders (Electric)
Materiales Aisladores	Insulating Materials	Molinos para Pulverizar Piedra	Stone Pulverising Mills
Materiales para Juntas	Jointing Materials	Molinos Harineros	Flour-Milling Machinery
Materiales 'Rok' para Tejados	'Rok' Roofing		Mills (Pulverising)
Materias tintóreas	Dyestuffs.	Molinos Pulverizadores	
Mecanismos Lubricantes	Lubricating Devices	Montacargas Hidráulicos. *Véase* Maquinaria para Elevar Pesos, etca.	Hydraulic Lifts. *See* Lifting and Hoisting
Medición de Agua de Alimentación	Feed-Water (Measurement of)		
Medidas ó Codos Acero	Steel Rules	Motores Eléctricos. *Véase* Dinamos y Motores	Electric Motors. *See* Dynamos and Motors
Metal de Bull y Melloid	Bull's Metal and Melloid		

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ESPAÑOL.	INGLÉS.
N	
Nitrógeno	Nitrogen
O	
Obra de Alambre y Alambre Tejido	Wire Work and Woven Wire
Obra de Latón de Plomeros	Plumbers' Brass-work
Obra de Metal en Planchas, Cubiertas de Cilindros, etca.	Sheet Metal Work, Cylinder Cases, etc.
Obras de Edificación de Hierro y Acero	Structural Iron and Steel Work, etc.
Oscilógrafos	Oscillographs
Oxígeno	Oxygen
P	
Palastros y Lingotes de Acero	Steel (Blooms and Billets)
Paleros Mecánicos	Mechanical Stokers
Paleros (Mecánicos). *Véase* Paleros Mecánicos	Stokers (Mechanical). *See* Mechanical Stokers
Pantómetras. *Véase* Instrumentos de Matemáticas, etca.	Slide Rules. *See* Instruments, Mathematical, etc.
Papel impermeable	Paper (Waterproof)
Papel y Cañamazo 'Willesden'	'Willesden' Paper and Canvas
Pararrayos	Lightning Conductors
Pavimentos y Losetas de caucho	Rubber Flooring and Tiles
Peldaños	Stair Treads
Periódicos Técnicos. *Véase* Libros y Periódicos	Journals (Technical). *See* Books and Journals
Perforaciones (Bombas para pozos profundos)	Borehole (Deep Well Pumps)
Pernos Aisladores de Telégrafo y toda clase de obra de Hierro para Telégrafo y Teléfono	Telegraph Insulator Bolts and all kinds of Ironwork for Telegraph and Telephone
Pernos y Tuercas de Hierro, Acero, Cobre, Bronce Naval, etca.	Bolts and Nuts (Iron, Steel, Copper, Naval Brass, etc.)
Pernos y Tuercas de Latón y Cobre. *Véase* Pernos y Tuercas de Hierro, etca.	Brass and Copper Bolts and Nuts. *See* Bolts and Nuts
Picos y Palas, etca.	Picks, Shovels, etc.
Pieza fundida de Aluminio para Dados	Aluminium Die Castings
Piezas de Acero Forjado y Fundido. *Véase* Piezas Fundidas y Forjadas	Steel Forgings and Castings. *See* Castings and Forgings
Piezas de Cobre Forjadas	Copper Forgings
Piezas de fundición en general	General Foundry Castings
Piezas de Latón prensadas en caliente	Hot Brass Pressings
Piezas Forjadas y Fundidas. *Véase* Piezas Fundidas y Forjadas	Forgings and Castings. *See* Castings and Forgings
Piezas Fundidas para Matrices	Die Castings
Piezas Fundidas para Válvulas	Valve Castings
Piezas Fundidas y Forjadas	Castings and Forgings
Piezas Prensadas Hidráulicamente	Hydraulic Pressings
Pilas y Baterías de Acumulación	Storage Cells and Batteries
Pilas y Baterías de Acumulación Eléctrica. *Véase* Baterías (Acumulación Eléctrica)	Electrical Storage Cells and Batteries. *See* Storage Cells
Pintura al Temple	Distemper
Pintura Anticorrosiva	Anti-corrosive Paint
Pintura Silica-Grafito 'Foliac'	'Foliac' Silica-Graphite Paint
Pinturas, Colores, Esmaltes y Barnices	Paints, Colours, Enamels, and Varnishes

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ESPAÑOL.	INGLÉS.
Pinturas para Conservar Obra de Hierro y Acero	Paints for Preserving Iron and Steel Work
Pirómetros	Pyrometers
Pizarras para techos	Slating
Pizarras y Planchas de Cemento	Cement Slates and Boards
Planchas con marcas de fábrica	Trade Mark Plates
Planchas con nombres para todas las industrias	Name Plates for all Trades
Planchas con números	Number Plates
Planchas de acero	Steel Sheets
Planchas de acero a prueba de balas	Bullet-Proof Steel Plates
Planchas de Acero para Calderas	Boiler Plates (Steel)
Planchas de hierro	Iron Sheets
Planchas para Suelos	Plates (Floor)
Planímetros	Surface Gauges
Plataformas giratorias	Turntables
Poleas	Pulleys
Poleas para Correas y Cuerdas de Transmisión	Belt and Rope Pulleys
Poleas para Cuerdas. *Véase* Poleas para Correas y Cuerdas de Transmisión	Rope Pulleys. *See* Belt and Rope Pulleys
Pólvora para Barrenos	Blasting Powder
Postes de Hierro para Telégrafos	Telegraph Poles (Iron)
Prensas con Fuerza Motriz	Power Presses
Prensas de Cimbrar	Bending Presses
Prensas de Forjar	Forging Presses
Prensas para Desperdicios de Metales	Scrap Presses
Prensas para Llantas	Tyre Presses
Preparaciones para última Mano á las Máquinas	Machinery Finishes
Preservativos (Calderas)	Preservatives (Boiler)
Preservativos de Calderas	Boiler Preservatives
Preservativos (Madera)	Preservatives (Wood)
Preservativos de la Madera	Wood Preservatives
Preventivos del Moho	Rust Preventives
Productores de Gas	Gas Producers
Productos Químicos	Chemicals
Propulsión Electrica de Buques	Electric Ship Propulsion
Propulsores	Propellers
Protectores de Indicadores de Cristal	Gauge Glass Protectors
Provisión de Ingeniería y Material de Ferrocarriles. *Véase* Establecimiento de Ferrocarriles y Tranvías	Engineering and Railway Supplies. *See* Railway and Tramway Plant
Publicaciones Técnicas. *Véase* Libros y Periódicos	Publications (Technical). *See* Books and Journals
Puentes de báscula	Weighbridges
Puentes Colgantes de Cables de Alambre	Bridges (Wire Rope Suspension)
Puertas Abatibles	Collapsible Gates
Pulverizadores (Molinos)	Pulveriser Mills
Puntales de Acero	Stanchions (Steel)
Punzones y Matrices	Punches and Dies
Q	
Químicos Hidrológicos	Hydrological Chemists
R	
Rampa de encarrilamiento	Railway Re-railing Ramps
Rampas de ferrocarriles	Railway Ramps
Recalentadores	Superheaters
Recalentadores de Locomotoras	Locomotive Superheaters
Recalentadores Marinos	Marine Superheaters
Recipientes de almacenaje (para muebles de acero)	Storage Bins (for Steel Furniture)

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ESPAÑOL.	INGLÉS.
Recortes y Desperdicios de Metales	Metals (Scrap)
Redes de Alambre Galvanizado	Galvanised Wire Netting
Refrenadores y Aparatos de Arrancada (Líquido)	Controllers and Liquid Starters
Refrigeradores de Aceite	Oil Coolers
Refuerzos de Embragues	Clutch Linings
Refuerzos de Frenos y Embragues	Brake and Clutch Linings
Refuerzos para Hormigón Armado	Concrete (Reinforcement for)
Registradores de Agua	Water Recorders
Registradores de CO_2	CO_2 Recorders
Registradores de Gastos y Tiempo	Costs and Time Recorders
Registradores de la Producción de Cada Máquina	Machine Output Recorders
Registradores de Tiempo	Time Recorders
Reguladores Automáticos	Regulators (Automatic)
Reguladores de Agua de Alimentación	Water Regulators (Feed)
Reguladores de Temperatura	Temperature Regulators
Reguladores de Máquinas de Vapor	Governors (Steam Engine)
Reguladores Hidráulicos	Governors (Hydraulic)
Registradores de Velocidad	Recorders (Speed)
Relojes Eléctricos	Electric Clocks
Remachadoras Eléctricas	Riveters (Electric)
Remachadoras Hidráulicas y Neumáticas	Riveters (Hydraulic and Pneumatic)
Remaches de Hierro, Acero, Cobre, Bronce Naval etca.	Rivets (Iron, Steel, Copper, Naval Brass, etc.)
Removedores de Hollín	Soot Removers
Reparación de Buques y de Máquinas Motrices	Ship and Engine Repairers
Retortas de Gas	Gas Retorts
Rieles Fabricantes de	Rail Manufacturers
Rieles y Accesorios de Acero	Steel Rails and Accessories
Rieles y clavazón	Rails and Fastenings
Rociadoras	Spraying Machines
Rodillos de acero	Steel Rollers
'Rosseline' (para Máquinas de Gas de Petróleo)	'Rosseline' (for Gas and Oil Engines)
'Ruberoid,' Material para Tejados	'Ruberoid' Roofing
Ruedas de engrane de cadenas	Chain Wheels
Ruedas de Pelton	Pelton Wheels
Ruedas Hidráulicas, Motores Hidráulicos y Turbinas	Water Wheels, Water Motors, and Turbines
S	
Secaderos y Purificadores de Vapor	Steam Dryers and Purifiers
Secciones de (Metales Exturbados, con Privilegio de Invención) Bronce, Latón, etca.	Sections (Patent Extruded), Brass, Bronze, etc.
Señales. *Véase* Señales de Ferrocarriles	Signals. *See* Railway Signals
Señales de Ferrocarriles y Utensilios de Seguridad	Railway Signals and Safety Appliances
Señales Impermeables Herméticas para Minas	Mining Signals (Water-tight)
Separación de Aceite del Vapor Condensado	Separation of Oil from Condensed Steam
Separadores de Grasa	Grease Separators
Separadores de vapor	Steam Separators
Separadores Magnéticos	Magnetic Separators

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ESPAÑOL.	INGLÉS.
Separadores Magnéticos para Destructores	Destructors(Magnetic Separators for)
Separadores mecánicos	Mechanical Separators
Serpentinas	Pipe Coils
Sextantes	Sextants
Sierras para cortar madera y metales	Saws for Wood and Metal Cutting
Sistemas de Alambres Eléctricos Flexibles	Wiring Systems (Flexible)
Sistemas de Instalación de Alambres eléctricos. *Véase* Sistemas de instalación de Alambres Flexibles)	Electric Wiring Systems. *See* Wiring Systems (Flexible)
Sistemas para conducir dinero	Cash Carrier Systems
Soldadura	Solder
Soldadura á Martillo y Corte de Metales	Welding and Cutting of Metals
Soldadura 'Daysohms' de Arco Eléctrico	'Davsohms' Electric Arc Welding
Soldadura de Arco Eléctrico para Reparar Calderas	Boiler Repairs (Electric Arc Welding for)
Soldadura de Oxiacetileno	Oxy-AcetyleneWelding
Soldadura Eléctrica	Electric Welding
Soldadura 'Thermit'	'Thermit' Welding
Soportes de rodillos	Roller Bearings
Sopletes de Acetileno para Solda y Cortar	Blowpipes (Acetylene Welding & Cutting)
Sopladores. *Véase* Aparatos Soplantes	Blowers. *See* Fans
Suelos, etca. (Resistentes al Fuego)	Floors, etc. (Fire Resisting)
Sujetadores ('Jubilee' con movimiento de rosca (Patente))	Clips ('Jubilee' Worm - Drive (Patent))
Sujetadores de expansión	Expanding Clips
Sujetadores de mangueras	Hose Pipe Clips
Sujetadores de radiadores	Radiator Clips
Superficies de Fricción	Friction Surfaces
Superficies de Fricción de 'Ferodo'	'Ferodo' Friction Surfaces

T

Tableros de conmutadores de batería	Battery Switchboards
Tableros de conmutadores de baterías de acumulación	Storage Battery Switchboards
Tachones, Pernos y Tuercas de Aluminio	Aluminium Studs, Bolts and Nuts
Tachos al Vacío (Concentradores)	Vacuum Pans (Concentrating)
Tachos y Pailas para Azucar y otras Industrias	Evaporators for Sugar and Trade Liquors
Taladros de Punta de Diamante	Diamond Drillers
Taladros para Perforar Rocas	Rock Drills
Taladros Salomónicos	Twist Drills
Taladros y Cinceles para Minas de Carbón	Coal Drills and Cutters
Taladros y Máquinas para Taladrar	Drills and Drilling Machines
Taladros y Martinetes Portátiles Eléctricos	Electric Portable Drills and Hammers
Tambores para Aceite	Oil Drums
Tanques y Cisternas	Tanks and Cisterns
Taquímetros	Tachometers
Tejados, Edificios de Hierro, etca.	Roofs, Iron Buildings, etc.
Tejidos de Fricción 'CHEKKO'	'CHEKKO' Friction Fabrics
Tejas de Amianto	Asbestos Roofing Tiles
Tejas y Hojas acanaladas (Amianto-Cemento)	Corrugated Tiles and Sheets (Asbestos-Cement)
Tela metálica	Wire Gauze
Temple superficial	Case Hardening
Termómetros	Thermometers

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ESPAÑOL.	INGLÉS.
Tirantes de Trincheras	Trench Braces
Tiza	Whiting
Toberas de doble expansión de modelo 'DU-EX'	DU-EX' Double Expansion Nipples
Toberas de hornos de fundición	Blast Furnace Tuyères
Topes de Ferrocarriles	Railway Stop Blocks
Tornería de Metale	Turned Work (any Metal)
Tornillos Hechos á Máquina	Machine Screws
Tornillos (Hierro, Acero, Cobre y Bronce Naval)	Screws (Iron, Steel, Copper, and Naval Brass)
Tornos. *Véase* Fabricantes de Herramientas	Lathes. *See* Tool Makers
Torres de Agua	Water Towers
Torres de Enfriamiento	Cooling Towers
Transformadores de energía eléctrica	Transformers (Electric Power)
Transformadores en Cascada	Motor Converters.
Transformadores Rotatorios	Rotary Converters
Transmisión Hidraulica (Petróleo)	Transmission (Hydraulic, Oil)
Transportadores	Transporters
Transportadores. *Véase también* Correas de Transmisión	Conveyors. *See also* Belting
Tranvías (Cuerdas de Alambre de Acero para)	Tramways (Steel Wire Ropes for)
Tranvías y Ferrocarriles Eléctricos. *Véase* Ferrocarriles y Tranvías Eléctricos	Tramways and Railways (Electrical). *See* Electric Railways and Tramways
Trapiches y Maquinaria para Fabricar Azucar	Sugar Mills and Machinery
Tratamiento de metales al calor	Heat Treatment of Metals
Tubería Flexible Metálica	Tubing (Flexible Metallic)
Tubería Metálica Flexible	Flexible Metallic Tubing
Tubos. *Véase* Tubos y Accesorios, etca.	Pipes. *See* Tubes
Tubos de Acero. *Véase* Tubos	Steel Tubes. *See* Tubes
Tubos de Calderas	Boiler Tubes
Tubos de Cobre	Copper Tubes
Tubos de Hierro. *Véase* Tubos	Iron Tubes. *See* Tubes
Tubos de Hierro y de Acero	Iron and Steel Tubes
Tubos de Manguera, Mangueras de Cuero y de Lona, etca.	Hose Pipes, Leather and Canvas Hose, etc.
Tubos de Vapor. *Véase* Tubos	Steam Pipes. *See* Tubes
Tubos Flexibles para Calefacción á Vapor	Steam Heating Tubes (Flexible)
Tubos Hidráulicos	Hydraulic Tubes and Pipes
Tubos Neumáticos	Tubes (Pneumatic)
Tubos Neumáticos para Conducir Despaches, etc.	Pneumatic Despatch Tubes, etc.
Tubos para Condensadores (Cobre). *Véase* Tubos de Cobre	Condenser Tubes (Copper). *See* Copper Tubes
Tubos para Locomotoras	Loco Tubes
Tubos Accesorios	Tubes and Fittings
Tubos y Aparatos de Gas	Gas Tubes and Fittings
Tubos y Serpentines para Refrigerar	Refrigerating Tubes and Coils
Tuercas	Nuts
Turbinas con Engranaje (Auxiliares)	Geared Turbine Auxiliaries
Turbinas de Vapor. *Véase* Turbinas de Vapor y sus Accesorios	Turbines (Steam). *See* Steam Turbines
Turbinas de Vapor y sus Accesorios	Steam Turbines and Fittings
Turbinas, Ruedas Hidráulicas y Motores Hidráulicos	Turbines, Water Wheels, and Water Motors

Para hallar los nombres de los fabricantes de los articulos especiales antes mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3056.

ESPAÑOL.	INGLÉS.
Turboalternadores	Turbo Alternators
Turbo-Bombas	Turbo-Pumps
Turbo - Generadores. *Véase* Dinamos y Motores	Turbo - Generators. *See* Dynamos and Motors
U	
Utensilios para acarrear inmundicias	Sewage Disposal Appliances
Utensilios para Transmisión de Fuerza	Power Transmission Appliances
V	
Vagones de Volteo	Tip Wagons
Vagones para Ferrocarriles	Wagons (Railway)
Válvulas y Grifos	Valves and Cocks
Válvulas Atmosféricas y de Retención de Vapor	Vacuum and Steam Traps
Válvulas de Cojinete para Bombas de Aire	Bush Valves for Air Pumps
Válvulas de cuña	Wedge Gate Valves
Válvulas de Distribución	Slide Valves
Válvulas de Reducción. *Véase* Válvulas	Reducing Valves. *See* Valves
Válvulas de Retención de Vapor. *Véase* Manómetros, etca.	Steam Traps. *See* Steam Gauges, etc.
Válvulas de Vapor Automáticas	Steam Valves (Automatic)
Vapor (Empaquetadura 'Britimp' para)	Steam Packing ('Britimp')
Varillas Ahuecadas y Secciones de Latón, Cobre, etca.	Hollow Rods and Sections (Bras Copper, etc.)
Varillas de Acero	Steel Rods
Varillas de Cobre	Rods (Copper)
Varillas de Metal Amarillo 'Dixtampo' para Estampar en Caliente y Forjar	'Dixtampo' Yellow Metal Rods for Hot Stamping and Forging
Varillas y Secciones de Cobre	Copper Rods and Sections
Vasos de Vidrio para Lubricadores	Lubricator Glasses
Vehículos Automóviles Comerciales	Motor Vehicles (Commercial)
Ventanas de metal (de tipo corredizo y de abertura hacia afuera)	Metal Windows (Sashes and Casements)
Ventilación. Calefacción, etc.	Ventilating, Heating, etc.
Vigas, Puentes, etca. *Véase* Obras de Edificación de Hierro y Acero	Girders, Bridges, etc. *See* Structural Iron and Steel Work
Viguetas de Acero	Joists (Steel)
Voltímetros. *Véase* Instrumentos Eléctricos	Voltmeters. *See* Instruments (Electrical)
Vulcanita y Fibra Vulcanizada	Vulcanite and Vulcanised Fibre
W	
'Woodite'	'Woodite'
Y	
Yeso	Plaster
Z	
Zapatos de Frenos	Brake Blocks

Para hallar los nombres de los fabricantes de los artículos especiales antes mencionados, refiéranse á los títulos equivalentes en inglés en la Classified Directory and Buyers' Guide ('Guía Clasificada de Anuncios'), páginas 2993–3076.

ПЕРЕВОДЪ ЗАГОЛОВКОВЪ ПОДРОБНАГО УКАЗАТЕЛЯ СПЕЦІАЛЬНОСТЕЙ АНОНСОДАТЕЛЕЙ—

стр. 2993—3056

Листъ фабрикантовъ по вышеуказаннымъ спеціальностямъ—см. соотвѣтствующіе англійскіе заголовки въ Подробномъ Указателѣ Анонсодателей, на стр. 2993—3056 Адреса фирмъ и свѣдѣнія объ ихъ спеціальностяхъ въ „The Engineer's Year-Book" (Инженерный Ежегодникъ)—см. предыдущій алфавитный списокъ—стр. 2977—2990

ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
А		Альтернаторы	Alternators
Автоматическіе контролеры (электрическіе)	**Automatic Controllers (Electric)**	**Алюминіевые сплавы для штамповыхъ отливокъ**	**Aluminium Die Casting Alloys.**
Автоматическ. брызгалки	Automatic Sprinklers	Алюминіевые шпильки, болты и гайки	Aluminium Studs, Bolts, and Nuts
Автоматическихъ машинъ, фабр.	**Automatic Machine Makers**	Алюминіевыя полосы съ зарубками	Aluminium Notched Bars.
Автомобильныя принадлежности	**Motor - Car Accessories**	**Алюминіевый** порошокъ	**Aluminium Powder.**
Асбесто-цементные волнистые кровельные листы	**Asbestos Cement Corrugated Roofing Sheets**	Алюминій (слитки, листы, трубки, проволока, кабели, фасоны и пр.)	Aluminium (Ingots, Sheets, Tube, Wire, Cable, Sections; etc.)
Асбесто - цементные кровельные листы и черепицы „Этернитъ" (плоскіе и волнистые)	**'Eternit' Asbestos Cement Roofing Tiles and Sheets (Flat and Corrugated)**	Анализъ дымового газа въ котлахъ	Boiler - Flue Gases (Analysis)
Асбесто-цементные плоскіе листы для стѣнъ, перегородокъ, потолковъ, и т. д.	**Asbestos Cement Flat Sheets, etc.**	Антифрикціонные металлы	Antifriction Metals
Асбестовая набивка „Ліонъ"	Asbestos Packing ('Lion')	Аппараты для безпроволочнаго телеграфа	Wireless Telegraphic Apparatus
Асбестовая прокладка и фашинные тюфяки	Asbestos Coverings and Mattresses	Аппараты для дистилляціи воды, см. также Конденсаторы	Water Distilling Apparatus (see also 'Condensers')
Асбестовые листы и кровельныя черепицы „Пуалитъ"	**'Poilite' Asbestos Sheets and Roofing Tiles**	Аппараты для нагрѣванія (газовые)	Heating Plant (Gas)
Асбестовыя издѣлія, приспособл. и пр.	Asbestos Goods, Fittings, etc.	Аппараты для очищенія и смягченія воды — см. также Нагрѣватели питательной воды и пр.	Water Softening and Purifying Apparatus (see also 'Feed Water Heaters, etc.')
Асбестовыя кровельныя черепицы	Asbestos Roofing Tiles	Аппараты для очищенія газа	Gas Cleaning Plant
Азотная кислота	Nitric Acid	Аппараты для пожарной тревоги	Fire Alarms
Азотъ	Nitrogen	Аппараты для регистрованія производительности машины	Machine Output Recorders
Аккумуляторы — см. Батареи	Accumulators — (see 'Batteries')	Аппараты для сбереженія пара	Steam Saving Appliances
Аккумуляторы (гидравлическіе)	Accumulators (Hydraulic)		

ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Аппараты для сбереженія топлива — см. Экономайзеры	Fuel Economisers (see 'Economisers')	Барометры	Barometers
Аппараты для экстракта смолы	Tar Extractors	Батареи (электрическія аккумуляторныя)	Batteries (Electrical Storage)
Аппараты для электрическаго передвиженія, разгрузки и пр.	Telphers	Башмаки для наводки на рельсы	Railway Re-railing Ramps
		Башмаки и упорки (штампы)	Shoes and Dies
Арматура для бетона	Concrete (Reinforcement for)	Безопасныя рудничныя лампы	Miner's Safety Lamps
Арматура котловъ—см. Арматура къ машинамъ и котламъ	Boiler Fittings (see 'Engine and Boiler Fittings')	Бензино - воздушныя машины	Petrol Air Gas Machines
		Бензолевыя машины	Benzol Plants
Арматура котловъ—см. также Арматура къ машинамъ и котламъ	Boiler Mountings (see also 'Engine and Boiler Fittings')	Блестящей стали, фабр.	Bright Steel Manufacturers
		Блоки для наблюденія надъ котлами.	Inspection Blocks for Boilers
Арматура къ машинамъ и котламъ, котельныя тонки, трубы и пр.	Engine and Boiler Fittings, Boiler Furnaces, Tubes, etc.	Болванки (стальныя)	Billets (Steel)
		Болты и гайки (желѣзные, стальные, мѣдные, изъ морской мѣди и пр.)	Bolts and Nuts (Iron, Steel, Copper, Naval Brass, etc.)
		‚Бойлеринъ'	'Boilerine'
Асфальтъ	Asphalte	Бронза—см. Латунь и бронза	Bronze (see 'Brass and Bronze')
Ацетилено - газовыя машины для освѣщенія и отопленія	Lighting and Heating, Acetylene Gas Plants for	Бронзовая отливка для адмиралтейства	Admiralty Gunmetal Ingots
Ацетиленовые буойи и баканы	Acetylene Buoys and Beacons	Бронированныя комнаты (стальныя или каменной кладки)	Strong Rooms (Steel or Masonry)
Ацетиленовыя генераторныя установки	Acetylene Generating Plants	Брусья (мѣдные)	Rods (Copper)
		Брызгалки (автоматическія)	Sprinklers (Automatic)
Ацетиленъ	Acetylene	Брызгалки ‚Гриннель'	'Grinnell' Sprinklers
Аэронавтическіе инструменты	Aeronautical Instruments	Бумага (непромокаемая)	Paper (Waterproof)
Аэронавтическія механическія мастерскія	Aeronautical Engineers	Бумажныя шестерни	Paper Pinions
		Буойи и баканы	Buoys and Beacons
Аэроплановъ, строители	Aeroplane Builders	Бурильныя машины для камня и угля	Boring Machines for Rock and Coal
		Быстрорѣжущая инструментальная сталь	High - speed Tool Steel
Б		Быстрорѣжущая сталь ‚Спиндикутъ'	'Speedicut' High speed Steels
Балки (стальныя)	Joists (Steel)	**В**	
Балки, мосты и пр.—см. Желѣзныя и стальныя сооруженія	Girders, Bridges, etc. (see 'Structural Iron and Steel Work')	Вагонныя сцѣпки	Railway Couplings
Балки съ широкими фланцами (по способу Грэя)	Beams (Grey process), Broad Flange.	Вагонныя шины и оси	Railway Tyres and Axles

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Вагоны (Жел. Дор.)	Wagons (Railway)	Воздухомѣры	Air Meters
Вагоны (Пассажирскіе и Товарные)	Carriages and Wagons (Railway)	Водоизмѣрители и пр.—см. Паровые манометры	Water Gauges, etc. (see 'Steam Gauges')
Вагранки	Cupolas	Водолазные аппараты	Diving Apparatus
Вакуумные и Паровые отводчики	Vacuum and Steam Traps	Водомѣрныя стекла	Gauge Glasses
Вакуумныя чашки (концентраціонныя)	Vacuum Pans (Concentrating)	Водомѣры	Water Meters
Вакуумъ-испарители для химическихъ жидкостей	Vacuum Evaporators for Chemical Liquids	Водонапорныя башни	Water Towers
Вакуумъ-насосы—см. Насосы	Vacuum Pumps (see 'Pumps')	Водонепроницаемые составы	Waterproofing Compounds
Валы и приводы	Shafting and Gearing	Водонепроницаемые составы для зданій	Buildings (Waterproofing of)
Вентиляторы: воздуходувные, выпускные, электрическіе и пр.	Fans (Blowing, Exhaust, Electric, etc.)	Водоохладители	Water-cooling Apparatus
Вентиляціонные валы	Ventilating Shafts	Водорегиструющіе аппараты	Water Recorders
Вентиляціонные техники	Ventilating Engineers	Водотрубные котлы—см. Котельные Заводчики	Water-tube Boilers (see 'Boiler Manufacturers')
Вентиляція, Отопленіе и пр.	Ventilating, Heating, etc.	Водяныя колеса, Водяные двигатели и Турбины	Water Wheels, Water Motors and Turbines
Веревочныя подвѣски для летательныхъ машинъ	Rigging for Air Craft	Водяныя краски	Distemper
Вертикальные сверлильные станки	Vertical Drilling Machines	Воздуходувки для камина	Flue Blowers
Вещества, предохраняющія отъ ржавчины	Rust Preventives	Воздухолетательныхъ машинъ, фабр. (см. Аэроплановъ, строители)	Aircraft Manufacturers (see Aeroplane Builders)
Взрывающій порохъ	Blasting Powder	Воздушные компрессоры	Air-Compressors
Взрывчатыя вещества	Explosives	Воздушные насосы	Air Pumps
Виллесденская бумага и парусина	Willesden Paper and Canvas	Воздушные рельсовые пути	Overhead Runways
Винтовое зацѣпленіе	Helical Gearing	Воздушные фильтры	Air Filters
Винтовые валы	Propeller Shafts.	Воздушныя камеры	Air Receivers
Винтовые реостаты (Гидравлическіе)	Propeller Starters (Hydraulic)	Волнистыя черепицы и плиты (изъ асбестоваго цемента)	Corrugated Tiles and Sheets (Asbestos-Cement)
Винторѣзные станки	Screwing Machines	Волочильныя машины	Wire-drawing Machinery
Винты (желѣзные, стальные, мѣдные, изъ морской мѣди)	Screws (Iron, Steel, Copper and Naval Brass)	Вольтметры—см. Инструменты (Электрическіе)	Voltmeters (see Instruments — Electrical')
Владѣльцы доковъ	Dock Owners	Войлокъ для бумажныхъ фабрикъ	Paper Makers' Felts
Владѣльцы сухихъ доковъ	Dry Dock Owners		

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ПО РУССКИ.	ПО АНГЛІЙСКИ.
Войлокъ для печатныхъ машинъ, машинъ для производства бумаги и набивной бумажной ткани	Felts for Printing Machinery, Paper Making, and Calico Printing Machinery
Вращающіеся конвертеры	Rotary Converters
Вспомогательныя турбинныя передачи	Geared Turbine Auxiliaries
Вторичные элементы и батареи	Storage Cells and Batteries
Вулканитъ и вулканизированная фибра	Vulcanite and Vulcanised Fibre
Выдѣлка инструментовъ, машинисты и пр.	Tool Makers, Machinists, etc
Г	
Газогольдеры (см. газовыхъ заводовъ оборудованіе)	Gas Holders (see 'Gas Works Plant')
Газовые генераторы	Gas Producers
Газовые, нефтяные и керосиновые двигатели	Gas, Oil, and Petrol Engines
Газовые счетчики	Gas Meters
Газовыя реторты	Gas Retorts
Газовыя топки (печи) —см. Топки, плавильныя печи	Gas Furnaces (see 'Furnaces')
Газовыя трубы и приспособленія	Gas Tubes and Fittings
Газогенераторныя установки съ всасываніемъ	Suction Gas Plants
Газоочистительные вентиляторы	Gas Washing Fans
Газъ и его примѣненіе къ промышленности	Gas and its Industrial Applications
Гайки	Nuts
Гальванизаторы (машины для оцинковыванія)	Galvanisers
Гальванопластическія мастерскія	Metal (Electro Depositors)
Генераторы (электрическіе)—см. Динамо и двигатели	Generators (Electric) (see 'Dynamos and Motors')
Гибкія металлическія трубы	Flexible Metallic Tubing
Гибкое сцѣпленіе	Flexible Couplings
Гидравлическіе лифты — см. Подъемныя машины	Hydraulic Lifts (see 'Lifting and Hoisting')
Гидравлическіе манометры	Hydraulic Gauges
Гидравлическія машинныя установки, приспособленія и пр.	Hydraulic Plants and Appliances
Гидравлическія машины, инструменты и пр.	Hydraulic Machines, Tools and Appliances, etc.
Гидравлическія машины системы „Твелделя"	'Tweddell's System' Hydraulic Machinery
Гидравлическія трубы и трубопроводы	Hydraulic Tubes and Pipes
Гидравлическія штамповки	Hydraulic Pressings
Гидрологическіе химики	Hydrological Chemists
Гидротехники (Техники для оборудованія водяной силы)	Water-power Engineers
Гидро-электрическія установки	Hydro-Electric Plants
Гироскопы	Gyroscopes
Граверы, чертежники и типографы	Engravers, Draughtsmen, and Printers
Графитъ	Graphite
Графитъ для котловъ „Зодіакъ"	'Foliac' Boiler Graphite
Графитныя спеціальности „Зодіакъ"	'Foliac' Graphite Specialities
Графитовый составъ „Зодіакъ" для набивки трубъ	'Foliac' Graphite Pipe Joint Compound
Гребные винты	Screw Propellers
Громоотводы	Lightning Conductors
Грузоподъемныя машины—см. Подъемныя машины	Hoists (see 'Lifting and Hoisting')

Листъ фабрикантовъ по вышеуказаннымъ спеціальностямъ—см. соотвѣтствующіе англійскіе заголовки въ „Подробномъ указателѣ Анонсодателей" на стр 2993—3056.

ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ
Д		Желѣзнодорожные тормазы	Railway Brakes
Двери (для желѣзныхъ комнатъ и замуравленныхъ шкаповъ)	Doors (Strong Room and Party Wall)	Желѣзнодорожныя стрѣлки и крестовины	Railway Points and Crossings
Двигатели (Гидравлическіе)	Engines (Hydraulic)	Желѣзнодорожныя упорныя скобы	Railway Stop Blocks
Двигатели (Паровые) —см. паровые двигатели	Engines (Steam) (see 'Steam Engines')	Желѣзныя дороги: легкія, переносныя и пр.	Railways (Light, Portable, etc.)
Двигатели Дизель и полу-Дизель	Diesel and Semi-Diesel Engines	Желѣзныя и стальныя сооруженія	Structural Iron and Steel Work
Двигатели для ароплановъ	Aero Engines	Желѣзныя и стальныя трубы	Iron and Steel Tubes
Двигатели, работающіе на сырой нефти	Crude Oil Engines (see 'Oil Engines')	Желѣзныя трубы — см. Трубы	Iron Tubes (see 'Tubes')
„Дексинъ"	'Dexine'	Желѣзобетонное строительство	Ferro-Concrete (see 'Reinforced Concrete')
Деструкторы (машины для уничтоженія мусора.)	Destructors (Refuse)	Желѣзобетонъ — см. Желѣзобетонное строительство	Concrete (Reinforced) Construction
„Дикстампо" — Штанги изъ желтаго металла для штампованія и ковки въ горячемъ видѣ	'Dixtampo' Yellow Metal Rods for Hot Stamping and Forging	Жесть (бѣлая)	Tin Plates
„Дикструдо" Быстроходныя мѣдерѣзательныя и обтачивающія штанги	'Dixtrudo' High-speed Brass Screwing and Turning Rods	Животные остатки (полныя установки для использованія таковыхъ)	Animal Residuals (Complete Plants for Dealing with)
Динамитъ	Dynamite	Жидкіе пусковые реостаты и контролеры	Liquid Starters and Controllers
Динамо и Двигатели	Dynamos and Motors	Жидкій воздухъ	Liquid Air
Динамометры	Dynamometers	Жироотдѣлители	Grease Separators
Доки (пловучіе)	Docks (Floating)	Журналы (Техническіе)—см. Книги и журналы	Journals (Technical) (see 'Books and Journals')
Домкраты (гидравлическіе и винтовые)	Jacks (Hydraulic and Screw)	**З**	
Дорогъ (арматура для)	Roads (Reinforcement for)	Заводскихъ зданій (постройка)	Factory Buildings (Construction of)
Дрели и Сверлильные Станки	Drills and Drilling Machines	Загибающіе прессы	Bending Presses
Дымовыя каски (для пожарныхъ)	Smoke Helmets	Заграды (изъ желѣза и стали)	Fencing (Iron and Steel)
Дымовыя (печныя) Трубы	Chimney Stacks	Задвижки и клапаны	Sluice Gates and Valves
Ж		Заклепки (Желѣзныя, стальныя, изъ морской мѣди и пр.)	Rivets (Iron, Steel, Copper, Naval Brass, etc.)
Желѣзнодорожное и Трамвайное оборудованіе	Railway and Tramway Plant		

Листъ фабрикантовъ по вышеуказаннымъ спеціальностямъ—см. соотвѣтствующіе англійскіе заголовки въ „Подробномъ указателѣ Анонсодателей" на стр. 2993—3056.

ПО РУССКИ.	ПО АНГЛІЙСКИ.
Замазка для соединеній (муфтъ)	Jointing Cement
Замазка „Кисоль" для котловъ, паровыхъ трубъ и пр.	'Kisol' Cement for Boilers, Steam Pipes, etc.
Замазочные матеріалы	Jointing Materials
Замки, болты и пр.	Locks, Bolts, etc.
Запорные клапаны и задвижки	Stop and Sluice Valves
Зацѣпленіе	Gearing
Защитныя сѣти для торпедъ	Torpedo Defence Nets
Звенья водомѣрныхъ стеколъ	Gauge Glass Rings
Звонки (электрическіе)	Bells (Electric)
Земледѣльческія орудія и машины	Agricultural Tools and Machinery
Землемѣрные и чертежные инструменты	Surveying and Drawing Instruments
Землечерпалка (стальной троссъ для)	Dredgers (Steel Wire Rope for)
Землечерпательныя машины	Dredge Plant
„Зодіакъ" котельный графитъ	'Foliac' Boiler Graphite
Золотники	Slide Valves
Зубчатая и коническая зубчатая передача	Spur and Bevel Gearing
И	
Известь и известнякъ	Lime and Limestone
Изданія (Техническія)—см. Книги и Журналы	Publications (Technical) (see 'Books and Journals')
Измѣрители для шахтъ	Minemeters
Измѣрители растяжимости	Extensometers
Измѣрители силы напряженія	Strainmeters
Изолирующіе матеріалы	Insulating Materials
Изоляторы	Insulators
Изоляціонные лаки и составы	Insulating Varnishes and Compounds
Индикаторы (паровыхъ котловъ)	Indicators (Steam Engine)
Инжекторы, эжекторы и разные струйчатые приборы—см. Паровые инжекторы	Injectors, Ejectors, and General Jet Appliances (see 'Steam Injectors')
Инженерная фотографія	Engineering Photography
Инженерное обученіе—см. Колледжи	Engineering Training (see 'Colleges')
Инженерные и желѣзнодорожные поставщики—см. Желѣзнодорожное и трамвайное оборудованіе	Engineering and Railway Supplies (see 'Railway and Tramway Plant')
Инженерные инструменты и принадлежности	Engineers' Tools and Fittings
Инженеры (гидравлическіе)	Engineers (Hydraulic)
Инженеры (механики)	Engineers (Mechanical)
Инженеры-консультанты	Advisory Engineers
Инженеры-металурги	Metallurgical Engineers
Инженеры-электротехники	Electrical Engineers
Инженеры (по части экономіи топлива)	Engineers (Fuel Economy)
Инженеры (по устройству маяковъ)	Engineers (Lighthouse)
Инструментальная сталь	Tool Steel
Инструментные заводы	Tool Makers
Инструменты для измѣренія (электрическіе)—см. Инструменты	Measuring Instruments (Electrical) (see 'Instruments')
Инструменты для каменоломенъ	Quarrying Tools
Инструменты: для межеванія, готовальни, чертежные и пр.	Instruments (Surveying, Mathematical, Drawing, etc.)

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ	ПО АНГЛІЙСКИ.
Инструменты для производства испытаній (электрическіе) — см. Инструменты	Testing Instruments (Electrical) (see 'Instruments')	Кальціевый карбидъ	Calcium Carbide
Инструменты для снятія накипи (котельнаго камня)	Scaling Tools	Каменноугольныхъ копей (канаты изъ стальной проволоки для)	Collieries (Steel Wire Ropes for)
Инструменты и аппараты (электрическіе)	Instruments and Apparatus (Electrical)	Каменноугольныхъ копей (электрическое устройство)	Collieries (Electrical Equipment of)
Инструменты изъ быторѣжущей стали ‚Спидикутъ'	'Speedicut' High Speed Tools	Камеры и затворы	Cameras and Shutters
Инструменты, научные	Scientific Instruments	Камнебурильныя машины	Rock Drills
Испарители для сахара, ликеровъ и пр.	Evaporators for Sugar and Trade Liquors	Канатные трамваи	Wire Rope Tramways
Испарители, конденсаторы, аппараты для дистилляціи воды и пр.	Evaporators, Condensers, Water Distilling Apparatus, etc.	Канаты: проволочные, пеньковые, манилла, кожаные, хлопчато-бумажные и азбестовые	Ropes (Wire, Hemp, Manilla, Leather, Cotton, and Asbestos)
Испарители многократнаго эффекта	Multiple Effect Evaporators	Канаты для нефтяныхъ источниковъ	Oil Well Ropes
К		Канаты и жгуты изъ стальной проволоки для аэроплановъ	Aeroplane Steel Wire Strands & Cables
Кабели: Телеграфные, телефонные, для электрическаго освѣщенія и подводные	Cables (Telegraph, Telephone, Electric Light, and Submarine)	Карбидъ кальція	Carbide of Calcium
Кабели для мореходства, подъема и пр.	Cables for Shipping, Haulage, etc.	Каскадные конверторы (патенты—Peebles - la Cour)	Motor Converters (Peebles-la Cour Patents)
Кабели изъ массивной резины — см. Кабели	Solid Rubber Cables (see 'Cables')	Кинитическіе конденсаторы марки ‚Контрафло'	'Contraflo' Kinetic Condensers
Кабельные пути	Cableways	‚Кирассъ' (фабричныя марки)	'Cuirass'
Кабельныя воздушныя дороги	Aerial Ropeways	Кирки, лопаты и пр.	Picks, Shovels, etc.
Кабестановъ, фабр.	Capstan Lathe Makers	Кислородныя и водородныя генераторныя установки)	Oxygen and Hydrogen Generating Plants
Калильныя печи — см. Топки, плавильныя печи	Tempering Furnaces (see 'Furnaces')	Кислородъ	Oxygen
‚Каллендритъ' непромокаемые гудронные листы	'Callendrite' Damp-course and Sheeting	Кислота для аккумуляторовъ	Accumulator Acid
Калориметры для испытанія топлива	Calorimeters for Fuel Testing	Кислотостойкіе чаны	Acid Resisting Pans
Калориферы	Calorifiers	Клапаны и краны	Valves and Cocks
		Клапаны съ втулками для воздушныхъ насосовъ	Bush Valves for Air Pumps
		Клепальныя машины (гидравлическія и пневматическія)	Riveters (Hydraulic and Pneumatic)

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ПО РУССКИ.	ПО АНГЛІЙСКИ.
Клепальныя машины (электрическія)	Riveters (Electric)
Клепанныя стальныя трубы	Riveted Steel Pipes
Книги и Журналы, научные	Books and Journals, Scientific
Ковкія отливки	Malleable Castings
Ковочные молота	Forging Hammers
Ковочные прессы	Forging Presses
Кожаные приводные ремни — см. Приводные ремни	Leather Belting (see 'Belting')
Колеса Пелтона	Pelton Wheels
Колесное зацѣпленіе	Wheel Gearing
Колледжи (инженерные)	Colleges (Engineering)
Колокольные заводы	Bell Founders
Колонны и чугунныя приспособленія для стока грязной воды, для газа и для водопроводовъ	Columns and Castings for Sewage, Gas, and Water Works
Комплектъ частей къ замочной шайбѣ	Lock-Washer Equipment
Конденсаторы, испарители, машины для очистки и перегонки воды и пр.	Condensers, Evaporators, Water Softening and Distilling Apparatus etc.
Конденсаторы пара (конденсаціонные горшки) — см. Паровые манометры и пр.	Steam Traps (see 'Steam Gauges, etc.')
Конторская мебель	Office Furniture
Конторскіе книги съ свободно вынимающимися страницами	Loose Leaf Ledgers
Конторскія системы	Office Systems
Котельная листовая сталь	Boiler Plates (Steel)
Котельные заводы	Boiler Manufacturers
Котельныя топки	Boiler Furnaces
Котельныя трубы	Boiler Tubes
Котлы для подогрѣванія мятымъ паромъ	Exhaust Heat Boilers
Котлы для снабженія горячей воды	Hot Water Supply Boilers
Конвертеры (каскадные) (патенты — Peebles - la Cour)	Converters (Motor (Peebles-la Cour Patents)
Котлы, употребляющіеся въ химическомъ производствѣ	Digesters
Краны (изъ желтой мѣди) для воды, пара и газа	Cocks (Brass) for Water, Steam and Gas
Краны—см. Подъемныя машины	Cranes (see 'Lifting and Hoisting Machinery')
Красильныя машины	Painting Machines
Краски „Минерва"	'Minerva' Paints
Краски для предохраненія желѣзныхъ и стальныхъ сооруженій	Paints for Preserving Iron and Steel Work
Краска противъ разъѣданія	Anti-Corrosive Paint.
Краски и лаки	Colours, Paints and Varnishes
Краски, эмали и лаки	Paints, Colours, Enamels and Varnishes
Краскотерки	Paint Mills
Кремнево-графитная краска „Зодіакъ"	Foliac Silica Graphite Paint
Кровельныя папки	Roofing Felts
Кровля, Руберойдъ'	'Ruberoid' Roofing
Крытый кабель „Кэбъ Тайръ"	'Cab Tyre' Sheathed Cables
Крыши (кровли), желѣзныя зданія и пр.	Roofs, Iron Buildings, etc.
Кузнечные горны и приспособленія	Smiths' Hearths and Plant
Кузнечныя топки — см. Топки, плавильныя печи	Forging Furnaces (see 'Furnaces')
Кузницы (переносныя)	Forges (Portable)
Кессоновъ (строители)	Caissons (Builders of)
Л	
Лаки	Varnishes

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ПО РУССКИ.	ПО АНГЛІЙСКИ.
Лампы: Паяльныя и для двигателей для жидкаго топлива	Lamps (Brazing and Oil Engine)
Лампы: факели, для ларей и т. д., и вообще для всѣхъ надобностей механиковъ	Lamps (Torch, Bunker, etc., for Engineers generally)
Лампы (рабочія)	Lamps (Industrial)
Лампы (электрическія) — см. Приспособленія для электрическаго освѣщенія и пр.	Lamps (Electric)(see 'Electric Light Fittings, etc.')
Латунные и мѣдные болты и гайки — см. Болты и гайки	Brass and Copper Bolts and Nuts (see 'Bolts and Nuts')
Латунь и бронза	Brass and Bronze
Латунь и мѣдь (листовая и обручная)	Brass and Copper (Sheet and Strip)
Лебедки (паровыя, электрическія и бензиновыя)	Winches (Steam, Electric and Petrol)
Лебедки (фрикціонныя)	Winches (Friction)
Легкіе грузовые автомобили	Motor Vehicles (Commercial)
Листы (мѣдные и латунные)	Plates (Copper and Brass)
Литейные заводы	Founders
Литейные ковши	Foundry Ladles
Литейный чугунъ	Cast Iron
Литые металлы	Ingot Metals
„Ліонъ" набивка	'Lion' Packing
Лодки (паровыя и моторныя)	Launches (Steam and Motor)
Локомотивныя трубы	Loco Tubes
Локомотивы	Locomotives
Локомотивы для жидкаго топлива (внутренняго сгоранія)	Oil Locomotives (Internal Combustion)
Локомоторы (тракторы), паровые и электрическіе	Traction Engines (Steam and Electric)
Ломъ металловъ	Scrap Metals
Лѣстницы (огнеупорныя)	Staircases (Fire-Resisting)

ПО РУССКИ.	ПО АНГЛІЙСКИ.
М	
Магнитная сталь	Magnet Steel
Магнитные патроны	Magnetic Chucks
Магнитные сепараторы	Magnetic Separators
Магнитные сепараторы для деструкторовъ	Destructors, Magnetic Separators for
Мазь для ремней	Belting Cream
Марганецъ и марганцовые сплавы	Manganese and Manganese Alloys
Марганцевая бронза	Manganese Bronze
Марганцевая сталь	Manganese Steel
Масленки и Смазочныя масла	Lubricators and Lubricants
Масленки ручныя, всякаго рода	Oil Feeders and Cans
Масло (смазочное)	Grease (Lubricating)
Масло для употребленія при нарѣзкѣ винтовъ	Screwing Oil
Маслоотдѣлители для питательной воды для котловъ	Boiler Feed-water, Oil Elimination from
Маслоуловители	Oil Eliminators
Математическіе, чертежные и измѣрительные инструменты	Mathematical, Drawing, and Surveying Instruments
Матеріалъ для желѣзо-бетона	Fabric (Reinforcing)
Матеріалъ марки „Рокъ" для крытія крышъ	'Rok' Roofing
Машинная набивка „Ліонъ"	Engine Packing ('Lion')
Машинная сталь закаленная на воздухѣ	Air-hardening Gear Steel
Машинные винты (болты)	Machine Screws
Машинные и ручные инструменты — см. Инженерные инструменты и принадлежности, также Инструментные заводы	Machine and Hand Tools (see 'Engineers' Tools and Fittings,' also 'Tool Makers')

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Машинные приводы, приводные валы и пр. — см. Валы и приводы	Mill Gearing, Shafting, etc. (see 'Shafting and Gearing')	Машины для нефтепрогонныхъ заводовъ	Oil Mill Machinery
Машинные ремни и бичевки	Mill Banding and Twines	Машины для оборудованія газовыхъ заводовъ	Gasworks Plant
Машины (электромагнитныя)	Machinery (Electro-Magnets)	Машины для оборудованія заводовъ для сахарнаго производства	Sugar Mills and Machinery
Машины для бороздованія камня	Stone-channelling Machines	Машины для оборудованія копей—см. Установки для оборудованія копей и подъемныя установки	Mining Machinery (see 'Mining and Hauling Plants')
Машины для буренія и облицовки	Boring and Facing Machines	Машины (станки) для обрабатыванія дерева	Wood-working Machinery
Машины для бѣленія, крашенія и отдѣлки	Bleaching, Dyeing and Finishing Machinery	Машины для обработки резины	Rubber Machinery
Машины для взвѣшиванія, вѣсы	Weighing Machines	Машины для охлажденія и овлажненія	Air-cooling and Humidifying Apparatus
Машины для выдѣлки брикетовъ	Briquette Machinery	Машины для подъема	Hauling Plant (see 'Winding and Hauling')
Машины для выдѣлки кирпичей и черепицъ	Brick and Tile Making Machinery	Машины для полировки	Polishing Machinery
Машины для выдѣлки плитъ и черепицъ изъ асбестоваго цемента	Asbestos Cement Sheet and Tile Making Machinery	Машины для производства бумаги и древесной массы	Paper and Pulp Making Machinery
Машины для генераторнаго газа—см. Газовые генераторы	Producer Gas Plants (see 'Gas Producers')	Машины для производства льда—см. Холодильныя машины	Ice-making Machinery (see 'Refrigerating Machinery')
Машины для дистиллированія (свѣжей воды)	Distilling Apparatus (Fresh Water)	Машины для производства патроновъ	Cartridge Machinery
Машины для загрузки и выгрузки для газовыхъ заводовъ и коксовальныхъ печей	Charging and Discharging Machinery for Gasworks and Coke Ovens	Машины для производства химическихъ продуктовъ	Chemical Plant and Machinery
Машины для испытанія цемента	Cement-testing Machines	Машины для производства цемента	Cement Machinery
Машины для кольцеванія гибкихъ валовъ	Flexible Shaft-Coiling Machines	Машины для прокладки кабелей	Cable-laying Machinery
Машины для литейнъ	Foundry Plant	Машины для промывки угля	Coal Washing Machinery
Машины для мукомольныхъ мельницъ	Flour Milling Machinery	Машины для раздробленія и пульвиризированія	Crushing and Pulverising Machinery
Машины для нагрузки и транспорта	Loading and Transport Plants		

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ПО РУССКИ.	ПО АНГЛІЙСКИ	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Машины для размельченія угля и Элеваторы и Транспортеры для угля	Coal Grinding, Elevating and Conveying Machinery	Металлъ „Буллъ" и Меллоидъ	Bull's Metal and Melloid
Машины для сгибанія трубъ	Pipe-bending Machines	Металлъ Дельта	Delta Metal
Машины для тунельныхъ работъ	Tunnelling Plants	Металлъ для подшипниковъ и пр.	Bearing Metals, etc.
Машины для угольныхъ копей	Colliery Plant	Металлы: для подшипниковъ, антифрикціонный и пр.	Metals (Bearing Anti-friction, etc.)
Машины для улавливанія побочныхъ продуктовъ	Bye-Product Recovery Plants	Металлы (ломъ)	Metals (Scrap)
Машины для уничтоженія мусора	Refuse Destructors	Металлы съ продырявленными отверстіями	Perforated Metals
Машины для чистки верна и семянъ	Grain and Seed Cleaning Machinery	Метеорологическіе инструменты	Meteorological Instruments
Машины и инструменты для строительныхъ работъ	Contractors' Tools and Plant	Метчики и матрицы	Taps and Dies
Машины и топки на отходящихъ газахъ	Industrial Gas Furnaces and Plants	Механическіе кочегары	Mechanical Stokers
Мельницы (размельчительныя)	Mills (Pulverizing)	Механическіе молота —см. Молота	Power Hammers (see 'Hammers')
Мельницы для размельченія камня	Stone Pulverizing Mills	Механическія мастерскія (Аэронавтическія) см. „Аэронавтическія Механическія Мастерскія'	Engineers, (Aeronautical) see 'Aeronautical Engineers
Металлическая набивка — см. Набивка машинъ	Metallic Packing (see 'Engine Packing')	Микрометры	Micrometers
Металлическая набивка для поршневыхъ штоковъ (марки „Lancaster")	Metallic Piston Rod Packings ('The Lancaster')	Микроскопы	Microscopes
Металлическая набивка поршневого штока „Ліонъ"	Metallic Piston Packing ('Lion')	Минеральная шерсть	Mineral Wool
Металлическая набивка поршневого штока „Юнайтедъ Стэйтсъ"	Metallic Piston Rod Packing ('United States')	Молота (паровые, компрессорные, пневматическіе и пр.)	Hammers (Steam, Compressed Air, Pneumatic Power, etc.)
Металлическіе листы, цилиндрическія коробки (кожухи) и пр.	Sheet Metal Work Cylinder Cases, etc.	Молоты (для вбиванія свай)	Hammers (Pile Driving)
Металлическія трубы (гибкія)	Metallic Tubing (Flexible)	Морской клей	Marine Glues
Металлурги сты (Электро-)	Metallurgists, Electro	Мосты висячіе (на проволочныхъ канатахъ)	Bridges (Wire Rope Suspension)
		Мосты, фермы (балки) и пр.	Bridges, Girders, etc.
		Мѣдники (Мѣднолитейни)	Coppersmiths
		Мѣднолитейщики	Brass Founders
		Мѣдные стержни и фасонная мѣдь	Copper Rods and Sections
		Мѣдныя издѣлія	Coppersmiths' Work
		Мѣдныя ковки	Copper Forgings
		Мѣдныя принадлежности для свинцоработъ	Plumbers' Brasswork

Листъ фабрикантовъ по вышеуказаннымъ спеціальностямъ—см. соотвѣтствующіе англійскіе заголовки въ „Подробномъ указателѣ Анонсодателей" на стр. 2993—3056.

ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Мѣдныя соединительныя кольца	Copper Jointing Rings	Нефтяные двигатели—см. Нефтяные и газовые двигатели	Petrol Engines (see 'Oil and Gas Engines')
Мѣхи—см. Вентиляторы	Blowers (see 'Fans')	Нефтяныя топки—см. Топки (печи)	Oil Furnaces (see 'Furnaces')
Мѣхи (паропроводные)	Blowers (Steam Flue)	Никкелевая и никкелево-хромовая сталь	Nickel and Nickel-Chrome Steels
Мѣшалки для бетона	Concrete Mixers.	Ножи для ножницъ (всѣхъ размѣровъ)	Shear Blades (all sizes)
Н		Нормализированіе	Normalizing
Набивка Валькера, Ліонъ'	Walker's ('Lion') Packing	**О**	
Набивка, Вудайтъ'	'Woodite'	Обмазка (блестящихъ частей) и апретура машинъ	Coatings (Bright Part) and Machinery Finishes
Набивка для нефтяныхъ двигателей	Gas-engine Packing	Обмотка котловъ и трубъ	Boiler and Pipe Coverings
Набивка, Ліонъ'	Packing ('Lion')	Обмотка трубъ	Pipe Coverings
Набивка машинъ	Engine Packing	Обмуровка котловъ	Boiler Setting
Набивка (паровая)—см. Набивка машинъ	Packing (Steam) (see 'Engine Packing')	Обмуровка котловъ (усовершенствованная)	Boiler Settings (Improved)
Набивка поршня	Piston Packing	Оборудованіе для осмоленія, мощенія и асфальтованія дорогъ	Tar, Macadam and Asphalt Plant
Набивка, Юнайтедъ Стейтсъ'	Packing ('United States')	Оборудованіе для сооруженія построекъ	Building Construction Plant
Нагрѣватели питательной воды, фильтры и очистители	Feed-water Heaters, Filters and Purifiers	Оборудованіе доменныхъ печей	Blast Furnace Plant
Наждачныя колеса, машины и пр.	Emery Wheels, Machinery, etc.	Оборудованіе производства водянаго газа	Water Gas Plants
Напильники	Files	Оборудованіе производства газа системы, Мондъ'	Mond Gas Plants
Насосы	Pumps	Обработка металловъ нагрѣваніемъ	Heat Treatment of Metals
Насосы и машины для насасыванія	Pumps and Pumping Machinery	Обшивка изъ волокнистаго шлака и шлаковой шерсти	Silicate Cotton and Slag Wool Coverings
Насосы перемѣнной емкости	Variable Capacity Pressure Pumps	Огнеупорный кирпичъ и продукты изъ огнеупорной глины	Fire Bricks and Fire Clay Goods
Наугольники	Squares	Огнеупорный полъ, Деколитъ'	'Decolite' Fireproof Flooring
Непромокаемые гудронные листы	Damp-course and Bitumen Sheeting	Огнеупорныя листы для перегородокъ и стѣнъ	Fireproof Partition and Wall Sheets
Непромокаемые листы гудрона (толя)	Bitumen Damp-proof Sheeting		
Нержавѣющая сталь	Rustless Steel		
Нержавѣющая сталь, Фирта'	Firth's Stainless Steel		
Несгораемые шкафы и желѣзныя комнаты (сопротивляющіеся огню и взлому)	Safes and Strong Rooms (Fire and Burglar Resisting)		
Нефтяные, газовые и керосиновые двигатели	Oil, Gas and Petrol Engines		

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Огражденія для лифтовъ (подъемныхъ машинъ)	Lift Enclosures	**П**	
Окись-ацетиленовая сварка	Oxy-Acetylene Welding	Палатки и будки	Tents and Shelters
Опоры (усовершенст.) ланкаширскихъ котловъ (котлы съ двумя жаровыми трубами)	Lancashire Boiler Settings (Improved)	Паровая замазка—см. Замазочные матеріалы	Steam Jointing (see 'Jointing Materials')
Опрокидывающіеся вагоны	Tip Wagons	Паровозные колѣнчатые валы	Railway Crankshafts
Оружейные и аммуниціонные заводы	Gun and Ammunition Works	Паровозныя трубы	Loco Tubes
Освѣщеніе мастерскихъ	Workshops (Lighting of)	Паровые двигатели	Steam Engines
Освѣщеніе поѣздовъ	Lighting (Train)	Паровые инжекторы	Steam Injectors
Освѣщеніе фабрикъ и заводовъ	Factories, Lighting of	Паровые, компрессорные и пневматическіе молота	Steam, Compressed Air and Pneumatic Power Hammers
Осцилографы	Oscillographs	Паровые котлы—см. Котельные заводы	Steam Boilers (see 'Boiler Manufacturers')
Отводчики (конденсаціонные горшки) и очистители пара	Steam Dryers and Purifiers	Паровые манометры, краны, водомѣрныя стекла, предохранительные клапаны, волотники, индикаторы, конденсаціонные горшки и пр.	Steam Gauges, Cocks, Water Gauges, Safety Valves, Slide Valves, Indicators, Steam Traps, etc.
Отдѣленіе масла отъ сгущеннаго пара	Separation of Oil from Condensed Steam	Паровые молота—см. Молота	Steam Hammers (see 'Hammers')
Отдѣлка (апретура) машинъ	Machinery Finishes	Паровые насосы—см. Насосы	Steam Pumps (see 'Pumps')
Отдѣлочные станы	End Mills	Паровыхъ машинъ набивка	Steam Packing
Отливка для клапановъ	Valve Castings	Паровыхъ машинъ набивка „Ліонъ"	Steam Packing ('Lion')
Отливки (ковкія) марки „Black Heart"	Black-Heart Castings (Malleable)	Паровыя суда, лодки и яхты	Steam Ships, Launches and Yachts
Отливка изъ стальныхъ сплавовъ	Steel Alloy Castings	Паровыя Турбины и приспособленія	Steam Turbines and Fittings
Отливки и фасонныя ковки	Castings and Forgings	Пароизмѣрители	Steam Meters
Отопленіе, вентиляція и пр.	Heating, Ventilating, etc.	Паромовъ (металлическіе канаты для)	Ferries (Wire Rope)
Отопленіе для желдор. вагоновъ	Heating for Railway Carriages	Паропроводныя трубы—см. Трубы	Steam Pipes (see 'Tubes')
Охлаждающія башни	Cooling Towers	Пароструйные инжекторы	Steam Injectors
Оцинкованнаго желѣза и стали, фабр.	Galvanized Iron and Steel Manufacturers	Патроны	Chucks (Lathe)
Оцинковочныхъ мастерскихъ, оборудованіе	Galvanizing Plant	Патроны (магнитные)	Chucks (Magnetic)
Очистители сточныхъ водъ	Sewage Purification	Патрубки котловъ	Boiler Seatings
		Паяльныя машины	Soldering Machines

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Паяльныя трубки (для алюминіевой сварки и разрѣзанія)	Blowpipes (Acetylene Welding and Cutting)	Пневматическіе инструменты и приспособленія	Pneumatic Tools and Appliances
Перегрѣватели	Superheaters	Пневматическія трубы для телеграммъ и пр.	Pneumatic Despatch Tubes, etc.
Перегрѣватели для локомотивовъ	Locomotive Superheaters	Поверхности для спуска товаровъ	Runways
Перегрѣтая набивка для локомотивовъ	Locomotive Superheated Packing	Поверхностная цементація	Case Hardening
Передаточные ремни, канаты и пр.	Driving Bands, Ropes, etc.	Поверхностное сгораніе	Surface Combustion
Передаточныя цѣпи	Driving Chains	Поворотные столы	Turntables
Передачи и зацѣпленія	Shafting and Gearing	Поворотныя и подъемныя машины и приспособленія	Winding and Hauling Engines and Plant
Перекрытіе и облицовка дымохода	Flue Covers and Linings	Поворотныя лебедки	Crab Winches
Переносные электрическіе дрели и молота	Electric Portable Drills and Hammers	Подвижной составъ —см. Желѣзно-дорожное и трамвайное оборудованіе	Rolling Stock (see 'Railway and Tramway Plant')
Переносныя желѣзныя дороги	Portable Railways	Подводные кабели— см. Кабели	Submarine Cables (see 'Cables')
Переносныя машины	Portable Engines	Подвѣсные шлифовальные станки (электрическіе)	Aerial Grinders (Electric)
Печи для закалки и затвердѣнія	Annealing and Tempering Furnaces	Подрядчики и строители стѣнокъ и огнеупорныхъ сооруженій	Partition Contractors and Fireproof Builders
Пестовые молота (фрикціонные и паровые)	Stamps (Friction and Steam Drop)	Подрядчики по землечерпательнымъ работамъ	Dredging Contractors
Пильныя ленты (для ножевокъ для металловъ)	Hack Saw Blades	Подрядчики по строенію крышъ	Roofing Contractors
Пилы для дерева и металловъ	Saws for Wood and Metal Cutting	Подрядчики электрическаго освѣщенія	Electric Lighting Contractors
Пирометры	Pyrometers	Подставки и крышки для котловъ	Boiler Blocks and Covers
Питательной воды (измѣреніе)	Feed-water, Measurement of	Подшипники (кокильной отливки)	Bearings (Chill Cast)
Питательные насосы для котловъ	Boiler Feed Pumps	Подшипники (шариковые)	Bearings (Ball)
Пишущія машины	Typewriters	Подъемные канаты	Winding & Hauling Ropes
Плавильныя печи (для металловъ кромѣ желѣза)	Furnaces (non-ferrous metal)	Подъемные магниты	Lifting Magnets
Пластичный металлъ (Ричардса)	Plastic Metal (Richards)	Подъемныя машины и полиспасты (сложные блоки)	Lifting and Hoisting Machinery and Lifting Tackle
Плиты и черепицы (плоскія и волнистыя) для кровлепокрытій изъ асбестоваго цемента Everite'	'Everite' Asbestos-Cement Roofing Sheets and Tiles (Flat and Corrugated)		

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Пожарныя кишки (трубы), гибкія металлическія	Hose (Flexible Metallic)	Предохранительныя средства отъ разъѣданія	Corrosion, Prevention of
Покрытія для котловъ и пр.	Coverings for Boilers, etc.	Прессованные металлы	Extruded Metals
Полиспасты	Pulley Blocks	Прессованныя издѣлія	Presswork
Полоса ковкой стали	Mild Steel Strips	Прессы для лома	Scrap Presses
Полоса стали холодной прокатки	Cold-rolled Steel Strip	Прессы для масла	Oil Presses
Полукруглые алюминіевые прутья для сталедѣлательныхъ заводовъ	Steel Makers' Half-round Aluminium Sticks	Прессы для снарядовъ	Shell Presses
Полы и пр. (огнеустойкіе)	Floors, etc. (Fire-resisting)	Прессы для шинъ	Tyre Presses
Портландскій цементъ (машины для испытанія)	Portland Cement, Testing Machines for	Приборы, водолазные	Diving Apparatus
Портовые шлюзы	Dock Gates, Builders of	Приборы для испытанія портландскаго цемента	Testing Machines for Portland Cement
Поршневыя кольца	Piston Rings	Приборы для отдѣленія желѣза	Separators (Magnetic)
Поршни насоса	Pump Buckets	Приборы для производства испытаній	Testing Machines
Постройки	Buildings	Приборы для просмаливанія	Road Tarring Appliances
Починки котловъ сварка (вольтовой другой для)	Boiler Repairs, Electric Arc Welding for	Приборы для тушенія пожаровъ	Fire Extinguishing Appliances
Предохраненія отъ молній для зданій	Buildings, Protection of from Lightning	Приборы для форсированной и искусственной тяги	Forced and Induced Draught Apparatus
Предохранительные ободки для водомѣрныхъ стеколъ	Gauge Glass Protectors	Приводные прессы	Power Presses
Предохранительныя приспособленія для котловъ	Machinery Guards	Приводные ремни и пр., кожаные, бумажные, волосяные, каучуковые и пр.	Belting, etc. (Leather, Cotton, Hair, India-rubber, etc.)
Предохранительныя приспособленія для машинъ	Boiler Preservatives	Приводные ремни изъ балаты	Balata Belting
Предохранительныя средства (для дерева)	Preservatives (Wood)	Приводныя ножевки и машины	Hacksaws and Machines
Предохранительныя средства (для котловъ)	Preservatives (Boiler)	Приводы (изъ сырой кожи)	Gears (Raw Hide)
Предохранительныя средства отъ образованія накипи въ котлахъ и разъѣданія	Scale and Corrosion in Boilers, Preventives of	Придаваніе водонепроницаемости цементу	Cement, Waterproofing of
		Принадлежности для производства дугообразной сварки и электроды	Quasi-Arc Welding Accessories and Electrodes
		Принадлежности для чертежныхъ работъ	Drawing Office Requisities
		Приспособленія для аэропландовъ	Aeroplane Accessories
		Приспособленія для передачи силы	Power Transmission Appliances

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Приспособленія для предотвращенія дыма и производства пара	Smoke Preventers and Steam Generators	Производство и торговля желѣзомъ и сталью	Iron and Steel Manufacturers and Merchants
Приспособленія для угля, кокса и золы	Coal, Coke and Ash Handling Plants	Производство проволоки	Wire Manufacturers
Приспособленія для удаленія сажи	Soot Removers	Производство стали и торговля	Steel Manufacturers and Merchants
Приспособленія для урегулированія клапановъ	Valve Reseaters	Производство туманныхъ сигналовъ	Fog Signal Manufacturers
Приспособленія для форсированія болтовъ	Bolt Forcers	Прокатанные металлы	Rolled Metals
Приспособленія для электрическаго освѣщенія и электрическія принадлежности	Electric Light Fittings and Electrical Accessories	Прокатныхъ становъ (электрическое устройство)	Rolling Mills (Electrical Equipment of)
Пробковыя плиты и оболочки для покрытія трубъ	Cork Slabs and Pipe Covering	Прокатныя машины	Rolling Mill Engines
Проволочная прокладка (гибкая)	Wiring Systems (Flexible)	Промежуточные нагрѣватели и перегрѣватели	Interheaters and Reheaters
Проволочная ткань	Wire Gauze	Пропеллеры	Propellers
Проволочные канаты	Wire Ropes	Пуле-непробиваемая листовая сталь	Bullet-Proof Steel Plates
Проволочныя издѣлія и плетеная проволока	Wire Work and Woven Wire	Пунсоны и штампы	Punches and Dies
Проволочныя канатныя дороги	Wire Ropeways	Пусковые реостаты и жидкіе пусковые реостаты	Controllers and Liquid Starters
Проволочныя щетки	Wire Brushes	Пустотѣлые стержни и профили (изъ желтой и красной мѣди и проч.)	Hollow Rods and Sections (Brass, Copper, etc.)
Провода—см. Стальныя изолирующія трубы и системы электрическихъ проводовъ	Conduits (see 'Steel Conduits and Wiring Systems')	**Р**	
Провѣтриваніе, вентиляція	Ventilation	Радіально-сверлильные и нарѣзочные станки	Radial Drilling and Tapping Machines
Производство бурильныхъ инструментовъ (артезіанскихъ)	Boring Tool Makers (Artesian)	Радіо - телеграфные аппараты	Radio - Telegraphy Apparatus
Прожекторы (оксиацетиленовые)	Searchlights (Oxyacetylene)	Разбрызгивающія машины	Spraying Machines
Производство аппаратовъ для маяковъ	Lighthouse Apparatus Manufacturers	Развертки и метчики	Reamers and Taps
Производство (изоляціонной) проволоки	Wire (Insulated) Manufacturers	Разгрузка судовъ	Lighterage
		Раздвижные калибры, Счетныя линейки (штангециркуля) см. Инструменты, математическіе и пр.	Slide Rules (see 'Instruments, Mathematical, etc.')
		Размагнители	Demagnetizers
		Размельчительныя мельницы	Pulverizer Mills
		Разрѣзаніе и сварка металловъ	Metal Cutting and Welding

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Рамы для вбиванія свай	Pile Driving Frames	„Росселинъ" (для газовыхъ и нефтяныхъ двигателей)	'Rosseline' (for Gas and Oil Engines)
Рамы и шкворни	Underframes and Bogies	Роликовые подшипники	Roller Bearings
Распредѣлительная установка	Switch Gear	Ротаціонные турбинные насосы „Ротурбо"	'Roturbo' Pumps
Распредѣлительныя доски для аккумуляторовъ	Battery Switchboards	Рудничные инструменты	Mining Tools
Распредѣлительныя доски для аккумуляторовъ	Storage Battery Switchboards	Рудничные кабели и приспособленія	Mining Cables and Accessories
Расширяющійся (прокатанный) металлъ	Expanded Metal	Рудничные сигнальные приборы (водонепроницаемые)	Mining Signals (Watertight)
Револьверные токарные станки	Turret Lathes	Рудничныя взрывчатыя вещества	Mining Explosives
Региструющіе аппараты (для воды)	Recorders (Water)	Рудничныя и подъемныя машины	Mining and Hauling Plant
Региструющіе счетчики времени	Time Recorders	Рудничныя и подъемныя цѣпи	Mining and Hauling Chains
Регуляторы (Гидравлическіе)	Governors (Hydraulic)	Ручные краны (см. Лифты и подъемныя машины	Hand Cranes (see 'Lifting & Hoisting Machinery')
Регуляторы (Паровыхъ двигателей)	Governors (Steam Engine)		
Регуляторы (питательной воды)	Regulators (Feed-water)		
Редукціонные клапаны—см. Клапаны	Reducing Valves (see 'Valves')		
Редукціонныя вубчатыя колеса	Reduction Gears		
Резервуары (водонепроницаемые)	Reservoirs, Waterproofing of	Самопишущіе измѣрительные инструменты	Recording Instruments
Резервуары для масла	Oil Cabinets	Сваи изъ листовой стали	Steel Sheet Piling
Резервуары и цистерны	Tanks and Cisterns	Сваи (изъ лист. стали)	Piles (Steel Sheet)
Резиновыя, каучуковыя и битуменныя производства	India-rubber, Guttapercha, and Bitumen Manufacturers	Сваренные резервуары	Welded Tanks
		Сваренныя стальныя трубы	Welded Steel Pipes
Рельсы и скрѣпленія	Rails and Fastenings	Сварка и разрѣзаніе металловъ	Welding and Cutting of Metals
Ремни изъ верблюжьей шерсти марки „Камель" — единственные фабриканты этихъ ремней	'Camel' Hair, 'Camel' Brand Belting (Sole Makers of)	Сварка процессомъ „Термитъ"	'Thermit' Welding
		Сварочное и листовое желѣзо	Wrought and Sheet Ironwork
Ремонтъ судовъ и машинъ	Ship and Engine Repairers	Сверла и рѣзцы для угля	Coal Drills and Cutters
Ресмусы	Surface Gauges	Сверлильные стержни изъ быстрорѣжущей и серебристой стали.	High-Speed and Silver Steel Drill Rods
Респираторы	Respirators		
Рессоры (пружины)	Springs		

Листы фабрикантовъ по вышеуказаннымъ спеціальностямъ—см. соотвѣтствующіе англійскіе заголовки въ „Подробномъ указателѣ Анонсодателей" на стр. 2993—3056.

ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Сигналы — см. Сигналы для желѣзныхъ дорогъ	Signals (see 'Railway Signals')	Составъ для предохраненія блестящихъ частей машинъ	Bright-part Coatings
Сигнальные и предохранительные приборы для желѣзныхъ дорогъ	Railway Signals and Safety Appliances	Составы для кровлепокрытій	Roofing Compounds
Силикато-графитная краска „Зодіакъ"	'Foliac' Silica-Graphite Paint	Спеціалисты по устройству установокъ экономіи топлива	Coal Economy Specialists
„Сиронитъ" — средство, предохраняющее отъ ржавчины	'Syronite' Rust Preventive	Спеціальной стали, фабр.	Alloy Steel Manufacturers
Система „Snercold" для безопаснаго храненія, транспорта и измѣриванія воспламеняемыхъ жидкостей	'Snercold' System of Safety Storage, Transport and Measuring of Inflammable Liquids	Спиральныя сверла	Twist Drills
Системы электрической проводки (см. Системы прокладки проводовъ (гибкихъ)	Electric Wiring Systems (see 'Wiring Systems (Flexible)'	Сплавы	Alloys
Сита и грохоты	Sieves and Screens	Спускные жолобы для чая	Tea Shoots
Складныя ворота (двери)	Collapsible Gates	Средства для предохраненія дерева	Wood Preservatives
Слитки бронзовой отливки (томпака)	Gunmetal Ingots	Средство противъ котельнаго камня (для внутренняго употребленія)	Boiler Composition (for inside use)
Слюда	Mica	Стали для машинъ, фабр.	Machinery Steel Manufacturers
Смазки, смазочные матеріалы и пр.	Oils, Lubricating Compounds, etc.	Сталь (въ штыкахъ и квадратныхъ болванкахъ)	Steel (Blooms and Billets)
Смазочная передача для перемѣнныхъ скоростей	Variable Speed Oil Transmission Gears	Сталь высокаго напряженія	High Tensile Steels
Смазочные матеріалы для двигателей	Motor Lubricants	Сталь для авіаціонныхъ приборовъ	Aircraft Steels
Смазочные приборы	Lubricating Devices	Сталь для штамповъ	Die Steels
Смазочныя вещества для трактеровъ	Tractor Lubricants	Сталь Сименсъ-Мартэна	Siemens-Martin Steel
Смазочныя средства	Lubricating Compounds	Сталь съ закаленной поверхностью	Case-hardening Steels
Соединенія (замазки) „Ліонъ" и „Вальнеритъ"	Joints ('Lion' and 'Walkerite')	Сталь съ закаленной поверхностью „Месмерикъ"	'Mesmeric' Case-hardening Steel
Соляная кислота	Hydrochloric Acid	Стальные брусья	Steel Rods
Сооруженія, остовы „Треллитъ" изъ легкой стали	Buildings, 'Trellit,' Light Steel Framed	Стальные листы	Steel Sheets
Сопла для доменныхъ печей	Blast Furnace Tuyeres.	Стальные рельсы и принадлежности	Steel Rails and Accessories
		Стальные ящики для храненія продуктовъ и стальные чуланы	Steel Storage Bins and Racks
		Стальныя изолирующія трубы и системы электрическихъ проводовъ	Steel Conduits and Wiring Systems

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ПО РУССКИ.	ПО АНГЛІЙСКИ.
Стальныя линейки	Steel Rules
Стальныя трубы — см. Трубы	Steel Tubes (see 'Tubes')
Стальныя трубы для электрической проводки	Steel Conduits for Electrical Wiring
Станины и телѣжки изъ прессованной стали	Pressed Steel Underframes and Bogies
Станки—см. Инструментные заводы	Lathes (see 'Tool Makers')
Станки для пробиванія дыръ, разрѣзанія и сгибанія	Punching, Shearing and Bending Machines
Станки для фрезованія зубчатыхъ колесъ	Gear Cutting Machines
Стартеры для моторовъ	Motor Starters
Стеклянныя вещи для надобностей освѣщенія и т. п.	Glassware for Ships' Lighting, etc.
Стеклянныя масленки	Lubricating Glasses
‚Стеллитъ' для инструментовъ	Stellite for Tools
Стойки (стальныя)	Stanchions (Steel)
Строгательныя, долбежныя, винторѣзныя и поперечно-строгательныя (шепингъ) машины	Planing, Slotting, Screwing, and Shaping Machines
Строители артезіанскихъ колодцевъ	Artesian Well Engineers
Строители и владѣльцы баржъ	Barge Builders and Owners
Строители плавучихъ доковъ	Floating Dock Builders
Строительныя(фасонныя) желѣзо и сталь	Structural Iron and Steel Work, etc.
Строительство изъ желѣзобетона	Reinforced Concrete Construction
Струганные стальные листы	Planished Steel Sheets
Ступени для лѣстницъ	Stair Treads
Судна для перевозки нефти (строители)	Oil-tank Ships, Builders of
Судовые нефтяные двигатели	Marine Oil Engines
Судовые перегрѣватели	Marine Superheaters
Судовые тахометры	Marine Speed Indicators
Судовыя паровыя машины, котлы и вспомогательныя машины	Marine Engines, Boilers and Auxiliary Machinery
Судовыя принадлежности	Shipping Tackle
Судостроители	Ship Builders
Сухіе доки	Graving Dock Owners
Сушильные аппараты	Drying Apparatus
Счетные приборы	Counting Instruments.
Счетныя машины (для рабочей платы)	Calculators (Wages)
Счетчики времени	Recorders (Time)
Счетчики (для воздуха)	Meters (Air)
Счетчики (для газа)	Meters (Gas)
Счетчики (для пара)	Meters (Steam)
Счетчики для рабочей платы	Wages Calculators
Счетчики углекислоты	CO_2 Recorders
Счетчики утечки воды	Waste Water Meters
Сцѣпленія (муфты)	Clutches
Сцѣпленія (муфты) упругія — см. Упругое сцѣпленіе	Couplings (Flexible) (see 'Flexible Couplings')
Сѣрная кислота	Sulphuric Acid
Сѣрнокислая мѣдь (мѣдный купоросъ)	Sulphate of Copper
Сѣтки испытанныя противъ бомбъ	Bomb-Proof Netting
Сѣченія (патент. пресованныя) латуни, бронзы и пр.	Sections (Patent Extruded), Brass, Bronze, etc.
Т	
Тахометры	Tachometers
Текстильныя машины	Textile Machinery
Телеграфная проволока—см. Проволока	Telegraph Wire (see 'Wire')

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Телеграфные изоляціонные болты и всякаго рода желѣзныя издѣлія для телеграфовъ и телефоновъ	Telegraph Insulator Bolts and all kinds of Ironwork for Telegraph and Telephone	Тормазы (динамометры)	Brakes (Dynamometers)
Телеграфные инженеры	Telegraph Engineers	Тормазы (желѣзнодорожные)	Brakes (Railway)
Телеграфные столбы (желѣзные)	Telegraph Poles (Iron)	Тормазы (электромеханическіе)	Brakes (Electro-Mechanical)
Телефонное устройство	Telephone Equipment	Тормазы съ колодками	Brake Blocks
Термометры	Thermometers	Точильные (шлифовальные) круги	Abrasive Wheels
Техническое обученіе—см. Коллежи и училища	Technical Training (see 'Schools and Colleges')	Точильные приборы для дрелей (сверлъ)	Drill Sharpeners
Тигельная сталь	Crucible Cast Steels	Точильные станки	Grinding Machinery
Тигельныя печи	Crucible Furnaces	Точильныя машины	Grinding Machinery
Тигли	Crucibles	Трамваевъ (стальные проволочные канаты для)	Tramways (Steel Wire Ropes for)
Типографы, литографы, чертежники и граверы	Printers, Lithographers, Draughtsmen and Engravers	Трамваи (канатные)	Tramways (Wire Rope)
Токарныя издѣлія (изъ любого металла)	Turned Work (any Metal)	Трамваи и желѣзныя дороги (электрическіе)—см. Электрическіе жел. дор. и трамваи	Tramways and Railways (Electrical) (see 'Electrical Railways and Tramways').
Толь и толевыя кровли	Felt and Felt Roofs	Транспортеры — см. также Приводные ремни	Conveyors (see also 'Belting')
Топки (плавильныя печи)	Furnaces	‚Треллитъ' остовы для сооруженій изъ легкой стали	'Trellit' Light Steel Framed Buildings
Топки (котельныя) см. Арматура къ машинамъ и котламъ	Furnaces (Boiler) (see 'Engine and Boiler Fittings')	Тросы (изъ оцинкованной стальной проволоки)	Hawsers (Galvanised Steel Wire)
Топки (печи), отапливаемыя жидкимъ топливомъ, газомъ и отходящими газами	Furnaces (Gas and Oil Heated and Industrial)	Трубоочистители	Tube Cleaners
Топки для судовыхъ и стаціонарныхъ котловъ	Furnaces for Marine and Land Boilers	Трубопроводы — см. Трубы	Pipes (see 'Tubes')
Топки съ автоматической нагрузкой — см. Механическіе кочегары	Stokers (Mechanical) (see 'Mechanical Stokers')	Трубы (гибкія, металлическія)	Tubing (Flexible Metallic)
Топки (печи) электрическія	Furnaces (Electric)	Трубы (гибкія) для пароваго отопленія	Steam Heating Tubes (Flexible)
Топливо-сберегательныя системы	Fuel Economy Systems	Трубы (пневматическія)	Tubes (Pneumatic)
		Трубы конденсатора (мѣдныя) — см. Мѣдныя трубы	Condenser Tubes (Copper) (see 'Copper Tubes')
		Трубы (кишки) для пожарныхъ командъ, фабрикъ и заводовъ и пр.	Hose for Fire Brigades, Mills, etc.
		Трубы и принадлежности	Tubes and Fittings

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ПО РУССКИ.	ПО АНГЛІЙСКИ.	ПО РУССКИ.	ПО АНГЛІЙСКИ.
Турбины (Паровыя) — см. Паровыя турбины	Turbines (Steam) (see 'Steam Turbines')	Установки для бетонныхъ работъ	Concrete Placing Plants
Турбины, водяныя колеса и водяные двигатели	Turbines, Water Wheels, and Water Motors	Установки для измельченія угля	Powdered Coal Plants
Турбины съ зубчатыми передачами	Geared Turbines	Установки для концентраціи амміака	Ammonia Concentration Plants
Турбинные насосы	Turbo Pumps	Установка для провариванія и отвариванія смолы	Tar Distillation and Dehydrating Plants
Турбинныя лопатки	Turbine Blading	Установки для сушенія крови	Blood Drying Plants
Турбинныя передачи —см. Турбины съ зубчатыми передачами	Turbine Gears (see 'Geared Turbines')	Установки нефтянаго отопленія	Oil Burning Installations
Турбо-Алтернаторы	Turbo Alternators	Устройство для вбиванія свай	Pile Driving Equipments
Турбо-генераторы — см. Динамо и двигатели	Turbo-Generators (see 'Dynamos and Motors')	Устройства освѣщенія на поѣздахъ	Train Lighting Plant
		Учебныя заведенія —см. Колледжи и училища	Educational Institutions (see 'Colleges and Schools')
У		Училища и колледжи	Schools and Colleges
Угольники (угольныя линейки)	Angles	**Ф**	
Угольныя топки — см. Топки, плавильныя печи	Coal Furnaces (see 'Furnaces')	Фасонная сталь	Sections (Steel)
Ударные штанцы (песты) съ барабаномъ и прессы	Drop Stamps and Presses	Фасонныя ковки и отливки—см. Отливки и фасонныя ковки	Forgings and Castings (see 'Castings and Forgings')
Указатели уровня воды	Water Level Indicators	„Ферodo" фрикціонная поверхность	'Ferodo' Friction Surfaces
Упорные подшипники	Thrust Bearings	Фибра (вулканизированная)	Fibre (Vulcanised)
Управленіе судами при помощи электричества	Electric Ship Propulsion	„Фибрентъ" асбестоцементные волнистые и плоскіе листы	'Fibrent' Asbestos Cement Corrugated and Flat Sheets
Упругое сцѣпленіе	Flexible Couplings	Фильтры	Filtering Apparatus
Установка газовыхъ двигателей	Power Plant (Gas)	Фильтры для масла	Oil Filters
Установка котловъ	Settings (Boiler)	Фильтры для питанія котловъ — см. Питательная вода	Boiler Feed Filters (see 'Feed-water')
Установка для плавленія металловъ	Metal Melting Plants	Фосфорная бронза	Phosphor Bronze
Установка для производства проволочныхъ гвоздей	Wire-Nail Making Machinery	Фотографическіе аппараты	Photographic Apparatus
Установка для производства проволоки	Wire-Working Machinery	Фотостатъ	Photostat
Установка для производства пружинъ	Spring making Machinery	Фрезовальныя машины	Milling Machines
Установка ретортъ	Settings (Retort)		

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ПО РУССКИ.	ПО АНГЛІЙСКИ.
Фрикціонная поверхность муфты	Friction Surfaces
Фрикціонное сцѣпленіе	Friction Clutches
Футеровка муфтъ (сцѣпленій)	Clutch Linings
Футеровка (прокладка) тормазовъ и муфтъ	Brake and Clutch Linings
Х	
Химическіе и электро-химическіе аппараты	Chemical and Electro-Chemical Apparatus
Химическіе продукты	Chemicals
Хлопчатобумажные канаты	Cotton Driving Ropes
Хлопчатобумажные ремни	Cotton Belting
Холодильники	Cold Storage
Холодильныя машины	Refrigerating Machinery
Холодильныя трубы и змѣевики	Refrigerating Tubes and Coils
Хромо-ванадіевая сталь	Chrome-Vanadian Steels
Ц	
Цементные шиферы и доски	Cement Slates and Boards
Центробѣжные насосы—см. Нассосы	Centrifugal Pumps (see 'Pumps')
Центровыя сверла	Core Drills
Цилиндры	Cylinders
Цинкъ (не покрывающійся накипью) — для аккумуляторовъ	Zincs (non-encrusting for Primary Batteries)
Цѣпи и крюки для крановъ	Crane Chains and Hooks
Цѣпи и цѣпная передача	Chains and Chain Driving
Цѣпи и цѣпные кабели	Chains and Chain Cables
Ч	
Часы для контроля времени и расходовъ	Costs and Time Recorders
Часы (электрическіе) — см. Электрическіе часы	Clocks (Electric) (see 'Electric Clocks')
Червячные механизмы	Worm Gearing
Черная жесть	Black Plates
Чистители для котловъ (механическіе и электрическіе)	Boiler Cleaners (Mechanical and Electrical)
Чугунъ въ болванкахъ	Pig Iron
Чугунные резервуары	Cast Iron Tanks
Чугунныя трубы для воды и газа	Cast Iron Pipes for Water and Gas Purposes
Ш	
Шасси для автомобилей	Motor Chassis Frames
Шайбы	Washers
Шайбы (пластинки) для водомѣрныхъ стеколъ	Gauge Glass Washers
Шарашки, фрезера	Milling Cutters
Шарики и шариковые подшипники	Balls and Ball Bearings
Шестерни изъ сжатой бумаги	Compressed Paper Pinions
Шестерни изъ сырой кожи	Raw Hide Pinions
Шкафы для папокъ и карточной системы	Filing and Card Index Cabinets
Шкивы	Pulleys
Шкивы для пеньковыхъ канатовъ—см. Шкивы для ремней и для пеньковыхъ канатовъ	Rope Pulleys (see 'Belt and Rope Pulleys')

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Шкивы для ремней и для пеньковыхъ канатовъ	Belt and Rope Pulleys
Шланги, кожаныя и холщевыя и пр.	Hose Pipes, Leather and Canvas Hose, etc.
Шлифовальные станки—см. Машины для точки	Grinders (see 'Grinding Machinery')
Шлифовальные станки (электрическіе) съ центрами	Centre Grinders (Electric)
Шпунты для стѣнъ и потолковъ	Wall and Ceiling Sheets
Штамповки	Stampings
Щ	
Щетки для динамо	Dynamo Brushes
Э	
Эбонитъ	Ebonite
Экономайзеры	Economisers
Экскаваторы и транспортеры	Excavators and Transporters
Элеваторы—см. Подъемныя машины	Elevators (see 'Lifting and Hoisting')
Электрическая сварка	Electric Welding
Электрическіе аккумуляторы и батареи—см. Вторичные элементы	Electrical Storage Cells and Batteries (see 'Storage Cells')
Электрическіе вентиляторы—см. Вентиляторы	Electric Fans (see 'Fans')
Электрическіе двигатели — см. Динамо и Двигатели	Electric Motors (see 'Dynamos and Motors')
Электрическіе инструменты и аппараты—см. Инструменты и аппараты (Электрическіе)	Electrical Instruments and Apparatus (see 'Instruments and Apparatus (Electrical)')
Электрическіе кабели (см. Кабели: Телеграфные, Телефонные, Освѣтительные и Подводные)	Electric Cables (see 'Cables: Telegraph, Telephone, Electric Light and Submarine')
Электрическіе кабели (типа ‚C.T.S.') — см. Кабели типа ‚C.T.S.'	Electric Cables ('C.T.S.' Type) (see '"Cab Tyre Sheathed" Cables')
Электрическіе кабели марки ‚Эндураль'	'Endural' Electric Cables
Электрическіе нагрѣвательные и кухонные аппараты	Electric Heating and Cooking Apparatus
Электрическіе часы	Electric Clocks
Электрическія воздуходувки	Electric Blowers
Электрическія дуговыя лампы, фонари—см. Приспособленія для электрическаго освѣщенія	Arc Lamps (see 'Electric Light Fittings')
Электрическія желѣзныя дороги и трамваи	Electric Railways and Tramways
Электрическія лампы съ калильной ниткой	Metal Filament Lamps
Электрическія подъемныя машины и краны	Electric Lifts and Cranes
Электрическія топки	Electric Furnaces
Электрическое дугообразное сварочное оборудованіе	Electric Quasi-Arc Welding Equipment

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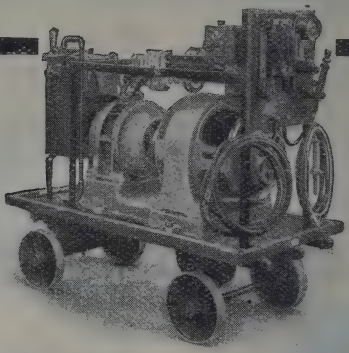

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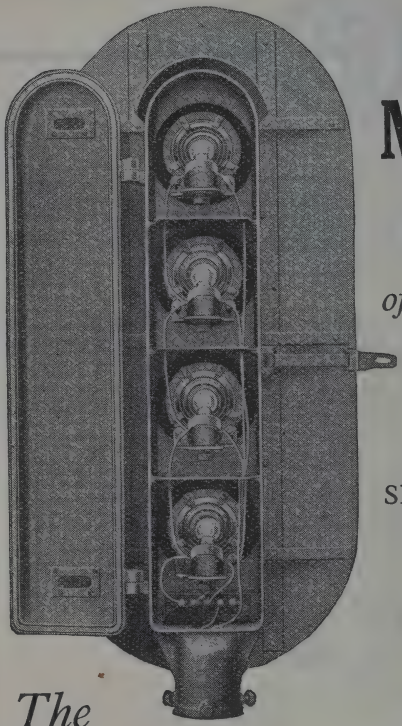

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VISITOR—H.M. THE KING.

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The City and Guilds (Engineering) College, the Engineering Section of the Imperial College, provides complete Courses of Instruction leading up to, and including, the highest specialised instruction to fit Students to take leading positions in the industrial world as Civil, Mechanical or Electrical Engineers, Scientific Advisers, Investigators or Experts in the Engineering industries. The College also provides opportunities for those already qualified who desire to take up more advanced courses of training and research in branches of Engineering in which they are specially interested.

The Departments of the College are as follows :—

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Under the direction of Prof. Dalby, F.R.S., M.Inst.C.E.

ENGINEERING, CIVIL, AND SURVEYING—
Under the direction of Prof. Dixon, M.Inst.C.E.

ENGINEERING, ELECTRICAL—
Under the direction of Prof. Fortescue, M.I.E.E.

MATHEMATICS—
Under the direction of Prof. Chapman, F.R.S.

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B.Sc. in Engineering of University of London.

Students who enter by the Matriculation Examination of the University of London are eligible for the B.Sc. in Engineering of the University through the College Examinations alone.

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(For advanced specialised or fourth-year work.)

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LONDON

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UNIVERSITY OF LONDON
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Complete courses of study, extending over three years, are arranged in :—

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F. S. ROBERTSON, M.I.E.E. Lecturer.
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There is a College Hostel and a large Athletic Ground.

For full information apply to

The SECRETARY, King's College, Strand, W.C.2.

LONDON

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Courses extending over three years are offered in Mechanical, Structural, Electrical and Motor Engineering, Each Course embraces lectures, laboratory, and workshop drawing-office practice.

The Courses in Mechanical and Electrical Engineering are recognised by the Institutions of Mechanical and Electrical Engineers respectively and the Board of Education for the award of Senior and Advanced National Diplomas.

School Diplomas are awarded in all branches.

Entrance Examinations are held in July and September.

Evening Classes.

Courses of Study are offered in Civil, Mechanical, Electrical, Motor and Gas Engineering. These are designed to afford a thorough training, of an advanced standard, in the science and practice of Engineering. The work undertaken covers the requirements of the examinations for admission to the several Engineering Institutions.

The Courses in Mechanical and Electrical Engineering are recognised for the award of National Certificates.

Prospectuses, and full particulars, may be obtained from the Director of Education, The Polytechnic, 309 Regent Street, W. 1.

LONDON

ENGINEERING TRAINING

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Founded 1872.

Mechanical and Civil Divisions.

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Principal: MAURICE WILSON, M.Inst.C.E., Past President, Society of Engineers. *Vice-Principal:* F. C. P. LAWRENCE, M.S.E., A.M.Inst.Struct.E.

ASSISTED BY A STAFF OF LECTURERS AND INSTRUCTORS.

The School may be Inspected on application to the Principal, from whom all further information may be obtained.

This School was established for the purpose of providing Students of any branch of Engineering with thorough practical and theoretical instruction in the rudiments of the profession and in the manipulation of materials. The institution has since been largely extended.

The School is approved by the Council of the Institution of Civil Engineers' and Students who pass through its complete course and otherwise comply with the current regulations of the Institution are eligible for their Examinations; they are also eligible for election as Students of the Institution of Mechanical Engineers, Associates of the Society of Engineers, etc.

The usual age for admission to the School is 16 to 17 years, but there is no limit as to the age of Students. They may commence work at the beginning of any term.

Mechanical Engineering (First Year).

The Students spend one Term each in the Drawing Office, the Pattern Shop and Foundry, and the Fitting and Smith's Shop, besides attending Lectures on 'Steam and the Steam Engine,' 'Railways: their Construction and Appliances,' 'Materials and their Manufacture,' and other Special Subjects, including Mathematics.

Civil Engineering (Second Year).

The first Term in this section is devoted to Practical Preparation by actual Levelling, Surveying, Theodolite work, etc., of Plans for a complete Public Work, and the necessary Plans, Estimates, etc., for a Railway.

The second Term is devoted to the Preparation of Working Plans, Calculations, Estimates, etc., of the said Work for the Contractors.

The third Term is utilised for Original Designing, Theory of Structures, and other necessary Calculations, Specifications, etc., for Bridge, Reinforced Concrete and other Work, reporting upon existing Engineering Works, and the testing of Cement.

Debates are held to afford Students an opportunity of gaining confidence in public professional speaking.

At the meetings of the 'Crystal Palace Engineering Society' (affiliated to the Society of Engineers) Students read and discuss papers on Professional subjects. Professional visits to Engineering Works are made from time to time.

Of the Students who have passed through the School, many have obtained appointments as Chief Engineers at home and abroad; and upwards of 1,400 are employed in Engineering work in various countries in the World.

LONDON

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St. John Street, London, E.C.1.

Principal: S. C. LAWS, M.A., M.Sc.

ENGINEERING DAY COLLEGE.

The College provides courses in Civil, Mechanical, Electrical, Aeronautical and Radio Engineering. Each course occupies four years, and includes provision for students to spend two summer periods, April to September, in commercial works. Students should be not less than 16 years of age at entrance.

Fees. **£18** per annum for students residing during term in London, Kent, or (in approved cases) Middlesex and Hertfordshire. **£60** for students resident elsewhere.

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Professional and Trade courses are provided in all branches of Civil, Mechanical, Electrical, Aeronautical, Automobile and Radio Engineering. Special classes in Telegraphy and Telephony are organised for Post Office employees.

Professional courses are recognised for the award of National Certificates in Engineering and are adapted to the requirements of the Associate-Membership examinations of the various engineering institutions. Special courses are provided in preparation for the B.Sc. (Eng.) degree of London University.

Students preparing for University degrees are able to enter as Internal candidates for the University examinations.

Full particulars and prospectuses may be had on application to the Principal.

LONDON

ENGINEERING TRAINING

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Secretary—C. G. BURTON, M.Com.

Departments of Civil, Mechanical & Electrical Engineering.

The FULL COURSES EXTEND OVER FOUR YEARS, and students who enter after Matriculation and who pass successfully the Examinations at the end of each year WILL BE ENTITLED to the DEGREE of BACHELOR OF SCIENCE in the branch of Engineering to which they devote themselves.

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Lectures on the Strength of Materials, Theory of Steam, Gas, and other Heat Engines, Hydraulics, Machine Design, Strength of Structures, Distribution of Power.

Drawing: Design of Tools, Prime Motors, Dynamos, and other forms of Machinery.

Courses in Civil Engineering, including Constructional Work in Masonry and Steel, Railway Work, Dams, Bridges, and Water Engineering.

Field Work: Practical Surveying in the Field throughout the Summer Term.

Engineering Laboratory: Determination of the Strength of Materials, including Compressive, Bending, Tensile, and Torsion Tests, Experimental Study of the Steam Engine and Boiler, Frictional Efficiency Tests, the Flow of Water over Weirs and through Orifices, etc.

Lectures and Demonstrations on all branches of Electrical Engineering.

Electrical Laboratory: Testing of Continuous and Alternate Current Machinery: Electrical Instruments, Meters, Lamps and Batteries: Insulation and Magnetic Testing Work.

The Courses also include Instruction in Mathematics, Physics, Chemistry, Geology, and Metallurgy.

For detailed Syllabus, with full particulars of **University** Regulations, Lecture and Laboratory Courses, Fees, Scholarships, etc., apply to the Secretary.

BIRMINGHAM

ENGINEERING TRAINING

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FULL-TIME (DAY) COURSES extending over three or four years, and leading to the Diploma of the College, are arranged in the following Departments :

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CHEMISTRY
DYEING
MECHANICAL ENGINEERING
CIVIL ENGINEERING, ARCHITECTURE and BUILDING
ELECTRICAL ENGINEERING
BIOLOGY
COMMERCE and BANKING
PHARMACY

These Courses are designed to meet the needs of Students wishing to present themselves for the Degree Examinations of the London University.

Special facilities are available for advanced study and research.

EVENING COURSES

PART-TIME (EVENING) COURSES are also arranged, on the successful completion of which students are awarded Senior and Advanced Course Certificates.

Further particulars and prospectuses may be obtained on application to the PRINCIPAL, Technical College, Bradford.

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The Heriot-Watt College offers complete Courses of Instruction in these subjects, and a Diploma or Certificate at the end of the Course.

The complete Diploma Courses in Mechanical Engineering and Electrical Engineering last over three years, and in Applied and Analytical Chemistry over four years.

The Diploma Course in Mining (Coal, Metalliferous and Oil) lasts over three years.

Arrangements have been made with local Engineering Firms for shortened apprenticeships for students who hold the Diploma of the College.

The Associateship of the College in Chemistry is recognised by the Institute of Chemistry as a qualification exempting students from the examinations for the Associateship of the Institute of Chemistry. In the Chemistry Department there are also Courses in Bio-Chemistry, and in Pharmaceutics for the Professional Examinations of the Pharmaceutical Society of Great Britain.

Special arrangements have been made for **POST-GRADUATE COURSES** in **ELECTRICAL ENGINEERING, PRIME MOVERS,** and **APPLIED CHEMISTRY.** Students wishing to take these post-graduate Courses must either hold the B.Sc. of some University or the Diploma of the Heriot-Watt College or of the Royal Technical College, Glasgow.

There is also a Course extending over two Winter Sessions for Clerks of Works, Builders' Clerks, and Surveyors' Apprentices.

EVENING CLASSES.—Advanced Classes in various Departments of Pure and Applied Science, Commerce, and Languages, which will prove of use to students who have already taken a Degree or who are studying for a Degree, are held in the College in the Evening.

FEES.—Day Classes. Composition Fees for Diploma Courses, £27 to £31 10s. per annum. **Evening Classes,** 10s. to 75s.

All particulars regarding the College Classes, both Day and Evening, can be obtained from the PRINCIPAL at the College.

For the Scheme for Degrees in Civil, Electrical and Mechanical Engineering, Mining and Metallurgy, and Technical Chemistry arranged with the University of Edinburgh, see University Calendar, or the Calendar of Heriot-Watt College.

EDINBURGH

ENGINEERING TRAINING

The Royal Technical College, GLASGOW.

The College is affiliated to the University of Glasgow, and the Degrees of the University in Engineering, Applied Chemistry, Architecture, and Pharmacy are open to students.

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MECHANICAL ENGINEERING.

CHEMICAL ENGINEERING.
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Associate Professor WM. KERR, Ph.D., A,R.T.C., M.I.Mech.E.

ELECTRICAL ENGINEERING.
Professor STANLEY PARKER SMITH, D.Sc., M.I.E.E.

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Professor DANIEL BURNS, M.Inst.M.E.

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The courses are designed for students desiring to qualify as MECHANICAL, ELECTRICAL, CIVIL or MARINE ENGINEERS, as NAVAL ARCHITECTS and METALLURGISTS or METALLURGICAL ENGINEERS. These courses cover the subjects of Examination for Associate Membership of the Institutions of Civil, Mechanical, and Electrical Engineers. The Institutions named, subject to certain conditions, accept the degree of B.Eng. in lieu of part, and in some cases the whole, of the examinations for Associate Membership. The various departments are housed in commodious and well-equipped buildings, and provide ample facilities for research.

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Appointments are found for all Students who satisfactorily complete the College Course.

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LOUGHBOROUGH

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NEWCASTLE-UPON-TYNE

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Mining: Professor W. H. MCMILLAN, B.Sc., M.I.Min.E.
Director of the Sub-Department of Electrical Engineering: H. COTTON, M.B.E., M.Sc., A.M.I.E.E.

DEGREE COURSES.

The College provides complete courses of study extending over three or four years for the Degrees of London University in Engineering and Mining.

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The Course for the Diploma of University College, Nottingham, in Engineering or Mining extends over three years. Short courses for special purposes can be arranged.

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For those who have not passed the London University Matriculation or an equivalent examination, an Entrance Examination is held in July and September.

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THE

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The object of Professor Louis is to give an account of the theory and practice of the subject, and the present volume—the first English treatise on the subject—will prove of the greatest service to the miner or metallurgist who desires to understand the principles upon which the art is based, as also to the manufacturer who supplies the necessary appliances, and above all to the student who is preparing for either of the above professions.

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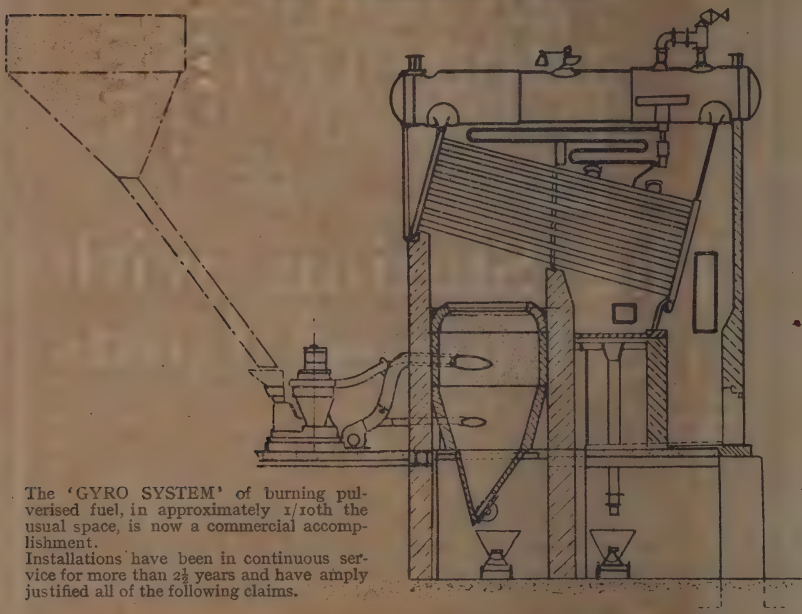

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